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The National Surface Transportation Safety Center for Excellence

Geospatial Analysis of High-Crash Intersections and Rural Roads using Naturalistic Driving Data

Final Report

Brad R. Cannon • Jeremy Sudweeks

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Lighting | Technology
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3500 Transportation Research Plaza • Blacksburg, Virginia 24061

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EXECUTIVE SUMMARY

Despite the fact that overall road safety continues to improve, intersections and rural roads persist as trouble areas or *hotspots*. Using a previously developed method, naturalistic driving data were identified through intersection and rural road hotspots and compared to naturalistic driving data through similar intersections and rural road locations, but with low crash counts. Few significant differences were found between driver behaviors in the low-crash and high-crash areas of study. For the few significant differences, there was not an apparent consistent pattern. A compelling possibility that warrants further investigation is that drivers may not recognize when they have entered an area with high-crash counts and that a change in driving behavior would be appropriate.

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LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
ESRI	Environmental Systems Research Institute, Inc.
GIS	Geographic Information System
GPS	Global Positioning System
SQL	Structured Query Language
UA	Urbanized Area
UC	Urban Cluster
VDOT	Virginia Department of Transportation
VTTI	Virginia Tech Transportation Institute

CHAPTER 1. INTRODUCTION

As overall road safety continues to improve, some problem areas continue to have a disproportionate number of fatal and injurious crashes. Two types of areas that often have an unusually high number of injuries and fatalities are intersections and rural areas. Recently, naturalistic driving data have been able to provide a new opportunity for exploring crashes in more detail than was previously possible with only crash report data. Naturalistic data also provide the possibility of studying drivers' behavior during non-crash situations. This allows comparisons of behavior while driving through an area in both crash and non-crash situations and comparisons of driving behavior in different areas.

Geographic information systems (GIS) allow analysis based on geographical location variables (i.e., latitude and longitude from Global Positioning System [GPS]) contained within the data. Data containing geographical information are known as geospatial data. Previous work developed a method using GIS to find rural driving within large naturalistic driving datasets.[(1)] In the latest work, naturalistic data through high-crash rural roads were identified and compared to naturalistic data through low-crash rural roads. This method was also adapted and used to compare naturalistic data through high-crash intersections with naturalistic data from low-crash intersections.

CHAPTER 2. METHODS

In previous work, a method was developed to identify naturalistic driving data in rural areas.(1) That method was used here to identify rural driving in the two naturalistic driving datasets used in this work. These processes were also adapted to identify driving through intersections in the same datasets. The naturalistic driving data used were collected in the 100-Car Study(2) and the Virginia Tech Transportation Institute's (VTTI) Older Driver Collection. The 100-Car Study data were collected in the northern Virginia/Washington, DC metro area and provide a resource of naturalistic driving data for a variety of drivers in different situations. Due to the collection area's urban location, most of the driving data in the dataset are on urban roads, but still provide some driving data for rural areas. The Older Driver data were collected from drivers in and around Blacksburg in the New River Valley area of southwestern Virginia. The Older Driver data were used to augment the 100-Car data because of a higher prevalence of rural driving in southwestern Virginia than in northern Virginia.

The method for identifying rural driving is dependent on the use of GIS software. In the naturalistic driving data, the latitude and longitude pair that identifies the current location of the car is recorded at a rate of 1 Hz. Collectively, these points are referred to as breadcrumb trails. The definition of a rural road used here is the same as the definition used in the earlier study(1), which is a road outside of an urbanized area (UA) or urban cluster (UC) as defined by the U.S. Census Bureau, excluding interstate highways. Consequently, breadcrumb trails outside the boundaries of any UA or UC and not falling on an interstate highway were identified for study in this work.

Geographic data describing the boundaries of UAs and UCs were obtained from the Census Bureau in the shapefile format, which stores geographic data for use with commonly available GIS software. Shapefiles were also acquired from the Virginia Department of Transportation (VDOT) which describe the centerlines of the roadways in Virginia. Tables describing crashes in Virginia from 1999 through 2005 were also obtained from VDOT. These tables included details such as the latitude and longitude of the crash, the type of crash, and the number of vehicles involved.

IDENTIFYING RURAL ROAD HOTSPOTS

Choosing the problematic rural locations for specific study required the development of a method for identifying problem areas or *hotspots*. The first attempt at doing this made use of the point density tool provided in the Environmental Systems Research Institute's (ESRI) ArcGIS Desktop software. The latitude and longitude from the VDOT crash tables were plotted in ArcGIS and the densities of these crash locations were calculated using the point density tool. The initial results of using this tool made it difficult to identify rural hotspots because the numbers of crashes in urban areas outnumbered the crashes in rural areas to such a large degree that the differences in crash counts between individual rural areas was indistinguishable. This process was refined by excluding the crash points within UAs and UCs or on interstate highways. In this way, only the crashes that are on rural roads using the rural-road definition described previously were used to calculate the crash densities of areas around the state. While this method could show promise for identifying a jurisdiction with a crash density problem, it identifies an area where crashes tend to cluster, and this could include multiple roads as well as multiple road segments. For example, the method frequently identified areas where roads intersected, particularly when several other roads were in the near vicinity. This result may not clearly indicate whether or not a certain approach to the intersection, or a certain road, could be considered the hotspot. It could also identify an area as a hotspot simply because many roads are close together, even though the individual road segments have typical crash counts.

To more specifically identify a road segment with a crash problem, a different method was needed. A spatial join was used to associate each crash with the nearest road segment. This was done by joining the crashes in the 1999–2005 VDOT crash data with the nearest road segment in VDOT's centerline road data. The result of the spatial join was a geospatial table in a PostgreSQL database. By writing the result to a database table, a count of the crashes and crash types on each road segment could be obtained through simple SQL queries.

Selecting Hotspots with Naturalistic Driving Data for Analysis

The 100 road segments with the most crashes were mapped and overlaid with 100-Car and Older Driver breadcrumb data to find segments with large enough numbers of naturalistic driving traversals to provide a sample size sufficient for analysis. A spatial join was used to associate the breadcrumbs from the 100-Car and Older Driver datasets with the nearest (within 200 ft) road segment with the top 100 crash counts. This result was also written to a geospatial table in a PostgreSQL database. Using SQL queries, the number of traversals through each road segment by each driver was used to identify the hotspots for further review by data reductionists. The selection of the high-crash road segments process is shown in Figure 1. Another SQL query was used to randomly choose trips through the chosen high-crash road segments. The identifying trip File ID and frame numbers were given to the data reductionists in a database table for question reduction as discussed below.

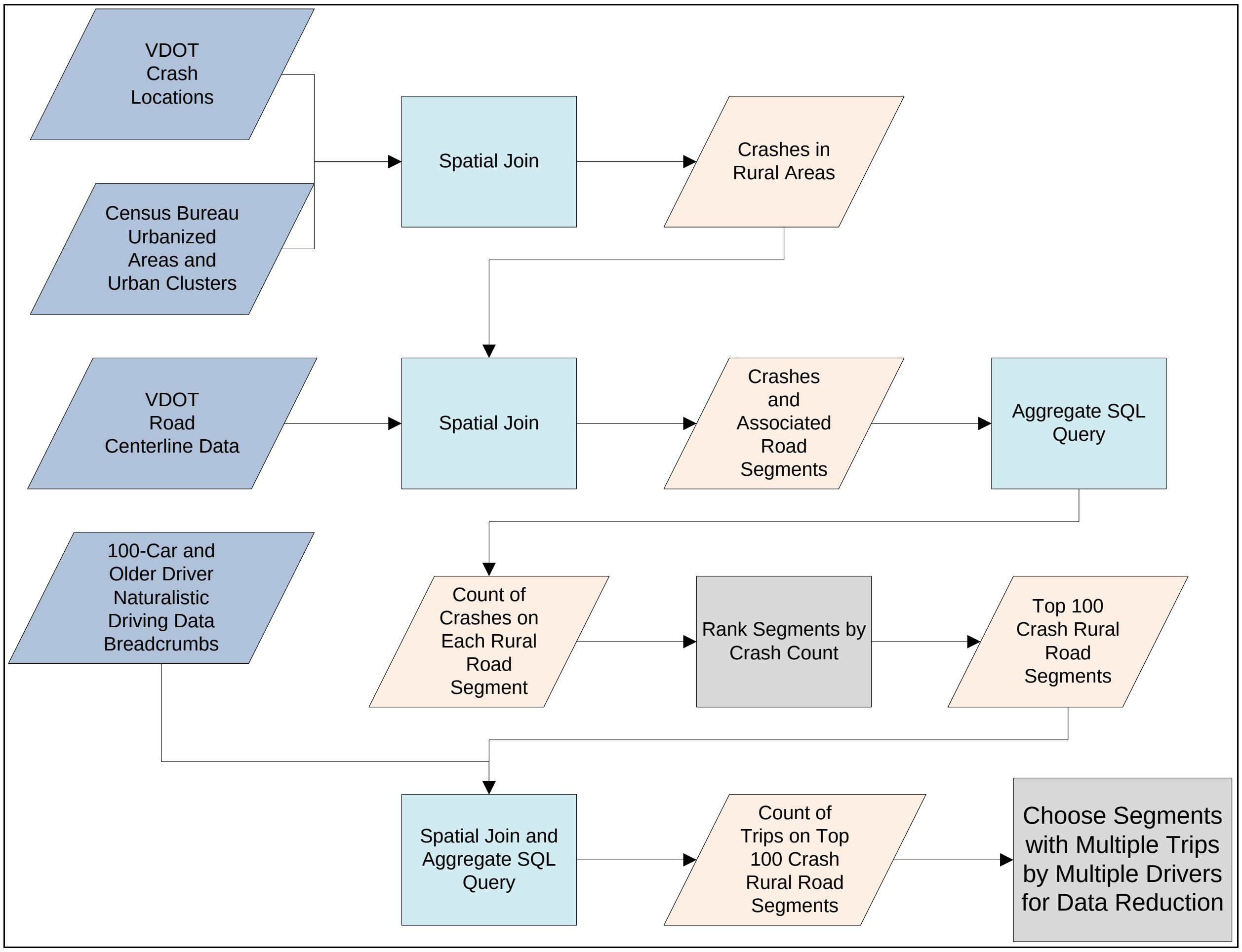

Figure 1. Diagram. Flow chart of high-crash road segment selection process.

Two high-crash rural roadway segments in northern Virginia and two additional high-crash rural roadway segments in southwestern Virginia were chosen for analysis. All four segments had crash counts in the top 100 of rural roadway segments in the state and had similar lengths. For comparison, each of the four high-crash segments was matched up with a similar low-crash segment. To control for traffic volumes, nearby segments on the same roadway were chosen. This also helped find low-crash road segments with geometries similar to their high-crash counterparts. In one case, the low-crash and the high-crash segments were contiguous segments. In two cases, they were separated but near each other. In the final case, the high-crash segment was the eastbound lanes of a divided roadway. The westbound lanes were on a low-crash segment and were chosen for comparison to the high-crash eastbound lanes. The road segments used in the analysis were on Prices Fork Road in Montgomery County (Figure 2), US-460 in Giles County (Figure 3), VA-28 in Prince William County (Figure 4), and VA-7 in Loudoun County (Figure 5).

