Final Report:

Driving Simulator Studies of the Effectiveness of Countermeasures to Prevent Wrong-Way Crashes

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Disclaimer

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SI* (Modern Metric) Conversion Factors

Approximate Conversions to SI Units

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2

FORCE and PRESSURE or STRESS				
lbf	pound force	4.45	newtons	N
lbf/in^2	pound force per square inch	6.89	kilopascals	kPa
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
^oC	Celsius	1.8C+32	Fahrenheit	^oF
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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16. Abstract Wrong-way crashes (WWCs) are severe and more likely to be fatal compared to other highway crashes. We report two tasks aimed at understanding and reducing this type of crash. Task 1 was a review of five decades of research on the characteristics of wrong-way drivers, interchange designs associated with wrong-way entries, and the effectiveness of countermeasures that have been implemented to reduce wrong-way crashes and entries. Task 1 also involved the development of a cue-based decision model to explain wrong-way movements. Task 2 included laboratory and driving simulator studies to better understand effective countermeasures to prevent wrong-way entries and crashes, testing younger and older drivers under conditions in which they are most likely to be involved in a WWC (younger drivers at night, older drivers during the day). A subset of younger participants was asked to drive scenarios while under conditions of simulated impairment (with visual distortion and under cognitive load). Within the context of our previously proposed cue-based decision framework, our goal was to understand the most effective cues to convey to drivers of all ages information about correct and incorrect interstate entry points so they can make safe and accurate driving decisions. Since wrong-way entries are rare events, in the simulator, we explored a number of potentially more sensitive metrics to detect driver confusion at interchange decision points (e.g., lane deviation, speed, braking behavior). A non-simulator decision task involving photos of interchanges was also conducted to understand the best countermeasures to quickly alert drivers regarding correct and incorrect entry points. The decision task revealed that the visibility of wrong way (R5-1a) signs was one of the best predictors of correctly rejecting an exit ramp with respect to countermeasures. The presence of other vehicles was also a strong predictor of accuracy, consistent with the fact that many WWCs occur at night with few other vehicles on the road. In general, a greater number of different types of countermeasures present benefited the correct rejection of exit ramps in the decision task. Both younger and older adults benefited from an increase in diversity of countermeasures. In addition to a greater variety of countermeasures, the presence of redundant signs (Wrong Way, Do Not Enter) improved the identification of exit ramps, though in this case, more so for younger adults compared to older adults. In the simulator task, drivers (N = 120) were instructed to enter a highway, and exit ramps were marked with the minimum number of countermeasures recommended by the MUTCD or with a greater number of countermeasures and countermeasure enhancements recommended by a recent analysis of Florida exit ramps by the Florida Department of Transportation's Statewide Wrong Way Crash Study. A total of four wrong way entries were observed (2 older drivers, two younger drivers under conditions of simulator impairment). All four occurred in the minimum countermeasure condition. Evidence also suggested that speed and braking patterns differed as a function of countermeasure configuration, highlighting the potential of subtle driving behavior measures as indicators of driver confusion/uncertainty. Overall, results of the simulator study provide initial evidence that countermeasure configurations including a greater number and greater diversity of countermeasures may assist in reducing confusion regarding entrance and exit ramps. However, some caution is warranted with respect to claims of reducing the number of wrong-way entries as statistical significance is difficult to achieve when investigating such low probability events in the absence of very large samples. Based on the developed decision model and the results of the ramp classification and driving simulator task, new countermeasure standards that increase the number and diversity of countermeasures at exit and entrance ramps are a promising approach to reduce this dangerous type of crash.

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Executive Summary

The reported tasks explored the effectiveness of countermeasures to reduce wrong-way entries and Wrong-Way Crashes (WWCs).

