



RESEARCH & DEVELOPMENT

Strategies to Reduce Wrong Way Movements

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<p>Abstract</p> <p>Wrong way driving crashes continue to be a persistent highway safety problem for North Carolina. The objective of this project was to develop recommendations for geometric elements, traffic control devices, and other strategies to reduce wrong way driving at priority freeway ramp locations in North Carolina. The research team developed two main products in this research project. The first product was a 24-page toolbox of signs, markings, and geometric design strategies that can be implemented at any freeway ramp terminal to reduce the potential for wrong way driving. This compilation of strategies was based on a state-of-the-practice review from other states and recent research. The second product was a set of site-specific recommendations for selected priority interchanges. The team reviewed 129 reports from wrong way crashes in Durham, Forsyth, Guilford, Mecklenburg, and Wake counties. The team identified 34 interchanges where wrong way driving had originated or likely had originated. Team members conducted a field review of each interchange to identify whether there were characteristics linked with increased risk of wrong way driving. The team produced recommendations for improvements to the signs, markings, and geometrics of the ramp intersections to reduce the potential for wrong way driving.</p>			
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EXECUTIVE SUMMARY

Wrong way driving crashes continue to be a persistent highway safety problem for North Carolina. Although these crashes represent a small percentage of crashes occurring statewide, they are understandably serious when they occur. In 2006 and 2012, NCDOT developed reports on wrong way crashes. The later report recognized that the most highly urbanized counties, such as Mecklenburg, Forsyth, and Wake, continue to experience wrong way crashes on their freeways. The report concluded that a systematic approach to design and traffic control may be successful in reducing wrong way crashes.

Many other states have also undertaken efforts in recent years to reduce the problem of wrong way crashes. In the summer of 2013, Illinois DOT hosted a Wrong Way Driving Summit to provide a platform for the exchange of ideas and practices to reduce wrong way driving. The proceedings of this summit were made available (Zhou, 2014) and included current practices in the areas of engineering, enforcement, and education to prevent wrong way driving and to mitigate the impact of wrong way crashes.

The objective of this project was to develop recommendations for geometric elements, traffic control devices, and other strategies to reduce wrong way driving at priority freeway ramp locations in North Carolina. The research team developed two main products in this research project. The first product was a 24-page toolbox of signs, markings, and geometric design strategies that can be implemented at any freeway ramp terminal to reduce the potential for wrong way driving. This compilation of strategies was based on a state-of-the-practice review from other states and recent research.

The second product was a set of site-specific recommendations for selected priority interchanges. The team reviewed 129 reports from wrong way crashes in Durham, Forsyth, Guilford, Mecklenburg, and Wake counties. The team identified 34 interchanges where wrong way driving had originated or likely had originated. Team members conducted a field review of each interchange to identify whether there were characteristics linked with increased risk of wrong way driving. The team produced recommendations for improvements to the signs, markings, and geometrics of the ramp intersections to reduce the potential for wrong way driving.

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Appendix D Recommendations by County

Durham	33
Forsyth	99
Guilford	152
Mecklenburg	211
Wake	290

INTRODUCTION

During a six-month span around early 2006, seven people were killed in wrong way crashes in the Charlotte area. This intense concentration of crashes of an unusual nature caught the attention of many parties, including media, government officials, and the public. Speculation ranged widely, raising questions such as: *“There have been so many wrong way driving deaths in the Charlotte area, particularly on I-485. Is drunk driving the blame, or poor road design? Could it be a combination of both? ... what is the problem?”*¹

NCDOT investigated the issue and developed a report in 2006 (Braam). This report presented the characteristics of statewide wrong way crashes on freeways from 2000-2005. The report noted that alcohol and/or drugs were involved in approximately half of all wrong way crashes, and older drivers were overrepresented. It included an overview of potential countermeasures, such as sensors, lights, and barriers, but concluded that the high cost of the countermeasures coupled with the lack of geographic concentration of wrong way crashes made such an effort infeasible. The report concluded that a strong emphasis on reducing alcohol related crashes would likely have a beneficial effect on wrong way crashes.

The topic of wrong way crashes continued to be a frequently highlighted topic in the news through the years following the 2006 report. In 2012, NCDOT conducted another analysis of wrong way crashes, focusing on 2006-2012, the years since the previous report (Wrong Way, 2012). This report showed that wrong way crashes had decreased through the years and continued to be a small percentage of all crashes. However, NCDOT recognized that certain counties, such as Mecklenburg, Forsyth, and Wake, continue to experience wrong way crashes on their freeways. The report concluded that a systematic approach to design and traffic control may be successful in reducing wrong way crashes.

The wrong way issue was again highlighted in the summer of 2015 when a highly publicized and horrific crash took the lives of three people on I-85 in Orange County. In addition to being high-profile, wrong way crashes also carry a high cost to society. These crashes typically result in serious injuries or fatalities, with associated costs to society ranging from \$564,000 to \$10 million per crash. If even a portion of these crashes can be prevented, this would represent substantial savings to the state of North Carolina.

The question at hand is, “What design or traffic control elements should be modified at interchanges associated with wrong way crashes to decrease the likelihood of these crashes?” This project focused on answering that question for the highest priority interchanges on North Carolina freeways.

RESEARCH OBJECTIVE

The objective of this project is to develop recommendations for geometric elements, traffic control devices, and other strategies to reduce wrong way driving at priority freeway ramp locations.

¹ Online forum comment, March 2006, <http://www.urbanplanet.org/forums/index.php/topic/23007-wrong-way-driving-deaths/>

RESULT OF LITERATURE REVIEW

The issue of wrong way driving has been the topic of occasional studies in the past, but in recent years it has become a more prominent topic nationally. This proposed project will build on the experiences and knowledge gained from these efforts and will tailor specific recommendations for North Carolina.

In the mid-2000's, Texas DOT created a Wrong Way Driver Task Force which identified potential countermeasures such as wrong way detection devices and active/illuminated signing (Cooner et al., 2004). They also developed a wrong way checklist for engineers to review suspected problem locations.

Illinois DOT published a report in 2012 on contributing factors in wrong way driving on freeways (Zhou et al., 2012). They found that alcohol and drug impairment and driver age were among the significant factors in wrong way crashes. They also presented very pertinent information from other studies on scenarios that lead to wrong way driving, such as when drivers:

- Miss an intended exit (ITARDA 2002)
- Choose the exit road instead of the entry road when joining from a non-freeway (SWOV 2007; Cooner, Cothron, and Ranft 2004; NTTA 2009)
- Enter a roadway going the wrong direction at the road's terminus (NTTA 2009)
- Make a U-turn and misunderstand that the next lane will be in the opposite direction (ITARDA 2002; Cooner, Cothron, and Ranft 2004; NTTA 2009)
- Attempt to get back on the main road after stopping at a service or parking area (ITARDA 2002)

In the summer of 2013, Illinois DOT hosted a Wrong Way Driving Summit to provide a platform for the exchange of ideas and practices to reduce wrong way driving. The proceedings of this summit were made available (Zhou, 2014) and included current practices in the areas of engineering, enforcement, and education to prevent wrong way driving and to mitigate the impact of wrong way crashes.

