WRONG WAY DRIVING IN SAN ANTONIO, TEXAS:

A TRANSPORTATION ROUTE STUDY USING NETWORK ANALYST

by

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DEDICATION

I dedicate this paper to my parents and family for their loving support throughout my graduate studies. Their encouragement has truly been a blessing as I finished this thesis.

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LIST OF ABBREVIATIONS

CMV	Commercial Motor Vehicle
CRIS	Crash Records Information System
DOT	Department of Transportation
Esri	Environmental Systems Research Institute
GIS	Geographic Information Systems
GPS	Global Positioning Systems
HPMS	Highway Performance Monitoring System
ITS	Intelligent Transportation Systems
MPO	Metropolitan Planning Organization
NAD 83	North American Datum 1983
SAPD	San Antonio Police Department
SQL	Structured Query Language
TABC	Texas Alcohol Beverage Commission
Task Force	San Antonio Wrong Way Driver Task Force
WWD	Wrong-Way Driving

ABSTRACT

San Antonio in Bexar County is the seventh largest-populated city in the United States, and resides centrally in the state of Texas (United States Census 2010). Texas ranks first in total roadway miles by ownership, with over 300,000 roadway miles built for public use (United States Census 2012). With such a vast roadway infrastructure comes many critical problems including wrong-way driving (WWD), the focus of this study.

An Environmental Systems Research Institute (Esri) ArcGIS geoprocessing task, *Closest Facility*, utilizing Network Analyst 10.1 extension has been customized to create a Wrong-Way Driving Transportation Model (WWD Model) (Esri 2013). This model directly addresses several key challenges faced by the San Antonio Wrong Way Driver Task Force (herein referred to as Task Force). Using geographic information systems (GIS) this model performs a route analysis that models the travel paths of such crash incidents from their likely point of origin – alcohol-serving facilities as determined by the Task Force (San Antonio Wrong Way Driver Task Force 2012). The WWD Model methodology is structured such that a specified *Network Dataset* – in this case, roadways provided by Bexar County Metro 911 – is analyzed to route WWD crash *incidents* from the nearest suspected *facilities* of origin. The customized geoprocessing toolkit then utilizes the resulting polyline dataset output to estimate the route taken by drivers based on the validated spatial relationship of reported crash *incidents* to reported WWD events as recorded in real-time by TransGuide Operators. A data validation of the resulting

routes yield a 77 percent match to the total TransGuide reported events, concluding that the WWD Model can be used to map wrong-way travel behavior with 77 percent accuracy given the parameters specified throughout this paper (Maldonado 2013).

CHAPTER 1: INTRODUCTION & MOTIVATION

The Wrong-Way Driving (WWD) issue can compromise any transportation infrastructure if not addressed with data-driven analysis and appropriate countermeasures. As a GIS Transportation Analyst, it was my task to develop a logical methodology to achieve such a goal with the use of transportation datasets provided by Bexar County Metro 911 (3.1 Data Sources). This chapter serves as the preface to this manuscript to better outline the geospatial characteristics of San Antonio, Bexar County region and WWD thereof.

1.1 Introduction

Defined as the act of driving head-on into opposing traffic in the opposite lane of travel, WWD throughout Texas is a serious traffic safety concern. The same road network used for efficient traffic flow is inadvertently serving as a danger to disoriented drivers. In San Antonio, Bexar County, Texas from January 1, 2006 to December 31, 2011, 314 reported WWD crashes occurred, 13 of which resulted in a fatality (3.1.1 Point Location Data). These 13 represent approximately 4 percent of the total 314 WWD crashes, but there were several hundred crash-related injuries ranging from “unknown” to “fatal” in severity. An overview crash density map can be seen in Figure 1, which illustrates high concentrations of WWD crashes near highway interchanges and throughout downtown San Antonio.

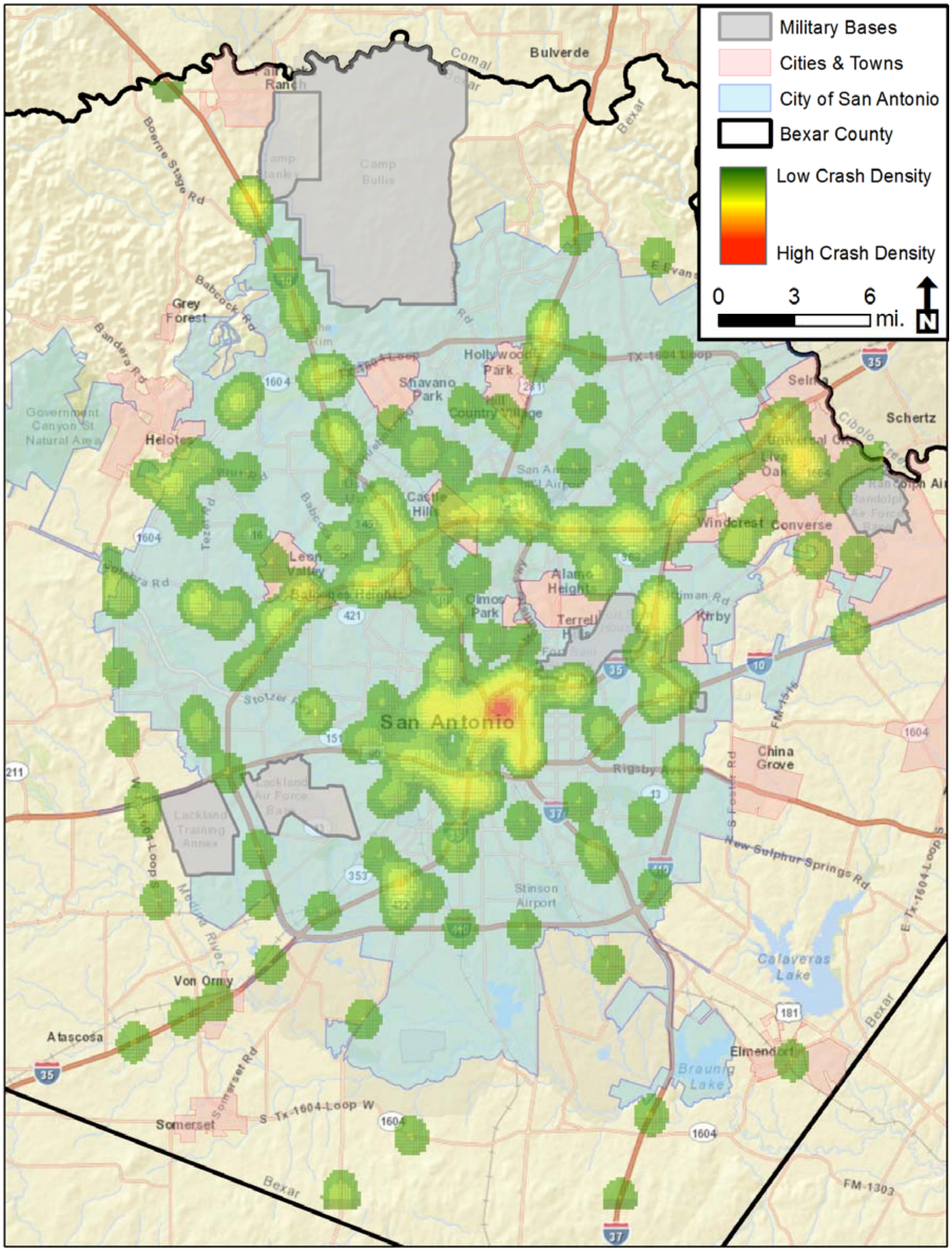


Figure 1: WWD Crash Density Map

This WWD analysis is unique in its use of the Bexar County boundary rather than the Metropolitan Planning Organization (MPO) boundary, to allow uniformity in comparison to similar metropolitan areas like Dallas, Tarrant, Travis, and Harris counties. Those counties represent the top most-populated cities in Texas, respectively. MPO boundaries are subject to change since they are based on population density as determined by the U.S. Census Bureau, whereas county boundaries are relatively static throughout the time frame considered in this study.

Another important phase of this study is the validation of the WWD route analysis results within Bexar County. The Task Force focuses their efforts on crashes occurring primarily on high-capacity highways in 2011 and beyond, which is how the problem was initially identified. In this study, the actual crash data collected between 2006 and 2011 were analyzed to discern any spatial patterns related to WWD routes traveled which resulted in crashes.

The growing concern by local transit and enforcement authorities over these crashes evidenced the need for this analysis and an accurate assessment of crash data, to better plan appropriate future countermeasures for San Antonio. One such measure is the collaboration of traffic and law enforcement agencies that meet to discuss regional issues and options for corrective action (San Antonio Wrong Way Driver Task Force 2012). As a contribution to the Task Force, this Master's thesis developed a geoprocessing task to assist in the identification of possible WWD routes to be later used by law enforcement to stake out WWD crash hotspots and corridors.

The City of San Antonio and County of Bexar were used as a preliminary study area for this analysis and development of the WWD Model due to the ongoing research of local agencies in search for a solution to the WWD problem. San Antonio's large road network and population serve as an advantageous input dataset for this study, since a successful route analysis and validation of the WWD Model in such an intricate environment has the potential to demonstrate the model's applicability to other similar regions.

However, it was necessary to exclude some regional features like the Riverwalk and surrounding regional metropolitan connectivity from the analysis. In this thesis, metropolitan connectivity refers to "the density of connections in path or road network and directness of links" (Victoria Transport Policy Institute 2012, 1). The Riverwalk serves as a pedestrian walkway with a unique permit allowing consumption of alcohol while on property, thus making it a possible *facility* and potentially contributing to WWD *incidents* (City of San Antonio 2011). Nevertheless, the Riverwalk is a sub-grade construction inaccessible to vehicle traffic, so it was deleted from the input network dataset.

In regards to exclusion of surrounding regional metropolitan connectivity from the study, San Antonio, Bexar County is approximately 70 miles from the nearest metropolitan area – Austin, Travis County, Texas – and thus lacks the inter-metro connectivity of cities like Dallas, Dallas County and Fort Worth, Tarrant County which would require different parameters for handling issues specific to such areas.

1.2 Motivation

As a GIS Transportation Analyst, the author's role is to use the Texas DOT Crash Records Information System (CRIS) records to illustrate crashes according to attributes and to develop a flexible model for determining or estimating the routes drivers take from alcohol-serving retailer *facilities* to point of crash *incidents* (Texas DOT 2011). Despite ongoing research into the causes of WWD within transportation, little has been reported in the literature about theories concerning modeled travel behavior of drivers based on available data. In this case, State of Texas funding cannot immediately support an infrastructure-wide integration of WWD detection systems; therefore countermeasures must be added in phases during planned construction projects of high priority corridors such as US-281, IH-35, and LP-1604 which are all within San Antonio – Bexar County MPO's Metropolitan Transportation Plan (San Antonio - Bexar County MPO 2013). Harris County Toll Road Authority (Houston) and North Texas Tollway Authority (Dallas and Ft. Worth) have previously performed WWD research, however, their focus was on similarly functioning highways and high-capacity roadways like US-281, IH-35, and Loop-1604, which does not entirely account for surface street crashes that may be the source of drivers taking wrong-way routes onto exit ramps of higher capacity roads (North Texas Tollway Authority 2009) (Willey 2011).

Perhaps the most obvious historic trend previously identified was that many wrong-way drivers that caused accidents in the San Antonio area were impaired by alcohol and drug consumption (San Antonio Wrong Way Driver Task Force 2012). Of the 314 total crashes in the dataset analyzed in this study, 100 were identified as impaired using relevant attributes – had been drinking, taking medication, drug/alcohol influence – as described by Texas Department of Transportation (DOT) (Cooner, Cothron and Ranft 2004, 25; Texas DOT 2011). Because impaired driving represents roughly 32 percent of total crashes, there are other important variables that should also be considered in a WWD analysis. These factors include drivers' familiarity with a particular area, and presence or absence of appropriate signage. Some countermeasures currently being implemented within the study area include installing larger signage, radar-triggered LED signs, and increased enforcement in known high crash density areas.

Despite implementation of additional safety measures, several problems persist that need be addressed to support these types of safety measures. These challenges include identifying how drivers are traveling from their points of origin that leads them onto wrong-way paths of travel. Identification of WWD routes through this study is intended to assist in ranking problematic corridors and intersections, which in turn could improve law enforcement response time and prioritization of locations identified as requiring countermeasures. Geospatial data analysis such as this is also important for assessing quality of real field data for research use and future comparison of Bexar County analysis results to other similar metropolitan areas.

Problems encountered in the crash data obtained from San Antonio – Bexar County MPO included incomplete data (e.g. location, contributing factors), and possible miscoded records in the retrieved version of data that may have resulted in underreported crashes. At this time, the procedure for processing incomplete data is to include these incidents in the total crash count, but in an "other" category in graphic visualizations (e.g. maps, charts, graphs). These data are often missing precise coordinates, dates or time fields.

Public awareness is also critical to the region's success in reducing WWD, but informing a large population comes with challenges as well. In theory, a web GIS could streamline the process, but at this time gathering and maintaining the data is a significant task in itself. For example, City Sourced, Inc. has developed an interactive public website and mobile application where the general public can report local infrastructure issues such as potholes in roads or perceived illegal dumping incidents (City Sourced, Inc 2013). Many government agencies have access to near real-time data analysis tools, and as interagency collaboration becomes more refined at some point in the near future more agencies will have access to such web services (Lomeli, et al. 2011).

One particular local news story further highlights the need for this study; recently impaired driving in Olmos Park has become such a critical problem that a frequently hit fountain is being removed, as it’s been deemed hazardous to impaired drivers (Ramdass 2012). The roundabout fountain is part of Olmos Park’s urban landscape, but after approximately 25 crashes – including at least one that occurred during its construction phase – local officials have decided to remove and perhaps relocate it (Gerber 2012).

CHAPTER 2: BACKGROUND & LITERATURE REVIEW

San Antonio, Texas is by no means a unique case of WWD behavior. This issue has roots, "since the interstate highway system was founded in the late 1950s," through current times. WWD is a nationwide issue, illustrated by the catastrophic 2001 drunk WWD crash on IH-90 in Seattle, Washington (Moler 2002, 24). The San Francisco, California region has experienced similar incidents ranging from early morning WWD crashes on highways and tunnels to violent altercations ending with gunfire (San Francisco Chronicle 1986, 5; Hallissy 1996, A19; Lee 2008, B3). In 2006 a drunk-driving man collided head-on with a vehicle holding a pregnant passenger on a local Wisconsin highway (Wisconsin State Journal 2006, C3). In 2009 law enforcement in Corpus Christi, Texas arrested a man after an early morning fatal WWD crash on IH-37 (Marsillo 2009, B13).

Even beyond U.S. borders WWD threatens transportation networks internationally. Known as *ghost drivers* in France, "the scope of the phenomenon goes beyond accident rates…as the vast majority of [them] don't cause accidents," despite one confirmed sighting "every 1 to 15 days" (Vicedo 2007, 43). The prior mentioned events and the lack of published nationwide WWD statistics combined with the ongoing crashes in San Antonio led to sponsored research projects focused on WWD countermeasures and distracted driving (Finley 2012; Texas A&M Transportation Institute 2013).

2.1 Background

Local transportation and law enforcement agencies of the San Antonio region have partnered together to create the Task Force to discuss countermeasures, research, and related matters, as described in the following section. Summaries of their objectives and ongoing research as an interagency collaborative effort are provided in the following subsections.

2.1.1 San Antonio Wrong Way Driver Task Force

The WWD issue was discussed among several agencies and organizations in the San Antonio area. Eventually the multi-agency collaborative Task Force was created in May 2011 to coordinate personnel and financial resources into one focused effort. The professional skill of each agency affords such a group to combine data, research, and experience to better engineer countermeasure solutions. Task Force members discuss recent incidents and countermeasure updates in monthly meetings (San Antonio Wrong Way Driver Task Force 2012). Agencies participating in the Task Force include: Texas DOT, San Antonio Police Department (SAPD), City of San Antonio, Bexar County Sheriff's Department, Federal Highway Administration, Texas A&M Transportation Institute, and San Antonio – Bexar County MPO. At the request of San Antonio – Bexar County MPO, the author joined this Task Force to provide GIS analysis support.

2.1.2 Goals

The Task Force initiated goals as a metric to quantify their success of countermeasure implementation. These goals include: 1) Identifying high-risk locations, 2) Investigating research and countermeasure applications of other regions, 3) Identifying potential countermeasures for San Antonio, Bexar County, and 4) Identifying funds for implementation of countermeasures (San Antonio Wrong Way Driver Task Force 2012). This thesis project forwards the first goal by identifying high-risk locations in that the WWD Model was created to identify routes that can be used to better visualize high-risk locations and corridors, based on transportation data and crash incidents provided by the Task Force.

2.1.3 Challenges

Several challenges to achieving the Task Force goals were anticipated to include the following: 1) Determining highway points of entry for wrong-way drivers, 2) Determining methods of attracting impaired drivers attention, 3) Identifying total number and location of the 400+ highway exit ramps, 4) Identifying cost effective countermeasure solutions compliant with the Texas DOT Manual of Uniform Traffic Control Devices, and 5) Standardizing data management to accommodate multi-source inputs, consistent query language, data redundancy, and spatial representation (San

Antonio Wrong Way Driver Task Force 2012). This WWD thesis project directly addresses the first and fifth challenges by providing a validated geoprocess in the form of the WWD Model that can be implemented in a GIS. The model is capable of simulating highway points of entry while accommodating multi-source user inputs with consistent structured query language (SQL), documentation, and methodology.

2.1.4 San Antonio – Bexar County MPO

The San Antonio – Bexar County MPO was not listed in the Task Force website, but did participate as a regional partner agency offering technical GIS support for roadway and crash analysis. San Antonio – Bexar County MPO is a federally funded state agency consisting of a staff, committees, and Transportation Policy Board made up of regional transportation agencies and elected officials (San Antonio - Bexar County MPO 2011). The MPO's purpose is to plan short and long range funding for improving the road network so that it becomes more safe and efficient for multimodal transportation. Several safety analyses and studies have been conducted by the MPO in an effort to provide public awareness of roadway safety concerns. These studies have looked into impaired driving, road rage, speeding, driver inattention, bicycling, pedestrian, and motorcycle related crashes. Additionally, there are ongoing analyses in the areas of Commercial Motor Vehicles (CMV), Elderly Driving, and WWD. Standard practice at MPO is to quantify crash counts by year, month, weekday, time of day, and further visualize the queried CRIS dataset with a web GIS (San Antonio - Bexar County MPO 2012). Most studies are done with respect to the MPO boundary, which is larger than the Bexar County boundary.

2.1.5 San Antonio Wrong Way Driver Task Force Research Analysis

Analysis performed by the Task Force revealed “approximately 80 percent of the reports of wrong-way drivers resulted in no accident, with the wrong-way driver not encountered by law enforcement,” meaning the 314 reported crashes in the 2006-2011 dataset may only represent 20 percent of total incidents. Hence it is more likely the total number of WWD incidents in San Antonio, Bexar County is 1,570 (San Antonio Wrong Way Driver Task Force 2012). In addition to possible underreporting of total wrong-way driver events, it was also observed “that over 80 percent of wrong-way driver reports in San Antonio occur 10:00PM – 6:00AM, and 45 percent of reports occur 2:00 AM – 4:00 AM”; the latter were attributed to drivers traveling from late hour alcohol-serving establishments the previous day (San Antonio Wrong Way Driver Task Force 2012). Additionally, approximately one third of the 314 reported crashes involved an impaired driver based on the author’s analysis, which seems to justify a direct correlation between the offense categories Driving Under the Influence, Driving While Intoxicated, and WWD (Maldonado 2013).

2.1.6 High Risk Locations

One of the Task Force’s goals was to identify and prioritize high-risk locations. Figure 2 depicts the crash density map from Figure 1 along with reported WWD sightings from TransGuide Operator logs and SAPD’s 911 call logs (3.1.1 Point Location Data). Records were spatially selected for the San Antonio region, and contained the keywords “wrong-way” in their description (San Antonio Wrong Way Driver Task Force 2012). It is important to note that some sightings have occurred where there was no crash, and likewise some crashes have occurred without nearby reported sightings.