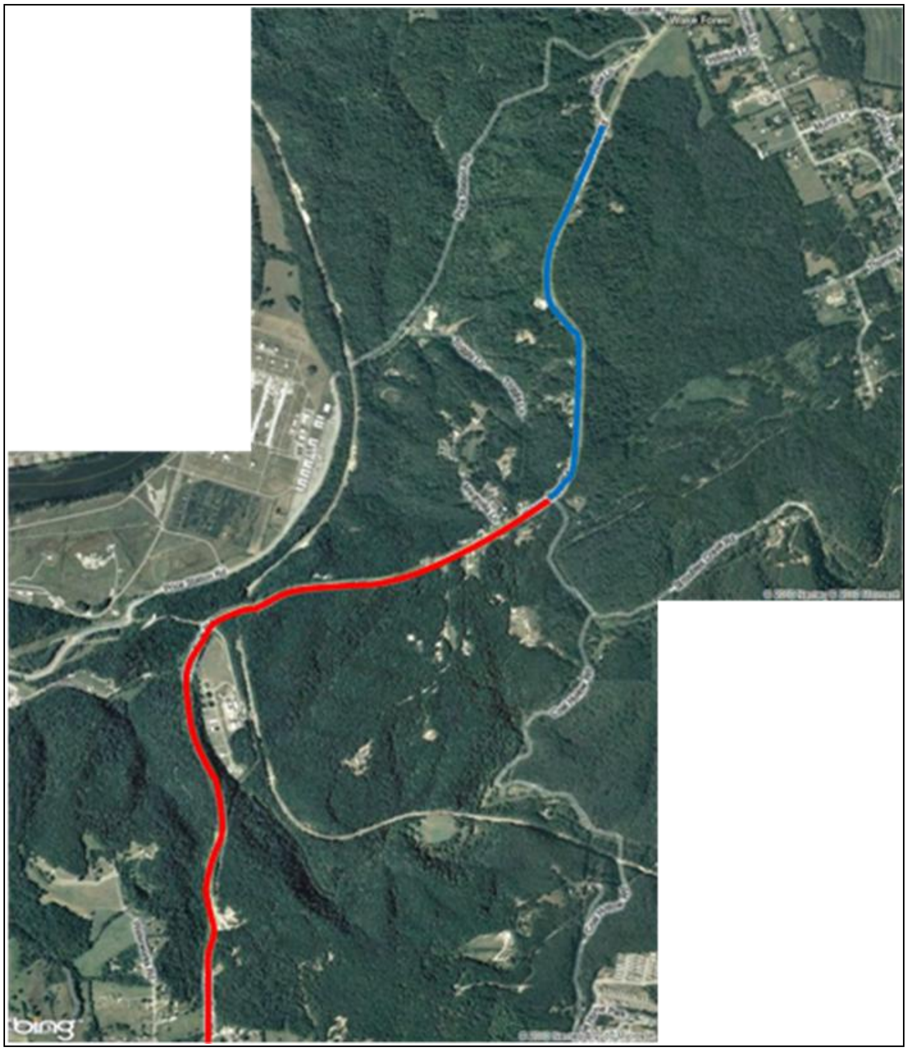

Figure 2. Aerial Image. Prices Fork Road contiguous high-crash (red) and low-crash (blue) road segments. (Source: www.bing.com, 2010)

The high-crash segment of Prices Fork Road is a two-lane road with no shoulder and several horizontal and vertical curves. The segment has center and side lane markings. There are a number of side roads and driveways (gravel and paved) that branch from the road segment. The road segment is generally surrounded by trees and steep hillsides with a few homes and small businesses. The low-crash segment is very similar to the high-crash segment, but with more straight driving and not as many steep hillsides. The high-crash and low-crash segments are contiguous segments and are shown in the aerial image in Figure 2.

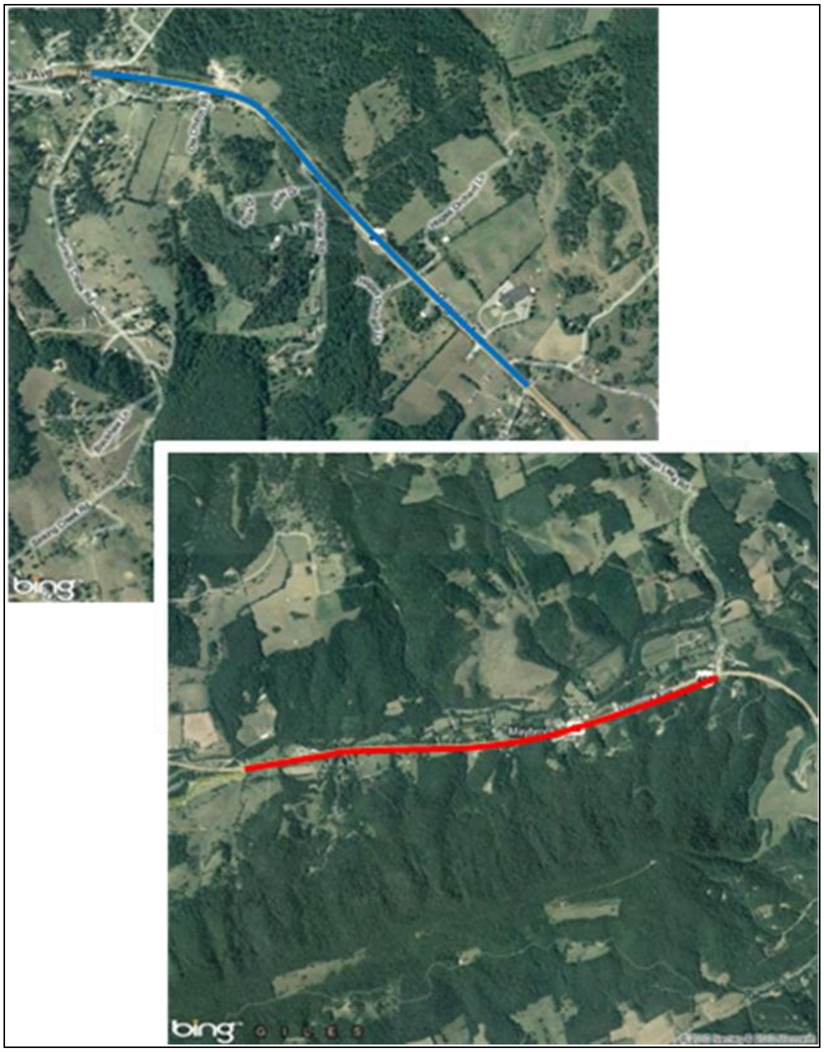

Figure 3. Aerial Images. US-460 separated high-crash (red) and low-crash (blue) road segments. (Source: www.bing.com, 2010)

The high-crash segment of US-460 is a section of the westbound lanes where US-460 is a divided highway with two lanes traveling in each direction. There are several un-signalized intersections throughout the road segment. There is a solid lane marking on the right side of the right lane and the left side of the left lane with a dashed line dividing the two lanes. There is a shoulder to the right of the right lane. Some parts of the road segment are surrounded by trees and hills, while other parts have an open view and homes or small businesses. The low-crash segment of US-460 is similar to the high-crash segment. The low-crash segment has more open views and fewer intersections. The traffic on the low-crash segment is also traveling in a primarily westbound direction away from the Blacksburg UA. The high-crash and low-crash segments are separated segments, but are near each other. They are shown in the aerial images in Figure 3.

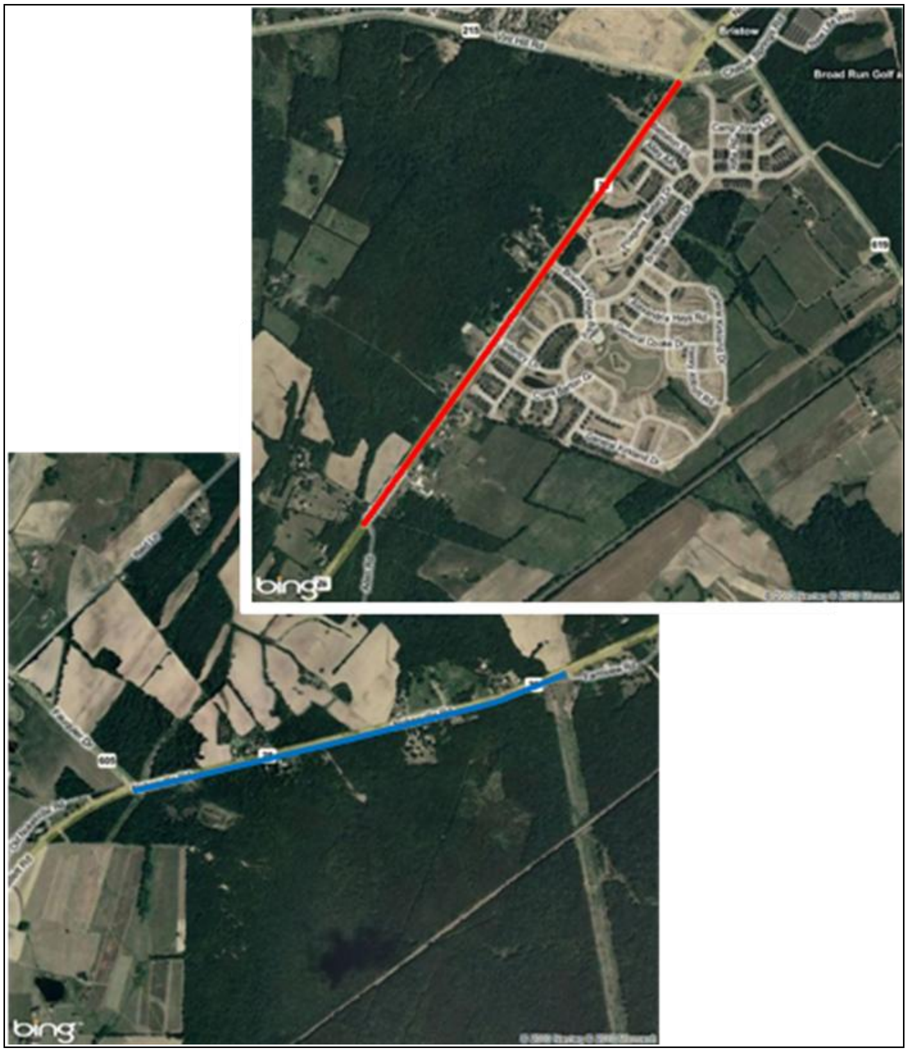

Figure 4. Aerial Images. VA-28 separated high-crash (red) and low-crash (blue) road segments. (Source: www.bing.com, 2010)

The high-crash segment of VA-28 is a two-lane road with a single solid line on each edge. The road is partially divided by double yellow lines, dashed lines, mixed dash and solid, and mixed solid and dash. The roadway is surrounded at times by trees but includes some sections with open views. The road segment is mostly straight driving with one traffic signal toward the end and some un-signaled intersections throughout the segment. There are some homes and driveways off of the road. The low-crash segment is very similar to the high-crash segment with more trees surrounding the roadway and a shoulder for most of the roadway. The high-crash and low-crash segments are separated, but are near each other. They are shown in the aerial images in Figure 4.

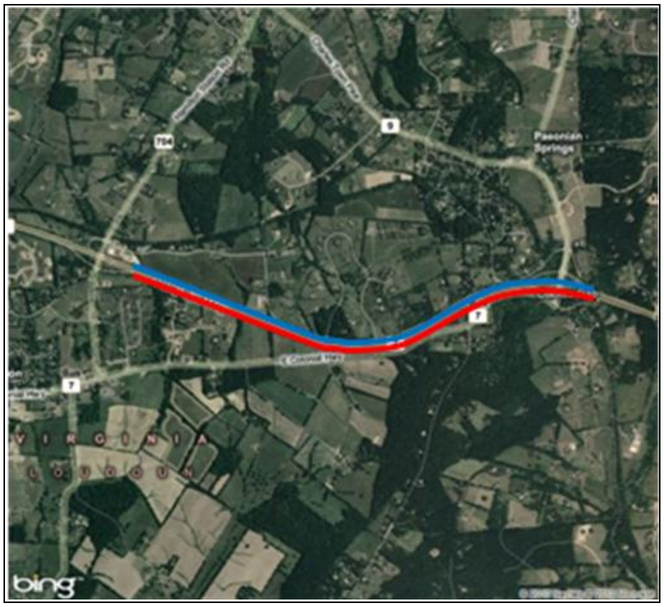

Figure 5. Aerial Image. VA-7 Opposing Direction High-Crash (Red) and Low-Crash (Blue) Road Segments. (Source: www.bing.com, 2010)

The high-crash segment of VA-7, shown in red in Figure 5, is one side of a divided highway with two lanes traveling in the eastbound direction. There is an on-ramp at the beginning and at the end of the segment. There is a solid line on the left side of the left lane and one on the right side of the right lane. The two lanes are separated by a dashed line. There is a shoulder to the right of the right lane. The road segment is mostly straight driving with some wide turns and short trees along the road, but has an open view for the most part. The low-risk road segment parallels the high-crash segment, containing the westbound lanes. This segment is almost identical to the high-crash segment. Note that the high-crash and low-crash segments are both on a bypass section of VA-7. A portion of a business loop of VA-7 can also be seen in Figure 5 splitting from the bypass road segments.

A count of the crash types was calculated for each of the high-crash and low-crash road segments by using an aggregate SQL query on the geospatial table created from the spatial join of the VDOT crash tables and the VDOT centerline data. The graph of this result is shown in Figure 6. The terms in Figure 6 are from VDOT’s crash tables. A non-collision crash is a crash where the vehicle runs off the road and does not collide with another object.