NCHRP Project 03-117, Traffic Control Devices and Measures for Deterring Wrong-Way Movements, is national in scope and seeks to identify the effect of traffic control devices and median widths on wrong way driving with the goal of proposing new language for the next edition of the MUTCD. This project is scheduled to be completed in September 2017.

The Transportation Research Board hosted a webinar on April 20, 2016, on the topic of wrong way driving. PI Daniel Carter attended this webinar. Speakers from various state DOTs related their experience in addressing wrong way driving. The strategies and countermeasures employed by these agencies included:

- Hard guidance such as channelization, which is far more effective than signing and awareness (another example is a roundabout at a ramp terminal);
- Wrong way arrows (reflective on pavement);
- Wrong way signs with reflective tape, flashing lights, rapid flashing beacons, and lowered sign height;
- Warning signs for other motorists (shown for both travel directions in the vicinity);
- Detection technologies, including radar on exit ramps or mainline, loops in pavement, cameras, or any combination of these; and
- Centralized or regionalized reporting (manned) offices that receive the indication of WWD and issue warnings or police summons.

REPORT BODY

Initial Meeting with Steering Committee

NCDOT and the UNC-HSRC research team held a kickoff meeting on August 26, 2016, at the Garner office. The majority of the meeting consisted of the research team presenting their approach by task and asking for decisions and input from the steering committee. Following the meeting, the team sent NCDOT the content of the presentation (Powerpoint file) used in the kickoff meeting and a documented summary of the decisions and comments from the kickoff participants to guide the research team's effort. The summary of notes is as follows:

- What is the best way to contact police for their information on wrong way driving incidents?
 - For local police, the Governor's Highway Safety Program staff may have contacts in each area. For North Carolina State Highway Patrol (NCSHP), Major Johnson would be the primary contact.
 - Police records may be unavailable if the incident is still being adjudicated.
 - NCSHP keeps files for 5 years on fatal cases. However, individual troopers may keep their case records for a very long time.
 - Kevin Lacy offered to get a letter from the Executive Committee for Highway Safety if needed.
- Which are the priority counties for examining wrong way crash data?
 - Mecklenburg, Wake, Forsyth, Guilford, Durham.
 - The team will examine crashes from 2000-2013 for these counties. Data for more recent crashes may be unavailable due to ongoing legal activity.
- Are there any particular interchanges that should be included in the site visits?
 - Interchanges where there is video data available
 - Interchanges with side-by-side ramps.
 - Possibly prioritize ramp locations that are not lighted.
- What kind of traffic camera access or past footage is available at interchanges?
 - There is some recorded footage available for several interchanges (to be supplied by NCDOT).
- Is there any interchange inventory data available statewide for comparison?
 - There is no interchange database.
- What scope of strategy costs/magnitudes should be considered?
 - The scope should be low to moderate cost. Interchange rebuilding is out of the question, and NCDOT cannot currently assign people to monitor locations.
 - NCDOT noted that the research team should consider all ideas, even if some proposed strategies may be inconsistent with the MUTCD.
 - Any recommendations for specific sites should be discussed with NCDOT prior to documentation.

Other notes from the meeting:

- NCDOT is already employing several strategies to combat wrong way driving. There is widespread use of red raised pavement markers in the shape of arrows that reflect toward wrong way drivers. Division 10 has installed red bright strips on the poles of wrong way signs.
- There was some discussion about the possibility that the turnpike authority could use their roadway instrumentation (i.e., at toll check points) to detect wrong way movements.

Development of a Wrong Way Driving Toolbox

The team reviewed information on wrong way driving mitigation strategies used in other states. The team used this knowledge of the practices and countermeasures used in other states to combat wrong way driving and developed a toolbox of strategies for NCDOT. The following resources were consulted in the development of this toolbox (full citations available in the reference section):

- Guidelines for Reducing Wrong-Way Crashes on Freeways (Zhou and Rouholamin, 2014)
- Wrong Way Crashes: Statewide Study of Wrong Way Crashes on Freeways in North Carolina (Braam, 2006)
- Countermeasures for Wrong-Way Movement on Freeways (Cooner et al., 2004)
- Assessment of the Effectiveness of Wrong Way Driving Countermeasures and Mitigation Methods (Finley et al., 2014)
- Wrong Way Driving Road Safety Audit Prompt List (FHWA, 2013)
- “Where These Drivers Went Wrong” (Morena and Leix, 2012)
- Wrong Way Driving, Highway Special Investigation Report (NTSB, 2012)
- “Stop. You’re Going The Wrong Way!” (Moler, 2002)

The team developed the toolbox as a standalone document entitled, “Wrong Way Driving Toolbox: A Resource of Engineering Strategies to Reduce Wrong Way Movements at Freeway Interchanges.” The toolbox focuses on engineering strategies to prevent wrong way driving. Other types of efforts to decrease wrong way driving, such as enforcement and education, would be beneficial, particularly related to drunk driving (a major factor in wrong way driving), but were not covered in the toolbox.

Additionally, the strategies in the toolbox were focused on changes that can be made to individual freeway interchanges to reduce wrong way movements. Strategies such as a corridor-level monitoring and manned response teams are not included. It was assumed that MUTCD-required features such as DO NOT ENTER and ONE WAY signs are already present.

The toolbox is included as a separate document delivered with this final report.

Identification of Priority Interchanges

The first step to identifying priority locations was to review data for wrong way crashes to determine (if possible) the point at which the driver entered the freeway the wrong way and to identify characteristics of the crash (i.e., day vs. nighttime).

Crash Report Review

NCDOT had already identified wrong way crashes in past years based on automated searches and manual inspection of crash reports. The team obtained the list of crash IDs for wrong way crashes from

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NCDOT and used the NCDMV Crashweb to obtain copies of the police reports for each crash. Pursuant to the direction given by the steering committee, this consisted of wrong way crashes from 2000 to 2013 in the five priority counties (Mecklenburg, Wake, Forsyth, Guilford, Durham) for a total of 129 crashes examined. The following tables provide a descriptive summary of the wrong way crashes examined in this task. The list of all crashes with details and notes can be found in Appendix A.

Table 1. Wrong Way Crashes by Severity

Severity	Number of Crashes
Fatal	23
Injury	60
PDO	46
Total	129

Table 2. Wrong Way Crashes by County

County	Number of Crashes
Mecklenburg	42
Forsyth	29
Wake	27
Durham	16
Guilford	15
Grand Total	129

Table 3. Wrong Way Crashes by Light Condition

Light Condition	Number of Crashes
Dark	98
Light	31
Grand Total	129

Table 4. Wrong Way Crashes by Alcohol Involvement

Alcohol Involved	Number of Crashes
No	61
Yes	68
Grand Total	129

The team examined the police reports for each of these crashes to determine what information on the probable or possible entry point could be gained from the sketch, narrative, and other details. The most conclusive information regarding wrong way entry point came from the sketch and/or narrative. Figure 1 shows an example sketch and narrative from a crash where the wrong way entry point was clearly

apparent. In the 19 crashes where the wrong way entry point could be identified, it was commonly the case that the crash occurred on or near the ramp. Most of these involved drivers who had just begun their wrong way movement.