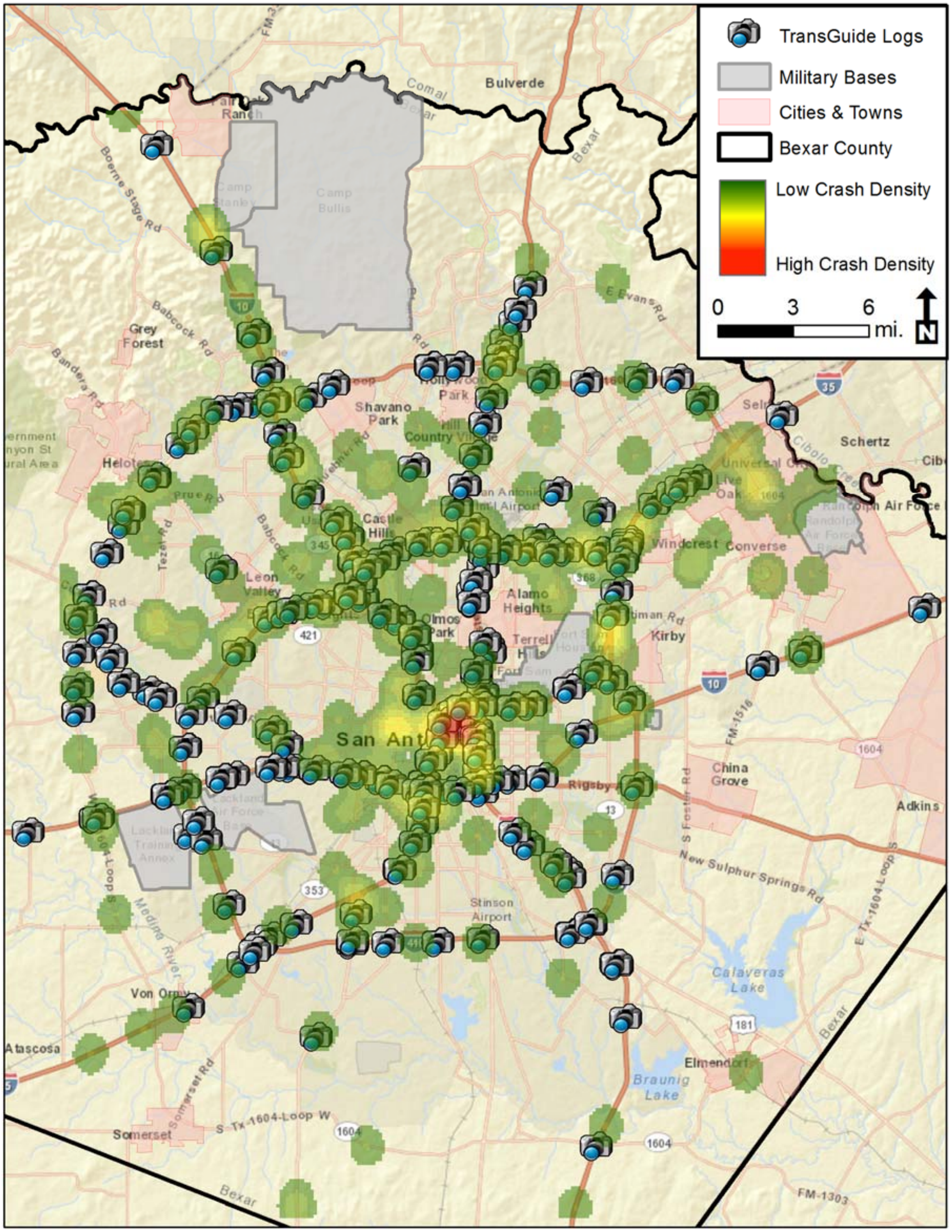


Figure 2: Wrong-Way Driver locations, as a subset of the total crashes

In the records mentioned above, most of the results are from the call and operator logs. Operators concluded that: “drivers either missed the necessary exit, or were driving away from their intended destination to begin with,” and when reported by phone, their [wrong-way driver] location had changed, and as such the event(s) may no longer exist (San Antonio Wrong Way Driver Task Force 2012). According to the Task Force website, “cross streets and interchanges are the typical reporting locations referenced by 911 callers and TransGuide operators, therefore wrong-way driver event locations tended to be exaggerated at freeway interchanges and major cross streets” (San Antonio Wrong Way Driver Task Force 2012). This contributes to the intensity of wrong-way crashes on the density map, particularly around downtown and major highway junctions (San Antonio Wrong Way Driver Task Force 2012). Based on Figure 2, Texas DOT selected US-281 corridor as the first priority “operational test project…from the IH-35 Interchange (downtown) to Stone Oak Parkway…[as] more than 20 percent of all wrong-way driver events reported in San Antonio have been on this [15 mile] corridor” (San Antonio Wrong Way Driver Task Force 2012). With the use of LED illuminated signs combined with radar devices on select mainlanes and exit ramps, the US-281 corridor serves as a pilot project for future corridor countermeasures, which also includes US-90, IH-35, IH-37, IH-10, Loop-410, and SH-151.

2.1.7 Physical Preventative Measures To-Date

LEDs & Signage

Presently, to combat this rising threat the Task Force has installed a limited number of LED illuminated signage and radar equipment on problematic US-281 corridor ramps to mitigate further incidents (San Antonio Wrong Way Driver Task Force 2012). Whether these countermeasures improve traffic safety remains to be seen, but spatially viewing the crash data can assist in locating wrong-way points of origin. Other than these physical measures, no data analysis such as the modeling accomplished as part of this thesis has previously been conducted utilizing the type of data analyzed in this study.

The Texas DOT Roadway Design Manual notes that stopping distance is a critical factor in highway design (Texas DOT Design Division, Roadway Design Section 2010, 36-37). The sight distance combined with the actual braking distance of the vehicle is used to calculate the time and distance needed to stop before reaching a stationary object, but a wrong-way driver complicates this calculation by having an equally high, if not faster velocity, than the right-way driver ergo the implementation of illuminated LED signage on exit ramps to help mitigate such circumstance. In addition to LED signage standard sized “WRONG WAY [and] DO NOT ENTER” signs were replaced with larger enhanced static signage to increase visibility and roadway safety awareness.

Radar & TransGuide

Instead of relying solely on public input and TransGuide personnel for wrong-way driver locations, radar devices were implemented on high-risk mainlanes and exit ramps to achieve real-time geo-location of wrong-way drivers, and provide statistics for analyzing future countermeasures. When a wrong-way driver activates the radar device a notification is sent to TransGuide Operators and SAPD dispatchers to relay the news to the public, via digital message signage, and to law enforcement in the area.

Spikes Strips

A common misconception is the use of spike strips for mitigating wrong-way drivers. Though effective in small, low-speed areas such as parking lots and tollbooths, spike strips become dangerous at high speeds in areas such as highways where not all traffic may be of the same vehicle type (e.g. CMVs, mopeds, motorcycles). Additionally, a WWD vehicle may be inoperable after running over a spike strip, and still cause damage to drivers due to blocking right-of-way for free flowing right-way traffic. As such, permanent spike strips are not being considered by Texas DOT or the Task Force as a safe countermeasure at this time. Typically trained law enforcement personnel immobilize and apprehend wrong-way drivers, as necessary, using portable spike strips (Wilson 2013, 41). Additionally, earlier tests concluded that permanent spikes "were sometimes damaged and their presence often led to panicky reactions by right-way drivers," which may further worsen transportation safety conditions particularly in high-volume traffic (Scifres 1974, 38; Zhou, et al. 2012, 20).

Channelization

Channelization is the use of curbs to separate entering lanes from exiting lanes to provide a curve in the direction of right-way travel for traffic exiting an area onto a frontage road. This is oftentimes seen at airports where one-way paths are necessary for directing high-volume traffic. On-site channelization development is incumbent upon property owners; therefore the Task Force plans to work with them, especially late hour alcohol-serving establishments (San Antonio Wrong Way Driver Task Force 2012).

2.2 Literature Review

The main take-away for this study related to this literature review is the potential misuse of "passing sight distance" within passing lanes contributing to WWD crashes, and that such events may have an increased occurrence on roadways with rolling terrain grades as noted in a 2009 WWD crash in Corpus Christi, Texas on IH-37 (Marsillo 2009, B13). This chapter discusses several manuals that describe possible challenges to the identification, geo-location, and analysis of wrong-way drivers performed in this study (Transportation Research Board Committee on Highway Capacity and Quality of Service

2000; Texas DOT Design Division, Roadway Design Section 2010; Federal Highway Administration 2012). In addition, Esri tools similar to the WWD Model are briefly compared to the *Closest Facility* geoprocess chosen (Esri 2012).

2.2.1 Highway Capacity Manual 2000

Two-lane highways are a key element in this analysis since a significant proportion of WWD crashes in the dataset analyzed occurred on two-lane highways. According to the Highway Capacity Manual 2000 edition published by the Transportation Research Board, historically “two-lane highways are a key element in the highway systems of most countries; they perform a variety of functions, are located in all geographic areas, [and] serve a wide range of traffic…for use by traffic in each direction. Passing a slower vehicle requires use of the opposing lane as sight distance and gaps in the opposing traffic stream permit” (Transportation Research Board Committee on Highway Capacity and Quality of Service 2000, 12-11). Due to uninterrupted traffic flow lanes, changing lanes may not be possible “in the face of oncoming traffic in the opposing lane [as] passing demand increases rapidly as traffic volumes increase, and passing capacity in the opposing lane declines as volumes increase. Therefore, on two-lane highways, unlike other types of uninterrupted-flow facilities, normal traffic flow in one direction influences flow in the other direction;” it is incumbent upon motorists to adjust their driving behavior to the varying traffic volume and pass capacity available

(Transportation Research Board Committee on Highway Capacity and Quality of Service 2000, 12-12 - 12-13). The principal function of major two-lane highways is to connect links in the state and national highway networks to serve commercial and recreational travelers, so they may pass through rural areas without traffic-control interruptions (Transportation Research Board Committee on Highway Capacity and Quality of Service 2000, 12-11). This information is important to mention since two-lane highways are a major consideration in this study, inherent within the input crash data and treated within the model developed by way of dual-roadbeds where available in the network dataset used in the analysis.

2.2.2 Texas DOT Roadway Design Manual

The "inability to pass in the opposing lane" is another key element in this analysis since this is reported as a possible contributing factor in WWD crashes as seen in Table 1. The inability to pass in the opposing lane must be assessed by passing sight distance as recommended in the Texas DOT Roadway Design Manual. It defines passing sight distance as "applicable [only] to two-lane highways [and] two-way frontage roads as [it] is the length of highway required by a driver to make a passing maneuver without cutting off the passed vehicle and before meeting an opposing vehicle...based on 3.5 ft. object and driver eye height, 10 mph between passing vehicles, with greater distance provided wherever practical" (Texas DOT Design Division, Roadway Design Section 2010, 3-31).

Moreover, most two-lane highways are impractical for continuous passing sight distance, but segments therein should be engineered to accommodate such design wherever feasible (Texas DOT Design Division, Roadway Design Section 2010, 3-31). Table 1 shows “minimum passing sight distance values for design of two-lane highways”. This information is important to this study only in that drivers passing in the opposing traffic lane for extended periods of time increase their chances of becoming a WWD threat.

DESIGN SPEED (mph)	MINIMUM PASSING SIGHT DISTANCE FOR DESIGN (ft.)
20	710
25	900
30	1090
35	1280
40	1470
45	1625
50	1835
55	1985
60	2135
65	2285
70	2480
75	2580
80	2680

Table 1: Minimum passing sight distance values for two-lane highways (Texas DOT Design Division, Roadway Design Section 2010, 3-32)

2.2.3 Highway Performance Monitoring System Field Manual

The Federal Highways Administration’s Highway Performance Monitoring System (HPMS) Field Manual requires state transportation agencies to collect and report Percent Passing Sight Distance data for a defined set of roadway segments, which are referred to as “sample panel sections” (Vaughn Jr. 2013). Within the scope of HPMS, this data is used by Federal Highway Administration “to calculate capacity and estimate running speed and for truck size and weight analysis purposes” as seen in Figure C1 (Appendix C: HPMS Manual Figures). The data collection extent requirement for this information specifies rural functionally classified roadways, which includes Bexar County and perhaps some integrated cities therein, excluding San Antonio. This is important to this study because roadways engineered for passing in the opposing lane could lead to drivers having WWD collisions despite being within their legal bounds.

Figure 3 illustrates how data collection values are coded by the HPMS for various roadway scenarios in the field. These scenarios include the possibilities of having passing permitted in one directional approach along a given roadway but not the other. However, despite the HPMS inventory direction – as depicted by the HPMS arrow – only single broken yellow striped sections of the sample panel roadway count towards this data item (Vaughn Jr. 2013). A recommendation for a future continuation of this WWD thesis study would be to generate a “real world” set of route events representing this data, in addition to the existing dataset. This would consist of broken yellow striped sections overlain on the linear reference system, which could then be spatially joined to this study’s route analysis results in order to analyze the number of drivers traveling in the face of oncoming traffic from their facility of origin. This would be particularly interesting because such examples of misuse of this particular roadway design may contribute to the 80 percent of unreported wrong-way drivers that are not apprehended (2.1.5 San Antonio Wrong Way Driver Task Force Research Analysis).

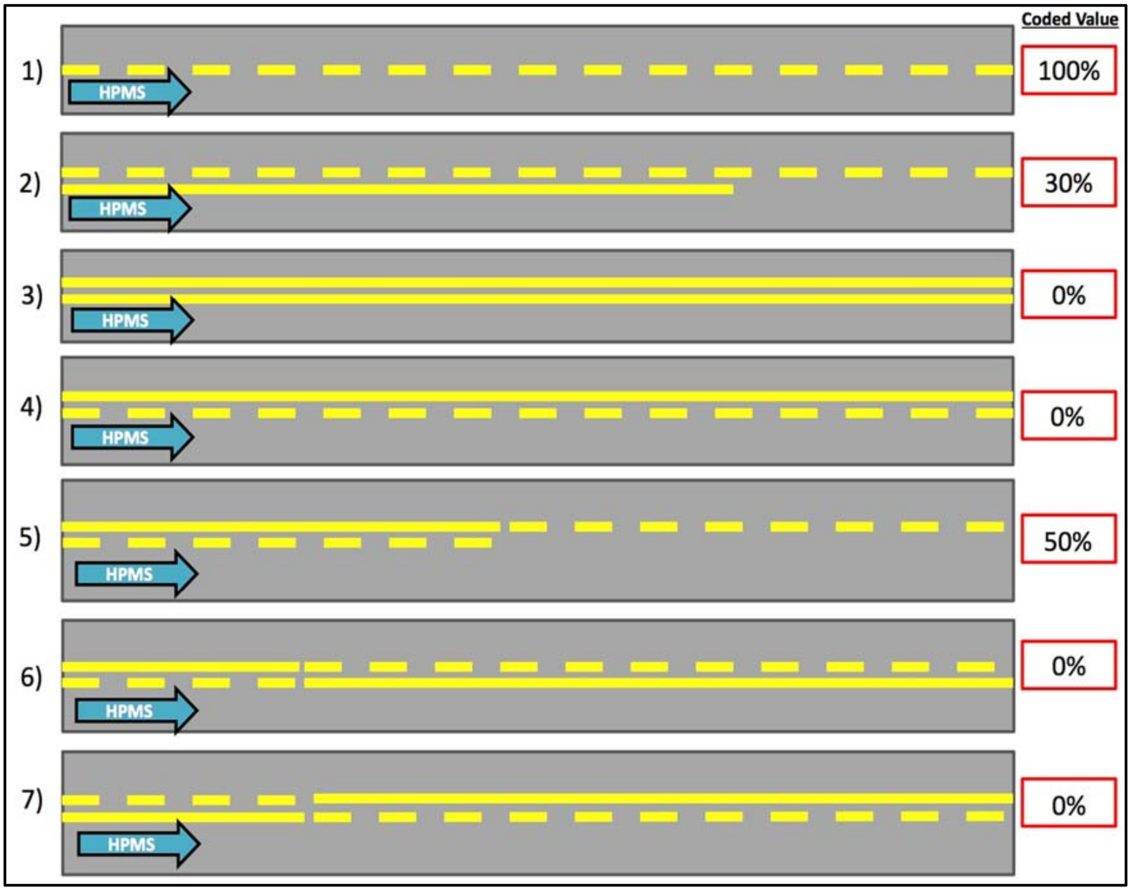


Figure 3: Examples of HPMS Percent Passing Sight Distance

Another significant contributing factor to WWD incidents is “rolling terrain” as seen in Figure C2 (Appendix C: HPMS Manual Figures). Climbing lanes may be a more economical alternative than achieving a vertical alignment with adequate passing sight distance” (Texas DOT Design Division, Roadway Design Section 2010, 3-31). Thus a wrong-way driver may instigate crash incidents based on the limited visibility of surrounding drivers in both directions of traffic.

The manuals summarized above describe possible exceptions to the identification, geo-location, and analysis of wrong-way drivers performed in this study. From this information one may deduce that rural two-lane roadways are a critical point for drivers legally passing traffic en route to a destination. Nevertheless consideration must be given to such drivers as they may unknowingly transition into a WWD threat as traffic volumes increase, and passing capacity in the opposing lane declines (Transportation Research Board Committee on Highway Capacity and Quality of Service 2000, 12-11 - 12-12). Such additional details are recommended for future study.

2.2.4 Esri Network Analyst: Make Service Area Geoprocess

Table 2 shows a summary of tools available within Esri's Network Analyst toolbox that performs some of the tasks mentioned as part of this study (Esri 2012). Two new relevant tools were researched in the latest version, added to this toolbox after the majority of the data compilation and programming were completed for this thesis work. Though several tools in the latest release of Network Analyst could have been used to perform parts of this analysis – particularly *OD Cost Matrix* and *Route Layer* – only *Closest Facility* was utilized since it outputs route geometry. The *OD Cost Matrix* tool does not output route geometry, and the *Route Layer* tool requires nested stops that were also not desirable in this study (Esri 2012). Thus neither *OD Cost Matrix* nor *Route Layer* was deemed suitable for the WWD Model created as part of this study.

TOOL	DESCRIPTION
Closest Facility	Makes network analysis layer useful for determining closest facilities to an incident based on a specified network cost.
Location-Allocation	Makes network analysis layer useful for choosing a subset of facilities to model increased travel demand in an efficient manner.
OD Cost Matrix	Makes an Origin-Destination cost matrix network useful for representing a matrix of costs going from set of origin(s) to set of destinations.
Route Layer	Makes network analysis layer useful for determining the best route between a set of network locations based on specified network cost
Vehicle Routing Problem	Makes network analysis layer useful for optimizing a set of routes for a fleet of vehicles
Service Area Layer	Makes network analysis layer useful for determining accessibility within a specified cost from a facility location

Table 2: Description of Network Analyst 10.1 tools

2.2.5 WWD Safety and Countermeasures

Analysis of the crash incident data analyzed in this study revealed that approximately 32 percent of total WWD crashes in San Antonio, Bexar County involved an impaired driver, and contributed to 46 percent of total fatal crashes. This percentage is consistent with the national trend for alcohol-related crashes, which ranges from 40 percent to 42 percent (Chambers, Liu and Moore 2012). National Transportation Safety Board published an investigation report that further reiterated the alcohol and drug relationship between impaired drivers and fatal WWD crashes, moreover it cites, "disproportionate number of wrong-way collisions occurring on the weekends… and 78 percent of fatal wrong-way collisions occurring between 6:00 PM and 6:00 AM" (National Transportation Safety Board 2012, 32). This, too, is consistent with Bexar County WWD crash statistics as roughly 53 percent of total WWD crashes occurred during the weekend, and approximately 85 percent of fatal WWD crashes occurred between 6:00 PM and 6:00 AM (3.1.1 Point Location Data). Roadway geometrics may contribute to WWD entries onto exit ramps, and as such "many regional jurisdictions have undertaken initiatives to monitor WWD incidents to identify problematic designs for countermeasure implementation" as described below (National Transportation Safety Board 2012, 41).

When further examined by hour of day there is a noticeable spike at the early hour of 2:00 AM. This spike of WWD crashes during the 2:00 AM – 2:59 AM hour "corresponds to the closing time of most bars in Texas" which was noted by the Task Force, and clearly illustrated in Figure 4 (Cooner, Cothron and Ranft 2004, 22). This is largely attributed to the flux of traffic departing from alcohol-serving establishments en route to another point-of-interest, and likely driving while impaired (San Antonio Wrong Way Driver Task Force 2012).