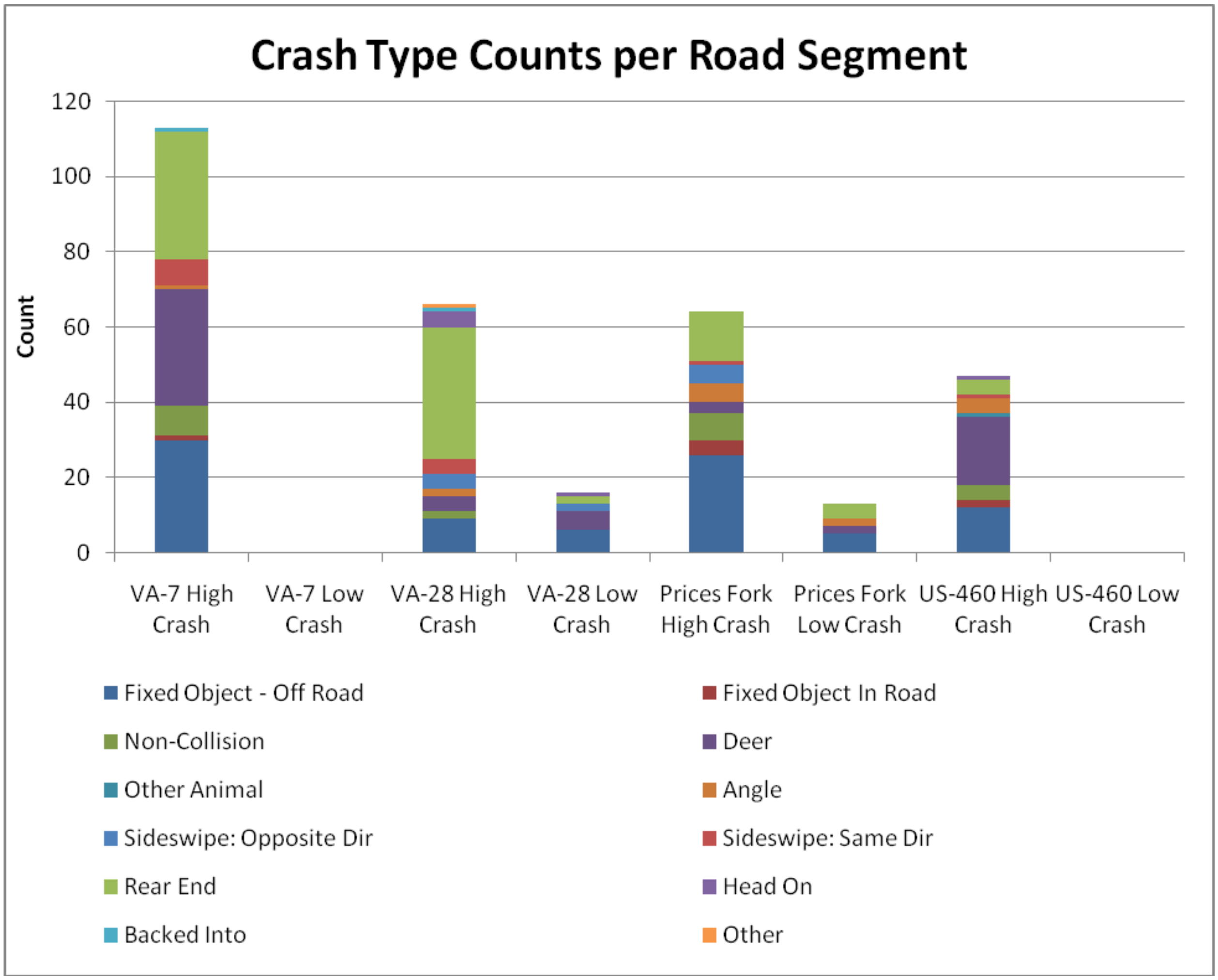

Figure 6. Chart. Crash type counts per road segment.

IDENTIFYING INTERSECTION HOTSPOTS

The process of retrieving intersection traversals for evaluation in this study followed a two-stage process in which the first stage was to identify intersections of interest, and the second stage was to select individual instances of drivers in the naturalistic data passing through the selected intersections.

Intersection Selection

The selection of intersections of interest was based on the number and types of crashes reported by VDOT and the coverage of the 100-Car dataset at these intersections. The 100-Car data were used in the intersection analysis because more of the intersection hotspots were in northern Virginia where the 100-Car data are more extensive. VDOT provided a listing of crashes for the years 2005 through 2007 at approximately 6,000 intersections, along with a ranking for each of the intersections based on the total number of fatal or injury crashes over this three-year period. ArcMap was used to create 200-ft buffers around each intersection's latitude-longitude pairing and to identify which of the 100-Car trips passed through the intersection. Summary measures were calculated for each intersection to estimate how many usable 100-Car trips passed through the intersection, how many distinct drivers passed through the intersection, and the largest contribution that a single driver made toward the total number of traversals.

High-Crash Intersections

Focus for selecting high-crash intersections was restricted to the 15 intersections with the largest number of fatal or injury crashes in the 2005 through 2007 timeframe. Table 1 below provides a listing of the summary measures relevant to high-crash intersection selection.

Table 1. Summary measures used in selection of high-crash intersections. Gray shading indicates high-crash intersections used in analysis.

Fatal / Injury Rank (frequency)	Node Number	Fatal / Injury Crash Count	Number 100-Car Trips	Number Distinct Drivers	Percentage of Largest Participant Contribution	Fatal / Injury Percentage of Total Crashes
1	276819	70	649	39	36.52	63.64
2	547483	67	295	23	31.53	56.30
3	264119	62	157	35	13.38	61.39
3	722678	62	423	20	64.54	50.00
5	546653	61	494	17	79.35	95.31
6	278648	60	456	30	53.73	50.00
7	703414	59	166	9	74.70	86.76
8	263375	57	1260	56	24.37	60.00
8	265204	57	185	21	48.65	63.33
10	263249	56	461	45	13.88	41.18
10	263290	56	436	34	22.25	61.54
12	264849	55	408	38	32.11	39.01
13	263347	54	636	31	43.08	65.06
14	263090	51	249	25	36.14	83.61
15	277764	48	627	30	29.51	77.42

It was determined that a single participant should not contribute more than 30% of the total observed intersection crossings in the 100-Car data and that fatal and injury crashes should account for at least 60% of the total crashes reported at the intersection. Based upon these criteria, the large number of 100-Car trips and relatively large number of distinct drivers observed, the following intersections were selected: Braddock Rd at Backlick Rd (node 263290) and Lee Hwy at Waples Mill Rd and Shirley Gate Rd (277764). Figure 7 and Figure 8 provide aerial imagery of the selected intersections.

Figure 7. Aerial Image. Braddock Rd at Backlick Rd (node 263290). This intersection served as a high-crash intersection in the analysis. (Source: www.bing.com, 2010)

Figure 8. Aerial Image. Lee Hwy at Waples Mill Rd and Shirley Gate Rd (node 277764). This intersection served as a high-crash intersection in the analysis. (Source: www.bing.com, 2010)

Low-Crash Intersections

In order to provide a normative comparison for the high-crash intersections, low-crash intersections were identified. Although traffic density measures such as average annual daily traffic (AADT) were not explicitly used in the normative intersection selection, efforts were made to select intersections comparable to the high-crash intersections. The selection criteria for low-crash intersections included the following: total fatal or injury crashes at low-crash candidate intersections do not exceed 50% of the high-crash intersection total count; similar geometry and curvature on approach legs; a single participant does not contribute more than 30% of the total observed intersection crossings in the naturalistic driving data; a large number of 100-Car trips; and a relatively large number of distinct drivers. Based on these criteria, the following intersections were selected as low-crash intersections: Waxpool Rd at Farmwell Rd (713920) and Balls Ford Rd at Sudley Rd (546133). Table 2 contains the summary measures used in selecting a low-crash intersection.

Table 2. Summary measures used in selection of low-crash intersections.

Fatal / Injury Rank (frequency)	Node Number	Fatal / Injury Crash Count	Number of 100-Car Trips	Number of Distinct Drivers	Percentage of Largest Participant Contribution	Fatal / Injury Percentage of Total Crashes
189	546133	20	1373	74	29.78	32.78
170	713920	21	1497	30	26.11	33.87

It can been seen in Table 1 and Table 2 that, although the low-crash intersections have a number of fatal or injury crashes, these numbers are significantly less than those for the high-crash intersections. Figure 9 and Figure 10 provide aerial imagery of the selected low-crash intersections.

Figure 9. Aerial Image and Map. Waxpool Rd. at Farmwell Rd (node 713920). This intersection served as a low-crash intersection in the analysis. (Source: www.bing.com, 2010)

Figure 10. Aerial Image. Balls Ford Rd at Sudley Rd. This intersection served as a low-crash intersection during analysis. (Source: www.bing.com, 2010)

The graphs in Figure 11 and Figure 12 provide a breakdown of the crash types reported at each location for the years 1999 through 2005. Earlier (Figure 6), raw counts of crashes had been used to identify road segments with high crashes. Percentages were used here to compare crash types between intersections. The high-crash intersections had been previously identified by VDOT using raw counts.

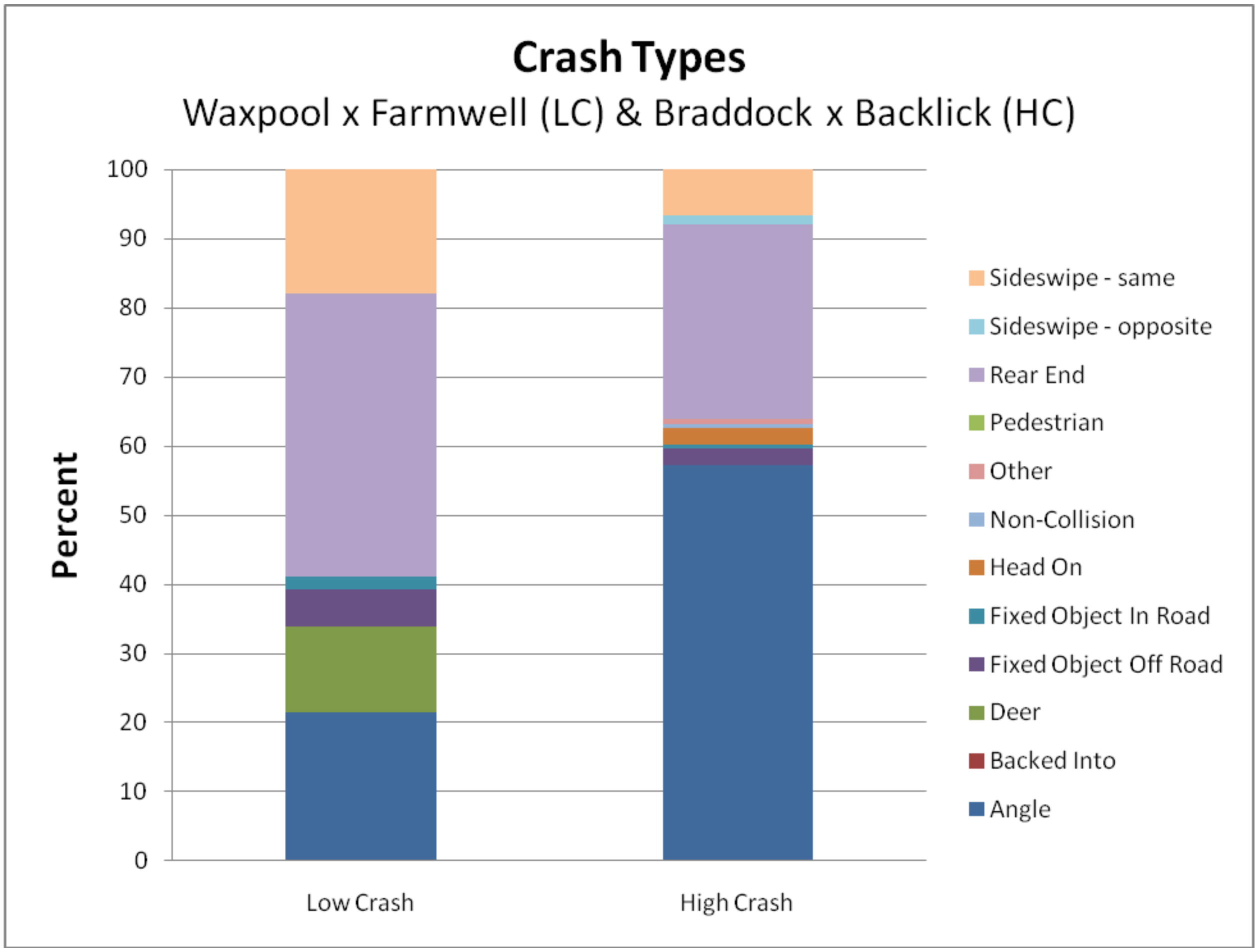

Figure 11. Chart. Crash types reported at two intersections between the years 1999 and 2005.