I-77 NORTH EXIT RAMP TO SUNSET ROAD

DIRT SHOULDER

DIRT SHOULDER

Vehicle 1 was: Traveling Parked Facing N S E W on I-77 EXIT RAMP

Vehicle 2 was: Traveling Parked Facing N S E W on I-77 EXIT RAMP

65 NARRATIVE (Include pertinent and unusual aspects, which are not listed elsewhere on the form)

VEHICLE 1 WAS TRAVELING SOUTHBOUND IN THE NORTHBOUND TRAVEL LANE OF I-77'S EXIT RAMP TO SUNSET ROAD. THE DRIVER OF VEHICLE 2 SAW THE VEHICLE HEADING TOWARD HER AND SHE ATTEMPTED TO AVOID CONTACT WITH HIM. SHE WAS UNABLE TO AVOID CONTACT AND THEY HIT (LOW IMPACT). BOTH VEHICLES PULLED OVER TO THE SHOULDER.

Figure 1. Example Crash Report Where Entry Point Could Be Identified

In many of the crashes, the sketch and/or narrative did not provide information about the wrong way driver's entry point. Figure 2 shows an example sketch and narrative from a wrong way crash that did not occur near the driver's entry point, but rather after the driver had been driving the wrong way for some longer amount of time. In these cases, the team could not identify the wrong way entry point and examined other data about the crash to determine if any assumptions could be made about the entry point. In some cases, the crash occurred near the wrong way driver's home address, and the team could make assumptions about the most likely route between the home and crash locations to identify potential interchanges that would be eligible for field visit investigations. The team recognizes that this identification of interchanges was highly subjective and kept notes on which interchanges were identified for investigation due to "definite" knowledge of wrong way entry and which ones were only "likely" or "possibly" related to wrong way entry. Those distinctions can be seen in the list of interchanges in Appendix B.

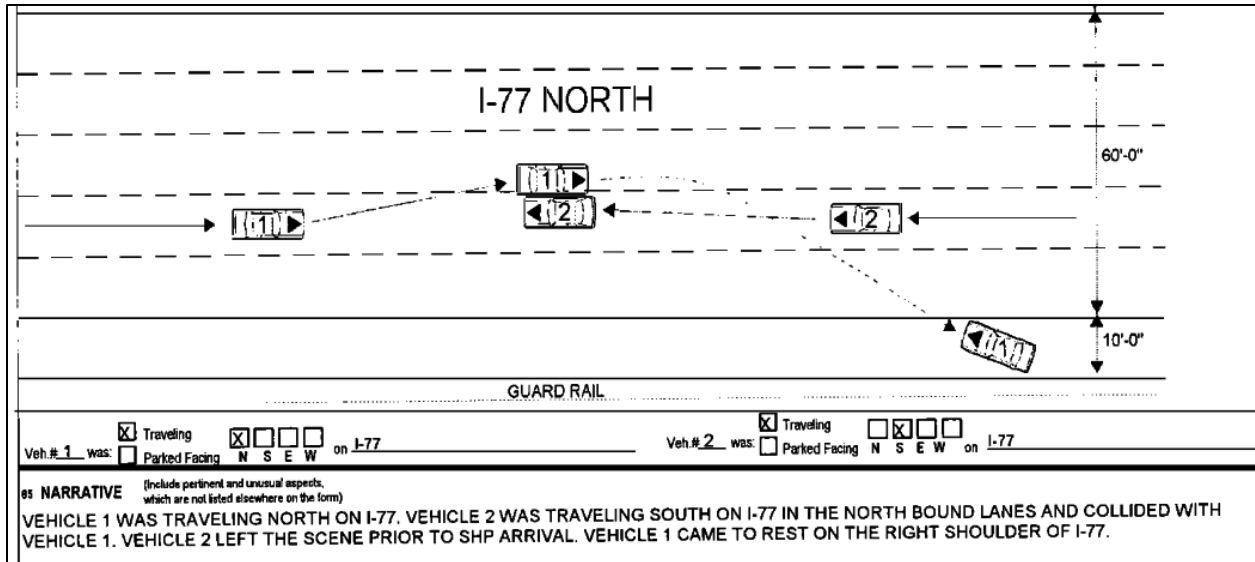


Figure 2. Example Crash Report Where Entry Point Could Not Be Identified

Out of the 129 crashes examined, the team could conclusively identify the wrong way entry point for only nineteen (Table 5). Eleven crashes were not considered in this effort to identify priority interchanges due to the fact that the events surrounding those crashes were out of the scope of this project. These largely included crashes that occurred when a driver crossed the median or turned around in the road, rather than wrong way entries at ramp terminals. Although these crashes still represent a highway safety problem, they could not be reliably related to corrective measures at the ramp terminals, which is the focus of this project.

Table 5. Wrong Way Crashes by Entry Point Identification

Entry Point Identification	Number of Crashes
N – Could not be identified	99
Y – Could be identified	19
N/A – Out of scope*	11
Grand Total	129

* Some crashes were due to a wrong way movement that did not originate at a ramp or occurred under conditions that fell outside the scope of the corrective measures sought in this project.

Video Data Review

Steering Committee Chairman Chris Oliver sent the team video data that had been taken at several interchanges in Guilford County. These locations included:

- I-40 WB/I-85 SB Ramps and SR 3045 (Mt. Hope Church Rd)-Exit 132
- I-40 EB/I-85 NB Ramps and SR 3056 (Rock Creek Dairy Rd)-Exit 135

Additionally, the following interchanges were highlighted as being of potential concern for wrong way driving:

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- I-40 EB Ramps and NC 68-Exit 210
- I-40 EB Ramps and SR 1541 (Wendover Ave)-Exit 214)

These location were selected for video filming due to concerns from the NCDOT division about wrong way movements at these locations. The team reviewed the video and took note of the wrong way movements and the characteristics of the ramp terminal intersections. This experience was helpful in developing the methodology for the field visits. The team also included two of these interchanges (I-40 and Mt. Hope Church; I-40 and Rock Creek Dairy Rd) on the priority list of field visits.

Law Enforcement Data Review

The team also communicated with law enforcement (NC State Highway Patrol and local law enforcement) to gather additional input regarding priority locations. The team desired to pursue this avenue of information to supplement the information gained from the crash reports, knowing even early on that most wrong way entry points would not be identifiable through crash report information alone. The team pursued information from law enforcement agencies through two means – obtaining and examining supplemental records and conducting interviews with law enforcement personnel.

Law Enforcement Supplemental Records

The team worked with Steering Committee Member Major Freddy Johnson to obtain any files kept by NCSHP for the wrong way crashes that were reported by their agency. The team provided Maj. Johnson with a list of the wrong way crashes, and he made a centralized request and forwarded to the Patrol troops in the areas of interest. Several weeks were needed for the request to be completed, and a large amount of information was obtained. Upon examining the supplemental documents, the team found that the troopers tended to compile a variety of information, including crash drawings and distances, driver contact information, alcohol test results, and statements by witnesses. The crash report form was almost always provided. In some crashes there were numerous photographs, including the damaged vehicles and where the crash occurred.