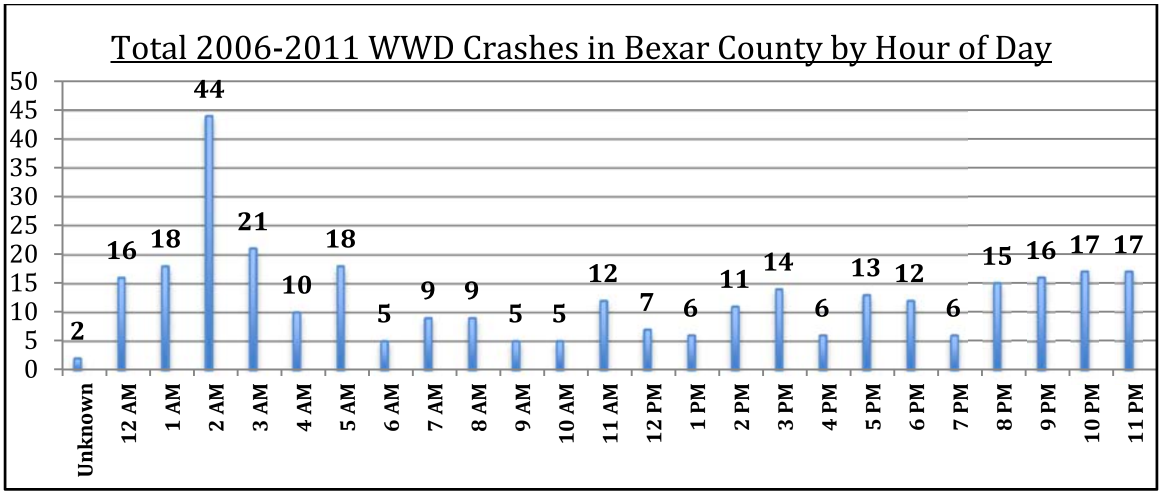


Figure 4: Total 2006-2011 WWD crashes in Bexar County by Hour of Day

To confront the issue of late hour impaired WWD, several countermeasure techniques have been researched and developed throughout the nation including signage, markings, barriers, geometrics, and Intelligent Transportation Systems (ITS) (Vaswani 1973, 11; Cooner, Cothron and Ranft 2004, 31). Increased signage on highway exit ramps has proven to be a successful countermeasure especially when combined with improved lower-mounted, oversized, and illuminated signage designs (Tamburri 1965, 20; National Transportation Safety Board 2012, 45). Early research by Virginia DOT has shown pavement markings such as double yellow lines on undivided roads, and stop lines at exit ramps to detour potential WWD (Vaswani 1973, 25-28). More recent research published by Transportation Research Board suggested using red reflectorized raised pavement markings for increased nighttime visibility – "dark" light conditions accounted for nearly 62 percent of WWD – to alert wrong-way travelers particularly for "tourists from countries with left-hand drive" (Miles, et al. 2008, 34) (3.1.1 Point Location Data). Many physical barrier designs have been considered, however, only "small-width, raised median" barriers in lieu of double yellow lines, and barriers on highway exit ramps have been recommended due to the "inherent problems in the systems proposed" such as spike strips (Vaswani 1973, 31) (2.1.7 Physical Preventative Measures To-Date). Some roadway configurations are more prone to WWD than others; however, such roadway geometric changes can require vast reengineering of infrastructure ergo difficult to implement, but more simple tasks such as channelization are viable options (National Transportation Safety Board 2012, 48). Various state DOT's early ITS applications involved cameras installed at exit ramps to capture vehicles to better understand the volume of WWD, and in some cases identify specific drivers based on their license plates (Tamburri 1965, 10-17; Cooner, Cothron and Ranft 2004, 5-7). More refined ITS developments include web GIS and Global Positioning System (GPS) enabled vehicles capable of real-time ubiquitous data mining; automobile manufacturers Toyota and BMW have already produced prototypes of such usable technology (National Transportation Safety Board 2012, 52-53). Alternatively, use of non-motorized transportation can mitigate crashes around downtown where dense traffic restricts roadway travel, but does not affect Riverwalk commutes (Maldonado 2012).

2.2.6 WWD Research and Development

Currently public transportation agencies are working towards “an assessment tool that the states can use to select appropriate countermeasures for problematic controlled-access highway locations” (National Transportation Safety Board 2012, 57). Additionally, University of Southern California’s National Center for Risk and Economic Analysis of Terrorism Events is developing “a system that provides risk driven intelligence collection, analysis, and decision-support for use [to] local law enforcement” (Orosz, Southers and Heatwole 2012). Internet empire corporation, Google, engineered one solution with its autonomous vehicle that has been approved by Nevada Department of Motor Vehicles after several tests throughout Carson City and Las Vegas (Hachman 2012). Google’s autonomous automobile is a self-driven motor vehicle that leverages “cameras, radar, lasers, and databases” to eliminate human input and inherent error thereof (Slosson 2012). Even before Google’s 2012 achievement autonomous vehicle applications have been demonstrated using a motorcycle as early as 2005 (Levandowski, et al. 2007). Widespread commercial use of autonomous vehicles will likely precipitate improvements to transportation infrastructure, as well as more accurate “signature traffic pattern” spatial awareness (Banaei-Kashani, Shahabi and Pan 2011, 16). Such ITS advancements are the beginning of an ideal real-time crash detection system – 100 percent detection, 0 percent false reports – that eliminates driver error thus saving billions in roadway costs (Mussa, et al. 1998, 137; Krishnaswamy, et al. 2005, 1).

CHAPTER 3: DATA SOURCES & METHODOLOGY

To successfully test and validate the WWD Model, several datasets were required to serve as *facility, incident,* and *barrier* inputs as described throughout this chapter. The following datasets were gathered from San Antonio – Bexar County MPO, Texas Alcohol Beverage Commission (TABC), Bexar Metro 911, Texas DOT, and City of San Antonio, specifically for use in this study. All of the data presented in this discussion were used in this analysis, described in detail throughout this manuscript.

3.1 Data Sources

3.1.1 Point Location Data

Spatial analysis of the WWD crashes dataset

The WWD crash records were retrieved from San Antonio – Bexar County MPO by way of Texas DOT CRIS (Texas DOT 2011). These data consist of 2006-2011 crashes categorized by their spatiotemporal attributes (e.g. spatial, temporal, severity), and were obtained from November 2011 to March 2012, as data was made available. Originally a simple tabular dataset with latitude and longitude fields, the dataset was displayed using its X,Y coordinate values in ArcMap. Then the event records were exported as ArcGIS shapefiles and feature classes with an assigned geographic coordinate system of North American Datum 1983 (NAD 83, U.S. feet). The data were queried using SQL syntax for “wrong-way – one way road” contributing factors. The resulting selection was used as the *incidents* input dataset for the WWD Model.

The CRIS dataset provided to the San Antonio – Bexar County MPO by Texas DOT contains several attributes that can be used to visualize a summary of Bexar County as well as statewide data. In the following discussion various graphs and charts based on the available data summarized by year were generated to illustrate overall countywide trends applicable to understanding the motivations behind this WWD analysis (1.2 Motivation).

Despite the high terminal velocity involved in WWD crashes, less than 10 percent of total crashes were fatal, and half of total drivers were not injured. However, among the latter half several possible and non-incapacitating injuries are widely present. In Figure 5 crash severity can be seen by injury type ranging from unknown to fatal.

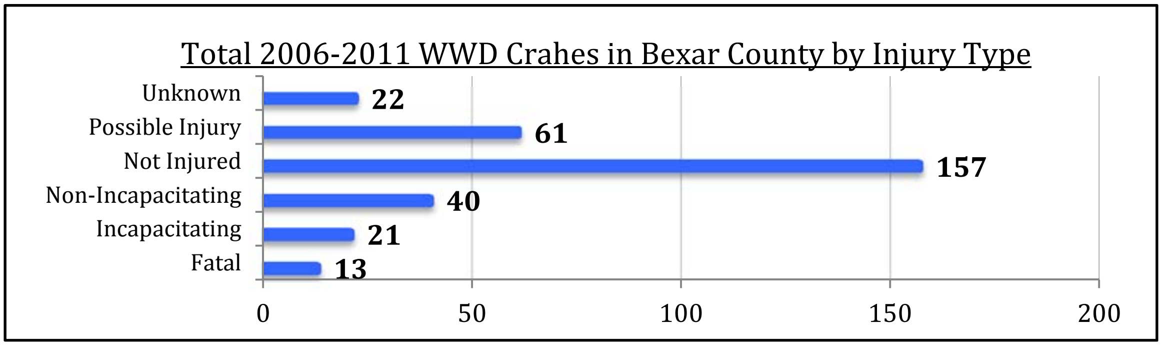


Figure 5: Total 2006-2011 WWD crashes by Injury Type

Of the five major counties – and cities therein – Bexar County ranks fourth in total WWD crashes, with less than 10 percent difference to tie with third place, Tarrant County, as seen in Figure 6. It should be noted that the San Antonio region is unlike Dallas and Tarrant counties whose metropolitan areas function as a metroplex, and similarly Houston, Harris County, which is the fourth most populated city in the United States (United States Census 2010).

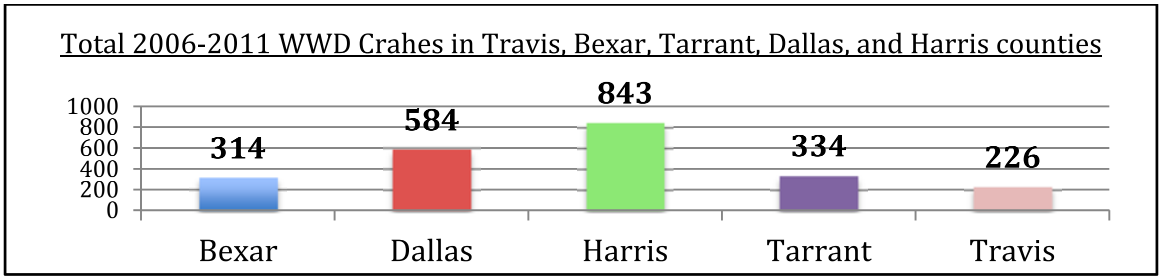


Figure 6: Total 2006-2011 WWD crashes in select counties

When the aggregate numbers of crashes are viewed temporally a trend can be seen throughout the 2006-2011 timespan, illustrated in Figure 7. In nearly all the counties a spike in crashes occurs in 2007, and a general downward trend as time progresses toward 2011, with the exception of Tarrant County.

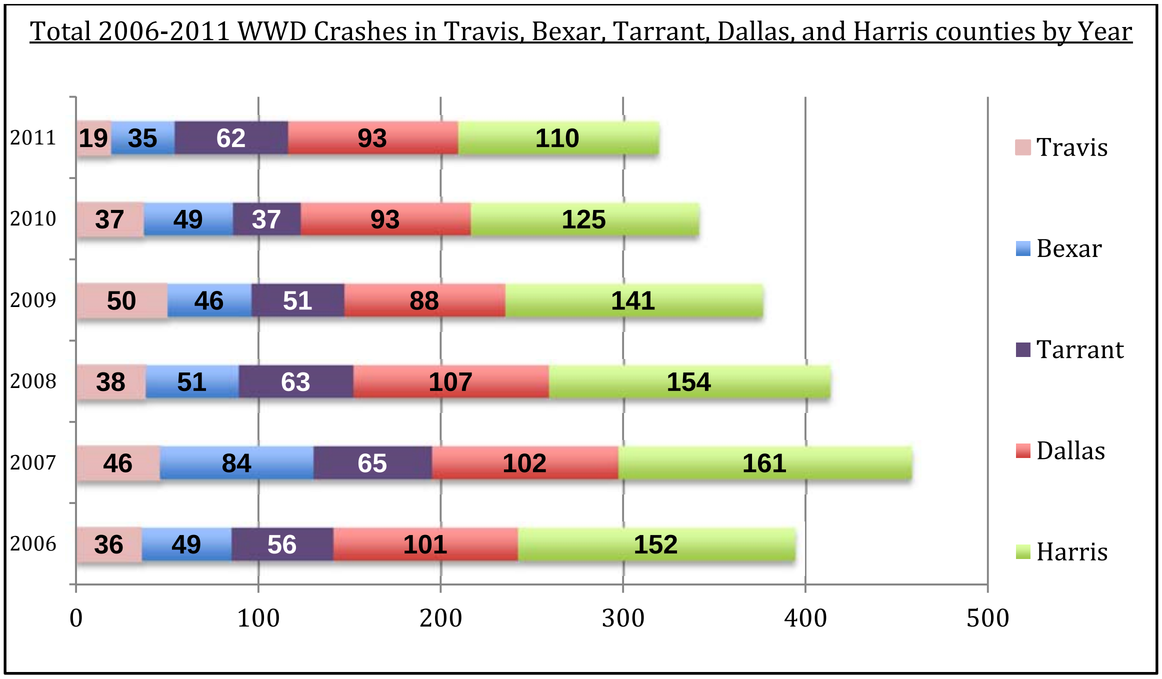


Figure 7: Total 2006-2011 WWD crashes in select counties by Year

The crash date is a record of when the crash occurred in a MM/DD/YYYY format. The exact date of a crash discovered or reported at a later date than the estimated date was also provided, thus allowing this data to be broken down into various temporal components as seen in in Figure 8 through 18 (Texas DOT 2011). Taking an exclusive look at Bexar County's WWD crashes by year, a relatively steady average of 49 can be seen in 2006 and 2008-2010 (Figure 8). In 2007 WWD crashes increased by over 50 percent from this average, while in 2011 there was over 25 percent decrease from this average.

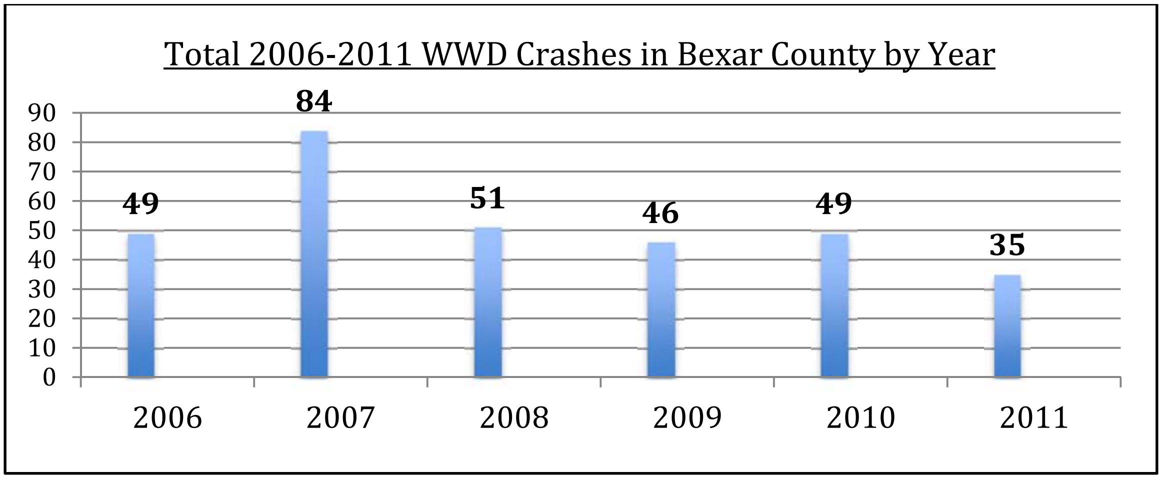


Figure 8: Total 2006-2011 WWD crashes in Bexar County by Year

When evaluated by month a temporal pattern can be observed as shown in Figure 9, particularly within end of year holiday months October-December as well as March-April, which may be contributed to City of San Antonio's annual "Fiesta" event (Fiesta San Antonio Commision 2013).

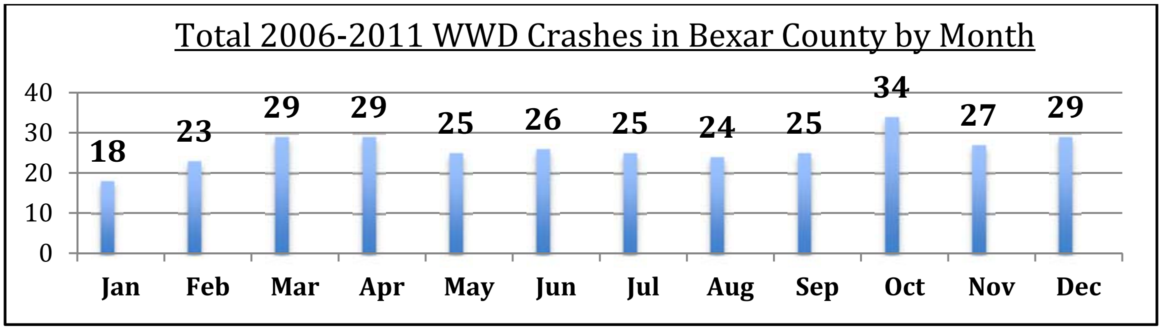


Figure 9: Total 2006-2011 WWD crashes in Bexar County by Month

When observed by day of week there is perhaps little surprise weekend trends are higher than weekdays in regard to WWD crashes, presumably this spike is the result of late hour alcohol consumption (Figure 10). Moreover, between Monday – Thursday, the greatest number of crashes occur on Wednesday with roughly 10 percent less than Friday.

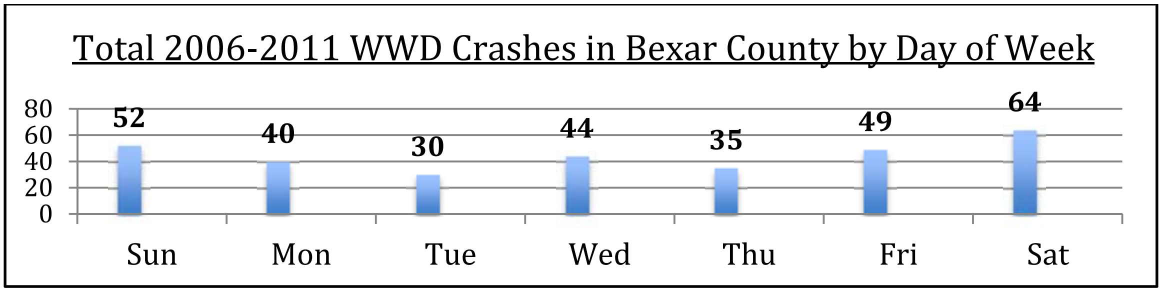


Figure 10: Total 2006-2011 WWD crashes in Bexar County by Day of Week

Figure 11 summarizes traffic devices correlated to the total number of crashes. This information is included because it “best describes the type of traffic control element present; even if it is not related to the crash” (Texas DOT 2011). Though various traffic control devices are reported, over half of crashes have no applicable traffic control device or none present at all. Thus, many crashes may be due in part to lack of visible traffic control devices near the scene of crash.