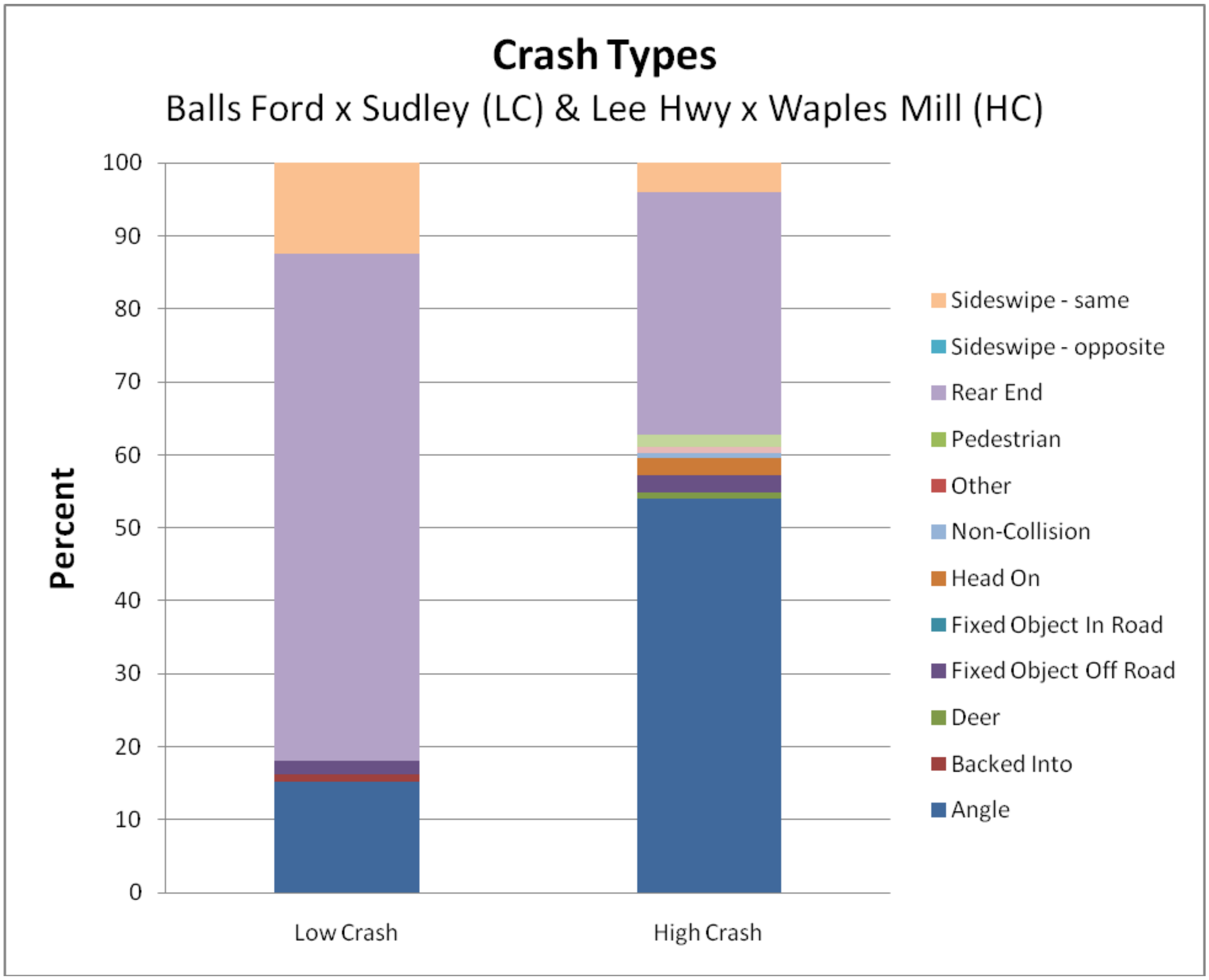

Figure 12. Chart. Crash types reported at two intersections between the years 1999 and 2005.

Epoch Selection

The process of selecting individual intersection traversals for inclusion in the analysis was straightforward and simple. Based on previous reduction efforts, files with undesirable attributes (such as obstructed video views) were excluded from consideration. A random sample of 120 files per intersection node were drawn from the remaining files and presented to video analysts for video validation and reduction.

VIDEO REDUCTION

Following the identification of 100-Car files with traversals through roadway segments or intersections of interest, video analysis was completed. This video analysis, also referred to as video reduction, was completed in order to collect information about the driving environment, driver states (e.g., inattentive or impaired), driver behavior, and roadway infrastructure elements. Trained video analysts completed the video reduction in secured computing labs using VTTI proprietary software. The following sections briefly describe the different types of video analysis completed, protocol development, and analyst training.

Reductionist Training

As the video reductionists employed in this task were quite experienced, training needs were minimal. Training consisted primarily of familiarizing reductionists with the objectives of the research task, discussing differences in video fidelity between the datasets, and reviewing the reduction protocol. Although certain questions were only applicable to roadway segments or intersections, there was one protocol provided for the video reduction. Aspects of this reduction task that likely differed from previous research efforts were emphasized during the review of the reduction protocol. After meeting with a researcher for the brief training session, reductionists were instructed to read and familiarize themselves with the reduction protocol prior to beginning reduction. Questions encountered during reduction were addressed to a researcher or the reduction manager.

Event Validation

The first step in the reduction process was to determine if a trip that had been labeled as passing along a roadway or intersection was, in fact, of interest. As can occasionally happen with naturalistic data collection, there are times at which the video quality does not allow for reliable video analysis. In addition, the GPS measures collected by the instrumentation package are at times not amenable to accurate geospatial processing, resulting in trips that seem too short or long for a particular road segment. In such cases, the reductionist does not complete the video analysis and the trip is excluded from further analysis. As is mentioned in the section describing trip selection, additional trips are sampled to account for the possibility of trips being discarded due to unusable data.

Question Reduction

The question reduction was a detailed analysis that sought to address several factors relevant to the traversal. Questions in the reduction were grouped according to the factor being addressed; for example: video quality, driving environment, driver states (e.g., inattentive or impaired), driver behavior, and roadway infrastructure. To the extent possible, questions included in this reduction were based upon reductions completed in previous studies. This provided the opportunity to make use of questions that have been successfully used in previous research efforts and with which the reductionists are familiar. The question reduction protocol is listed in the appendix.

Spot-Checking

The primary mechanism used to encourage consistent responses across reductionists was frequent spot-checking. Each reductionist would spend a small amount of time during each shift reviewing the work of another reductionist. Discrepancies between the reductionists were noted and the reductionists would discuss reduction differences in order to converge on consistent use of reduction values.

ANALYSIS METHODS

The focus of the analyses conducted in this study was on simple comparisons between high- and low-crash road segments across a number of measures. These comparisons were conducted at two different levels of aggregation, the first of which disregarded the specific roadway but simply made comparisons between high-crash and low-crash segments. For example, the VA-7 and VA-28 segments were simply collapsed into high- and low-crash groupings. The second comparison matched each segment within the roadway from which it was selected. For example, the VA-7 high-crash segment was compared only to the VA-7 low-crash segment. Table 3 displays the number of trips used in the analysis for each of the levels of aggregation.

Table 3. Number of trips analyzed per roadway and segment type.

Roadway	Naturalistic Dataset	Segment Type	Number of Trips
VA-7	100-Car	High-crash	81
VA-7	100-Car	Low-crash	94
VA-28	100-Car	High-crash	56
VA-28	100-Car	Low-crash	89
US-460	Older Driver	High-crash	48
US-460	Older Driver	Low-crash	38
Prices Fork Rd	Older Driver	High-crash	61
Prices Fork Rd	Older Driver	Low-crash	95
Braddock & Backlick	100-Car	High-crash	91
Lee Hwy & Waples Mill	100-Car	High-crash	107
Waxpool & Farmwell	100-Car	Low-crash	60
Balls Ford & Sudley	100-Car	Low-crash	102

As can be seen in Table 3, although sampling efforts sought to have at least 100 trips for each roadway and segment type, this could not be met in all cases. In particular, US-460 has a low number of trips possible, resulting in an unpowered analysis.

The measures used in analysis were grouped into those that address roadway infrastructure, and those that address driver states and behaviors. Driver state and behavior variables that were analyzed include the following: secondary task engagement; driver impairment; unsafe, illegal, or reckless actions; hand placement on the steering wheel; and seatbelt use. The roadway infrastructure variables considered include the following: roadway elements such as sight distance or roadway delineation; visual obstructions; traffic density; and lighting conditions. As can be seen in Figure 13, these categories align well with the most frequent major crash factors reported in the VDOT crash tables.

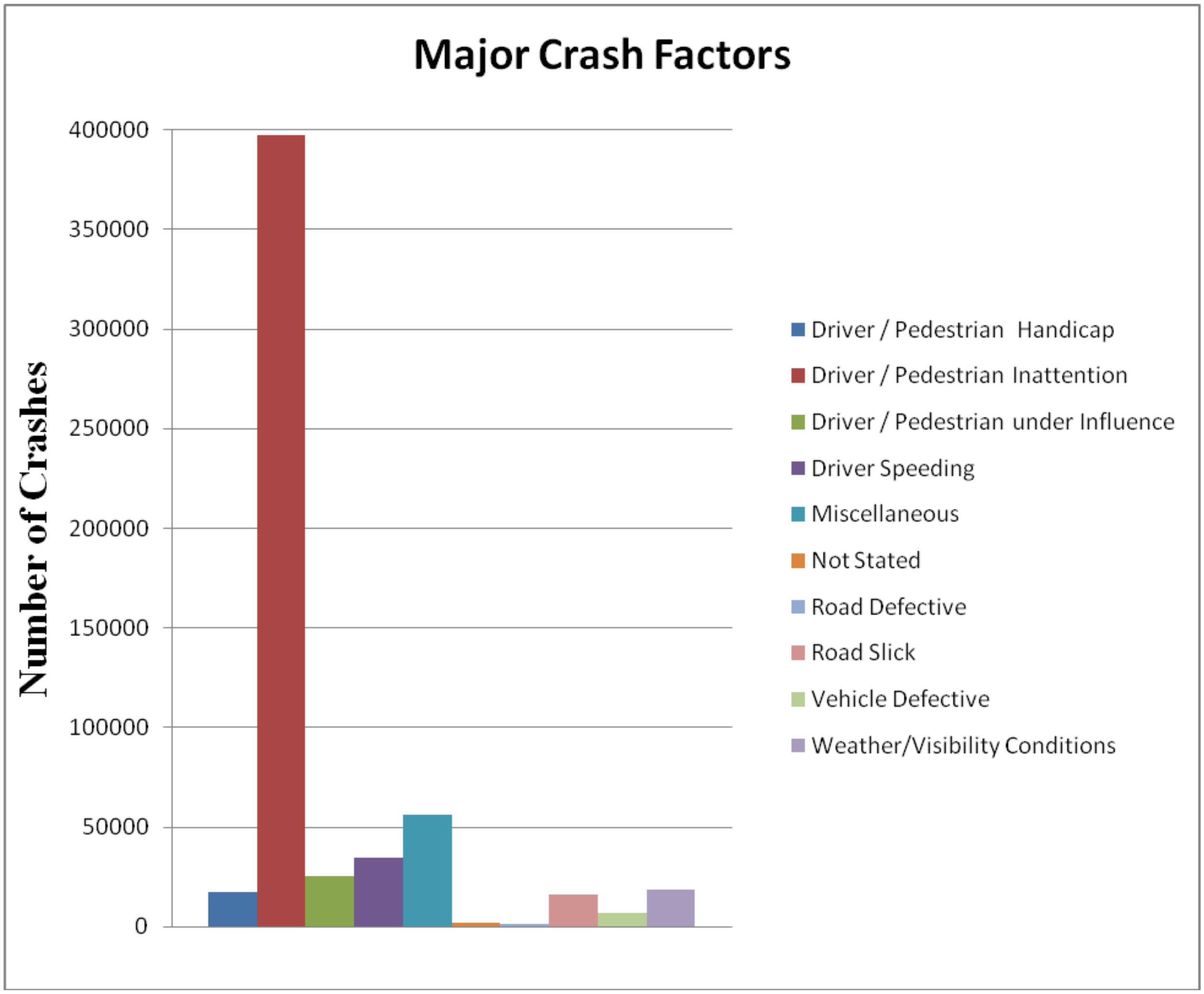

Figure 13. Chart. Major crash factors as reported in VDOT crash tables.

CHAPTER 3. RESULTS

DRIVER BEHAVIORS

This section describes the frequency of various driver behaviors, such as secondary task engagement, observed in each of the high- and low-crash road segments. Findings are reported separately for the 100-Car and Older Driver datasets.

Secondary Tasks

Table 4 through Table 9 provide comparisons of the crash segments using distraction-related measures. The comparisons include measures related to number and duration of tasks, as well as types of tasks. Table 4 focuses on the 100-Car dataset while Table 5 focuses on older drivers. Table 6 through Table 9 provide distraction comparisons within individual road segments.