Most of the witness information pertained to what happened in the crash (e.g., “all of a sudden I realized the car was coming directly at me”). It was rare that a witness had any thoughts about the entry point for the wrong-way driver. Occasionally a trooper would offer an opinion as to where the wrong-way driver entered the roadway, but it was obvious this was very difficult to determine. The most complete information was contained in reports prepared by crash reconstruction units, and some of these exceeded 100 pages. These included much information about the crash dynamics and many photographs.

It required many hours to examine all of the information provided, and many crashes were provided multiple times by various troopers. In the end, there was little information to be gained about the entry point of wrong way crashes. What information was uncovered typically was already available on the crash report form and did not substantially change the selection of priority interchanges for field visits.

Interviews with State Highway Patrol and Local Police

The team also conducted interviews with personnel of the North Carolina State Highway Patrol and local police departments to obtain their thoughts on issues and possible treatments relating to wrong-way crashes on freeways and interstates. The interviews were focused on the selected counties of interest and cities within the counties. Conversations were held with experienced members of the patrol and

police or with personnel who had recently been involved in the investigation of a wrong-way crash. The team also attempted to talk with personnel from crash reconstruction teams where possible.

The law enforcement personnel interviewed identified several issues that affect wrong way driving:

- Wrong-way crashes happen in a variety of ways, and many factors are involved. All of the interviewees agreed that alcohol, drugs, confusion of elderly drivers, and darkness were problems.
- Most wrong-way crashes appear to be associated with diamond interchanges and entering from the wrong ramp. However, newer interchanges, such as the diverging diamond and single point urban interchange, could be confusing to drivers and lead to incorrect maneuvers. Distracted driving, along with alcohol, drugs, and confusion, can be contributors.
- Partial cloverleaf interchanges are a problem with side-by-side ramps.
- Drivers sometimes mistakenly turn down a wrong-way ramp when they are attempting to turn onto a local road or street close to the interchange ramps.
- Wrong-way crashes can occur when drivers make a u-turn, either within the roadway or across a grass median to get to a wrong-way ramp. Through medians designed for use by patrol, police or other emergency providers are sometimes used.
- Dark, unfamiliar locations can be a problem for the elderly and those impaired.
- Some feel that wrong-way maneuvers are suicide attempts

In discussing what could be done to alleviate wrong-way crashes, the law enforcement personnel shared their thoughts on ways to prevent wrong way driving:

- STOP – TURN AROUND signs were mentioned by many interviewees. These are now being tested by the NCDOT and were seen in a field trip to Guilford County interchanges. They recommend using flashing lights and reflectors if possible.
- For WRONG WAY, DO NOT ENTER, or the STOP – TURN AROUND signs mentioned above, a number of people commented that flashing light systems sometimes used for 4-way stop signs could be used to bolster the effect. Some suggested using solar power for the signs. Highly visible signs with flashing lights activated by sensor were suggested. Increasing the number of signs to top, middle and bottom of ramp might also help.
- Continue use of the wrong-way arrows with reflectors.
- Use adequate lighting, especially at complicated interchanges or locations with side-by-side ramps. Continue to use in-pavement reflectors.
- Use overhead signs at locations that are potentially confusing or problematical. An example would be mounting a wrong-way warning sign on the back of an overhead guide sign at mid-ramp when traveling wrong-way on a ramp (e.g., at the single point urban interchange at Southpoint Mall in Durham County).
- Rumble strip crossings on ramps could be beneficial, particularly if designed so that the crossing would be quiet if traveling in the correct direction and noisy if wrong way. Consider other noise makers (e.g., “half balls”) or rough pavement to alert drivers.

- Designing the on ramp more abruptly to require more than a 90 degree turn could help at partial cloverleaf interchanges or other designs with side-by-side ramps. Make the wrong-way maneuver difficult.
- Employ raised medians near ramps and extend the raised median past the exit ramp (the wrong-way ramp) to near the appropriate entry ramp could prevent wrong-way left turns.
- Use dashed, painted and reflectorized lines to guide correct pathway. Bollards could be used in extreme situations.
- Although not without problems, many thought that use of tire shredders on wrong-way ramps would be an effective way to prevent these often catastrophic events. It was noted that these would require warning signs and could be problematic for emergency responders.

Using the information gained through the examination of crash data, input from law enforcement, and videos obtained from NCDOT, the team developed a list of priority interchanges to be investigated through field visits. A draft version of the list was sent to NCDOT and subsequently approved. The list of priority interchanges is presented in Appendix B.

Conduct Field Investigations

The team began this task by developing a field data collection form, based on several existing forms discovered during the literature review and state-of-practice review, such as the FHWA Wrong Way Driving Audit. The team used this form on a pilot field visit in March to three interchanges in the Durham area and revised it based on experiences in the field. The pilot field visits also provided the opportunity to determine what elements could be seen in the field and to determine how the remaining field visits would be conducted. The team determined that the field visits were useful in experiencing the approaches to the interchange from the driver's perspective and helpful in identifying potentially confusing factors which could lead to wrong way driving. Based on the pilot field visit, the team revised the data collection form and determined the method/protocol for how the remaining field visits would be conducted.

The team conducted site visits to all identified interchanges, using the modified data collection form and procedure developed during the pilot site visits. Each site visit consisted of team members driving the site multiple times from each direction, collecting information on characteristics of both ramp terminal intersections, and developing in-field recommendations for improvements to each intersection to reduce wrong way movements.

Site visits were conducted on the following days:

- April 4: Durham and Wake county sites
- April 17: Wake county sites
- May 15: Wake county sites
- May 27: Forsyth county sites
- May 30: Guilford county sites
- June 29: Mecklenburg county sites

Six sites in Durham and Wake counties were visited at night to better understand the potential issues facing drivers in dark hours. These sites were selected for night visits due to the fact that they were identified as related to a wrong way crash that occurred at night. The nighttime conditions provided a different perspective on the site (i.e., which elements are most influential or confusing in a dark environment). However, the team determined that the nighttime condition also created a difficulty in the team's ability to assess the interchange and ramp terminal fully, in terms of identifying the presence of pavement markings, medians, and islands.