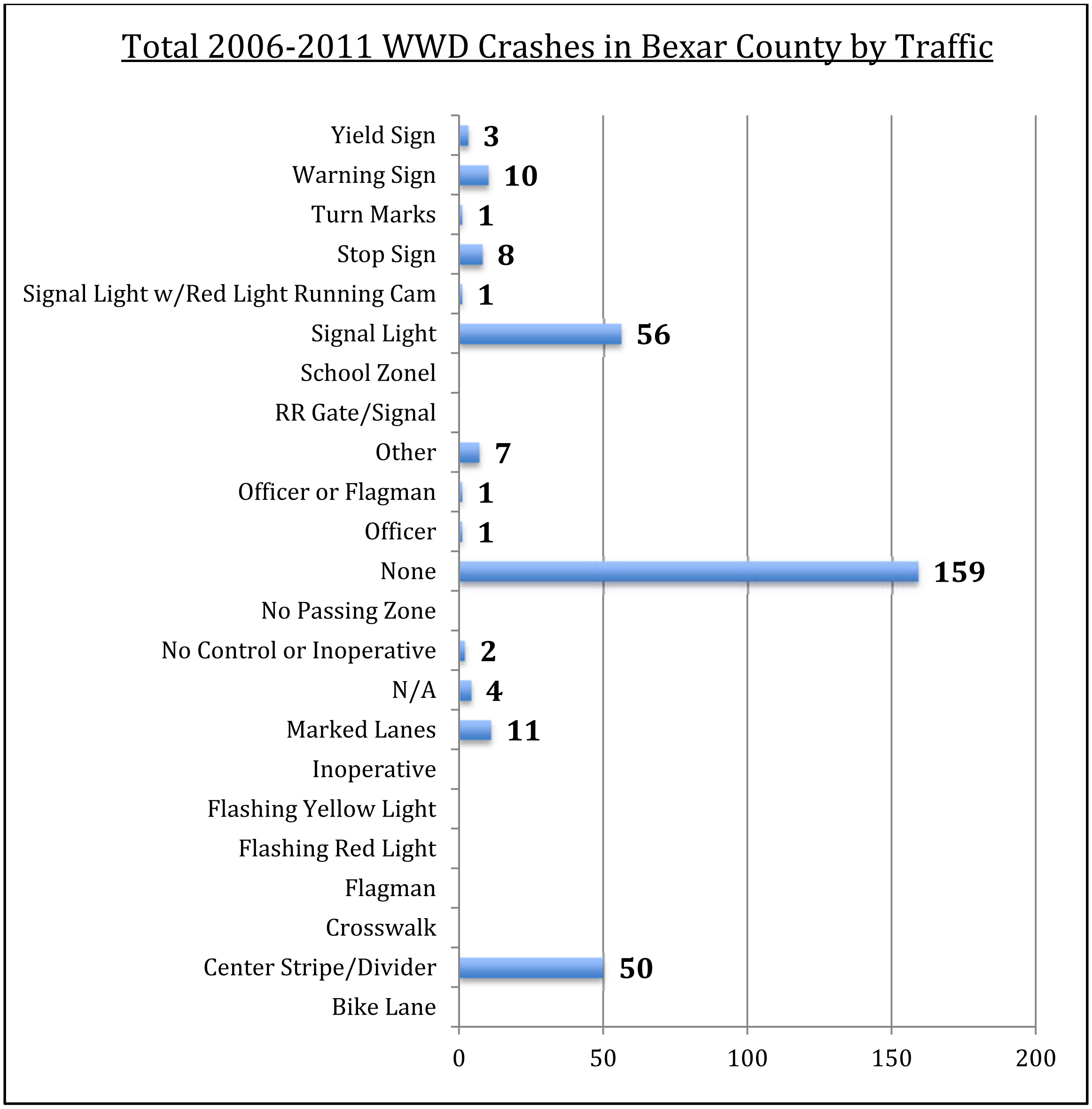


Figure 11: Total 2006-2011 WWD crashes in Bexar County by Traffic Device

Relevant Entering Roadway Configurations are used to “best describe the physical layout of the intersection” at each reported crash incident, but unfortunately most of the 2006-2011 wrong-way crashes have no applicable information available, evident in Figure 12. This may be due to a lack of intersecting roadways near crash incidents (Texas DOT 2011). Of entering roadway configurations that were reported, "4 Entering Roads" was most prevalent followed by "3 Entering Roads – T", both of which are traditional perpendicular style intersections in Texas.

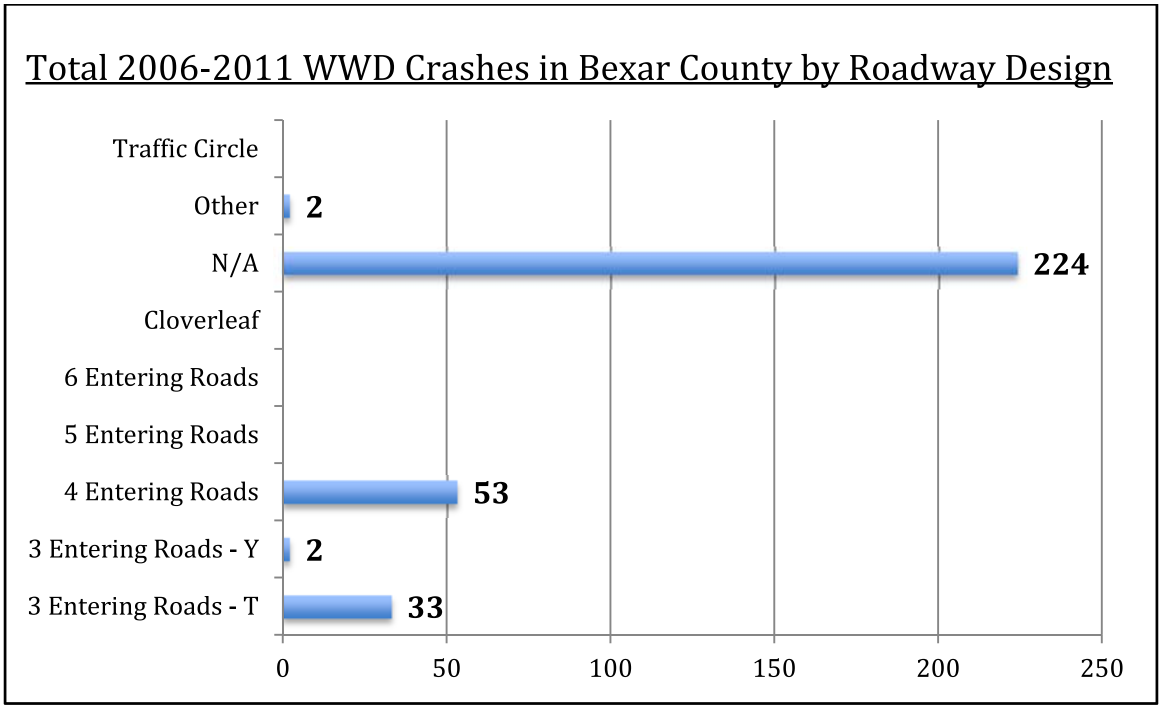


Figure 12: Total 2006-2011 WWD crashes in Bexar County by Roadway Design

Roadway Surface Conditions "best describe the prevailing surface condition present at the time and place the crash" (Texas DOT 2011). They are predominantly "Dry" which is expected as San Antonio, Texas has a historical pattern of a dry, arid climate often leading to severe draught and wildfires (National Oceanic and Atmospheric Administration 2003). Figure 13 shows the total crash data for this study summarized by specific surface conditions. From this basic comparison of wet versus dry driving conditions over the time period being examined, it may be reasoned that wet weather was not the most significant contributing factor to the total number of WWD crashes.

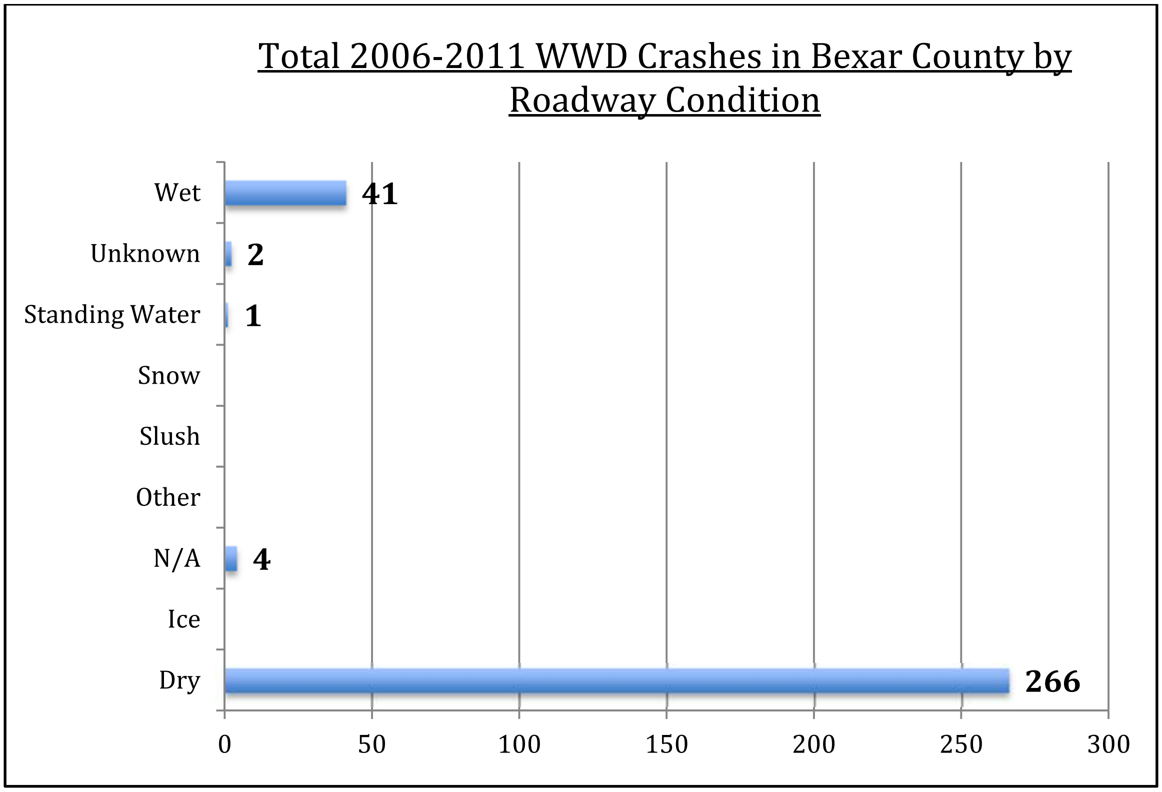


Figure 13: Total 2006-2011 WWD crashes in Bexar County by Roadway Condition

Weather Conditions "best describe the prevailing atmospheric condition that existed at the time of the crash [and] if additional atmospheric conditions existed, [they] are explained in the narrative" (Texas DOT 2011). The most common value for this item is "Clear/Cloudy" with over 60 percent of total crashes reported under this weather condition, as illustrated in Figure 14. The next highest category is "N/A" which may be owed to weather conditions outside the defined domain, or the weather information was not recorded. In either case, “Clear” followed by “Rain” are the next two most common weather conditions prevalent during WWD crashes with approximately 10 percent and 9 percent of total crashes respectively.

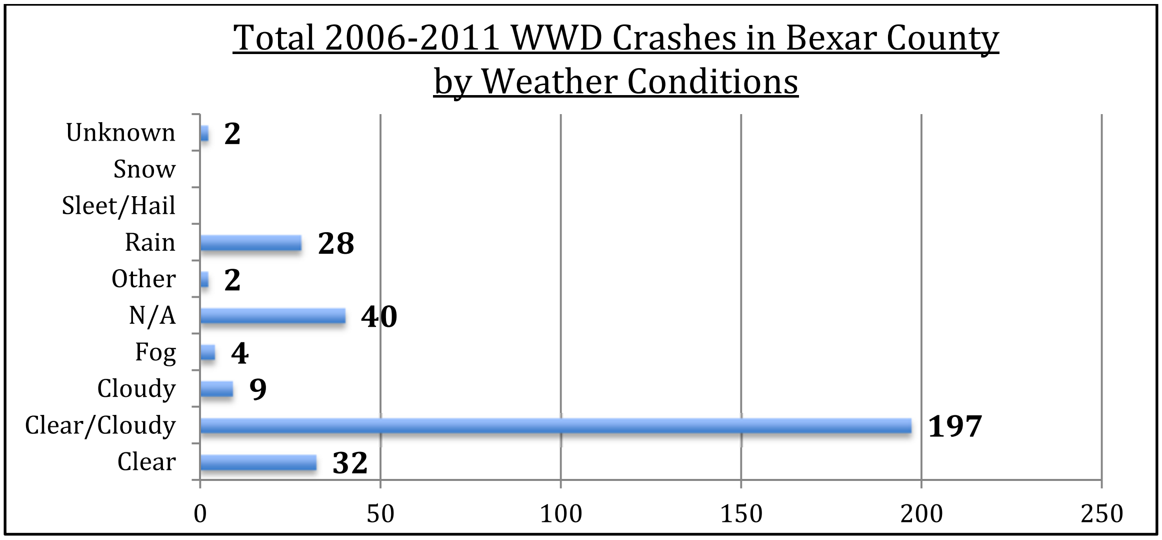


Figure 14: Total 2006-2011 WWD crashes in Bexar County by Weather Conditions

Outside Light Conditions are used to “best describe the prevailing type/level of light that existed at the time of the crash” (Texas DOT 2011). Given that roughly 45 percent of crashes occur between 10:00PM – 4:00AM it seems logical that nearly half – 47.1 percent – of WWD crashes involved “Dark, lighted” conditions, as illustrated in Figure 15. Ranking second is “Daylight” with 32.8 percent, followed by “Dark, not lighted” at 14 percent.

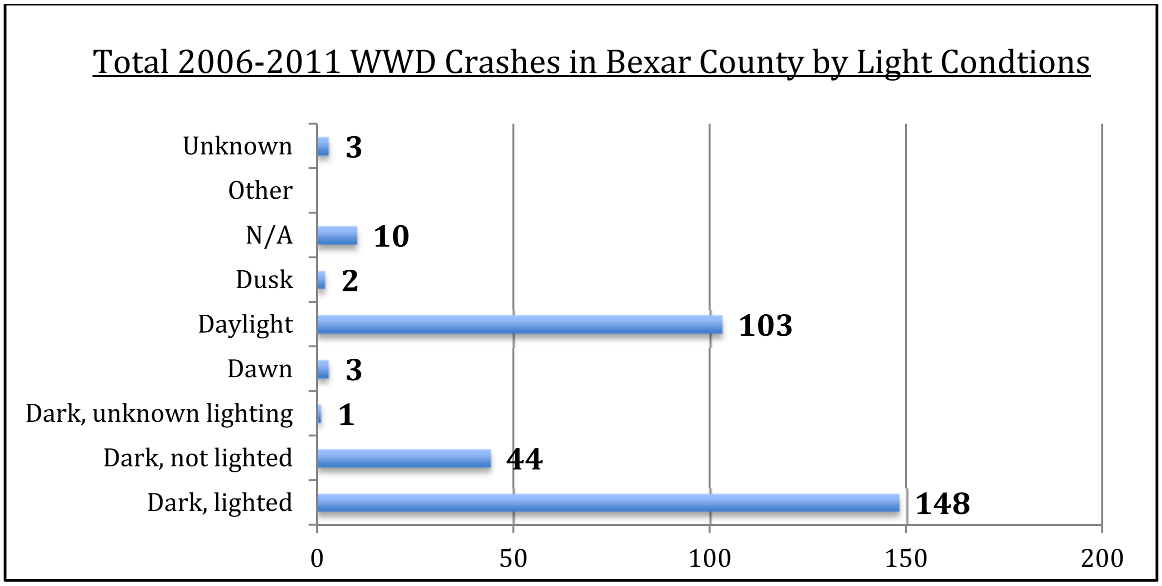


Figure 15: Total 2006-2011 WWD crashes in Bexar County by Light Conditions

Vehicle Body Style "best describes the body style of the vehicle involved in the crash" with regard to the ownership of the wrong-way driver (Texas DOT 2011). It is unclear why some categories such as "Sedan 4D" and "4D Passenger Car" are classified as two separate values; likewise the same could be asked for "2D Sedan/2D Passenger Car," and "Van/Van – All Varieties". As seen in Figure 16, presuming that each classification represents a unique body style, "Sedan 4D" is most common with 31.2 percent of all WWD crashes involving such a vehicle going against the flow of traffic, and "Pickup" trucks are second with 17.5 percent. Only one "Bus" vehicle body style was recorded, thus making it one of the statistically safest modes of travel. Perhaps the growing interest in public transportation – and infrastructure thereof – will prove to be an effective countermeasure alternative for potential impaired wrong-way drivers (Copeland 2013, A3; Fisher 2013; Becker, Bernstein and Young 2013, 6).

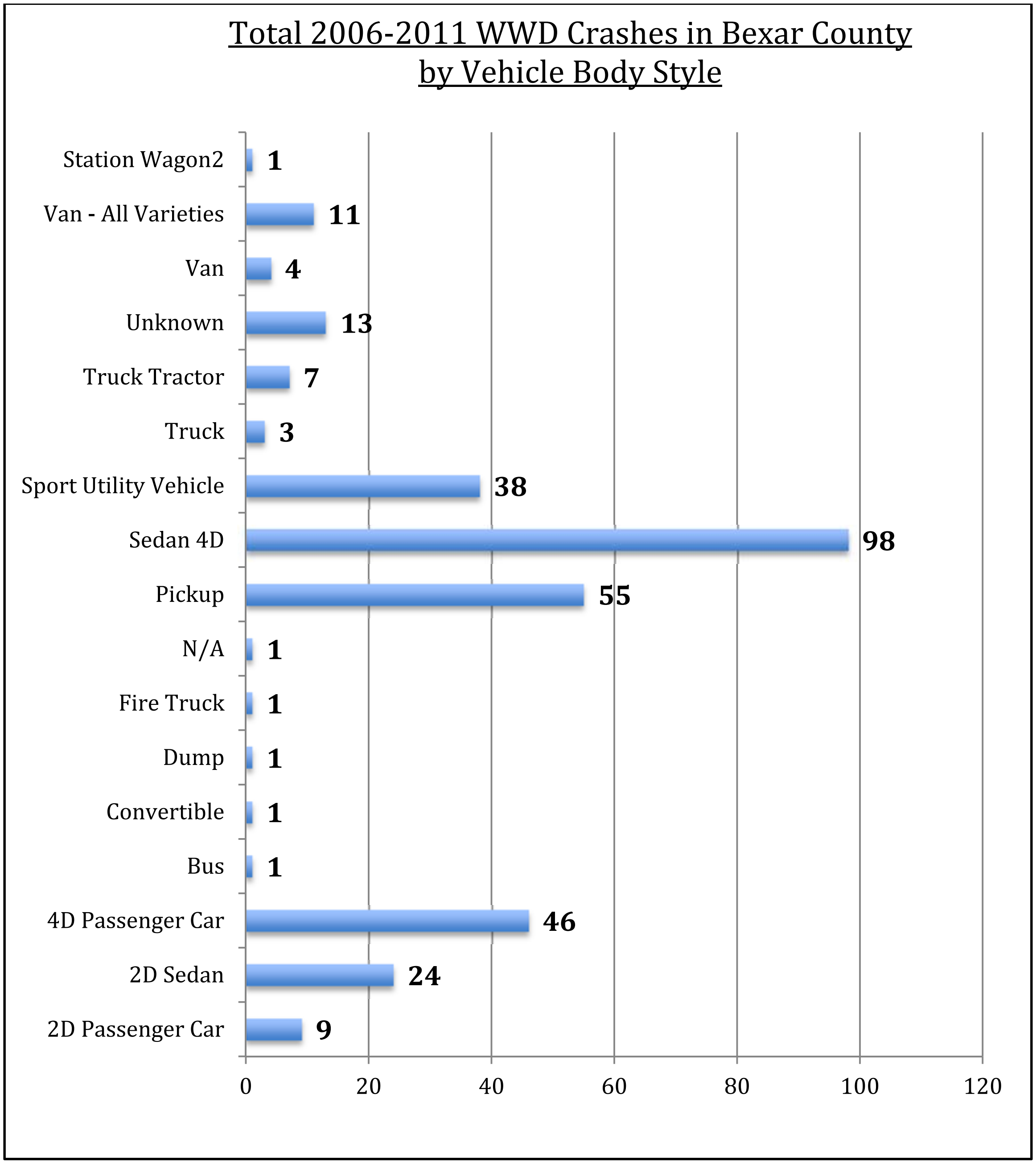


Figure 16: Total 2006-2011 WWD crashes in Bexar County by Vehicle Body Style

The term "Harm Event" describes what – if any – object the wrong-way driver impacted during their misdirected drive. It is uncertain if this value represents the first, last, or perhaps most significant object that was struck, but nonetheless "Motor Vehicle(s)" comprise over 67 percent of total WWD harm events, followed by "Fixed Object(s)" and "Parked Car(s)" at approximately 25 percent and 2.5 percent respectively (Figure 17).