Table 4. 100-Car aggregate 95% confidence intervals.

Distraction Type	Low-crash Mean or Proportion	High-crash Mean or Proportion	Difference	Lower Bound	Upper Bound	Segment with Higher Distraction Involvement
Number of secondary tasks per traversal	3.4200	3.0000	0.4208	0.0461	0.7954	Low-crash
Length of longest duration secondary task (sec)	0.3318	0.3453	0.0135	-0.0741	0.1012	Not significant
Number of distinct secondary tasks per traversal	2.3443	2.1387	0.2056	-0.0469	0.4581	Not significant
Proportion of traversals with passenger distraction	0.4809	0.4818	0.0009	-0.1098	0.1115	Not significant
Proportion of traversals with cognitive distraction	0.1366	0.1314	0.0052	-0.0701	0.0806	Not significant
Proportion of traversals with object in vehicle distraction	0.3169	0.1825	0.1345	0.0410	0.2279	Low-crash
Proportion of traversals with electronic device distraction	0.0383	0.1095	0.0712	0.0120	0.1305	High-crash
Proportion of traversals with vehicle controls distraction	0.3552	0.3796	0.0244	-0.0825	0.1312	Not significant
Proportion of traversals with external distraction	0.4973	0.1971	0.3002	0.2018	0.3986	Low-crash
Proportion of traversals with eating distraction	0.5082	0.5912	0.0830	-0.0266	0.1927	Not significant
Proportion of traversals with other distraction	0.0109	0.0657	0.0548	0.0106	0.0989	High-crash

Table 5. Older Driver aggregate 95% confidence intervals.

Distraction Type	Low-crash Mean or Proportion	High-crash Mean or Proportion	Difference	Lower Bound	Upper Bound	Segment with Higher Distraction Involvement
Number of secondary tasks per traversal	3.57	3.44	0.1294	-0.3108	0.57	Not significant
Length of longest duration secondary task (sec)	0.1232	0.1283	0.0051	-0.0540	0.0642	Not significant
Number of distinct secondary tasks per traversal	2.1053	2.0183	0.0869	-0.1726	0.3464	Not significant
Proportion of traversals with passenger distraction	0.4586	0.3945	0.0642	-0.0607	0.1890	Not significant
Proportion of traversals with cognitive distraction	0.0226	0.0459	0.0233	-0.0234	0.0700	Not significant
Proportion of traversals with object in vehicle distraction	0.2782	0.2477	0.0305	-0.0807	0.1417	Not significant
Proportion of traversals with electronic device distraction	NA	NA	NA	NA	NA	Not significant
Proportion of traversals with vehicle controls distraction	0.2105	0.2018	0.0087	-0.0937	0.1111	Not significant
Proportion of traversals with external distraction	0.8045	0.6789	0.1256	0.0150	0.2362	Low-crash
Proportion of traversals with eating distraction	0.3308	0.3761	0.0453	-0.0758	0.1664	Not significant
Proportion of traversals with other distraction	NA	0.0734	NA	NA	NA	High-crash

Table 6. VA-7 95% confidence intervals.

Distraction Type	Low-crash Mean or Proportion	High-crash Mean or Proportion	Difference	Lower Bound	Upper Bound	Segment with Higher Distraction Involvement
Number of secondary tasks per traversal	2.6	2.53	0.0649	-0.4317	0.5614	Not significant
Length of longest duration secondary task (sec)	0.329	0.353	0.024	-0.1082	0.1562	Not significant
Number of distinct secondary tasks per traversal	1.89	1.77	0.128	-0.1975	0.4539	Not significant
Proportion of traversals with passenger distraction	0.3723	0.4198	0.0474	-0.0979	0.1927	Not significant
Proportion of traversals with cognitive distraction	0.1702	0.1235	0.0468	-0.0577	0.1512	Not significant
Proportion of traversals with object in vehicle distraction	0.1596	0.0988	0.0608	-0.0377	0.1593	Not significant
Proportion of traversals with electronic device distraction	0.0319	0.0741	0.0422	-0.0250	0.1094	Not significant
Proportion of traversals with vehicle controls distraction	0.4681	0.4198	0.0483	-0.0991	0.1957	Not significant
Proportion of traversals with external distraction	0.2128	0.0988	0.1140	0.0088	0.2192	Low-crash
Proportion of traversals with eating distraction	0.4574	0.5062	0.0487	-0.0996	0.1970	Not significant
Proportion of traversals with other distraction	0.0213	0.0247	0.0034	-0.0412	0.0481	Not significant

Table 7. VA-28 95% confidence intervals.

Distraction Type	Low-crash Mean or Proportion	High-crash Mean or Proportion	Difference	Lower Bound	Upper Bound	Segment with Higher Distraction Involvement
Number of secondary tasks per traversal	4.29	3.68	0.6136	0.1468	1.08	Low-crash
Length of longest duration secondary task (sec)	0.3340	0.3370	0.0030	-0.1134	0.1193	Not significant
Number of distinct secondary tasks per traversal	2.8200	2.6800	0.1417	-0.1948	0.4782	Not significant
Proportion of traversals with passenger distraction	0.5955	0.5714	0.0241	-0.1408	0.1890	Not significant
Proportion of traversals with cognitive distraction	0.1011	0.1429	0.0417	-0.0693	0.1527	Not significant
Proportion of traversals with object in vehicle distraction	0.4831	0.3036	0.1796	0.0206	0.3386	Low-crash
Proportion of traversals with electronic device distraction	0.0449	0.1607	0.1158	0.0104	0.2212	High-crash
Proportion of traversals with vehicle controls distraction	0.2360	0.3214	0.0855	-0.0653	0.2363	Not significant
Proportion of traversals with external distraction	0.7978	0.3393	0.4585	0.3090	0.6079	Low-crash
Proportion of traversals with eating distraction	0.5618	0.7143	0.1525	-0.0044	0.3094	Not significant
Proportion of traversals with other distraction	NA	0.1250	NA	NA	NA	High-crash

Table 8. US-460 95% confidence intervals.

Distraction Type	Low-crash Mean or Proportion	High-crash Mean or Proportion	Difference	Lower Bound	Upper Bound	Segment with Higher Distraction Involvement
Number of secondary tasks per traversal	4.6	4.73	0.1239	-0.2604	0.5082	Not significant
Length of longest duration secondary task (sec)	0.2144	0.1387	0.0757	-0.0395	0.1909	Not significant
Number of distinct secondary tasks per traversal	2.68	2.43	0.2467	-0.1166	0.6101	Not significant
Proportion of traversals with passenger distraction	0.5263	0.3750	0.1513	-0.0584	0.3610	Not significant
Proportion of traversals with cognitive distraction	0.0263	0.0208	0.0055	-0.0595	0.0705	Not significant
Proportion of traversals with object in vehicle distraction	0.3947	0.4167	0.0219	-0.1869	0.2308	Not significant
Proportion of traversals with electronic device distraction	NA	NA	NA	NA	NA	NA
Proportion of traversals with vehicle controls distraction	0.2632	0.1875	0.0757	-0.1027	0.2540	Not significant
Proportion of traversals with external distraction	0.9737	0.9167	0.0570	-0.0363	0.1503	Not significant
Proportion of traversals with eating distraction	0.5000	0.4792	0.0208	-0.1919	0.2335	Not significant
Proportion of traversals with other distraction	NA	0.0417	NA	NA	NA	NA

Table 9. Prices Fork Road 95% confidence intervals.

Distraction Type	Low-crash Mean or Proportion	High-crash Mean or Proportion	Difference	Lower Bound	Upper Bound	Segment with Higher Distraction Involvement
Number of secondary tasks per traversal	3.16	2.44	0.7258	0.176	1.275	Low-crash
Length of longest duration secondary task (sec)	0.0826	0.118	0.0354	0.394	0.1102	High-crash
Number of distinct secondary tasks per traversal	2	2.02	0.0196	-0.2697	0.3089	Not significant
Proportion of traversals with passenger distraction	0.4316	0.4098	0.0217	-0.1369	0.1803	Not significant
Proportion of traversals with cognitive distraction	0.0211	0.0656	0.0445	-0.0240	0.1130	Not significant
Proportion of traversals with object in vehicle distraction	0.2316	0.1148	0.1168	0.0002	0.2334	Low-crash
Proportion of traversals with electronic device distraction	NA	NA	NA	NA	NA	NA
Proportion of traversals with vehicle controls distraction	0.1895	0.2131	0.0236	-0.1059	0.1531	Not significant
Proportion of traversals with external distraction	0.7368	0.4918	0.2450	0.0915	0.3986	Low-crash
Proportion of traversals with eating distraction	0.2632	0.2951	0.0319	-0.1128	0.1766	Not significant
Proportion of traversals with other distraction	NA	0.0984	NA	NA	NA	High-crash

In fact, no significant differences were observed in any category between the high- and low-crash segments on US-460 and only a single secondary task was significant for the VA-7 roadway. This would seem to indicate that the differences observed in the aggregate comparisons are being driven by the VA-28 and Prices Fork roadways.

It is interesting to note that in cases in which differences were observed it is difficult to discern generally applicable trends. For example, in Table 4 through Table 9 the direction of difference—whether the low- or high-crash segment proportion is larger—changes across the different types of secondary tasks within a road segment. However, the direction of difference was consistent across roadway types. For example, the external distraction secondary task was found to be significant on VA-7, VA-28, and Prices Fork, and in each case the proportion was higher on the low-crash segment.

The number of observed secondary tasks differs significantly between the low-crash and high-crash segments on the VA-28 and Prices Fork roadways, with the direction of difference toward the low-crash segment. It is interesting to note that on the Prices Fork segments, although drivers were engaged in more secondary tasks on the low-crash segment, the distraction-related glances with the longest duration occurred on the high-risk segment.

Some of the results are notable for lack of an available comparison or a complete absence of data. On VA-28, US-460, and Prices Fork Rd., the catchall ‘other distraction’ category was only observed on the high-risk segments. No electronic device distractions were noted on any of the Older Driver segments.

SUMMARY OF ANALYSIS

As noted in the descriptions of many of the graphs and as can be noted in Table 4 through Table 9 (which present secondary task confidence interval estimates), few significant differences were observed between the high-crash and low-crash segments, with the exception of a handful of secondary tasks. Despite not finding many significant differences, the simple comparison analysis revealed several potentially interesting findings, and these are discussed in the next chapter.

CHAPTER 4. DISCUSSION AND CONCLUSIONS

The objectives of this study were twofold. The first was to identify roadway infrastructure differences between high-crash and low-crash intersections and rural road segments that may contribute to the higher crash counts. The second was to determine if drivers exhibit different behavior when traversing a high-crash intersection or rural road segment as compared to when traversing a low-crash intersection or rural road segment.

The lack of many significant differences across the road segments for both 100-Car and Older Driver may be due to several different causes. One compelling possibility is that drivers simply may not recognize that they have transitioned from a low-crash to a high-crash road segment. That is, cues from either the infrastructure or driving environment are not sufficient or urgent enough to prompt drivers to significantly alter behavior. Along a similar vein, it is also possible that the low-crash segments that were selected for analysis are too similar to the high-crash segments and do not capture drivers transitioning between different types of road segments. The selection method for low-risk segments was based on the number of crashes reported on various road segments relative to the reported number of crashes on the high-risk segments. It is possible that the relative basis for selection was not sufficient to pair roadways with different characteristics. As always, a lack of significant differences could be due to a lack of statistical power due to using a small number of observations. Unlike controlled experimental comparisons, insufficient power can be a problem with naturalistic data due to the resources required to locate events of interest and complete the video reduction process.

The fact that consistent patterns are not apparent due to changing direction of difference may indicate that generally identifying causes for crashes in rural road hotspots may be very dependent on the specific location of interest. If this is the case, this may point to the need for some form of infrastructure-based data collection that is capable of collecting all traversals through a road segment for a specified period of time. This form of collection would allow for customized solutions for each problematic road segment.

FUTURE WORK

While the outcome of this method has not revealed specific differences between driving behavior and infrastructure in high- and low-crash locations, some possibilities have been identified that could be pursued in the future.

Of particular interest is further look into the ability of drivers to identify high-crash intersections and roadway segments. A study to examine the cues that drivers use to identify hotspots, or areas that require different levels of attention or driving techniques could be pursued by examining road segments with similar geometry and traffic patterns but with lower crash rates. What cues are available to drivers that encourage successful and safe traversal in these areas? Are some of the warnings, such as signage, more or less successful than others? Are there other cues that could be provided that are more successful than those that are currently in use?