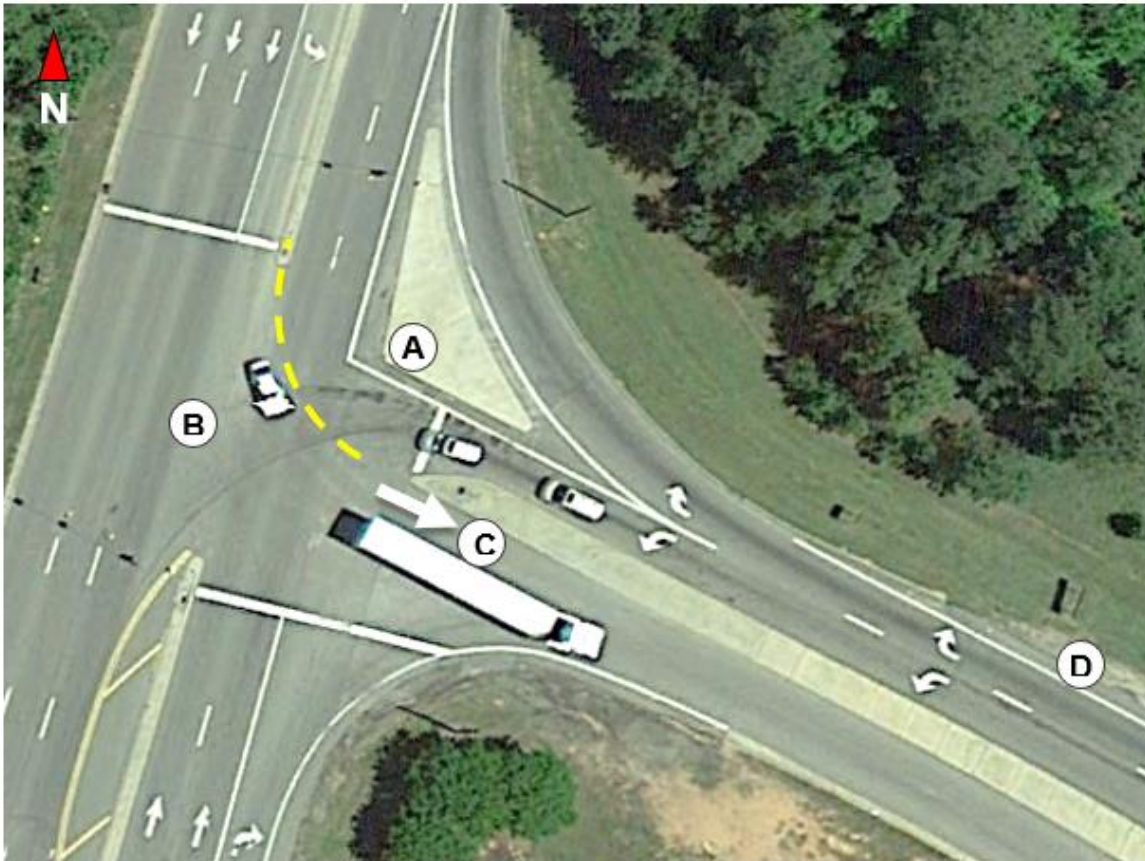
Identify Problem Factors and Produce Recommendations

At each site visit, the team used a data collection form to note specific characteristics, such as presence of medians, markings, and signs. An example form is presented in Appendix C. The team also took printed aerial maps of each site to draw specific recommendations on the map. These recommendations were converted to electronic drawings later to serve as one of the main deliverables of the research project (Appendix D).

As directed by the steering committee, the team focused the recommendations on low cost strategies having to do with signs, markings, and geometrics. Higher cost measures, such as active detection with monitoring responder staff, were not considered.

As shown in Figure 3, the team recommendations are provided as numbered indications on the overhead aerial map of each ramp terminal intersection. The placement of the circled letter indicates the location where the improvement is recommended, and the explanation of each improvement is listed below the photo.

I-40 WB Exit Ramp at Miami Blvd.



- A. Add Do Not Enter sign to splitter island**
- B. Add dotted lane line extension through intersection (yellow)**
- C. Add arrow indicating correct freeway entrance point**
- D. Add wrong way arrows with markers (crystal/red). Large Wrong Way ramp arrow with markers should be located just before multi-lane approach.**

Figure 3. Example of Wrong Way Prevention Recommendations

FINDINGS AND CONCLUSIONS

Entry point

Identifying the location where a wrong way driver entered the freeway was a difficult task and typically not possible. There was little information available in the crash report or from law enforcement records. Out of 129 wrong way crashes examined in this project, the entry point could be identified only for 19 of them.

Identifying Priority Interchanges

Even with the rarity of wrong way crashes and the scarcity of information on the wrong way entry point, the team was able to identify a good number of priority interchanges for further inspection. This

identification was based on known wrong way entry points combined with supplemental information on driver address and input from law enforcement. This information led to the identification of 34 interchanges that were visited in the field. This included 18 interchanges that were definitely associated with a wrong way entry, six interchanges that were likely related to wrong way entry, and 10 interchanges that had a possibility of being related to wrong way entry.

Infrastructure changes to reduce wrong way driving

The team was able to identify recommended changes to the signs, markings, or geometrics of most interchanges visited in this project. For some interchanges, the potential for improvement was readily apparent, such as a lack of extended turn lane lines or a space that allowed for wrong way left turns that could be mitigated by extending or installing a median. For some interchanges, there was not an apparent lack of guidance, channelization, or signing, and the recommendations for these locations were minimal.

RECOMMENDATIONS

The recommendation modifications to the selected interchanges are presented in Appendix D. Each interchange is presented as a set of pages that include aerial images with recommended improvements indicated on the image, street level imagery, and a set of completed data collection forms that indicate which wrong way risk factors were present.

The research team examined each ramp intersection to determine the factors most likely to lead to wrong way movements and recommended one or more options for reducing the likelihood of those movements. Although the recommendations included low cost improvements such as sign and marking additions, the team prefers that wrong way movements be prevented through “hard” countermeasures, such as median additions and extensions. These types of countermeasures are more likely to prevent wrong way driving, especially for incidents where the driver is intoxicated or confused. Additionally, these countermeasures have a much longer service life compared to signs and markings.

The most common recommendations found in Appendix D include:

- Addition of median or extension of existing median to prevent or reduce the potential space for a wrong way left turn from the cross street;
- Addition of dotted lane line extensions to guide left turning drivers to the appropriate freeway entry point (when entrance and exits ramps enter the cross street directly adjacent to each other);
- Addition of pavement arrow to indicate the correct entry point to the freeway (i.e., at mouth of entrance ramp); and
- Addition of wrong way signs or wrong way arrows.

Although this project focused on infrastructure improvements, the research team also recommends that NCDOT consider the following non-infrastructure strategies to address the problem of wrong way driving from a comprehensive highway safety approach.

- Work with developers of motor vehicle navigation systems (GPS devices) to develop and/or improve features that give a warning if the driver is making a wrong-way maneuver. Several auto manufacturers have begun integrating this feature into their GPS-based guidance systems.
- Develop media spots to alert public to the problem. Make beginning drivers aware of the problem in driver education programs. Use videos at DMV and driver license renewal locations.
- Start instruction about wrong-way driving in driver education classes. Develop videos to illustrate how the wrong-way maneuvers can take place. Use these and perhaps other safety videos in locations such as driver license offices. The videos could be run on a continuous loop.
- Given that alcohol involvement is so prevalent in wrong way crashes, work with legislators to develop tougher driving-while-impaired sanctions. There may be some movement for this, as Utah recently lowered their alcohol limit to 0.05, touted as the strictest drunk driving law in the nation.

IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

The team recommends that regional safety engineers and division traffic engineers should be the primary audience for implementing the findings and recommendations of this project.

Toolbox - The toolbox of strategies to prevent wrong way strategies should be sent to each division and district office as a resource for engineers as they seek to improve safety of ramp terminal intersections. The toolbox should also serve as a resource to the design offices of these divisions and the central office design unit as they consider how geometric design can be used to reduce the potential for wrong way driving.

Recommended Improvements – The improvements to signs, markings, and geometrics that are presented for each interchange in Appendix D are grouped by county. These recommendations should be sent to the respective division office for their information and review. The division engineers should be encouraged to consider the recommended improvements and how they can be implemented to reduce the potential for wrong way driving.

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APPENDIX A. WRONG WAY CRASHES EXAMINED

This appendix presents details on each of the 129 wrong way crashes examined in this project. The severity, alcohol involvement and light condition of each crash is noted, as well as indications of whether the entry point of the crash could be identified by the research team.

CRSH_ID	County	Severity	Alcohol Invlv.	Entry Point Known	Light	Notes
101266682	Durham	PDO	No	Y	Dark	Entry: I-85 and Duke St (at crash location)
100033518	Forsyth	Fatal	No	Y	Dark	Entry at I-40Bus and NC 66 (Exit ramp from I-40Bus EB)
100066277	Forsyth	PDO	Yes	Y	Dark	Entry at I-40Bus and NC 66 (Exit ramp from I-40Bus EB)
100850822	Forsyth	PDO	No	Y	Light	Entry I-40Bus and Cloverdale (Exit ramp from I-40Bus WB)
100550993	Forsyth	Fatal	Yes	Y	Dark	US 421 at Lewisville Clemmons Rd (Exit ramp from US 421 WB)
101043956	Guilford	Injury	Yes	Y	Dark	Entry at crash location, I-40 and Gallimore Dairy (WW on exit ramp from I-40Bus EB)
102516039	Guilford	PDO	Yes	Y	Dark	Entry at I-40Bus and Gallimore Dairy (WW on exit ramp from I-40Bus WB).
103050005	Guilford	PDO	No	Y	Dark	Entry: Summit and Phillips (US 29 SB off ramp)
100353420	Mecklenburg	Fatal	Yes	Y	Dark	Definite entry at I-77 and NC 73 (Exit ramp from I-77 NB)
100991447	Mecklenburg	Injury	Yes	Y	Light	Entry at I-77 and Sunset (Exit ramp from I-77 NB)
100364121	Mecklenburg	Injury	Yes	Y	Dark	Entry at I-85 and Sam Wilson Rd (Exit ramp from I-85 NB, left turn from Sam Wilson)
101188494	Wake	PDO	No	Y	Dark	Entry at Saunders interchange (WW on exit ramp from I40 WB)
101395793	Wake	PDO	No	Y	Dark	Entry: Airport Rd interchange (site of crash). WW driver was SB, made left onto exit.
100482121	Wake	PDO	No	Y	Dark	Entry: Falls of Neuse interchange off-ramp (specific ramp unknown).
101530386	Wake	Injury	No	Y	Light	Entry: Gorman Rd interchange (SB Gorman, left turn to I-40 exit ramp)
101152577	Wake	PDO	No	Y	Light	Entry: US 1 and Ten Ten (NB off ramp)
101639076	Wake	Injury	No	Y	Light	Entry: US 1 at NC 55 (US 1 NB off ramp)
101068583	Wake	PDO	Yes	Y	Dark	Entry: US 1 at Ten Ten (NB off ramp)
100756808	Durham	Fatal	No	N	Dark	Entry point unknown.

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CRSH_ID	County	Severity	Alcohol Invlv.	Entry Point Known	Light	Notes
102976768	Durham	Fatal	Yes	N	Dark	Entry point unknown. Likely: US 70 and Holloway (based on driver home address and design)
100420567	Durham	Injury	Yes	N	Dark	Entry point unknown. Likely: US 70 and Holloway, US 70 and Cheek (based on proximity and design)
103364607	Durham	Injury	No	N	Dark	Entry point unknown. No likely possibilities.
102176317	Durham	PDO	No	N	Dark	Entry unknown, self-reported
102176531	Durham	Injury	Yes	N	Dark	Entry unknown.
100543561	Durham	Injury	Yes	N	Dark	Entry unknown.
102020257	Durham	Injury	No	N	Light	Entry unknown.
100124806	Durham	PDO	Yes	N	Dark	Entry unknown.
102264665	Durham	Injury	No	N	Light	Entry unknown. Alzheimer situation likely.
101833413	Durham	Fatal	No	N	Dark	Entry unknown. Higher potential on interchanges to the east.
103628730	Durham	Injury	No	N	Dark	Entry unknown. Very likely could find more info in police incident notes. CMV driver.
101953209	Durham	Injury	Yes	N	Dark	Entry: Fayetteville Rd most likely (driver address).
101953183	Durham	PDO	No	N	Dark	Entry: Likely Miami interchange (phantom).
100104737	Forsyth	Injury	Yes	N	Dark	Entry unknown (but definitely not Lewisville Clemmons)
100009520	Forsyth	PDO	No	N	Dark	Entry unknown (swerved to avoid phantom WW driver)
102540036	Forsyth	Injury	Yes	N	Dark	Entry unknown (traveled at least 6 mi WW before crash according to report)
100067464	Forsyth	Fatal	No	N	Dark	Entry unknown.
100778923	Forsyth	Fatal	Yes	N	Dark	Entry unknown.
100608960	Forsyth	PDO	Yes	N	Dark	Entry unknown.
101201167	Forsyth	Injury	Yes	N	Dark	Entry unknown.
102313455	Forsyth	Injury	No	N	Dark	Entry unknown.
103600903	Forsyth	Injury	No	N	Dark	Entry unknown.
103139648	Forsyth	Injury	Yes	N	Dark	Entry unknown.
102206540	Forsyth	Fatal	Yes	N	Dark	Entry unknown.
100091982	Forsyth	Fatal	No	N	Dark	Entry unknown.
101567941	Forsyth	PDO	Yes	N	Dark	Entry unknown.
101222881	Forsyth	Fatal	Yes	N	Dark	Entry unknown.