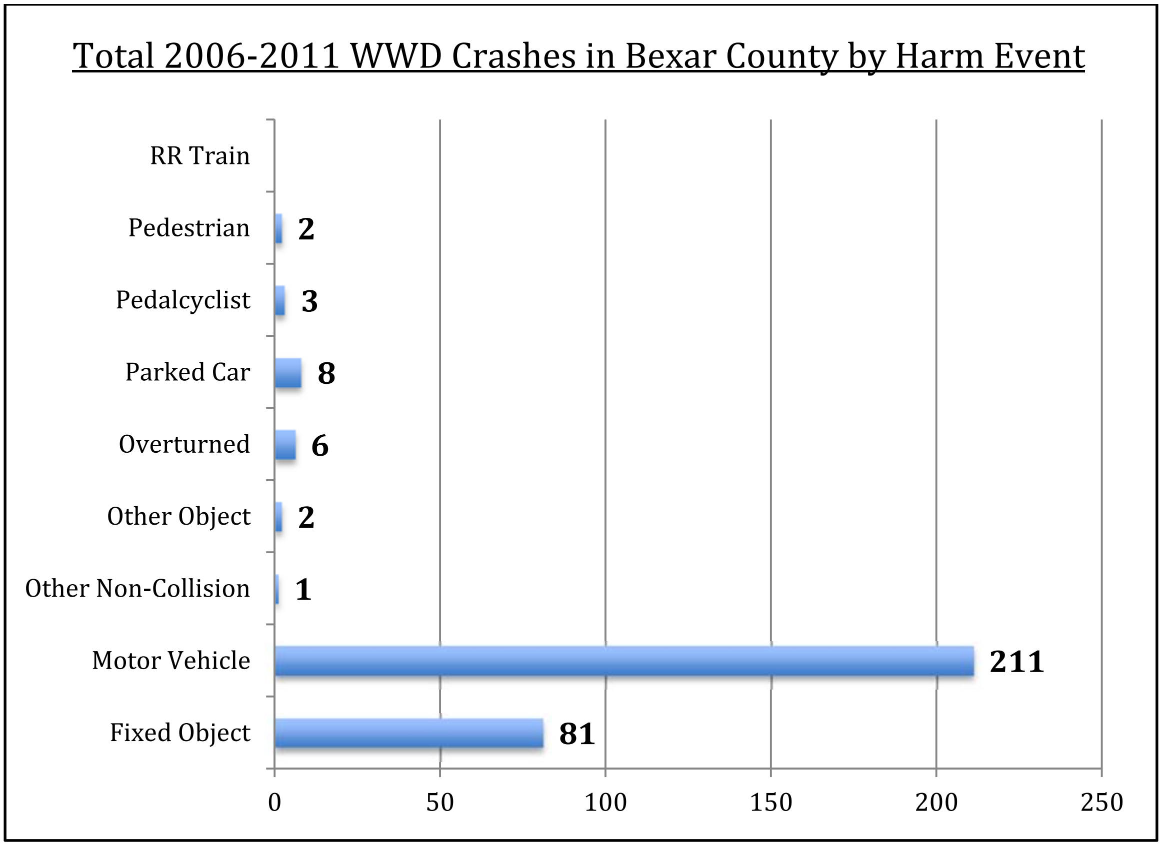


Figure 17: Total 2006-2011 WWD crashes in Bexar County by Harm Event

If a CMV is involved in any crash it must be reported along with several related attributes to describe the properties of the CMV such as: Vehicle Operation, Total Number of Axles and Tires, Vehicle Type, Registered Gross Vehicle Weight, Hazmat Information, and Trailer Information. A simple binary value of "Y/N" is used to "identify the unit as CMV (10,001+lbs, Transporting Hazmat, and 9+ Capacity)". This simple representation is provided in Figure 18, acknowledging that the count is all that is reported for this WWD analysis (Texas DOT 2011).

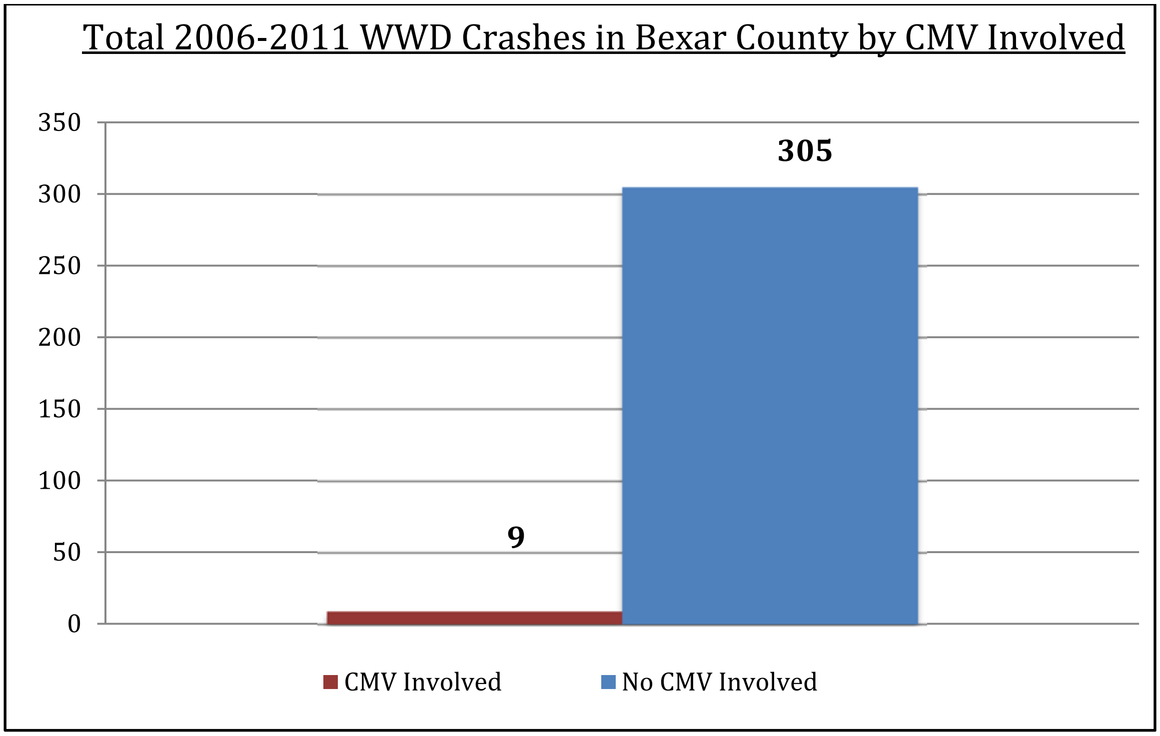


Figure 18: Total 2006-2011 WWD crashes in Bexar County by CMV Involved

As seen from the various figures above, the leadings trends among WWD crashes are as follows: Non-fatal, no injuries, most frequently occurs in October, on Saturdays, in the hour of 2:00 AM, on clear dark nights, with lighted roads that are dry and without nearby traffic control devices or entering roadway configuration, and involve a non-CMV, Sedan 4D crashing into another motor vehicle. The summation of all top trending attributes may coincide with popular sporting events, points-of-interest, or city holidays, and validation of such possibilities can be expressed using WWD Model results to complement multi-source information.

Alcohol-Serving Facilities

The alcohol-serving facilities dataset was retrieved from TABC by way of their online public roster record inquiry system (Jones, et al. 2011). All active licenses from 2006 – 2011 in Bexar County were queried and exported as an Excel worksheet. Originally a tabular dataset with separate address fields (e.g. Number, Prefix, Street, Suffix, Suite/Unit), the records were concatenated into one field then located using ArcGIS U.S. Streets 10.1 geocoder. All license types were chosen since the original dataset includes "food and beverage certificate" locations as well as "late hour" establishments open until 2:00 AM. A first draft of this dataset was retrieved and reviewed December 2012, then later replaced in March 2013 by an updated version of the same data that also included detailed metadata and documentation (Texas Alcohol Beverage Commission 2012). This dataset's coordinate system is NAD 83 U.S. feet.

TransGuide WWD reported events

As a specialized group of traffic camera operators within Texas DOT, TransGuide, has provided a dataset of 513 reported WWD incidents to assist in the validation of the WWD Model (2.1.6 High Risk Locations; 4.1 WWD Model Validation). Some reported events were provided by citizens calling 911 while TransGuide operators directly observed others. Additionally, some of the reported observations coincide with the CRIS derived WWD crashes. The dates for this dataset range from March 15, 2011 – April 26, 2013, and its coordinate system is NAD 83 U.S. feet.

3.1.2 Areal Extent Data

Bexar County

The official Bexar County boundary was retrieved from the San Antonio – Bexar County MPO (San Antonio - Bexar County MPO 2012). Within Bexar County there are 29 cities, including San Antonio. Additionally there are seven military bases, and in 2010 Bexar County had a population of 1,714,773 (United States Census 2010). This boundary dataset was projected in NAD 83 State Plane Texas South Central FIPS 4204 U.S. Feet in preparation for use in this study.

City of San Antonio

The San Antonio city limit boundary was retrieved from the official City of San Antonio website by way of their GIS data webpage which “depicts the city limits of San Antonio” (City of San Antonio 2012). This dataset was also re-projected into NAD 83 State Plane Texas South Central FIPS 4204 U.S. Feet in preparation for use in this study.

Other Cities and Towns

Other Cities and Towns is a “dataset depicting the Extraterritorial Jurisdiction of towns within Bexar County and surrounding counties; excluding San Antonio” (City of San Antonio 2012). Not including San Antonio, 28 cities lie within Bexar County, though some of them are not fully represented as their respective city boundary may have been clipped to that of Bexar County for the purpose of this analysis. The 28 cities include Alamo Heights, Balcones Heights, Bulverde, Castle Hills, China Grove, Cibolo, Converse, Elmendorf, Fair Oaks Ranch, Grey Forest, Helotes, Hill Country Village, Hollywood Park, Kirby, Leon Valley, Live Oak, Lytle, New Berlin, Olmos Park, Schertz, Selma, Shavano Park, Somerset, St. Hedwig, Terrell Hills, Universal City, Von Ormy, and Windcrest (City of San Antonio 2012). This dataset was then converted to projection NAD 83 State Plane Texas South Central FIPS 4204 U.S. Feet in preparation for use in this study.

Military Bases

Data for Military Bases were retrieved from San Antonio – Bexar County MPO, by way of their interactive map viewer, and represents the seven military installations within Bexar County (San Antonio - Bexar County MPO 2012). This dataset was also re-projected into NAD 83 State Plane Texas South Central FIPS 4204 U.S. Feet in preparation for use in this study.

3.1.3 Linear Spatial Datasets

Network Dataset

The roadway network dataset with one-way attributes was retrieved from Bexar Metro 911 and covers all roadways in San Antonio, Bexar County as of 2012. The City of San Antonio worked in partnership with Bexar Metro 911 to create the original dataset. Upon inspection it was determined that direction of travel fields correctly matched the digitized roadway linework; however, minor modifications were made to this field, by the author, such as two-character values replacing one-character values, to allow compatibility with Network Analyst to build a network dataset. Elevation fields of “0” and “1” were used to model at-grade and grade-separated roadway intersections such that routes created would simulate on-ground conditions and restrictions of traffic flow. Additionally, the downtown San Antonio Riverwalk segments of the network were removed since the Riverwalk is a sub-grade pedestrian walkway that does not allow motorized vehicle traffic.

Line Barriers

The prior mentioned jurisdictional boundaries were converted from polygons to lines then merged to create a single polyline feature class to be used as line barriers within the WWD Model. This merged output dataset was projected in NAD 83 State Plane Texas South Central FIPS 4204 U.S. Feet as well.

3.1.4 Basemaps

Basemaps Utilized in this Study

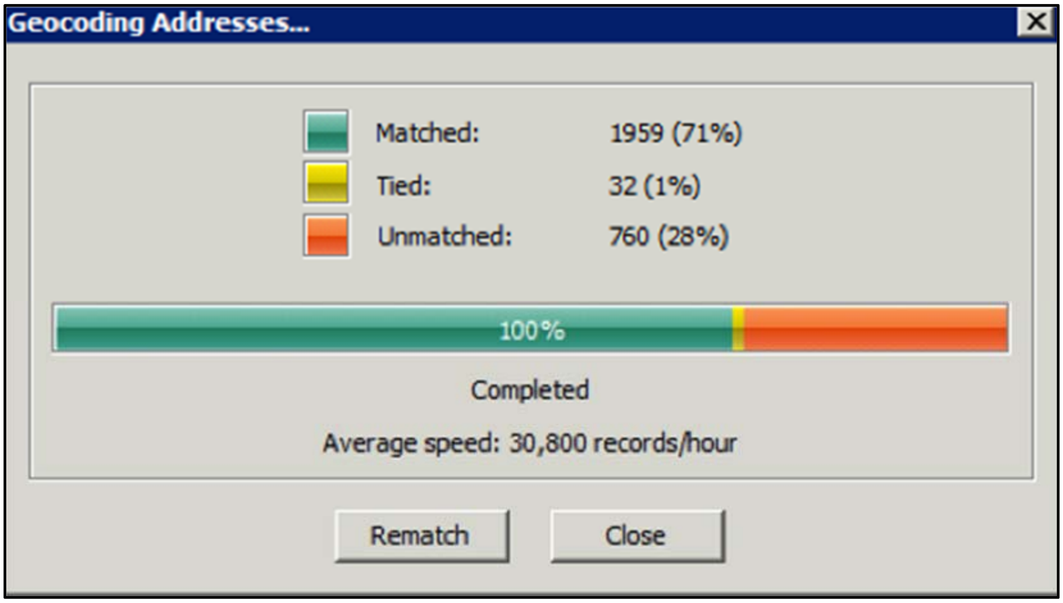
Esri supplied basemaps such as Microsoft Bing Maps and Esri StreetMap were used to visually reference datasets, but otherwise were not utilized in this analysis. The datasets mentioned above, including point, areal, and line, were used as the only inputs into the WWD Model described in the Methodology section. After the analysis was completed the basemap datasets were only utilized for cartographic purposes (i.e. to visualize data with respect to spatial boundaries of underlying shapes and create map layouts displaying the results of this study).

3.2 Methodology

This study seeks to identify which routes wrong-way drivers are taking that end in crashes. To accomplish this task, the ArcGIS 10.1 extension, Network Analyst, was customized using Python/ModelBuilder to generate a *Closest Facility* spatial analysis tool that allows users to estimate the likely *facilities* that drivers have visited in the vicinity of crash *incidents.* The most significant assumption in this study is that start and end points were chosen based on previous studies indicating that these are associated with 32 percent of crash events analyzed in this study (2.2.5 WWD Safety and Countermeasures). The second most important assumption is that traffic can be simulated with regard to WWD behavior, that the degree of impairment influences routes chosen, and that these can be categorized as prohibited, avoid high, avoid medium, avoid low, prefer low, prefer medium, and prefer high - implemented in the model using a one-way restriction attribute. The default *Closest Facility* model provides users with the option to modify input parameters such as the start point, to export results to layer packages, and even readily publish the model results to a web GIS. The traffic setting then allows the user to estimate WWD routes based on existing types of roadway restrictions. The combinations of features in this section comprise the WWD Model, described in detail below.

3.2.1 Input Data

Beginning with *facilities*, a 2006-2011 active roster of alcohol serving locations in Bexar County was retrieved from TABC (3.1.1 Point Location Data). Only “active-current” permits were queried as “alcoholic beverages are not sold or delivered to a suspended permittee” (Jones, et al. 2011). Of these 2,751 total locations, only 71 percent of the *facilities* comprising the total result of this query were able to be mapped using Esri ArcGIS 10.1 U.S. Streets geocoder. The other 29 percent of the resulting geocodes were not considered successful because the match accuracy was below 100 percent. Thus a total of 1,959 *facilities* comprising this 71 percent were utilized in this study from which 329 were modeled based on their queried “late hour” attribute values. Figure 19 shows a brief summary of the geocoding results process.



🟩 Matched: 1959 (71%)
🟨 Tied: 32 (1%)
🟥 Unmatched: 760 (28%)

100%

Completed

Average speed: 30,800 records/hour

Figure 19: Geocoding results summary

Crash point *incidents* that occurred between 2006-2011were retrieved from San Antonio – Bexar County MPO by way of Texas DOT's CRIS (3.1.1 Point Location Data). The original dataset was received in tabular format. All crash years were merged then queried for "Contributing Factor = 71" as that is the only data value approved by Texas DOT CRIS staff for standardized use in WWD analysis.

Table 3 summarizes the various wrong-way type values, their respective descriptions, and which is Texas DOT approved. The filtered data is then used in the analysis as the final destination points that drivers have presumably driven to using the wrong-way path of travel as provided by the WWD Model.

FIELD	VALUE	DESCRIPTION	Texas DOT APPROVED
Charge Category	28	Wrong Side / wrong-way	No
Contributing Factor	71	Wrong-way, one-way road	Yes
Contributing Factor	70	Wrong Side, not passing	No
Contributing Factor	69	Wrong side, approach or intersection	No
Other Factor	33	Swerved or veered to avoiding vehicle from opposite direction in wrong lane	No
Other Factor	44	Slowed or stopped for vehicle from opposite direction in wrong lane	No

Table 3: Description of WWD Contributing Factors

The unique *Closest Facility* spatial analysis programming structure that comprises the WWD Model completed as part of this study is detailed in the following discussion about how the WWD Model works, so that anyone with familiarity with ArcGIS Desktop can use or replicate the model.

3.2.2 The WWD Model

The following list summarizes the customized Python, ArcGIS Network Analyst and Desktop tool structure of the WWD Model in terms of its inputs, functionalities and outputs. The complete model is illustrated in Figure 20. A basic graphic user interface instruction for running the model follow this formal functionality outline.

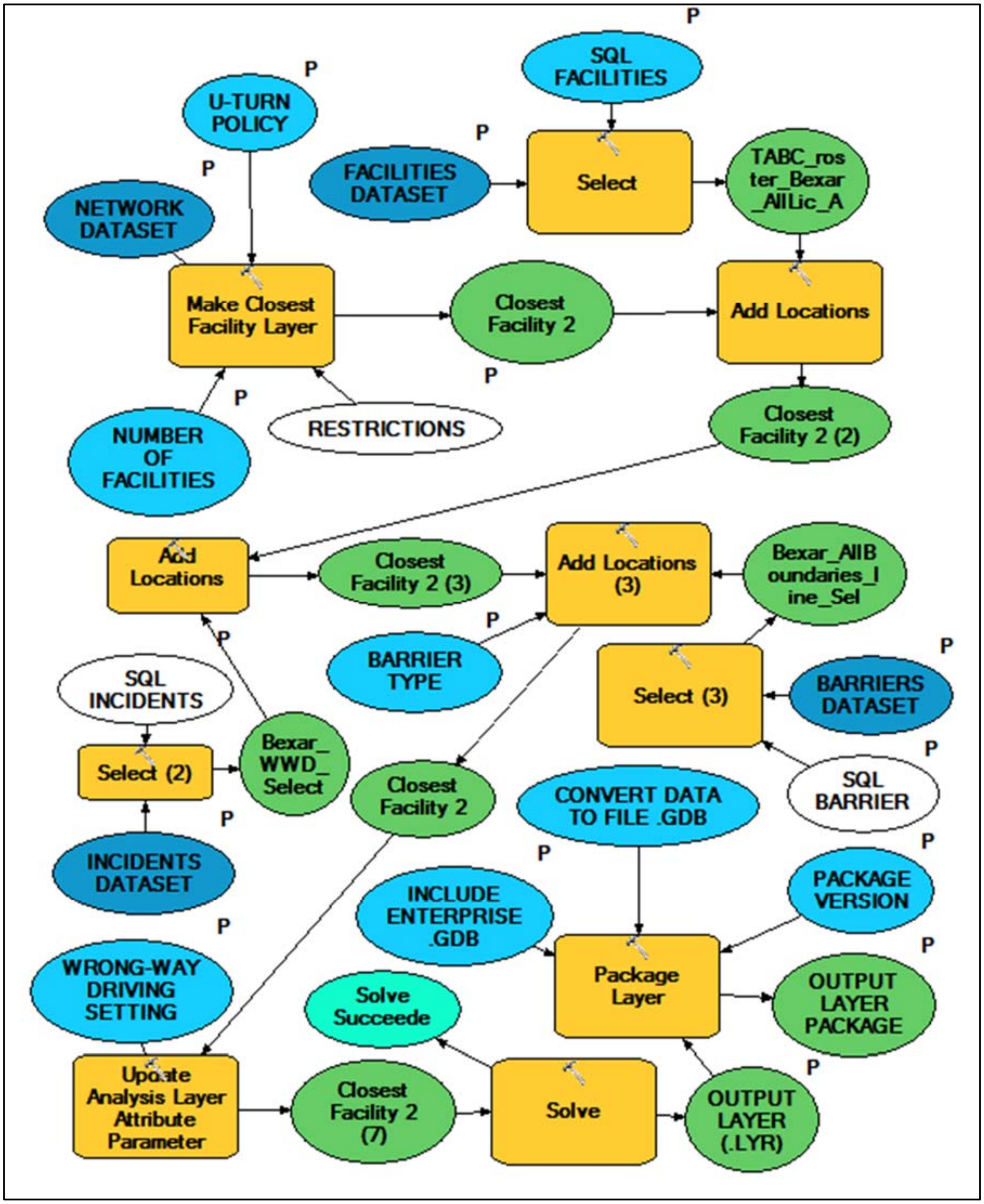


Figure 20: WWD Model, as viewed in ArcGIS ModelBuilder: Users can access this ModelBuilder view by right-clicking the model and selecting “Edit” in ArcCatalog

1. <u>Input Network Dataset</u> – The input data consists of a customized polyline feature class built using Bexar Metro 911 streets file with one-way road attributes and direction of traffic flow for all roadways in San Antonio, Bexar County. Optional features such as Traffic Restrictions and U-Turn Policy were also added as *model parameters* to allow more flexibility within the network dataset and simulated traffic patterns. A *model parameter* is a variable that a user is permitted to interact with in the user interface dialog box when the model is run. In this case, it is implemented in a drop-down menu and/or browse button where the user can select input data.