Also of interest is a more detailed evaluation of the different types of secondary tasks the different cohorts engage in. For example, no electronic device secondary tasks were observed among the older drivers but this was found to be significant on one of the 100-Car segments. Older drivers did show higher-than-expected rates of secondary task engagement, particularly in regard to external distraction and interacting with an object in the vehicle.

As with most safety-related events, problems arise infrequently, when a number of risk-increasing conditions occur at the same time. When aggregating many traversals, the infrequently occurring alignment of conditions into a high-risk situation may be obscured by the larger number of routine situations. For this reason, it may be of value to employ a method that focuses on the sequence of events occurring within the traversals. This approach might investigate, for example, how drivers increase or decrease focus on the driving task when approaching a segment or within a segment. Do numbers of distractions increase or decrease? Within each traversal, what is the rate with which primary task demands, such as braking and negotiating turns, arise?

In the course of the current work, the question of whether impairment influences route selection was raised. For example, do drivers who are drowsy or under the influence of alcohol tend to favor rural roads, interstates, or local roads? If so, is this different from the driver's typical route selection? Geospatial tools and naturalistic driving data like those used in this effort would be useful in this additional work.

Additional research projects that are of interest include selecting different control segments to compare to the high-crash segments to evaluate the extent to which that control segment selection has on the significance of differences. Other possibilities include increasing the sample size at currently selected locations or selecting a small number of files and watching for transition periods in which the drivers appear to alter behavior and determine if transitional cues can be identified.

LIMITATIONS OF THE STUDY

As with any research endeavor, there are limitations to the current study. Although naturalistic data collection provides valuable insight into many research questions of interest, it is constrained to the participants in the study and to the locations that the participants traversed. The primary limitation is that this study was restricted to eight roadway segments and a limited number of trips were observed. In addition, the simple comparisons that were used did not explicitly take into account participant-specific differences that may exist. These limitations should be kept in mind when drawing general conclusions from these results.

APPENDIX A.
VIDEO REDUCTION

Research Task

The purpose of this research effort is to determine if behavioral differences exist when a participant is traversing different roadway types. The following roadway types are under consideration: urban intersections and rural roadway segments.

Reduction Task

Each epoch included in this reduction will consist of a single traversal across a predetermined roadway segment. The reduction questions are grouped as follows:

1. questions regarding event spot-checking and video quality;
2. questions that use entry to roadway segment (i.e., the first sync of reduction epoch) for timing information;
3. questions regarding the participant (behavior, impairment, driving style) and the driving environment (lighting, weather, visual obstructions);
4. questions relevant only to intersection traversals.

In order to capture participant actions and behavior, multiple opportunities are provided for recording values for some of the variables. In the event that multiple values are recorded for a variable there is no need to attempt to rank the importance of the multiple values. For example, if a participant is adjusting radio controls and eating a sandwich there is no need to attempt to decide which is having a larger impact on driving performance.

The remainder of this manual lists the questions, responses, and answer guides for this question reduction. It is strongly recommended that you familiarize yourself with the questions and responses **prior to beginning reduction**.

<u>Reduction Questions</u>

1. **Spot checking – Has this event been spot checked?**
    - **Yes**
    - **No**

2. **Video quality – forward view, face view, over the shoulder view, rearward view – rear windshield, rearward view – passenger window**
    - The purpose of the video quality questions is to determine if reduction should continue on the current epoch and to provide an indication of video quality for a given file.
    - If the forward view, face view, or over-the-shoulder view video is missing or of unacceptable quality (including severe obstruction or misalignment) skip the current epoch and proceed to the next epoch. These views, at minimum, should be marked as "present and usable".

- If one or both of the rearward views are less than "present and usable" but the other views are acceptable, complete the event as best as possible.

  - **Present and usable** – the video view is present with good video quality and free of obstructions and misalignment. For the face view, this means that both eyes and mouth are visible for at least 75% of the event.
  - **Present with poor video quality** – the video view is present but with degradation of video quality.
  - **Present but obscured** – the video view is present but obscured. Obstructions might include the sun visor, a hat, or lighting conditions.
  - **Present but misaligned** – the video view is present but the camera is not properly aligned.
  - **Not present** – the video view is not present.

3. **Lane of travel – what was the participant lane of travel on entry to roadway segment?**
   - **1 thru 8**
     - The reference point for the lane of travel variable is the shoulder to the right of the vehicle. The lanes are number from right to left, 1 – 8.

4. **[roadway segment only] Other vehicles – how many other vehicles were present around the subject during roadway traversal?**
   - Only consider other vehicles that are close enough to restrict the participant's ability to maneuver.
   - Count each vehicle a single time.
   - Only answer this question for roadway segments; separate questions exist for other vehicles during intersection traversals.

5. **Infrastructure – Which of the following roadway elements seemed to impact the participant's ability to navigate the roadway segment?**
   - **None**
   - **Roadway alignment** – maneuver is difficult for the driver due to the geometry of the roadway or intersection
     - ex. Narrow roadway, sharp turn, short merge lane
   - **Roadway sight distance** – the driver is unable to see an adequate distance ahead
   - **Traffic control device** – lack of, positioning of, or poor visibility of traffic control devices
   - **Roadway delineation** – poor visibility or positioning of roadway or lane borders
     - ex. Faded paint on lane lines
   - **Weather, visibility** – roadway is not designed to accommodate certain weather conditions and thus weather conditions influence driver capabilities
     - Ex. Lane markings are difficult to distinguish on wet pavement
   - **Other**
     - This category would include infrastructure elements such as construction barrels or cones

- **Unable to determine**

6. **Visual obstructions – Which of the following best describes any visual obstructions that were present during the roadway traversal?**
   - **No obstruction** - No visual obstructions for the driver were obvious
   - **Rain, snow, fog, smoke, sand, dust** - Surrounding atmosphere included rain, snow, fog, smoke, and/or dust, which decreased visibility
     - If it is not raining or snowing, but rain or snow is on the windshield obstructing the view, use the category "Broken or improperly cleaned windshield"/If window is foggy (no fog in the air), use category "Inadequate defrost or defog system" or "Broken or improperly cleaned windshield"
   - **Reflected glare** - Glare reflected off of the vehicle or other exterior objects decreased visibility
   - **Sunlight glare** - Direct bright sunlight decreased visibility
   - **Headlights** - Headlights of other vehicle(s) decreased visibility
   - **Curve or hill** - The presence of a curve or hill in the field of view decreased visibility
   - **Building, billboard, or other roadway infrastructure design features** - The presence of a man-made structure in the field of view decreased visibility includes sign, embankment, building
   - **Trees, crops, vegetation** - The presence of trees, crops, or vegetation in the field of view decreased visibility
   - **Moving vehicle (with or without load)** - The presence of a vehicle in motion on the trafficway (with or without a load) in the field of view decreased visibility
   - **Parked vehicle** - The presence of a vehicle not in motion under its own accord in the field of view decreased visibility
     - Includes vehicles in-transport and not in-transport
   - **Splash or spray of passing vehicle** - A splash or spray of water, snow, sand, etc. from a passing vehicle in the field of view decreased visibility
   - **Inadequate defrost or defog system** - The presence of frost or fog on the windshield due to an inadequate defrost/defog system decreased visibility (defrost/defog system was in use)
     - If the defrost/defog system was not being used, use category "Broken or improperly cleaned windshield"
   - **Inadequate roadway lighting system** - Inadequate lighting of the roadway (other than lighting provided by vehicles) decreased visibility
   - **Inadequate vehicle headlamps** - An inadequate exterior lighting system of the driver's vehicle (malfunctioning or turned off) decreased visibility
     - Includes headlights, fog lights, but not lighting systems of other vehicles
   - **Obstruction interior to vehicle** - An interior vehicle feature (other than head restraints) decreased visibility
     - Includes interior mirrors
   - **Mirrors** - Exterior mirrors on the vehicle in the field of view decreased visibility
   - **Broken or improperly cleaned windshield** - The windshield of the vehicle was broken or otherwise disfigured, or was at least partially covered by some material

such as dirt, rain, or snow, which decreased visibility (no attempt to clean the windshield had been made)
    - Includes not utilizing the defrost/defog system or wipers
- **Vision obscured - no details** - The vision of the driver was obviously obscured, but the source of the impediment cannot be determined
- **Other obstruction** - A known impediment not listed in previous categories decreased visibility
- **Unable to determine**

7. **Surface conditions – Which of the following best describes roadway conditions during the roadway traversal?**
   - **Dry -** There is no foreign material (rain, snow, oil, etc.) on the roadway (nothing on the road to affect the driving task)
       - A roadway made of sand or dirt would be coded "Dry" under dry conditions, not "Other"
   - **Wet -**Roadway is completely or partially wet (not snowy, icy, muddy, or oily)
   - **Icy -** There is some amount of ice on the roadway, enough to affect the driving task
       - If there is ice on the surface that affects the event, code as icy, regardless of any other coexisting conditions
   - **Snowy -**There is some amount of snow or slush on the roadway, enough to affect the driving task (no ice on the road in the area of interest)
       - If other conditions are also present in the area affecting the event, choose the first category from this list that is applicable: icy, snowy, oily, or muddy
   - **Oily -** There is some amount of oil, grease, or other slippery fluid on the roadway enough to affect the driving task
       - If the road is also icy (or icy and snowy) in the area affecting the event, categorize as icy. If the road is also snowy, categorize as snowy.
   - **Muddy -**There is some amount of mud on the roadway, enough to affect the driving task
       - If other conditions (other than simply a wet road) are also present in the area affecting the event, choose the first category from this list that is applicable: icy, snowy, or oily
   - **Other -** There is some type of foreign substance on the road, not listed in previous categories, enough to affect the driving task
       - If the substance on the road can be driven over, but would affect the vehicle's coefficient of friction, code as "other" road condition (material large or harmful enough to necessitate maneuvering around it would be categorized as an object or obstacle in the road)
   - **Unable to determine**

8. **Traffic density – which of the following best describes traffic density during the roadway traversal?**
   - The traffic density variable is meant to assess the participant's ability to select their own travel speed and maneuver between lanes of travel.
   - **Level-of-service A: Free flow -** Individual drivers are virtually unaffected by the presence of others in the traffic stream.

    - Freedom to select desired speeds and to maneuver within the traffic stream is extremely high. The general level of comfort and convenience provided to the motorist, passenger, or pedestrian is excellent.
- **Level-of-service B: Flow with some restrictions -** In the range of stable flow, but the presence of other users in the traffic stream begins to be noticeable.
    - Freedom to select desired speeds is relatively unaffected, but there is a slight decline in the freedom to maneuver within the traffic stream from LOS A. The level of comfort and convenience provided is somewhat less than at LOS A, because the presence of others in the traffic stream begins to affect individual behavior.
- **Level-of-service C: Stable flow, maneuverability and speed are more restricted -** In the range of stable flow, but marks the beginning of the range of flow in which the operation of individual users becomes significantly affected by interactions with others in the traffic stream.
    - The selection of speed is now affected by the presence of others, and maneuvering within the traffic stream requires substantial vigilance on the part of the user. The general level of comfort and convenience declines noticeably at this level.
- **Level-of-service D: Unstable flow - temporary restrictions substantially slow driver -** High-density, but stable flow.
    - Speed and freedom to maneuver are severely restricted, and the driver or pedestrian experiences a generally poor level of comfort and convenience. Small increases in traffic flow will generally cause operational problems at this level.
- **Level-of-service E: Flow is unstable, vehicles are unable to pass, temporary stoppages, etc. -** Operating conditions at or near the capacity level. All speeds are reduced to a low, but relatively uniform value.
    - Freedom to maneuver within the traffic stream is extremely difficult, and-it is generally accomplished by forcing a vehicle or pedestrian to "give way" to accommodate such maneuvers. Comfort and convenience levels are extremely poor, and driver or pedestrian frustration is generally high. Operations at this level are usually unstable, because small increases in flow or minor perturbations within the traffic stream will cause breakdowns.
- **Level-of-service F: Forced traffic flow condition with low speeds and traffic volumes that are below capacity. -** Forced or breakdown flow.
    - This condition exists wherever the amount of traffic approaching a point exceeds the amount which can traverse the point. Queues form behind such locations. Operations within the queue are characterized by stop-and-go waves, and they are extremely unstable. Vehicles may progress at reasonable speeds for several hundred feet or more, then be required to stop in a cyclic fashion. Level-of-service F is used to describe the operating conditions within the queue, as well as the point of the breakdown. It should be noted, however, that in many cases operating conditions of vehicles or pedestrians discharged from the queue may be quite good. Nevertheless, it is the point at which arrival flow exceeds discharge flow, which causes the queue to form, and level-of-service F is an appropriate designation for such points.