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CRSH_ID	County	Severity	Alcohol Invlv.	Entry Point Known	Light	Notes
103213778	Forsyth	PDO	Yes	N	Dark	Entry unknown.
102891459	Forsyth	PDO	No	N	Dark	Entry unknown.
101769478	Forsyth	Injury	Yes	N	Dark	Entry unknown.
102698385	Forsyth	PDO	Yes	N	Dark	Entry unknown.
103227709	Forsyth	PDO	Yes	N	Dark	Entry unknown.
100930729	Forsyth	PDO	No	N	Dark	Entry unknown.
102134168	Forsyth	PDO	No	N	Dark	Entry unknown.
100922553	Forsyth	Injury	Yes	N	Dark	Entry unknown.
103143509	Forsyth	PDO	Yes	N	Dark	Entry unknown. Intentional spin out by police.
102162674	Forsyth	Injury	No	N	Dark	Likely entry at US 52 and Moore-RJR Dr (based on driver address and likely path)
103542419	Guilford	PDO	No	N	Dark	Entry unknown (this is collision related to WW driving incident)
101982265	Guilford	Fatal	Yes	N	Dark	Entry unknown, but more than 0.25 miles south of crash location based on witness.
103648058	GUILFORD	INJURY	NO	N	Dark	Entry unknown.
101760999	Guilford	Fatal	Yes	N	Dark	Entry unknown.
102769884	Guilford	PDO	No	N	Light	Entry unknown.
100309425	Guilford	Injury	Yes	N	Light	Entry unknown.
101176871	Guilford	Fatal	Yes	N	Light	Entry unknown.
101863528	Guilford	PDO	No	N	Light	Entry unknown.
101638639	Guilford	Injury	No	N	Dark	Entry unknown.
103435096	Guilford	Injury	No	N	Light	Entry unknown.
100203545	Guilford	Fatal	No	N	Light	Entry unknown. Most likely is US 401 at Gate City Blvd based on driver address and likely path.
101266266	Guilford	Fatal	Yes	N	Dark	Possible entry at NC 68 / I-40 interchange (to the west from here)
101860713	Mecklenburg	PDO	No	N	Dark	Entry unknown (phantom WW driver)
103444095	Mecklenburg	Injury	No	N	Dark	Entry unknown (phantom WW driver)
102040059	Mecklenburg	PDO	No	N	Light	Entry unknown, but report references "at least 0.6 miles, from Beatties Ford Rd"
103360544	Mecklenburg	Injury	Yes	N	Dark	Entry unknown.
103223636	Mecklenburg	Injury	Yes	N	Dark	Entry unknown.
101235106	Mecklenburg	Injury	Yes	N	Dark	Entry unknown.
103786175	Mecklenburg	Fatal	YES	N	Dark	Entry unknown.
103941982	Mecklenburg	Injury	YES	N	Dark	Entry unknown.

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CRSH_ID	County	Severity	Alcohol Invlv.	Entry Point Known	Light	Notes
103731104	Mecklenburg	Injury	NO	N	Dark	Entry unknown.
103941840	Mecklenburg	Injury	YES	N	Dark	Entry unknown.
103019127	Mecklenburg	PDO	Yes	N	Light	Entry unknown.
103177319	Mecklenburg	Injury	Yes	N	Dark	Entry unknown.
102912987	Mecklenburg	Injury	Yes	N	Dark	Entry unknown.
102481649	Mecklenburg	PDO	Yes	N	Dark	Entry unknown.
101622634	Mecklenburg	Fatal	Yes	N	Dark	Entry unknown.
102008336	Mecklenburg	Injury	No	N	Light	Entry unknown.
100814996	Mecklenburg	PDO	No	N	Light	Entry unknown.
102760243	Mecklenburg	Injury	Yes	N	Light	Entry unknown.
100094670	Mecklenburg	Injury	Yes	N	Dark	Entry unknown.
100088783	Mecklenburg	PDO	No	N	Light	Entry unknown.
100025310	Mecklenburg	Injury	No	N	Dark	Entry unknown.
102785384	Mecklenburg	Injury	Yes	N	Dark	Entry unknown.
103486905	Mecklenburg	Injury	Yes	N	Dark	Entry unknown.
101686472	Mecklenburg	Fatal	Yes	N	Dark	Entry unknown.
101400257	Mecklenburg	PDO	No	N	Dark	Entry unknown.
102283959	Mecklenburg	Injury	No	N	Dark	Entry unknown.
101287796	Mecklenburg	Fatal	No	N	Dark	Entry unknown.
100893518	Mecklenburg	Injury	Yes	N	Dark	Entry unknown.
102007849	Mecklenburg	Injury	No	N	Light	Entry unknown.
100779750	Mecklenburg	Injury	Yes	N	Dark	Entry unknown.
100797390	Mecklenburg	PDO	Yes	N	Dark	Entry unknown.
100700255	Mecklenburg	PDO	No	N	Dark	Entry unknown. Came from I-85 though.
103718894	Mecklenburg	PDO	YES	N	Dark	Possible entry at I-485 and Idlewild, based on driver address.
101894857	Mecklenburg	PDO	No	N	Dark	Entry unknown
100749156	Wake	Injury	Yes	N	Light	Entry unknown
100797047	Wake	PDO	No	N	Dark	Entry unknown, but WW driving on this on ramp. May have turned around on ramp to begin WW driving.
103193316	Wake	Injury	Yes	N	Dark	Entry unknown.
102625771	Wake	Injury	Yes	N	Light	Entry unknown.
102173210	Wake	Injury	Yes	N	Dark	Entry unknown.
102574049	Wake	PDO	No	N	Dark	Entry unknown.
102798950	Wake	Injury	Yes	N	Dark	Entry unknown.
100431710	Wake	Injury	No	N	Light	Entry unknown.
102902858	Wake	Injury	No	N	Dark	Entry unknown.

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CRSH_ID	County	Severity	Alcohol Invlv.	Entry Point Known	Light	Notes
103498604	Wake	Fatal	No	N	Dark	Entry unknown.
100136803	Wake	PDO	No	N	Light	Entry unknown. No chance of police records here.
101711511	Wake	PDO	Yes	N	Dark	Entry unknown.
102127213	Wake	Injury	Yes	N	Dark	Entry unknown.
100697578	Wake	Injury	No	N	Light	Entry unknown.
101791138	Wake	Injury	Yes	N	Light	Entry: Possibly Saunders, Hammond, or Rock Quarry (based on driver address and direction)
100409406	Durham	Fatal	Yes	N/A	Dark	Non-interchange entry (crossed through cable median barrier)
103687949	Forsyth	Fatal	No	N/A	Dark	Turned around on interstate
101036956	Mecklenburg	PDO	No	N/A	Light	Entry at I-77 and LaSalle, but it was a change of mind (vehicle backing up entrance ramp)
100102861	Mecklenburg	Injury	Yes	N/A	Dark	Not a wrong way crash (according to officer)
100258049	Mecklenburg	PDO	No	N/A	Dark	Not a wrong way driving crash (immobile vehicle following another wreck)
103107465	Mecklenburg	PDO	Yes	N/A	Dark	Out of scope. Not a freeway.
100235955	Mecklenburg	PDO	No	N/A	Light	Out of scope. Turned around in road.
101553521	Wake	PDO	No	N/A	Light	Crossed median at site of crash.
102577023	Wake	Injury	Yes	N/A	Dark	Out of scope - fleeing police
101253905	Wake	Injury	Yes	N/A	Light	Out of scope (fleeing hit and run crash, did not enter freeway)
101952509	Wake	Injury	Yes	N/A	Dark	Out of scope. Fleeing PD, turned around in interstate.
100482120	Wake	Injury	No	N/A	Light	Stopped vehicle. Not a WW crash.