2. <u>Add Locations</u> – Three additional datasets are required in this *Closest Facility* spatial analysis: *facilities*, *incidents*, and *barriers*. The user adds these datasets in sequence so that they are consecutively georeferenced along the network dataset, then routing and driving directions are computed. A *model parameter* has been designated for the input "Barrier Type" to allow the user a choice of input type – points, lines, or polygons – as possible traffic network barriers.

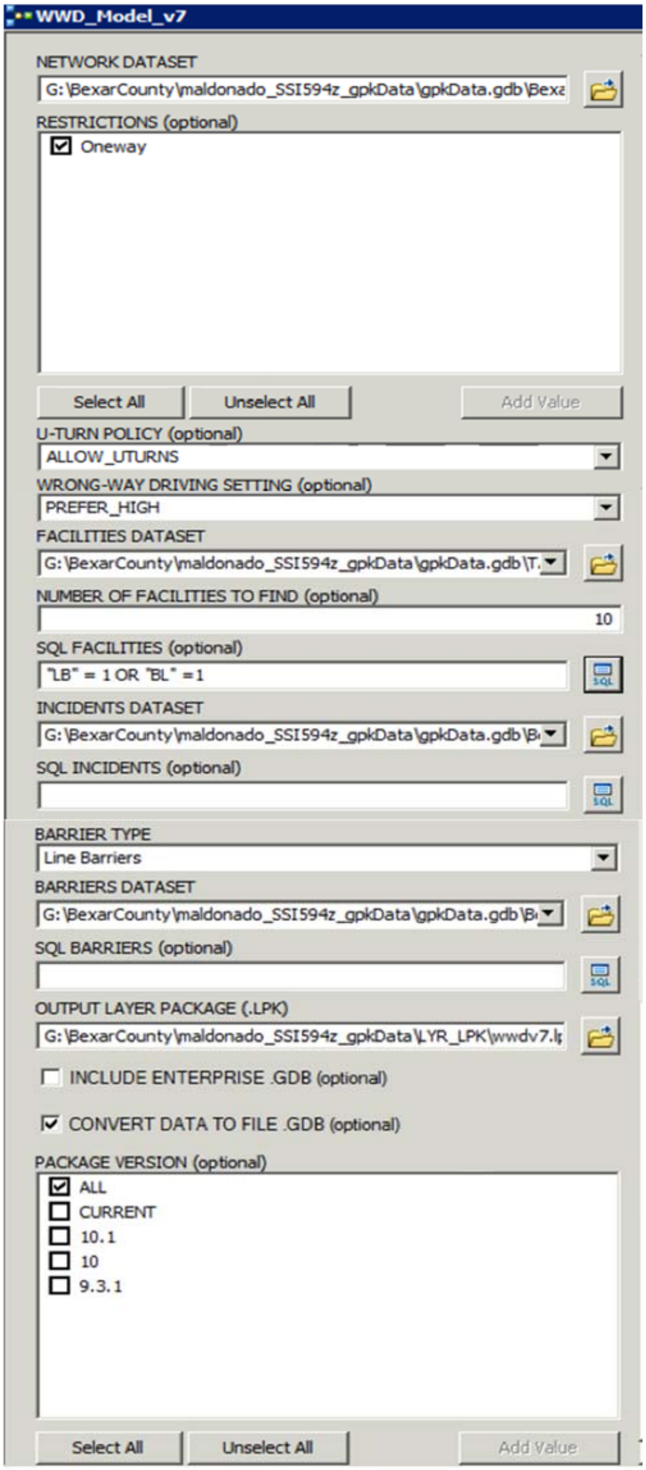
3. <u>Update Network Analyst Layer</u> – Network Analyst allows seven degrees of traffic simulation with regard to WWD behavior. These range from "prohibited" to "avoid high, avoid medium, avoid low, prefer low, prefer medium, and prefer high", based on the one-way restriction attribute. Using the *model parameter* of "Wrong-Way Driver Setting" this input may be toggled, but one of the available options must be selected in order for the model to run.

4. Package and Publish – At the conclusion of the geoprocessing tasks, the output layer is saved as a layer package file (.lpk) which may then be shared via email and/or uploaded to ArcGISonline.com. The ArcGIS layer package version, inclusion of enterprise data, and conversion of data to file geodatabase have all been purposefully coded as *model parameters* to allow the user a wide range of data interoperability. Additionally, users may save their customized inputs and parameters as a geoprocessing package (.gpk) after successfully running the WWD Model.

Figure 21 represents the graphic user interface dialog box of the same ModelBuilder model shown above in Figure 20. A model such as the WWD Model is saved and stored as a "tool" in the ArcGIS Desktop Toolbox. Thus the *Closest Facility* spatial analysis dialog box can be directly accessed by a user as a tool in ArcToolbox. When a user runs the WWD Model in ArcGIS Desktop, the dialog box is launched. A complete description of the required inputs as well as details about the *model parameters* is provided in the dialog box's metadata description. In addition to the form-field below, users can run a batch geoprocessing task using the WWD Model that allows multiple simultaneous iterations with varying inputs and *model parameters*. When using the sample data provided, some warning messages appear like those seen in the text that follows:

> “Barrier "Locations 35" in "Line Barriers" has no associated network location information.
> Barrier "Bulverde" in "Line Barriers" has no associated network location information.
> No "Facilities" found for "9066011" in "Incidents".
> WARNING 030025: Partial solution generated.”

Although there was a “Partial Solution [is] generated”, a general error message generated by ArcGIS 10.1 when running the WWD Model, the vast majority of the analysis runs and results were successful and thus fit for analysis. Depending on the geospatial accuracy of input data, and route preferences thereof, the resulting outputs may range from full solution to partial, or no solution at all.


WWD_Model_v7

NETWORK DATASET
G:\BexarCounty\maldonado_SSI594z_gpkData\gpkData.gdb\Bexa

RESTRICTIONS (optional)
☑ Oneway

U-TURN POLICY (optional)
ALLOW_UTURNS

WRONG-WAY DRIVING SETTING (optional)
PREFER_HIGH

FACILITIES DATASET
G:\BexarCounty\maldonado_SSI594z_gpkData\gpkData.gdb\T

NUMBER OF FACILITIES TO FIND (optional)
10

SQL FACILITIES (optional)
"LB" = 1 OR "BL" =1

INCIDENTS DATASET
G:\BexarCounty\maldonado_SSI594z_gpkData\gpkData.gdb\B

SQL INCIDENTS (optional)

BARRIER TYPE
Line Barriers

BARRIERS DATASET
G:\BexarCounty\maldonado_SSI594z_gpkData\gpkData.gdb\B

SQL BARRIERS (optional)

OUTPUT LAYER PACKAGE (.LPK)
G:\BexarCounty\maldonado_SSI594z_gpkData\LYR_LPK\wwdv7.l

☐ INCLUDE ENTERPRISE .GDB (optional)

☑ CONVERT DATA TO FILE .GDB (optional)

PACKAGE VERSION (optional)
☑ ALL
☐ CURRENT
☐ 10.1
☐ 10
☐ 9.3.1

Figure 21: WWD Model launched from ArcToolbox

The final result of this unique customization of Network Analyst is a geoprocessing package file (.gpk) that can be unpacked and utilized as-is with the example input data provided. In addition, if desired the model can also be further edited by Esri users in terms of inputs and functionality, and then shared as prior mentioned. The WWD Model metadata and readme.doc documentation that will be distributed with the WWD Model geoprocessing package file (.gpk), and will also include a creative commons agreement or statement that requires users who utilize or further customize the model to legally credit the author.

The WWD Model data inputs and *model parameters* are described in detail below in their respective order of operations. Each input was retrieved from the data sources mentioned above (3.1 Data Sources). The resulting output of the WWD Model geoprocessing step is a layer package file (.lpk) that may be readily distributed.

3.2.3 Description of Inputs

The following list of descriptions about restrictions, data inputs and model settings is provided to complement the basic user interface instructions provided above. Some parts of the following discussion are adapted from the parameter descriptions provided in Esri ArcGIS 10.1 Help for Network Analyst (Esri 2012).

Restrictions

Restriction attributes to apply during the analysis refers to the one-way attribute as defined by Bexar Metro 911 and City San Antonio in the Bexar County Streets file from which the network dataset was built (3.1.1 Linear Spatial Datasets). A user may also implement additional restrictions, but for the purposes of this analysis one-way road designation is the only type used.

This network dataset on which the closest facility analysis was performed was built using a feature class streets file provided by Bexar Metro 911 in partnership with City of San Antonio. All other parameters and inputs to this *Closest Facility* analysis of the WWD Model are dependent on this network dataset to correctly georeference data points, and provide routes as well as driving instructions.

Number of Facilities to Find

The default number of closest facilities to find per incident can be overridden by specifying a value for “TargetFacilityCount,” a property of *incidents*. For the purposes of this analysis this value has been designated as a *model parameter* to allow flexibility of choosing how many facilities to search and travel from so as to route for each WWD crash *incident*; the default number of facilities used for model demonstration is 10.

Facilities Dataset

This data was retrieved online from TABC; this input represents the point(s) of origin wrong-way drivers would be traveling from. As their presumed staring point, a respective SQL expression *model parameter* has been constructed to assist in analytical specificity. Within this SQL statement the coded values “LB” and “BL” refer to late hour alcohol-serving establishments open until 2:00 AM (Texas Alcohol Beverage Commission 2012). With both coded values set equal to “1” only late hour facilities will be used as *facilities*.

Incidents Dataset

WWD crashes serve as *incidents* and also have a respective SQL expression *model parameter* to assist in spatiotemporal selection of crashes for specific analysis.

Wrong-Way Driving Setting

It is possible to model impaired traffic driving behavior ranging from prohibited (correct and legal use of one-way) to prefer high (opting to go against the flow of traffic on one-way streets). The underlying assumption is that the degree of impairment influences routes chosen. For this analysis prefer high is chosen as the default, but there are a range of seven options: prohibited, avoid high, avoid medium, avoid low, prefer low, prefer medium, prefer high.

U-Turn Policy

Based on the U-Turn rule at intersections, WWD Model users may specify to allow, not allow, or only allow at dead ends and intersections as analysis input. By default U-Turns are allowed to fully demonstrate WWD behavior in traffic conditions at intersections and dead ends.

Barrier Type

Point, line, and polygon vector data may be used as barrier types for routing throughout the network dataset. Jurisdictional boundaries (cities and military bases) were converted from polygons to polylines then used as line barriers to allow each region to act as an independent network dataset. Theoretically such barriers separate traffic and points-of-interest from their neighboring regions.

Barriers Dataset

The polyline dataset used represents the merged boundaries of San Antonio, Military Bases, and Other Cities and Towns all within Bexar County. All boundaries were retrieved from San Antonio – Bexar County MPO and the City of San Antonio.

Layer Package Version

The previously stated resulting facilities, incidents, barriers, and routes can be saved as a packaged layer (.lpk) in ArcGIS version 9.3 – 10.1. "All" and "Current" versions may also be checked for added flexibility in data interoperability (Esri 2012).

Include Enterprise Geodatabase

If the option is checked when running the WWD Model, any enterprise data referenced will be included in a file geodatabase. ArcSDE users are recommended to check this option, otherwise the WWD Model will try to fetch the data each time it is run. This parameter is left unchecked by default, assuming that all data in [this] study is referenced locally.

Convert Data to File Geodatabase

This optional parameter can save all related data to a local file geodatabase on the user's machine. This option is checked to demonstrate WWD Model capabilities, and so the resulting layer package and geoprocessing package can be easily shared with others.

As demonstrated above, the WWD Model is a scalable, adjustable, and backwards-compatible tool for quickly performing routing analysis. With little background in GIS users can adjust parameters to fit their individual needs and desired geoprocessing tasks, and even conduct multiple iterations with varying inputs concurrently. Lastly, the ability to output ArcGIS geoprocessing packages allows more flexibility for users to quickly share material without manually referencing data for other users to access.

CHAPTER 4: RESULTS

Utilizing the methodology and assumptions described in Chapter 3, the following routes were calculated based on the seven possible settings of WWD traffic: prohibited, avoid high, avoid medium, avoid low, prefer low, prefer medium, prefer high. Each route analysis resulted in different traffic patterns based on the “one-way” restriction parameter, which are illustrated in the figures throughout this chapter.

To summarize, of the 1,990 total geocoded alcohol-serving facilities, 329 were selected using a SQL expression for “late hour” locations open until 2:00 AM (3.2.2 The WWD Model). The results of the route analyses also exposed an underreporting for crashes on military bases and several incorporated cities and towns within Bexar County such as Camp Bullis, Camp Stanley, Fair Oaks Ranch, Helotes, and Grey Forest. This could be owed to lack of specific reporting (i.e. Contributing Factor = 71), or that WWD crashes have yet to occur within such jurisdictions.

4.1 WWD Model Validation

The WWD Model results were validated against TransGuide’s WWD dataset described in 3.1.1 Point Location Data. Just over 77 percent of the actual TransGuide events were within 65 feet of the resulting WWD Model estimated routes. This validation analysis was computed using the *Select by Location* tool in ArcMap with 65 ft.

tolerance. The TransGuide events are illustrated in all of the map figures in this chapter as camera icons. The 65 ft. tolerance was chosen because it represents the widest measured point on an interstate that a paved surface extends from the respective network dataset linework. Using known routes of wrong-way drivers would be a more accurate validation method; however, such data was unavailable at the time this study was conducted. Drivers' intended destinations were unknown, but research has shown that traffic tends to go from attraction areas to residential areas (Banaei-Kashani, Shahabi and Pan 2011, 14). Use of alcohol-serving establishments for *facilities* was an operating logic of the Task Force based on the 2:00 AM spike of impaired WWD crashes (1.2 Motivation).

It is important to note that some *facilities* were left out of the results of the route analysis; this phenomenon is most likely due to an anomaly in Esri's *Closest Facility* algorithm for prioritizing routes, and as such will be addressed in future continuation of this study. Presently, *facilities* close to incidents missing from the results are excluded from this analysis, yet have been noted for future consideration. Theoretically, the entire Riverwalk and nearby parking lots could be considered *facilities* as wrong-way drivers may begin trips from this attraction area as a pedestrian en route to their parked vehicle. However, the Riverwalk was removed from the network dataset as motorized vehicles are not permitted, and parking lots were not considered by the Task Force and thus not included in this analysis.

4.2 Prohibited Setting

The results of the first analysis completed using the WWD Model utilized the prohibited model setting to obtain the estimated WWD routes. Figure 22 shows these prohibited routes with an enlarged map of northeast San Antonio including Route-1 selected to highlight this scenario. The prohibited one-way restriction means all routes must obey the law(s), and cannot drive against the flow of traffic, ergo all WWD in this situation simulates "crashes where the drivers were going in the right direction and made a U-turn to end up going the wrong-way" in their final moment before impact (Cooner, Cothron and Ranft 2004, 26). It is difficult to validate U-turn originated crashes based on available data, however, similar research has shown that WWD under such circumstances contributed less than 5 percent of total crashes (Cooner, Cothron and Ranft 2004, 26). WWD crashes in this prohibited situation may be owed to driver errors en route to various traffic generating points-of-interest such as malls, offices, or apartment complexes (Federal Highway Administration 2012, 4-59 - 4-62). For example in the hypothetical case of Route-1, a driver originating on Thousand Oaks Rd., who next traveled north on Stahl Rd., and then east on Loop 1604, at this point might make an incorrect U-turn and cause a WWD crash.

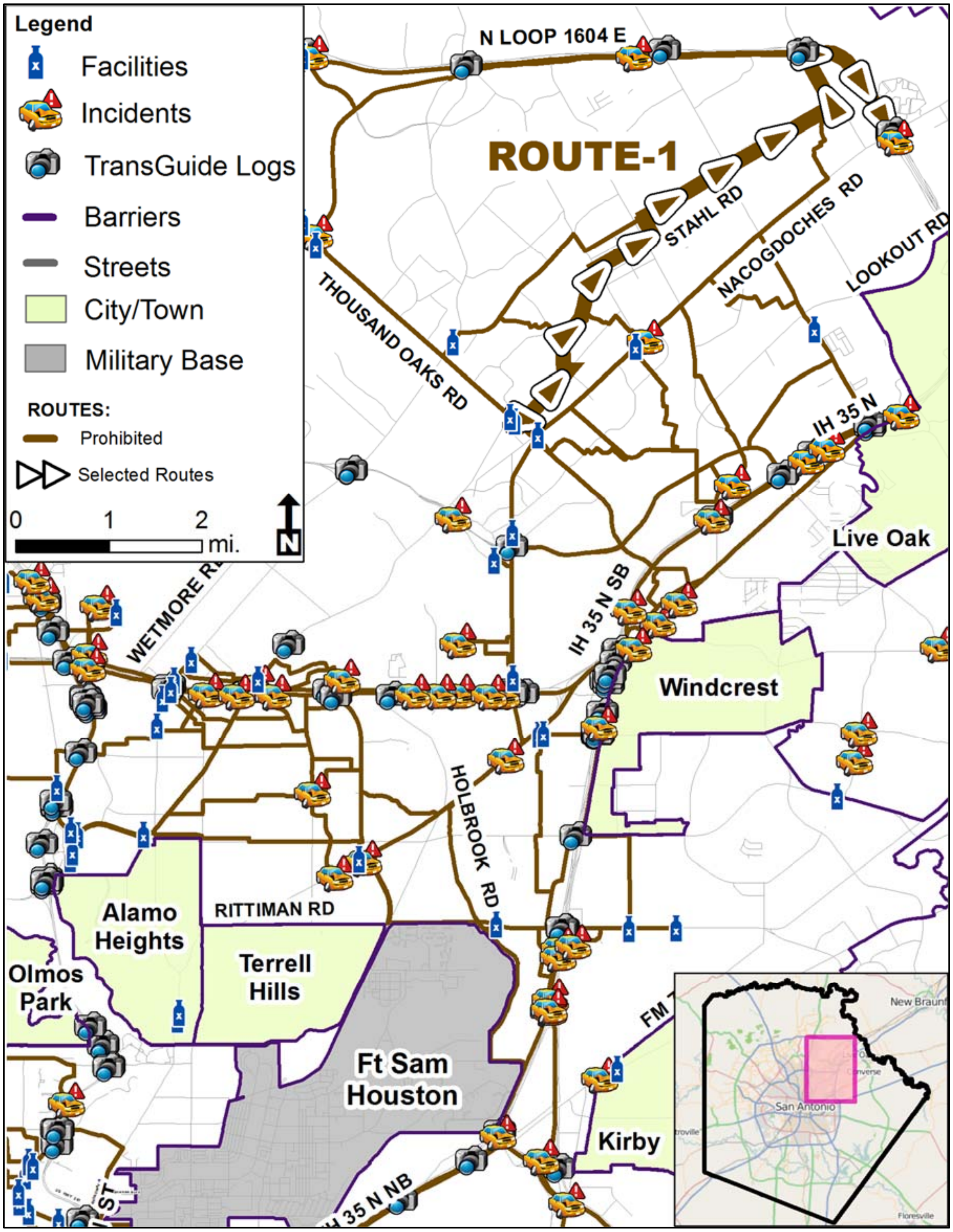


Figure 22: TransGuide validated Prohibited routes in northeast San Antonio

4.3 Avoid Route Setting

Figure 23 shows the second output of the WWD Model obtained utilizing the avoid route setting when running the analysis. This map depicts avoid routes in west San Antonio based on existing one-way traffic network restriction. Some of the routes run concurrently then detour at junctions as seen on Bandera Rd. within Leon Valley. This map shows resulting estimates labeled Route-2, Route-3, and Route-4 representing avoid high, avoid medium, and avoid low settings, respectively. Route-2 simulates highly avoided wrong-way travel and presumably followed all rules of traffic from the point of origin onto Alamo Downs Pkwy to Culebra Rd., then southbound on Loop 410 access road, and crashed nearly immediately after making a right onto Military Dr. despite the presence of a median to separate opposing traffic lanes. Route-3 is unique, as its WWD crash may be owed to an “absent-minded driver turning too soon onto an off-ramp” from a turnaround instead of continuing on the frontage road which led to the crash on SH-151 (Tamburri 1965, 8). Route-4 illustrates how streets that “transition directly into a freeway section,” in this case Hunt Ln. and SH 151, can experience multiple WWD crashes as left turns are not permitted onto one-way access roads (Cooner, Cothron and Ranft 2004, 29).