9. **Lighting conditions – which of the following best describes lighting conditions during the roadway traversal?**
    - **Dawn**
    - **Daylight**
    - **Dusk**
    - **Darkness, lighted** – it is dark during roadway traversal but the roadway is lighted
    - **Darkness, not lighted**
    - **Unable to determine**

10. **Weather conditions – which of the following best describes weather conditions during the roadway traversal?**
    - **No adverse conditions**
    - **Fog**
    - **Mist**
    - **Raining**
        - Check for windshield wiper use
    - **Snowing**
    - **Sleeting**
    - **Smoke, dust**
    - **Other**
        - Ex. smog, blowing sand, blowing snow, crosswind, hail
    - **Unable to determine**

11. **Lane change – did the participant complete a lane change during the roadway traversal?**
    - **Yes**
    - **No**
    - **Unable to determine**

12. **Hand placement – select the condition that exists during the majority of the road segment**
    - **No hands on wheel**
    - **One or two hands on the wheel (appropriate placement)**
    - **Inappropriate hand placement (e.g., cross placement or awkward placement, possibly due to secondary task engagement)**
    - **Unable to determine**

13. **Hand placement – did the participant have both hands off the wheel, inappropriate hand placement, or both at any moment during the road segment?**
    - **No, neither condition occurred**
    - **Yes, no hands on wheel**
    - **Yes, inappropriate hand placement (e.g. cross placement or awkward placement, possibly due to secondary task engagement)**
    - **Yes, both no hands and inappropriate hand placement**

- **Unable to determine**

14. **Seatbelt use – was the participant wearing their seatbelt during the roadway traversal?**
    - **Yes** – the participant was wearing their seatbelt during the entire traversal.
        - Acceptable seatbelt use includes lap and shoulder belt, lap only or shoulder only
    - **Partial** – the participant was wearing their seatbelt during a portion of the traversal.
        - Acceptable seatbelt use includes lap and shoulder belt, lap only or shoulder only
    - **No** – the participant was not wearing their seatbelt.
    - **Unable to determine**

15. **Vehicle Speed – Which of the following best describes the vehicle speed during roadway traversal?**
    - Consider speed only when vehicle is in motion. Things to check:
        1. Speed relative to other vehicles
        2. Speed and roadway navigation vs. other traffic
- **Driving at appropriate speed –** Driver is traveling at a speed appropriate for traffic and / or roadway conditions
- **Driving fast relative to other traffic –** Vehicle is traveling significantly faster than surrounding traffic
- **Driving slow relative to other traffic**- Vehicle is traveling significantly slower than surrounding traffic
- **Driving too fast (no surrounding traffic) –** No other vehicles in traffic stream, but subject seems to be traveling fast for the roadway segment
- **Driving too slow (no surrounding traffic) -** No other vehicle in traffic stream, but subject seems to be traveling slow for the roadway segment
- **Unable to determine**

16. **Driving behavior – Which of the following driving behaviors did the participant exhibit during roadway traversal**?
- consider driving behaviors only when vehicle is in motion. Things to check:
    1. Intersection crossings/adherence to signs/signals and turn signal usage
    2. Lane changes with proper turn signals and gaps
    3. Sudden maneuvers (steering, braking, etc.)
    4. General driver confidence
- **None**
- **Illegal passing -** Vehicle passes another vehicle in an unsafe or illegal manner (other than on the right)
    - Ex. passing across double line, going straight through turn lane
- **Passing on right -** Vehicle passes another vehicle in the lane immediately to the right of the other vehicle
    - This variable is not applicable in heavy traffic

- **Other improper or unsafe passing** -Vehicle passes another vehicle in a manner not included in previous categories
    - Ex. passing on two-lane road with limited sight distance or other vehicle present
- **Cutting in, too close in front of other vehicle** - Vehicle enters lane of another vehicle too closely to the front of that vehicle
- **Cutting in, too close behind other vehicle** - Vehicle enters lane of another vehicle too closely to the back of that vehicle
- **Following too closely** – vehicle is traveling at an unsafe distance (too close) behind the lead vehicle
- **Did not see other vehicle during lane change or merge** - Vehicle entered a lane or merged into a lane without being aware of another vehicle close by, already traveling in that lane
- **Driving in other vehicle's blind zone** - Vehicle is traveling close to another vehicle in such a way that the driver of the other vehicle is not able to see it
    - Code when vehicle maintaining this position for at least five seconds
- **Aggressive driving, specific, directed menacing actions** - Driver is driving in a purposefully aggressive manner, with actions intended for a specific recipient
    - Ex. exhibiting road rage
- **Reckless driving** - Driver is driving in an aggressive manner not described in previous categories
    - Ex. reckless driving without directed menacing actions, such as excessive speed, weaving in and out of traffic, tailgating
- **Wrong side of road, not overtaking** - Vehicle is traveling on the wrong side of the road with no intent of passing or overtaking another vehicle
- **Failed to signal, or improper signal** - Vehicle failed to properly signal its intent, either signaling incorrectly or not at all
    - Note: this category is partially redundant with the categories "Failure to signal, with other violations or unsafe actions" and "Failure to signal, without other violations or unsafe actions"--use with planned maneuvers, not sudden evasive maneuvers
- **Improper turn, wide right turn** - Vehicle turned right from the travel path, unnecessarily encroaching into the adjacent lane
- **Improper turn, cut corner on left** - Vehicle turned left from the travel path, unnecessarily encroaching into the adjacent lane
    - Ex. cuts into adjacent lane or oncoming traffic
- **Improper turn, other** – Vehicle turned left or right from the travel path in an unsafe manner not described in previous categories
- **Making turn from wrong lane** – vehicle turns left or right from a lane not intended for making that turn
- **Improper start from parked position** - Vehicle moved from a parked position (vehicle was turned on and advanced from a fully stopped position) in an unsafe manner
    - Ex. did not check mirrors

- **Disregarded officer or watchman** - Driver did not notice or obey an officer of the law or watchman providing guidance in the driving task
    - Ex. unaware or late to react
- **Stop sign violation, apparently did not see stop sign** - Driver did not notice and thus disobeyed a stop sign
    - Ex. unaware or late to react
- **Stop sign violation, intentionally ran stop sign at speed** - Driver saw a stop sign but purposefully drove through the intersection at a speed greater than 15 mph
    - Ex. purposefully ran stop sign without decelerating below a speed of 15 mph
- **Stop sign violation, "rolling stop"** – Driver did not come to a complete stop at a stop sign (speed was below 15 mph, but above 0 mph)
- **Other sign (e.g., Yield) violation, apparently did not see sign** - Driver did not notice and thus disobeyed a traffic sign (other than a stop sign)
- **Other sign (e.g., Yield) violation, intentionally disregarded** - Driver saw a traffic sign (other than a stop sign) but purposefully disobeyed that sign
- **Other sign violation** - Driver disobeyed a traffic sign in a manner not described in previous categories
- **Right-of-way error in relation to other vehicle or person, apparent recognition failure** - Driver made the incorrect decision regarding who had the right-of-way, his own vehicle or another vehicle or pedestrian, due to a misunderstanding of the situation
    - Ex. did not see other vehicle
- **Right-of-way error in relation to other vehicle or person, apparent decision failure** - Driver made the incorrect decision regarding who had the right-of-way, his own vehicle or another vehicle or pedestrian, due to improper analysis of the situation
    - Ex. did see other vehicle prior to action but misjudged gap
- **Right-of-way error in relation to other vehicle or person, other or unknown cause** - Driver made incorrect decision regarding who had the right-of-way, his own vehicle or another vehicle or pedestrian, for reasons not described in previous categories
- **Sudden or improper braking** - Vehicle braked suddenly or in an unsafe manner in the roadway (but did not come to a complete stop as a result)
    - If the sudden braking leads directly to stopping (speed indicator goes to zero), code as "sudden or improper stopping on roadway"
- **Sudden or improper stopping on roadway** - Vehicle stopped without ample warning or in an unsafe manner in the roadway
    - Ex. hard or late braking/code only when driver speed indicator goes to zero--code "sudden or improper braking" otherwise.
    - The only time to code braking and stopping for one event would be when the braking doesn't lead directly to the stopping (subject brakes, then a bit later has to suddenly stop).
- **Use of cruise control contributed to late braking** - Driver delayed applying brake pedal because the cruise control was activated, resulting in an unsafe situation
- **Failure to signal, with other violations or unsafe actions** - Driver failed to properly signal intent during actions consisting of other unsafe driving manner(s)

    - Ex. during an illegally executed lane change in the middle of an intersection - use with planned maneuvers, not sudden evasive maneuvers
- **Failure to signal, without other violations or unsafe actions** - Driver failed to properly signal intent but did not exhibit other unsafe driving action(s)
    - Ex. changing lanes without signaling or turning without signaling - use with planned maneuvers, not sudden evasive maneuvers
- **Failure to dim headlights** - Vehicle traveling with high beams activated on headlights, without dimming the lights when appropriate
- **Driving without lights or insufficient lights** - Vehicle traveling with no headlights on (or inappropriate headlights on) when the situation requires such lighting for safety
- **Avoiding object in roadway –** driver behaved in a manner intended to avoid conflict with an object in or near roadway.
    - Objects could include pedestrian, other vehicle, animal, boxes, snow / ice, pothole etc.
- **Apparent unfamiliarity with roadway** - Driver behaved in an unsafe manner, apparently due to an unfamiliarity with the surrounding traffic situation
    - Ex. repeated u-turns, reading maps, papers, etc.
- **Apparent unfamiliarity with vehicle -** Driver behaved in an unsafe manner, apparently due to an unfamiliarity with the vehicle
    - Ex. unfamiliarity with displays and controls
- **Apparent general inexperience driving** - Driver behaved in an unsafe manner, apparently due to lack of experience with the driving task
    - Ex. hyper-focused driving, overly cautious maneuvers, etc.
- **Other** - Other behavior not described in previous categories
- **Unable to determine**

17. **Participant impairment – Which of the following impairments did the participant exhibit during roadway traversal?**
    - **None apparent** - No observable driver impairment
    - **Drowsy, sleepy, asleep, fatigued -** Driver exhibits obvious signs of being asleep or tired, or is actually asleep while driving, degrading performance of the driving task
    - **Ill, blackout** - Driver exhibits obvious signs of physical illness or loss of consciousness, degrading performance of the driving task
    - **Angry -** Driver exhibits obvious signs of anger, whether directed at a specific target or not, degrading performance of the driving task
    - **Other emotional state** - Driver exhibits another emotional state not described in previous categories that degrades performance of the driving task
        - Ex. depressed, disturbed
    - **Drugs, medication** - Driver was obviously under the influence of a medication (prescription or over-the-counter) during the event (medication not necessarily a cause in the event)
        - Record if clearly seen
    - **Drugs, Alcohol** - Driver was obviously under the influence of alcohol during the event (alcohol not necessarily a cause in the event)
        - Record if clearly seen

- **Other illicit drugs** - Driver was obviously under the influence of an illegal drug or other type of drug not described in other categories during the event (drug not necessarily a cause in the event)
    - Record if clearly seen
    - ex. marijuana, cocaine
- **Restricted to wheelchair** - Driver must use a wheelchair for mobility
- **Impaired due to previous injury** - Driver is physically impaired due to some type of pre-existing injury not described in previous categories
- **Deaf** - Driver is obviously hearing impaired
- **Other** - Driver exhibits obvious physical or mental impairment not described in previous categories (specifics are known)
- **Unable to determine**

18. **Participant distraction – which of the following distractions did the participant exhibit during roadway traversal?**

- If less than five distractions are observed, mark remaining distractions as "Not Distracted"
- **Not Distracted** - There are no observable signs of driver distraction
- **Lost in thought** - Driver performs multiple non-specific eye glances within 6 second period of time
- **Looked but did not see** - Driver is looking right at where incident is occurring, but shows no reaction
- **Passenger in vehicle** -When the passenger is not visible, but the driver is clearly interacting with a passenger in the vehicle. This could be talking, listening, reacting to (i.e., laughing), moving toward or away from the passenger (i.e., reaching for the passenger, or avoiding a pat from the person). If the passenger is visible (even if the driver is not interacting at a given time), code this distraction.
    - If the passenger is visible, even if the driver is not interacting at a given time, code this distraction
    - Use this distraction if you can see the passenger in the camera or the driver is talking and looking in the direction of the passenger seat.
- **Talking/singing** without obvious passenger -When driver is moving lips as if in conversation or singing a song.
    - Mark this if driver is talking or singing and there is no other passenger visible in the car.
    - Only use this distraction if you cannot see a passenger in the camera or the driver is talking and not looking in the direction of a passenger seat and does not turn head as if communicating with someone.
- **Dancing** - This could be when the driver is using his/her arms to go with the beat of the music or moving head.
- **Reading** - This is reading material that is in the vehicle, but not a part of the vehicle (i.e., not reading external signs, or radio display).
    - This could be reading directions, paper material, or packaging. If reading a phone number, record as dialing cell phone.