Task 1: Task 1 was a comprehensive review of five decades of research on the characteristics of wrong-way drivers and interchanges associated with WWCs. Our analysis, consistent with previous reports, found that drug/alcohol impairment plays a major role in a significant number of WWCs. Further, older drivers are overrepresented in WWCs. Our review of pre-post field studies of problematic interchanges indicated that the introduction of additional countermeasures can substantially reduce wrong-way entries. However, general recommendations regarding specific countermeasures or sets of countermeasures are difficult to make because of the idiosyncracies of the interchanges studied and the fact that more and specific types of countermeasures tended to be implemented at the most problematic interchanges. This has the potential to present a biased view of the effectiveness of implemented countermeasures. This review suggested the usefulness of simulator studies in which the general characteristics of an interchange can be held constant while one or a set of countermeasures is manipulated. Given that wrong-way entries are rare, subtle behavioral cues within a driving simulator study may also be revealed as more sensitive measures of confusion regarding which ramp is the correct entry point of a highway (e.g., slowing or braking around an exit ramp). Our review of the literature led to the development of a cue-based decision framework for understanding wrong-way entries and crashes. A number of cues (lane markings, signs, presence of other traffic) differentiate entrance and exit ramps. Age-related perceptual and cognitive declines, and to a much greater extent, drug and alcohol impairment, can restrict the numbers of cues processed and cause cues to be processed more slowly and to a lesser extent. This model suggests that redundant cues (e.g., additional signs) and more salient cues (larger signs, lowered signs) may be an effective means to reduce wrong-way entries. Further, this model highlights the need to focus not just on the decision to enter a ramp but on cues related to the decision to continue on an exit ramp when an error has occurred. This comprehensive review and the model derived from it guided the development of two experimental tasks.

Task 2: Task 2a presented younger and older drivers with images of entrance and exit ramps for a brief period of time and asked participants whether what they saw was an entrance ramp. Consistent with the cue-based decision framework, a greater number of different types of cues present increased accuracy of rejecting an exit ramp as an entrance ramp. This effect was similar for younger and older adults. Further, a greater number of specific countermeasures was also associated with better accuracy. For example, performance increased with additional Wrong Way and Do Not Enter signs. However, in this case, increased redundancy benefited younger adults more than older adults. In general, results were broadly consistent with our model: a greater number of cues was associated with better rejection of exit ramps. Regarding specific cues, Wrong Way signs served as a crucial cue, and the presence of other traffic had a powerful effect on accuracy. Task 2b was a driving simulator study that instructed younger and older drivers to enter a highway. Exit ramps were marked with the minimum number of countermeasures recommended by the MUTCD or with a greater number of countermeasures and countermeasure enhancements recommended by a recent analysis of Florida exit ramps by the Statewide Wrong Way Crash Study. Half of the younger adult group experienced the task under conditions of simulated impairment. These participants completed the task while they wore goggles that distorted their vision and completed a dual-task that reduced cognitive resources toward the driving task. Four wrong-way entries occurred, all in the condition with the minimum number of countermeasures. Consistent with the literature, two wrong-way entries occurred in the impaired younger driver group, and two in the older driver group. However, some caution is warranted with respect to claims about reducing the number of wrong-way entries as statistical significance is difficult to achieve when investigating very low probability events in the absence of very large samples. Vehicle speed also differed between conditions, with slower speeds in the minimum countermeasure condition suggesting greater confusion/uncertainty compared to the enhanced countermeasure condition. There was also evidence for braking behavior and lane deviation to differentiate between the two countermeasure conditions.

Based on these findings, we offer a number of recommendations:

1) Problematic interchanges would likely benefit from an increase in the number and diversity of countermeasures to prevent WWCs. This report presents initial empirical evidence that the new minimum set of countermeasures proposed by the Statewide Wrong Way Crash Study, which increases the salience of countermeasures and the number of countermeasures at interchanges, may decrease confusion regarding the correct highway entry point.
2) The driving study presented here represents promising evidence that simulators can be used to investigate wrong-way entries and confusion. In addition to whether or not a wrong-way entry occurs, more sensitive metrics of speed, braking behavior, and lane deviation are available. We recommend further simulator studies with larger samples to provide additional evidence for the efficacy of specific countermeasures. Here, we compared two sets of countermeasures, but future studies may link decreased confusion to specific individual countermeasures (e.g., larger Do Not Enter signs). It is possible that one or a few of the additional countermeasures in the new proposed minimum have the most impact on reducing confusion, with other countermeasures having little or no effect. Eye tracking may also reveal the specific cues that aid in the decision process. Cost savings might be achieved by better understanding, out of the set of countermeasures implemented, which are responsible for decreased confusion.
3) In our review, alcohol and drug impairment appear to be the largest risk factor associated with WWCs. Efforts should be continued with respect to reducing impaired driving.