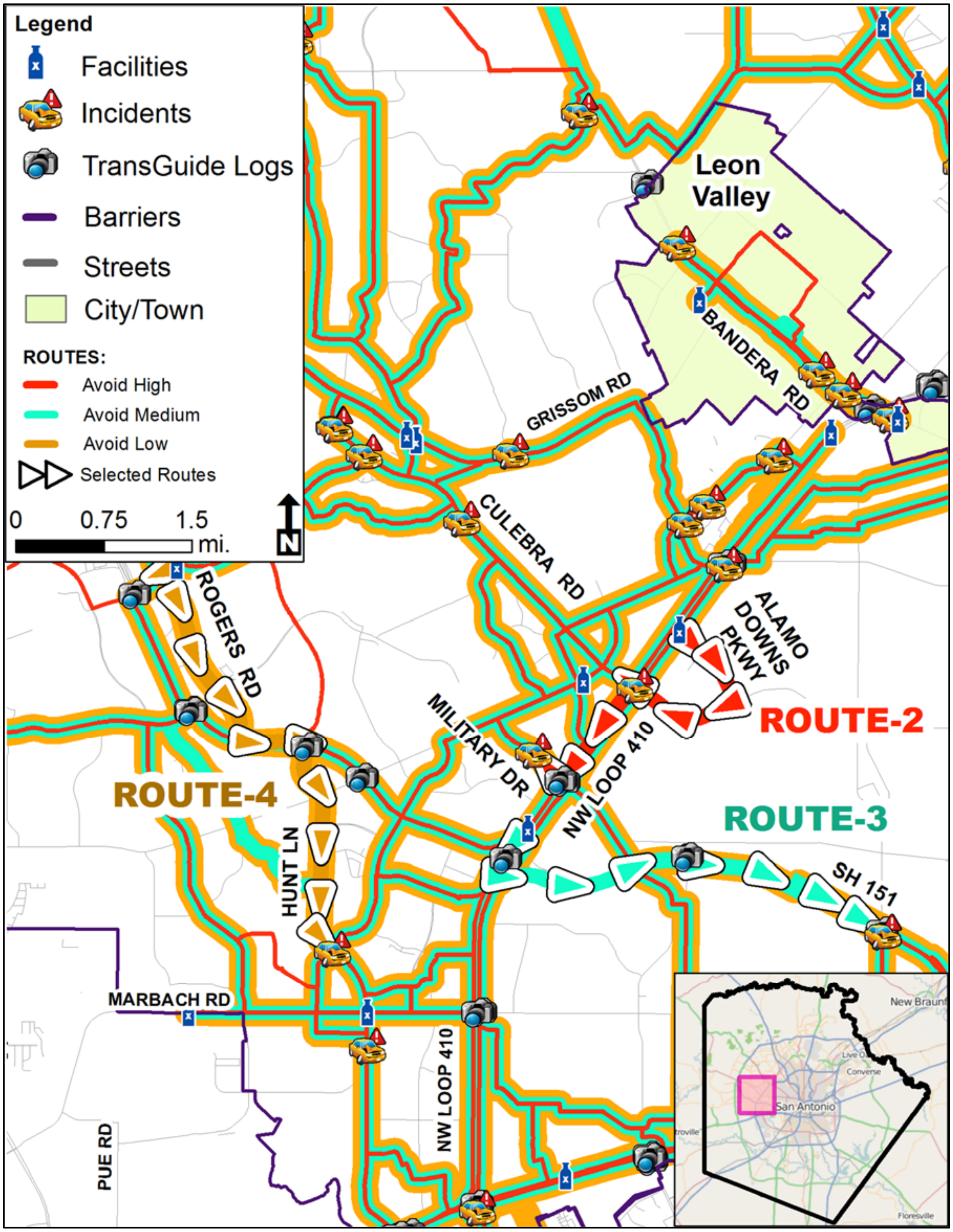


Figure 23: TransGuide validated Avoid routes in west San Antonio

4.4 Prefer Route Settings

The WWD Model results shown in Figure 24 displays the “prefer” route outputs of the model for downtown San Antonio. At this point each set of routes no longer models citizens that avoid wrong-way movements, but those who consciously prefer WWD to intentionally violate traffic laws for reasons unknown (Tamburri 1965, 8). WWD Model estimates including Route-5, Route-6, and Route-7 exhibit this as prefer low, prefer medium, and prefer high respectively. Route-5 demonstrates that different route configurations can run concurrently, and although this route could follow all traffic rules it is presumed that the driver was on the wrong side of the street at some point since N. Saint Mary’s St. is an undivided roadway. Route-6 is similar as it begins on Broadway St., continues south on Austin St., but travels against traffic on IH-35 access road en route to the point of crash at Pine St. and Duval St. intersection. This behavior characterizes the “prefer” option, since instead of avoiding WWD on one-way streets it prefers high-risk routes. Route-7 is perhaps the most dangerous scenario because it began WWD on a one-way, Commerce St., then continued onto the IH-37 exit ramp, and finally crashed on IH-35 merging lane after traveling the wrong-way all the while.

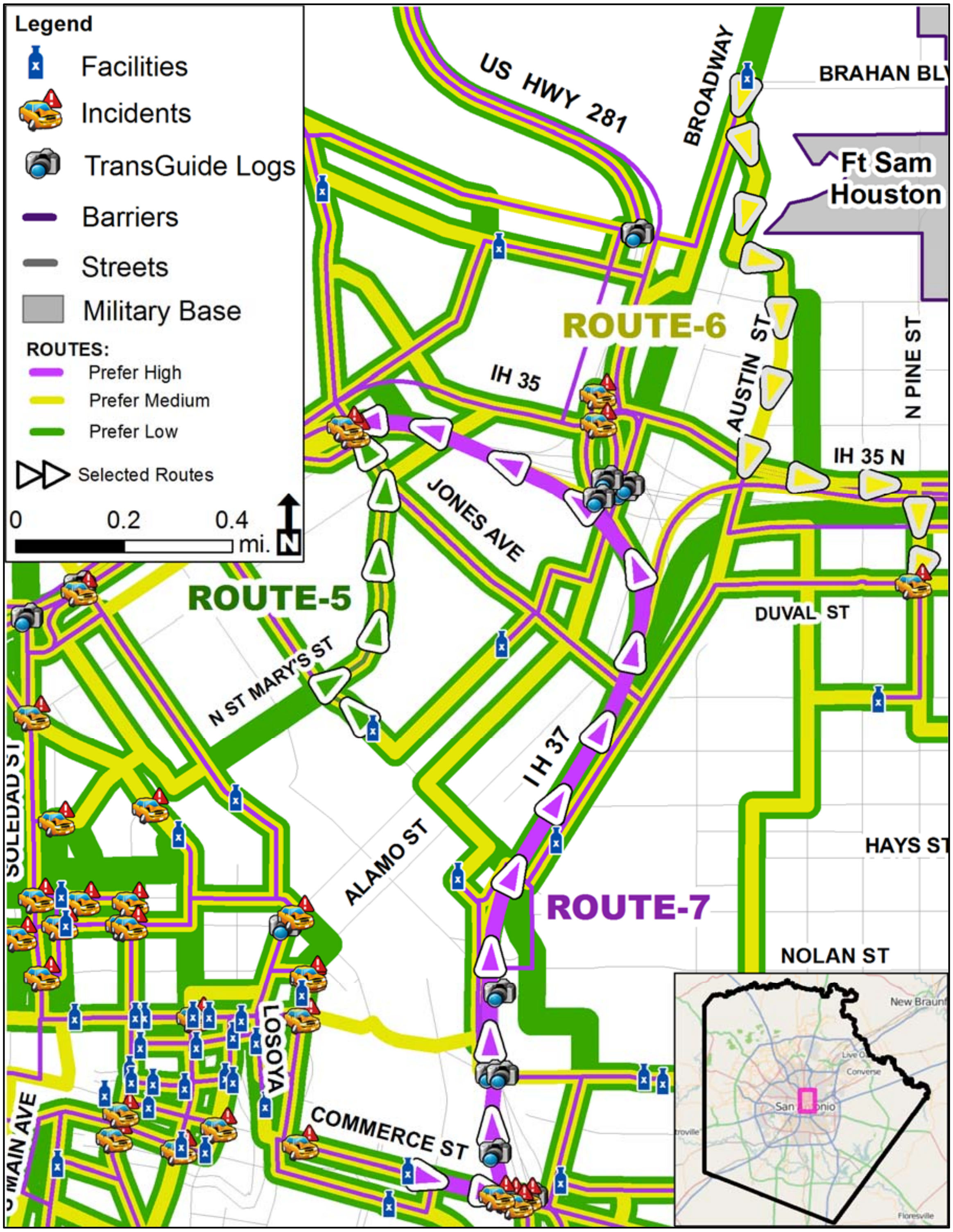


Figure 24: Map of Validated Prefer Route Preferences in Downtown San Antonio

The results of this analysis as described above successfully demonstrate the capabilities of the WWD Model in mapping routes. A number of assumptions are embedded in the WWD Model, including that start points are late hour *facilities*, intended end points are residences, and that traffic can really be simulated based on prohibited, avoid high, avoid medium, avoid low, prefer low, prefer medium, and prefer high types of physical roadway restrictions. These results have been reported to the Task Force as part of the ongoing research effort to discern the causes of WWD and thus assist in the prioritization of methods for addressing these events (2.1.3 Challenges). The route estimates can thus be evaluated individually or combined to determine the most urgent locations for implementation of prevention measures such as enforcement, signage, cameras, and radar countermeasures. Additional insights into possible ways to improve upon this analysis are discussed in the following chapter.

In addition to the visualization of route data, each route can further be analyzed by performing various spatial geoprocesses such as spatial joins, merge, and clips, which may be the case when analyzing routes by jurisdictional boundaries. Moreover, each parameter described in the Methodology section can be changed and thus alter the resulting routes based on the updated parameter values, including SQL syntax. Regardless of the input incident and facility datasets, the WWD Model leverages Esri's *Closest Facility* to create routes, which means that this model may be used for various travel pattern analyses, and not necessarily exclusive to WWD.

CHAPTER 5: DISCUSSION & CONCLUSIONS

The analysis accomplished as part of this thesis work identified potential WWD behavior and routes traveled from alcohol-serving *facilities* to their ultimate points of crash *incidents*, validated against real data obtained from TransGuide. Overall, the WWD Model can estimate travel routes that can be validated by WWD event information captured by deployed video cameras or law enforcement along the most likely routes, which ultimately will allow more precise evaluations of how well the WWD Model predicts reality. Ultimately the Task Force may deploy resources accordingly based on the WWD Model output routes to target estimated WWD crash hotspots as well as alcohol-serving establishments that may contribute to the flux of wrong-way drivers.

5.1 WWD Model Limitations

The WWD Model was developed using Microsoft Windows operating system and ArcGIS 10.1 software with Network Analyst extension. Continued use and improvements to the WWD Model is contingent upon actively maintaining compatibility with current ArcGIS software. ArcGIS 10.1 can be resource-intensive while executing the WWD Model from ArcToolbox, and may become unresponsive/unstable when processing large datasets. Despite the use of "from – to" fields for one-way roads and "elevation" fields for z-values, within the input network dataset accurate on-ground representation the WWD Model is limited in its capabilities. To begin with, the model's functionality is constrained to the included *model parameters* and cannot support inclusion of ad-hoc input parameters outside of the prescribed *restrictions* input(s). Additionally, the *Closest Facility* geoprocess chosen for this analysis only models start and end points of travel – *facilities* and *incidents* – whereas use of the tool *Route Layer* would have allowed nested sequential stops en route to crash points (2.2.4 Esri Network Analyst: Make Service Area Geoprocess). Most notably the *wrong-way driver setting* has only seven values in its domain – each an Esri developed algorithm that cannot be modified by the user. There should be customizable variables to better model the wide array of possibilities of WWD behavior (3.2.3 Description of Inputs). Moreover the *facilities* used do not represent a validated dataset as impaired drivers could begin their travel from potentially anywhere in Bexar County such as parking lots, gas stations, private residences, or the Riverwalk (Topolsek and Lipicnik 2009, 87). In some cases, the *barriers* dataset proved to be more limiting than beneficial as some incorporated cities had no routes available due to critical roadway interchanges being outside of the boundaries, so those particular boundaries were not accessible to the network dataset. Such underrepresentation can easily be remedied by using the largest geographic footprint available as the barrier (e.g. county, state, nation), and smaller jurisdictional boundaries for visual reference. These results indicate that more detailed input datasets will yield a more flexible set of traffic pattern scenarios, as a future study.

5.2 Conclusions

This study was successful in demonstrating potential routes simulating WWD behavior originating from alcohol-serving establishments, for seven specific types of physical traffic restrictions. Nearly all parameters and input datasets are variables within the WWD Model thus allowing users to vary the input data. No specific facility was queried for further analysis, however, this tool would likely be more effective when validated against additional real-world WWD observations by deployed cameras and local law enforcement. Regarding suggested countermeasures to combat WWD, no single approach completely resolved the issue in any given research study, but rather a combination of aforementioned countermeasures in context of surrounding transportation infrastructure successfully lowered WWD incidents (2.2.5 WWD Safety and Countermeasures). In conclusion, the WWD Model does not predict travel patterns, but does provide data-driven visualizations that may be further investigated by local law enforcement personnel with the goal of prioritizing resources for WWD prevention.

5.3 Future Research

Recommendations for improvements to the WWD Model may be addressed by other researchers interested in this type of study, and also by the author in a future study pending approval for new funding by the Task Force (2.1.2 Goals). Further research can improve this study by using real-time validated detections fetched from TransGuide as the *incident* input dataset, then combining Esri's *Route Layer* and *Closest Facility* geoprocesses to create a concurrent scenario of WWD travel patterns based on observed driving behavior. Implementing the revised model in an accessible online web GIS application could assist law enforcement in the field by providing temporally sensitive results on the fly, and possibly ranking routes based on spatial attributes as an added metric of prioritization. Ultimately the goal is to allow law enforcement to proactively mitigate WWD crashes in lieu of reacting to crashes after disaster has occurred. Perhaps answers will be found in next-generation autonomous vehicles and preemptive city planning using web GIS to prevent WWD incidents (Ghaaemi, et al. 2009, 486; Gerber 2012) (2.2.6 WWD Research and Development).

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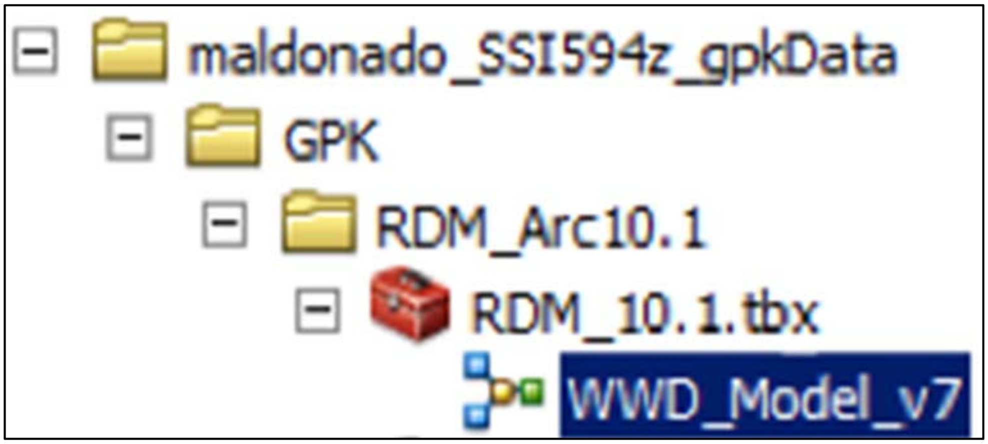
APPENDIX A: STEPS FOR RUNNING THE WWD MODEL

This discussion provides detailed user interaction instructions on how to run the WWD Model using Esri ArcGIS Desktop (ArcMap and Catalog) version 10.1. Detailed explanations of inputs and settings are provided immediately following these basic instructions.

If running the WWD Model as a *geoprocessing package file* (.gpk), simply right click on the file and open with *ArcGIS File Handler*. The WWD Model will unpack and open the Results in a new ArcMap document, automatically.

If running the WWD Model as a *tool* within *ArcToolbox*, first launch ArcMap, open a new ArcMap document and navigate to the WWD Model *geoprocessing package file* (.gpk), within Catalog, then right-click on it and choose Unpack (Figure A1).



- maldonado_SSI594z_gpkData
  - GPK
    - RDM_Arc10.1
      - RDM_10.1.tbx
        - WWD_Model_v7

Figure A1: Screenshot of WWD Model

Using a PC, the model and example input datasets are accessible within C:\Users\username\Documents\ArcGIS\Packages\rdm_model_ssi594_v7\, once the .gpk file is unpacked. Then double-click on the WWD Model (*WWD_Model_v7*, as of December 2013), as shown above in ArcMap Catalog to open the dialog box user interface shown in Figure 21. The user then inputs appropriate values for each item as described in detail in the following sequence of steps.

Network Dataset

Input the built network dataset with one-way attributes. Related parameters include *restrictions*, *U-Turn policy*, and *wrong-way driver setting*, which are described below. For this analysis, Bexar Metro 911 dataset was used as it contains all streets within Bexar County.

Restrictions

The one-way attribute will be used as the restriction here. Users may include additional restrictions depending on their network; this input is optional as it is not required to run the model if restrictions are unnecessary. By default the one-way restriction box is checked and thus enabled so it may be used when toggling various WWD Model settings.

U-Turn Policy

Adjust the degree that U-Turns are allowed on the network dataset; domain includes: Allowed, Not Allowed, Allowed at Dead Ends, Allowed and Dead Ends and Intersections. By default U-Turns are allowed on the WWD Model as they best simulate actual traffic conditions at intersections, dead ends, and other occurrences.

Wrong-Way Driver Setting

Adjust simulated variance of routes taken from *facilities* to *incidents*. Domain range setting, or physical traffic restrictions available includes: prohibited, avoid high, avoid medium, avoid low, prefer low, prefer medium, prefer high. This setting uses the one-way restriction inputted earlier in the model to create route variances based on avoiding, preferring, or prohibiting wrong-way travel on one-way roads. Assuming that the degree of impairment influences routes chosen. By default this variable is set to prefer high as the assumed closest representation of worst-case scenario for WWD behavior.

Facilities Dataset

Input point dataset that routes will be traveling from. By default the facilities are the geocoded TABC alcohol-serving locations as such venues have been identified by as likely points of origin for (WWD 3.1.1 Point Location Data). The underlying assumption in the WWD Model is that all *facilities* are alcohol-serving establishments.

Number of Facilities

The minimum of facilities to route incidents from, unless it [facility] cannot be routed due to lack of nearby network or geocoding errors. By default this value is set to 10 as it demonstrates capabilities of the WWD Model in reasonable time; larger values will increase geoprocessing time.

SQL Facilities

Optional expression for *facilities dataset*. By default this expression is *"LB" = 1 OR "BL" =1* to query the coded attributes for alcohol-serving, late hour, locations open until 2:00 AM. Several more attributes exist within this dataset that may be used to query with this statement.