- **Cognitive - Other** - Includes when driver is writing, emotionally upset or angry, or other activity that requires the driver to obviously be thinking about something other than driving.
- **Moving object in vehicle** - When an object inside the vehicle is in motion, either due to the motion of the vehicle or due to another passenger throwing the object.
  - Ex. object fell off seat when driver stopped hard at a traffic light.
- **Insect in vehicle** - Swatting at insect, moving body to avoid insect, looking around trying to locate insect.
- **Pet in vehicle** - Any interaction with pet, including petting, talking to, or moving pet or pet carrier.
  - Only code if animal/pet is visible at some point in the trip file or if there is history/context with the driver and the driver is exhibiting behaviors that are appropriate to having a pet in the vehicle.
- **Object dropped by driver** - When a driver is holding something and it drops and the driver then picks it back up.
- **Reaching for object (not cell phone)** - When driver reaches for an object, other than a cell phone.
  - Once the driver has finished reaching for the object and has it in hand, then it becomes 'object in vehicle_other', as long as it doesn't fit into any of the other categories (i.e. eating or drinking).
- **Animal/Object in Vehicle--Other** - When a driver clearly is looking at, handling, or manipulating an object (visible or not) or thing located in the vehicle, other than those listed in other categories
- **Talking/listening on cell phone** -When a driver is talking or has phone up to ear as if listening to a phone conversation or waiting for person they are calling to pick up the phone. If driver has ear piece, reductionist must observe the driver talking repeatedly.
  - Cell phone use is always categorized as distraction
- **Dialing / interacting with keys on hand-held cell phone** - When a driver is pushing buttons on a cell phone to dial a number or check something else on their cell phone. This would also include reading a phone number from a sheet of paper.
- **Dialing hands-free cell phone using voice activated software** - When a driver speaks into open or activated cell phone with long, prior delay of no speaking into device and no button presses (i.e., most likely not in prior conversation).
- **Locating/reaching/ answering cell phone** - When the driver is reaching towards his/her cell phone and then putting the phone to his/her ear.
  - If more than one distraction happens (i.e., driver looks for phone, reaches for it and then answers it), the last frame number would be the last distraction (i.e.., answering cell phone.)
- **Cell phone - Other** - When a driver is interacting with a cell phone in some manner, i.e., looking at a cell phone but not necessarily manipulating the cell phone in any way.
- **Locating/reaching PDA** - When driver reaches or starts to glance around for PDA.
- **Operating PDA** - When driver is pressing buttons on the PDA.
- **Viewing PDA** - When driver is looking at PDA, but not pressing any buttons

- **PDA - Other** - When a driver is interacting with a PDA in some manner, i.e., looking at a PDA but not necessarily holding or manipulating the PDA in any way.
- **Adjusting climate control** - When driver interacts with climate control either by touching the climate control buttons, or glancing at the climate control on dashboard.
- **Adjusting radio** - When driver interacts with radio either by touching the radio buttons on dashboard or steering wheel, or just glancing at the radio on dashboard.
- **Inserting/retrieving cassette** - When driver picks up cassette in vehicle and pushes it into cassette slot and presses any subsequent buttons to get cassette to play/rewind/fast forward and then play, or when driver presses button to eject cassette and then places it somewhere in vehicle.
- **Inserting/retrieving CD** - When driver picks up CD in vehicle and pushes it into CD slot and presses any subsequent buttons to get CD to play/rewind/fast forward and then play, or when driver presses button to eject CD and then places it somewhere in vehicle.
- **Adjusting other devices integral to vehicle** - When driver interacts with a manufacturer-installed device other than those listed in other categories, either by touching or glancing at the device.
    - Includes interaction with seat belt, door locks, etc.
- **External: Looking at previous crash or incident** - When a driver is looking outside of the vehicle in the direction of what is obviously an accident or incident.
    - Only mark if it is clear that the driver is tracking a specific external distraction as they drive by
- **External: Looking at pedestrian** - When a driver is looking outside of the vehicle in the direction of a pedestrian (not in a construction zone) either on the side of the road or in front of them (i.e., using a crosswalk or riding a bike at a red light).
- **External: Looking at animal** - When a driver is looking outside of the vehicle in the direction of an animal on either side of the road. This would not be used for an animal crossing the road.
- **External: Looking at an object** - When a driver is looking outside of the vehicle in the direction of an object (not in a construction zone) on the side of the road (i.e., a box).
- **External: Looking at construction** - When a driver is looking outside of the vehicle in the direction of a construction zone. A construction zone would be defined as seeing a barrel, person in a hard hat, construction equipment or vehicles.
- **Other external distraction** - When a driver is looking outside of the vehicle for purposes not described in previous categories
- **Eating**
- **Drinking**
- **Cigar/cigarette/tobacco**
    - Includes reaching for, lighting, smoking and extinguishing
- **Personal hygiene**
    - Includes activities such as combing or fixing hair, applying make-up, shaving, brushing teeth, biting nails, removing or adjusting jewelry, and removing or inserting contact lenses

    - EXCLUDE any minor activities which are not obvious distractions (i.e., lightly touching/rubbing/scratching the chin, ear, cheek, etc., but not picking at anything in particular)
- **Other**
- **Unable to determine**

19. **Duration of distraction – distraction start sync & distraction stop sync**
    - Distraction start sync
        i. If no distraction is observed leave this field blank
        ii. If the participant is engaged in the task prior to roadway entry then mark as one sync prior to trigger start sync
        iii. Else mark the sync the engagement begins after trigger start sync
    - Distraction end sync
        i. If no distraction is observed leave this field blank
        ii. If the participant is engaged in the task after exiting the roadway segment then mark as one sync after the trigger end sync
        iii. Else mark the sync the engagement begins prior to trigger end sync

A series of questions are relevant only to urban intersection traversals and are marked as such. In the event that a selected epoch is not an urban intersection traversal, simply skip these questions.

20. **[INTERSECTION ONLY] Other vehicles – how many other vehicles were present around the subject at the beginning of the intersection segment?**

21. **[INTERSECTION ONLY] Other vehicle location**
    - If other vehicles are not present this field should be left blank.
    - Only consider other vehicles that are close enough to restrict the participant's ability to maneuver.
    - The participant vehicle is always designated as vehicle #1. Other vehicles assume vehicle numbers 2 thru 5.
    - Figure A.1 below provides a reference when determining the location of other vehicles.
    - **A: in front of subject vehicle**
    - **B: in front and to the immediate right of the subject vehicle**
    - **C: on the right side of the subject vehicle, closer to the front seat of the vehicle**
    - **D: on the right side of the subject vehicle, closer to the rear seat of the vehicle**
    - **E: behind and to the immediate right of the subject vehicle**
    - **F: behind the subject vehicle**
    - **G: behind and to the immediate left of the subject vehicle**
    - **H: on the left side of the subject vehicle, closer to the rear seat of the vehicle**
    - **I: on the left side of the subject vehicle, closer to the front seat of the vehicle**
    - **J: in front and to the immediate left of the subject vehicle**
    - **Unable to determine**

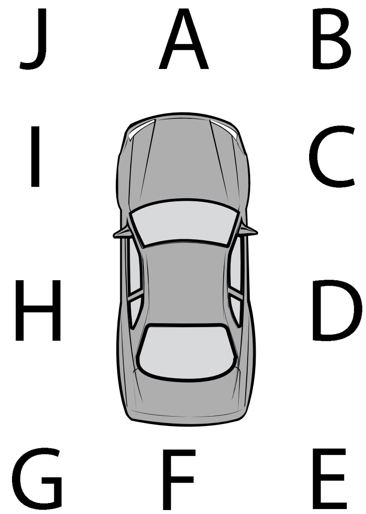

Figure A.1. Other vehicle location.

22. **[INTERSECTION ONLY]Other vehicle type**
    - **Car (sedan, coupe, station wagon)**
    - **Van (minivan or standard) / pickup truck (including regular tow trucks that are not towing) / SUV (includes Jeep, crossovers)**
    - **Bus (transit, motor coach or school bus)**
    - **Single-unit straight truck (includes panel truck, U-haul)**
    - **Tractor trailer (with or without the trailer)**
    - **Motorcycle or moped**
    - **Emergency vehicle (police (vehicle or on horseback), fire, EMS) - in-service**
    - **Vehicle pulling trailer**
    - **Other vehicle type**
    - **Pedestrian**
    - **Pedalcyclist**
    - **Animal**
    - **Unable to determine**

23. **[INTERSECTION ONLY] signal phase prompts**
    - If the signal phase is clearly visible mark the first signal phase prompt as "phase clearly visible" and disregard the second signal phase prompt question
    - In some instances it is not possible to clearly see the signal phase (green, amber, red) but is possible to use additional information from the video to estimate the signal phase. This additional information has been termed signal phase prompts.
    - **Phase clearly visible**
    - **Relative position of phase ball**
    - **Movement of vehicles in same direction**
    - **Movement of vehicles in opposite direction**
    - **Movement of cross-traffic**

- **Visible shift in signal phase**
- **Signal phase for cross-traffic clearly visible**
- **None**
- **Unable to determine**

24. **[INTERSECTION ONLY] – signal phase**
    - If the signal phase is clearly visible then use the unqualified categories (green, amber or red)
    - If only one signal phase prompt is available and it is possible to estimate signal phase then make use of the qualified ("Signal phase indiscernible – likely") categories
    - If two signal phase prompts are available and it is possible to estimate signal phase then make use of the unqualified categories (green, amber, red)
    - **Green**
    - **Amber**
    - **Red**
    - **Signal phase indiscernible**
    - **Signal phase indiscernible – likely green**
    - **Signal phase indiscernible – likely amber**
    - **Signal phase indiscernible – likely red**

25. **[INTERSECTION ONLY] Stopping behavior – which of the following best characterizes the participant's stopping behavior?**
    - **Participant does not come to a stop** – the driver does not bring the vehicle to a complete stop.
        - Include low speed "rolling stops" in this category
    - **Participant stops as first vehicle in queue, at or before the stop bar**
    - **Participant stops as first vehicle in queue, but beyond the stop bar**
    - **Participant stops behind leading vehicle**
    - **Unable to determine**

26. **[INTERSECTION ONLY] signal violation – which of the following best describes the type of observed signal violation?**
    - A signal violation is defined by the following conditions:
        1. the last visible signal phase is red or likely red
        2. the participant did not come to a stop
    - **No signal violation**
    - **Signal violation, apparently did not see signal** – participant did not notice and thus disobeyed traffic signal
    - **Signal violation, intentionally disregarded signal** – driver saw traffic signal purposefully disregarded it
    - **Signal violation, tried to beat signal change** – driver accelerated or continued at a speed intended to pass through an intersection before the signal turned red
    - **Unable to determine**

27. **[INTERSECTION ONLY] Vehicle path – which of the following best describe the vehicle path during intersection traversal?**
    - **Left turn**
    - **Right turn**
    - **Straight crossing** – the vehicle crosses straight through the intersection.
    - **U-turn** – the vehicle completes a turn resulting in a heading 180° from entry heading
    - **Unable to determine**

28. **[INTERSECTION ONLY] Appropriate destination lane – did the participant exit in the correct lane?**
    - **Yes**
    - **No – driver changed lanes during intersection traversal**
    - **No – driver changed lanes on intersection approach**
    - **No – driver changed lanes on approach and in the middle of the intersection**
    - **Unable to determine**

29. **[INTERSECTION ONLY] Was the intersection traversal in compliance with lane type?**
    - **Yes.**
    - **No – straight crossing from turn only lane.**
    - **No – turn from straight crossing only lane.**
    - **Unable to determine**

30. **Comments**
    - Please keep the following in mind to include in the comment text box
        i. Construction on the roadway segment
        ii. Any infrastructure element that seems relevant such as roadside signage with warnings or pavement markings with warnings
        iii. Anything that should be brought to the attention of the researcher such as driver or environmental conditions not captured by the reduction but relevant to intersection traversal.

REFERENCES

(1) Cannon, B.R., McLaughlin, S.B., & Hankey, J.M. (2009). *Method for Identifying Rural, Urban, and Interstate Driving in Naturalistic Driving Data* (09-UT-005). Blacksburg, VA: National Surface Transportation Safety Center for Excellence

(2) Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., Perez, M. A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., Jermeland J., & Knipling, R. R. (2006). The 100-Car naturalistic driving study, phase II - results of the 100-Car field experiment. Washington, DC: National Highway Traffic Safety Administration.