APPENDIX B. LIST OF SELECTED PRIORITY INTERCHANGES

This appendix presents the list of 35 interchanges that were selected for field investigation based on association with wrong way crashes. The “Level of Certainty” field indicates whether the interchange was definitely related to a wrong way crash (i.e., clearly apparent from the crash report), likely related to a wrong way crash (i.e., crash occurred in close proximity to the interchange and other indications point to the involvement of the interchange), or only possibly related to a wrong way crash (i.e., the route between the driver’s home address and the crash location would involve the interchange).

County	Interchange	Ramp where WW entry occurred	Crashes Associated	Level of Certainty	Visited	Notes
Durham	I-40 and Fayetteville Rd	Exit ramp from I-40 EB	101953209	Possible	4/4/2017 (in dark)	Based on driver address and likely path
Durham	I-40 and Miami Blvd		101953183	Likely	4/4/2017 (in dark)	
Durham	I-85 and Duke St	Exit ramp from I-85 SB	101266682	Definite	3/21/2017 (day), 4/4/17 (in dark)	
Durham	I-85 and E. Club Blvd		Recent crash – ID not yet assigned	Likely	4/4/2017 (in dark)	Based on conversation with Law Enforcement and recent crash (March 2017)
Durham	US 70 and Cheek Rd		100420567	Possible	4/4/2017 (in dark)	Based on proximity and design
Durham	US 70 and Holloway St		102976768	Possible	3/21/2017	Based on driver address, likely path, and design
Durham	US 70 and Holloway St		100420567	Possible	3/21/2017	Based on proximity and design
Forsyth	I-40 Bus/US 421 and NC 66	Exit ramp from I-40Bus EB	100066277	Definite	5/27/2017	Yes, two crashes on same ramp
Forsyth	I-40 Bus/US 421 and NC 66	Exit ramp from I-40Bus EB	100033518	Definite	5/27/2017	Yes, two crashes on same ramp

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County	Interchange	Ramp where WW entry occurred	Crashes Associated	Level of Certainty	Visited	Notes
Forsyth	I-40Bus and Cloverdale Ave	Exit ramp from I-40Bus WB	100850822	Definite	5/27/2017	
Forsyth	US 421 and Lewisville Clemmons Rd	Exit ramp from US 421 WB	100550993	Definite	5/27/2017	
Forsyth	US 52 and Moore-RJR Rd	Exit ramp from US 52 NB	102162674	Likely	5/27/2017	Based on driver address, proximity, and likely path
Guilford	I-40 and Gallimore Dairy Rd	Exit ramp from I-40 WB	102516039	Definite	5/30/2017	
Guilford	I-40 and Gallimore Dairy Rd	Exit ramp from I-40 EB	101043956	Definite	5/30/2017	
Guilford	I-40 and Mt. Hope Church	Exit ramp from I-40 WB	none	Likely	5/30/2017	NCDOT took video of this location
Guilford	I-40 and NC 68		101266266	Possible	5/30/2017	
Guilford	I-40 and Rock Creek Dairy	Exit ramp from I-40 EB	none	Likely	5/30/2017	NCDOT took video of this location
Guilford	US 29 and Summit and Phillips	Exit ramp from US 29 SB	103050005	Likely	5/30/2017	
Mecklenburg	Brookshire Frwy and Beatties Ford Rd	Exit ramp from Brookshire WB	102040059	Possible	6/29/2017	Report references WW driving for "at least 0.6 miles (From Beatties Ford Rd)"
Mecklenburg	I-485 and Idlewild Rd	Exit ramp from I-485 SB	103718894	Possible	6/29/2017	Based on driver address, proximity, and likely path
Mecklenburg	I-74 and Briar Creek	Exit ramp from I-74 EB	101894857	Possible	6/29/2017	Based on driver address and likely path
Mecklenburg	I-77 and NC 73/Sam Furr Rd	Exit ramp from I-77 NB	100353420	Definite	6/29/2017	
Mecklenburg	I-77 and Sunset Rd	Exit ramp from I-77 NB	100991447	Definite	6/29/2017	
Mecklenburg	I-85 and Sam Wilson Rd	Exit ramp from I-85 NB	100364121	Definite	6/29/2017	

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County	Interchange	Ramp where WW entry occurred	Crashes Associated	Level of Certainty	Visited	Notes
Wake	I-40 and Airport Rd	Exit ramp from I-40 WB (left turn from SB Airport)	101395793	Definite	3/21/2017	
Wake	I-40 and Gorman St	Exit ramp from I-40 WB (left turn from SB Gorman)	101530386	Definite	5/15/2017	
Wake	I-40 and Rock Quarry		101791138	Possible	5/15/2017	Based on driver address and likely path
Wake	I-40 and Saunders St	Exit ramp from I-40 WB	101188494	Definite	5/15/2017	
Wake	I-40 and Saunders St	Entrance ramp to I-40 EB	100797047	Definite	5/15/2017	Entry unknown, but WW driving on this ramp. May have turned around on ramp to begin WW driving.
Wake	I-40 and Saunders St		101791138	Possible	5/15/2017	Based on driver address and likely path
Wake	I-440 and Wake Forest Rd	Exit ramp entry	RPD P16058783	Definite	4/17/2017	Interchange identified by Raleigh Police as being associated with an October 2016 wrong way crash.
Wake	I-540 and Falls of Neuse	Exit ramp (exact ramp unknown)	100482121	Definite	4/17/2017	
Wake	US 1 and NC 55	Exit ramp from US 1 NB	101639076	Definite	5/15/2017	
Wake	US 1 and Ten Ten Rd	Exit ramp from US 1 NB	101152577 and 101068583	Definite	5/15/2017 (day), 7/10/17 (dark)	two crashes on same ramp

APPENDIX C. EXAMPLE FIELD VISIT DATA COLLECTION FORM

Date:	County:
Interchange:	
Location (exit ramp):	

Feature	Presence	Visibility	Notes or Potential Modifications
Wrong way sign			Location: Reflective strip?:
Wrong way arrows			
Do not enter sign			
One way			
No right turn			
No left turn			
Freeway entrance signs			
Dashed turning guide lines			
Stop bar at end of exit ramp			
If entrance and exit ramps are directly adjacent to each other:			
Median between			
Splitter sign on median between			
Barrier between			

Geometrics			
Feature	Presence	Visibility	Notes or Potential Modifications
Splitter island between directions of exit ramp	Type:		

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Raised median on crossroad			
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Other Questions	Yes/No	Notes
Sign clutter creates potential confusion?		
Barrier obscuring view of entrance ramp?		
Lighting possibly contributing to WW entry?		
Corner radii at exit ramp tight enough to prevent right turn WW entry?		
Wide/flared exit ramp terminal contributing to left turn WW entry?		
Horizontal or vertical curvature obscures view of signs or entrance ramp?		
Nearby intersections (i.e., small roads, service roads)		
Other distractors or confusing elements?		

Other Notes:

APPENDIX D. RECOMMENDATIONS BY INTERCHANGE

The following pages provide the recommendations provided by the research team for each interchange investigated in this project.