Incidents Dataset

Input point dataset that routes will be traveling to. By default the incidents are the WWD crash points retrieved from San Antonio – Bexar County MPO. An inputted dataset must have the same coordinate system and, if necessary, be geocoded to successfully be routed on the *network dataset*.

SQL Incidents

Optional expression for *incidents dataset*; by default this expression is left blank to better demonstrate routing total crashes using the WWD Model. Several attributes exist within this dataset that may be used to express a query.

Barrier Type

Type of vector data to be used (points, lines, polygons); by default this value is set to *lines* as it best represents jurisdictional boundaries and nested traffic networks thereof.

Barrier Dataset

Input vector dataset to be used with *network dataset* to represent restricted paths of travel. If no barriers exist, simply input the largest boundary footprint polyline available (e.g. study area, state, country, and world).

SQL Barriers

Optional expression for *barriers dataset*; by default this expression is left blank to better demonstrate routing total crashes using all the jurisdictional boundaries. Name attributes exist within this dataset that may be used to express a query.

Output Layer Package

Assign a new name and save the resulting output into a layer package file (.lpk).

Include Enterprise Geodatabase (.GDB)

Optional ArcGIS SDE feature to include data as file geodatabase instead of referencing data. By default the box is unchecked as no enterprise data was used.

Convert to File Geodatabase (.GDB)

Optional feature to convert data to file geodatabase format. By default the box is checked to maintain consistent datasets used when sharing with others.

Package Version

Check boxes to save layer package in respective compatible formats ranging from ArcGIS 9.3.1 to 10.1. Users may save in “All” and “Current” formats; “All” formats box is checked by default to allow increased compatibility to view WWD Model results.

Run

Click the “OK” button at the bottom of WWD Model dialog box to begin running. Any warnings or errors will write to screen during the geoprocess.

APPENDIX B: PYTHON SCRIPT OF WWD MODEL

The entire Python code for the WWD Model is provided herein. This code is also available to any user of the WWD Model geoprocessing package, simply by exporting the ModelBuilder model to Python script in ArcGIS Desktop (Esri, 2013).

```
# -*- coding: utf-8 -*-
# ---------------------------------------------------------------------------
# wwd_v7.py
# Created on: 2013-12-15 21:08:03.00000
#   (generated by ArcGIS/ModelBuilder)
# Usage: wwd_v7 <OUTPUT_LAYER___LYR_> <NETWORK_DATASET>
<RESTRICTIONS> <U-TURN_POLICY> <WRONG-WAY_DRIVING_SETTING>
<FACILITIES_DATASET> <NUMBER_OF_FACILITIES_TO_FIND>
<SQL_FACILITIES> <INCIDENTS_DATASET> <SQL_INCIDENTS>
<BARRIER_TYPE> <BARRIERS_DATASET> <SQL_BARRIERS>
<OUTPUT_LAYER_PACKAGE___LPK_> <INCLUDE_ENTERPRISE__GDB>
<CONVERT_DATA_TO_FILE__GDB> <PACKAGE_VERSION>
# Description: 
# ---------------------------------------------------------------------------

# Import arcpy module
import arcpy

# Check out any necessary licenses
arcpy.CheckOutExtension("Network")

# Script arguments
OUTPUT_LAYER___LYR_ = arcpy.GetParameterAsText(0)
if OUTPUT_LAYER___LYR_ == '#' or not OUTPUT_LAYER___LYR_:
    OUTPUT_LAYER___LYR_ = "Closest Facility 2" # provide a default value if
unspecified

NETWORK_DATASET = arcpy.GetParameterAsText(1)
if NETWORK_DATASET == '#' or not NETWORK_DATASET:
    NETWORK_DATASET =
"G:\\BexarCounty\\maldonado_SSI594z_gpkData\\gpkData.gdb\\Bexar_AllStreets_BM9
11CoSA_Flipped4_Elevation_noRiverwalk\\Bexar_AllStreets_BM911CoSA_Flipped4_
Elevation_noRiverwalk_ND" # provide a default value if unspecified

RESTRICTIONS = arcpy.GetParameterAsText(2)
if RESTRICTIONS == '#' or not RESTRICTIONS:
```

```
    RESTRICTIONS = "Oneway" # provide a default value if unspecified

U-TURN_POLICY = arcpy.GetParameterAsText(3)
if U-TURN_POLICY == '#' or not U-TURN_POLICY:
    U-TURN_POLICY = "ALLOW_UTURNS" # provide a default value if unspecified

WRONG-WAY_DRIVING_SETTING = arcpy.GetParameterAsText(4)
if WRONG-WAY_DRIVING_SETTING == '#' or not WRONG-WAY_DRIVING_SETTING:
    WRONG-WAY_DRIVING_SETTING = "PREFER_HIGH" # provide a default value if unspecified

FACILITIES_DATASET = arcpy.GetParameterAsText(5)
if FACILITIES_DATASET == '#' or not FACILITIES_DATASET:
    FACILITIES_DATASET = "G:\\BexarCounty\\maldonado_SSI594z_gpkData\\gpkData.gdb\\TABC_roster_Bexar_AllLic_Active_06to11_geocoded" # provide a default value if unspecified

NUMBER_OF_FACILITIES_TO_FIND = arcpy.GetParameterAsText(6)
if NUMBER_OF_FACILITIES_TO_FIND == '#' or not NUMBER_OF_FACILITIES_TO_FIND:
    NUMBER_OF_FACILITIES_TO_FIND = "10" # provide a default value if unspecified

SQL_FACILITIES = arcpy.GetParameterAsText(7)
if SQL_FACILITIES == '#' or not SQL_FACILITIES:
    SQL_FACILITIES = "[\"LB\" = 1 OR \"BL\" =1]" # provide a default value if unspecified

INCIDENTS_DATASET = arcpy.GetParameterAsText(8)
if INCIDENTS_DATASET == '#' or not INCIDENTS_DATASET:
    INCIDENTS_DATASET = "G:\\BexarCounty\\maldonado_SSI594z_gpkData\\gpkData.gdb\\Bexar_WWD" # provide a default value if unspecified

SQL_INCIDENTS = arcpy.GetParameterAsText(9)

BARRIER_TYPE = arcpy.GetParameterAsText(10)
if BARRIER_TYPE == '#' or not BARRIER_TYPE:
    BARRIER_TYPE = "Line Barriers" # provide a default value if unspecified

BARRIERS_DATASET = arcpy.GetParameterAsText(11)
if BARRIERS_DATASET == '#' or not BARRIERS_DATASET:
```

```
    BARRIERS_DATASET =
"G:\\BexarCounty\\maldonado_SSI594z_gpkData\\gpkData.gdb\\Bexar_AllBoundaries_l
ine" # provide a default value if unspecified

SQL_BARRIERS = arcpy.GetParameterAsText(12)

OUTPUT_LAYER_PACKAGE___LPK_ = arcpy.GetParameterAsText(13)
if OUTPUT_LAYER_PACKAGE___LPK_ == '#' or not
OUTPUT_LAYER_PACKAGE___LPK_:
    OUTPUT_LAYER_PACKAGE___LPK_ =
"G:\\BexarCounty\\maldonado_SSI594z_gpkData\\LYR_LPK\\04LPK.lpk" # provide a
default value if unspecified

INCLUDE_ENTERPRISE__GDB = arcpy.GetParameterAsText(14)
if INCLUDE_ENTERPRISE__GDB == '#' or not INCLUDE_ENTERPRISE__GDB:
    INCLUDE_ENTERPRISE__GDB = "true" # provide a default value if unspecified

CONVERT_DATA_TO_FILE__GDB = arcpy.GetParameterAsText(15)
if CONVERT_DATA_TO_FILE__GDB == '#' or not
CONVERT_DATA_TO_FILE__GDB:
    CONVERT_DATA_TO_FILE__GDB = "true" # provide a default value if unspecified

PACKAGE_VERSION = arcpy.GetParameterAsText(16)
if PACKAGE_VERSION == '#' or not PACKAGE_VERSION:
    PACKAGE_VERSION = "ALL" # provide a default value if unspecified

# Local variables:
Closest_Facility_2 = NUMBER_OF_FACILITIES_TO_FIND
Closest_Facility_2__2_ = Closest_Facility_2
Closest_Facility_2__3_ = Closest_Facility_2__2_
Closest_Facility_2__5_ = Closest_Facility_2__3_
Closest_Facility_2__7_ = Closest_Facility_2__5_
Solve_Succeeded = Closest_Facility_2__7_
TABC_roster_Bexar_AllLic_Act = FACILITIES_DATASET
Bexar_WWD_Select = INCIDENTS_DATASET
Bexar_AllBoundaries_line_Sel = BARRIERS_DATASET

# Process: Make Closest Facility Layer
arcpy.MakeClosestFacilityLayer_na(NETWORK_DATASET, "Closest Facility 2",
"Length", "TRAVEL_FROM", "", NUMBER_OF_FACILITIES_TO_FIND, "", U-
TURN_POLICY, RESTRICTIONS, "NO_HIERARCHY", "",
"TRUE_LINES_WITH_MEASURES", "", "NOT_USED")

# Process: Select
```

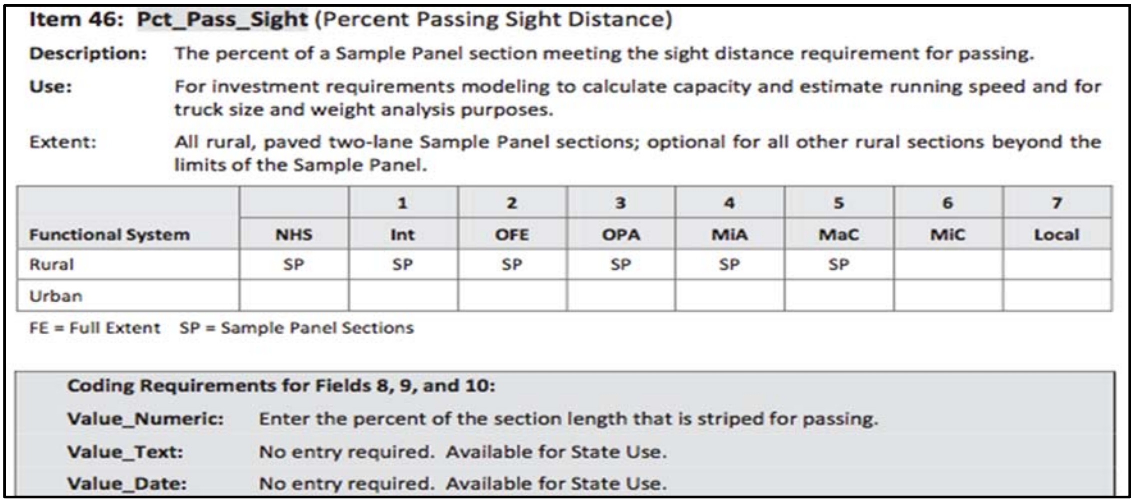
```
arcpy.Select_analysis(FACILITIES_DATASET, TABC_roster_Bexar_AllLic_Act,
SQL_FACILITIES)

# Process: Add Locations
arcpy.AddLocations_na(Closest_Facility_2, "Facilities",
TABC_roster_Bexar_AllLic_Act, "Name tradename #", "5000 Meters", "",
"Bexar_BM911CoSA_Flipped4_ElevationEtc_1
SHAPE;Bexar_AllStreets_BM911CoSA_Flipped4_Elevation_noRiverwalk_ND_Junctio
ns NONE", "MATCH_TO_CLOSEST", "CLEAR", "SNAP", "5 Meters", "INCLUDE",
"Bexar_BM911CoSA_Flipped4_ElevationEtc_1
#;Bexar_AllStreets_BM911CoSA_Flipped4_Elevation_noRiverwalk_ND_Junctions #")

# Process: Select (2)
arcpy.Select_analysis(INCIDENTS_DATASET, Bexar_WWD_Select,
SQL_INCIDENTS)

# Process: Add Locations (2)
arcpy.AddLocations_na(Closest_Facility_2__2_, "Incidents", Bexar_WWD_Select,
"Name Crash_ID #", "5000 Meters", "", "Bexar_BM911CoSA_Flipped4_ElevationEtc_1
SHAPE;Bexar_AllStreets_BM911CoSA_Flipped4_Elevation_noRiverwalk_ND_Junctio
ns NONE", "MATCH_TO_CLOSEST", "APPEND", "SNAP", "5 Meters", "INCLUDE",
"Bexar_BM911CoSA_Flipped4_ElevationEtc_1
#;Bexar_AllStreets_BM911CoSA_Flipped4_Elevation_noRiverwalk_ND_Junctions #")

# Process: Select (3)
arcpy.Select_analysis(BARRIERS_DATASET, Bexar_AllBoundaries_line_Sel,
SQL_BARRIERS)

# Process: Add Locations (3)
arcpy.AddLocations_na(Closest_Facility_2__3_, BARRIER_TYPE,
Bexar_AllBoundaries_line_Sel, "Name Name #", "1 Miles", "",
"Bexar_BM911CoSA_Flipped4_ElevationEtc_1
SHAPE;Bexar_AllStreets_BM911CoSA_Flipped4_Elevation_noRiverwalk_ND_Junctio
ns NONE", "MATCH_TO_CLOSEST", "APPEND", "NO_SNAP", "5 Meters",
"INCLUDE", "Bexar_BM911CoSA_Flipped4_ElevationEtc_1
#;Bexar_AllStreets_BM911CoSA_Flipped4_Elevation_noRiverwalk_ND_Junctions #")

# Process: Update Analysis Layer Attribute Parameter
arcpy.UpdateAnalysisLayerAttributeParameter_na(Closest_Facility_2__5_, "Oneway",
"Restriction Usage", WRONG-WAY_DRIVING_SETTING)

# Process: Solve
arcpy.Solve_na(Closest_Facility_2__7_, "SKIP", "TERMINATE", "")
```

```
# Process: Package Layer
arcpy.PackageLayer_management("'Closest Facility 2'",
OUTPUT_LAYER_PACKAGE___LPK_, CONVERT_DATA_TO_FILE__GDB,
INCLUDE_ENTERPRISE__GDB, "DEFAULT", "ALL", "ALL",
PACKAGE_VERSION, "", "", "")
```

APPENDIX C: HPMS MANUAL FIGURES

The following excerpt figures are taken from the HPMS Manual (Federal Highway Administration 2012). More specifically, from Chapter 4, which details data requirements for each collected attribute value.

Data item 46: Percent Passing Sight Distance is shown in Figure C1. It is used to describe roadway sections that “meet the sight distance requirement for passing” (Federal Highway Administration 2012, 4-83). Roadways with such traits could inadvertently facilitate WWD crashes as it presents legal circumstances for right-way drivers to pass using opposing traffic lanes. The definitions of the acronyms in Figure C1 can be found in the HPMS Manual (Federal Highway Administration 2012, A-1 - A-3).



Item 46: Pct_Pass_Sight (Percent Passing Sight Distance)

Description: The percent of a Sample Panel section meeting the sight distance requirement for passing.

Use: For investment requirements modeling to calculate capacity and estimate running speed and for truck size and weight analysis purposes.

Extent: All rural, paved two-lane Sample Panel sections; optional for all other rural sections beyond the limits of the Sample Panel.

		1	2	3	4	5	6	7
Functional System	**NHS**	**Int**	**OFE**	**OPA**	**MiA**	**MaC**	**MiC**	**Local**
Rural	SP	SP	SP	SP	SP	SP		
Urban								

FE = Full Extent SP = Sample Panel Sections

Coding Requirements for Fields 8, 9, and 10:

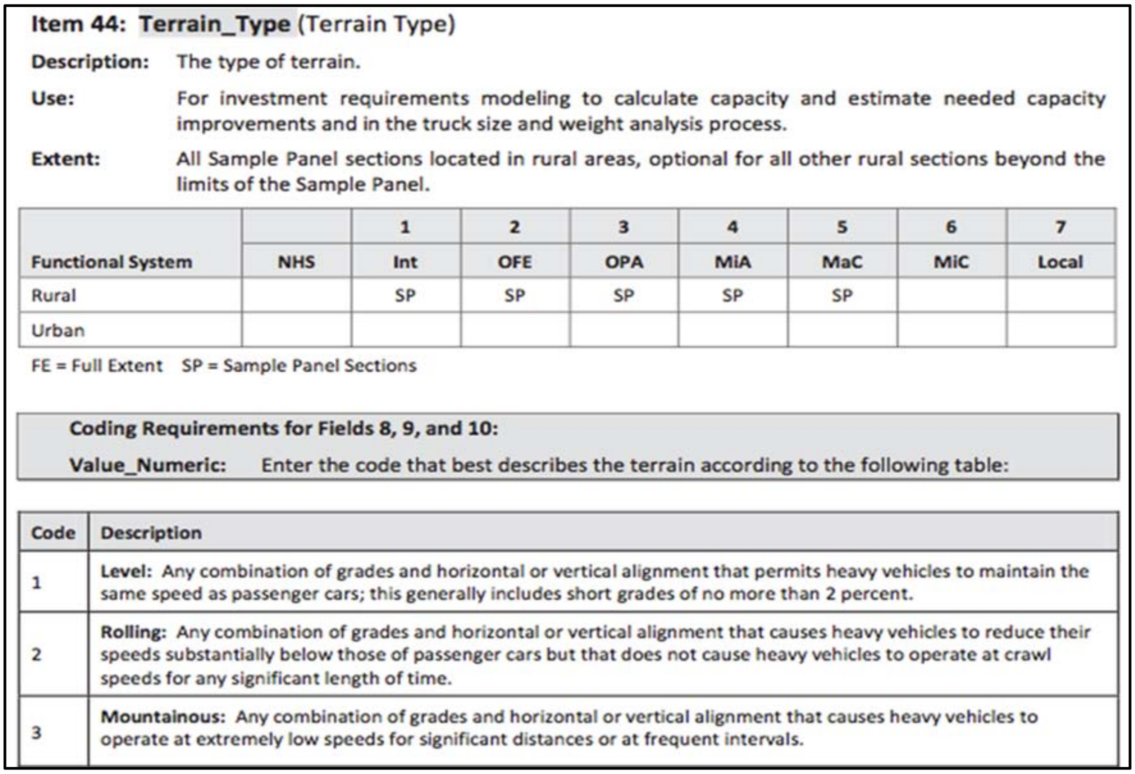
Value_Numeric: Enter the percent of the section length that is striped for passing.

Value_Text: No entry required. Available for State Use.

Value_Date: No entry required. Available for State Use.

Figure C1: HPMS Manual section describing “Percent Passing Sight Distance”: (Federal Highway Administration 2012, 4-83)

Data item 44: Terrain Type is shown in Figure C2. It is used to describe “the type of terrain” of each roadway section with “level, rolling, [and] mountainous” values allowed. Rolling and mountainous terrain types could facilitate WWD crashes as it creates blind spots at curves and grade changes. The terrain of such roadways could be especially dangerous when paired with broken yellow lines to allow passing in the opposing lane. The definitions of the acronyms in Figure C2 can be found in the HPMS Manual (Federal Highway Administration 2012, A-1 - A-3).



Item 44: Terrain_Type (Terrain Type)

Description: The type of terrain.

Use: For investment requirements modeling to calculate capacity and estimate needed capacity improvements and in the truck size and weight analysis process.

Extent: All Sample Panel sections located in rural areas, optional for all other rural sections beyond the limits of the Sample Panel.

		1	2	3	4	5	6	7
Functional System	**NHS**	**Int**	**OFE**	**OPA**	**MiA**	**MaC**	**MiC**	**Local**
Rural		SP	SP	SP	SP	SP		
Urban								

FE = Full Extent SP = Sample Panel Sections

Coding Requirements for Fields 8, 9, and 10:

Value_Numeric: Enter the code that best describes the terrain according to the following table:

Code	**Description**
1	**Level:** Any combination of grades and horizontal or vertical alignment that permits heavy vehicles to maintain the same speed as passenger cars; this generally includes short grades of no more than 2 percent.
2	**Rolling:** Any combination of grades and horizontal or vertical alignment that causes heavy vehicles to reduce their speeds substantially below those of passenger cars but that does not cause heavy vehicles to operate at crawl speeds for any significant length of time.
3	**Mountainous:** Any combination of grades and horizontal or vertical alignment that causes heavy vehicles to operate at extremely low speeds for significant distances or at frequent intervals.

Figure C2: Excerpt from HPMS Field Manual of Terrain Type: (Federal Highway Administration 2012, 4-80)