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Chapter 1. Introduction

The majority of wrong-way crashes (WWCs) involves a driver using an exit ramp to enter a freeway. As highlighted by a number of WWCs in Florida in recent years, these crashes are severe and often fatal. WWCs frequently involve impaired drivers, but there is also evidence that age-related perceptual and cognitive decline might put older drivers at greater risk for this type of crash. The current project aimed to use a human factors approach to understand the effectiveness of countermeasures to prevent WWCs. A comprehensive literature review is presented exploring the characteristics of wrong-way drivers and interchanges associated with wrong-way entries (Chapter 2). We also summarize and synthesize the results from various field studies that have attempted to reduce wrong-way entries through the addition of additional signage, lane-markings, and other countermeasures. From there, we conducted two studies that asked younger and older drivers to make decisions regarding correct highway entry points (Chapter 3). Drivers were presented with pictures of exit and entrance ramps for a single glance, and we explored properties of exit ramps most associated with accurate ramp classification. A driving simulator study also examined wrong-way entries. Drivers were asked to turn onto a ramp toward a destination city, and we varied countermeasures present at exit and entrance ramps. These tasks were intended to understand the effectiveness of countermeasures aimed to reduce this rare, but often fatal, type of crash.

Objectives and Supporting Tasks

In this project we studied the decision to erroneously enter freeways from an exit ramp and the effectiveness of countermeasures to prevent this error from a human factors perspective. We included both younger and older drivers to ensure that countermeasures are equally effective for older drivers who are at greater risk.

Task 1 was a detailed review of the literature on factors relating to wrong-way crashes on highways. We reviewed studies from over 50 years of research, including studies that used a wide range of methodologies.

Task 2a was a laboratory-based study in which we presented participants with images of entrance and exit ramps that varied in geometric features and the type and number of wrong-way countermeasures present, then evaluated which ramp features were associated with good or poor response accuracy.

Task 2b. A simulator study examined the complex decision processes involved in deciding to enter or not enter an exit ramp based on the available perceptual information.

Chapter 2. A Cue-Decision Framework of Wrong-Way Entries and Crashes: A Literature Review and Data Synthesis

Although wrong-way crashes represent only between one and three percent of crashes on interstate highways, the fatality rate in wrong-way crashes has been estimated to be 12 (Copelan, 1989) to as much as 27 times (Vaswani, 1973) that of other types of highway crashes (NTSB, 2013). Research on wrong-way crashes in the United States has spanned over 50 years and has yielded information about the characteristics of wrong-way movements and crashes, the characteristics of drivers involved in wrong-way crashes, and countermeasures designed to prevent or correct wrong-way movements. While some broad and consistent conclusions can be drawn from past work, such as the finding that a large proportion of wrong-way crashes involve impaired drivers and that improvements to signs, pavement markings, and channelization can substantially reduce the frequency of wrong-way entries at a given interchange, there has been considerably less work focusing on the decision-making process of individual wrong-way drivers.

The perspective we take frames drivers' decisions to enter the interstate at a given point as a cue-based decision. Road geometry, pavement markings, guide or warning signs, and the behavior of other traffic are all cues that drivers may consider when deciding which of available entry points is the correct one, and these cues may differ in their salience and informational value. For example, while seeing a yellow edge line on the right side of the road and a white edge line on the left would signal that one is driving the wrong way on an interstate ramp, this cue is likely less salient than a bright, retroreflective pavement marking showing an arrow pointing in the opposite direction. A cue-based approach allows for a flexible, generalizable way to categorize features of interchanges associated with a high risk of wrong-way entries and categorize features of current and proposed countermeasures.

In our review we also consider how characteristics of individual drivers may interact with the cue environment. Although advances in countermeasure and highway design have substantially reduced wrong-way driving incidents, with some authors going so far as to assert that wrong-way driving by unimpaired drivers due to confusion alone has been effectively eliminated (Copelan, 1989), the incidence of severe wrong-way crashes has remained relatively constant (NTSB, 2013). This is primarily due to the fact that a large proportion of drivers found to be at fault in wrong-way crashes were found to have some type of cognitive impairment at the time of the crash, either due to substance use, dementia, or other illness. Impairment affects drivers' ability to make use of cues, meaning that countermeasures in the form of additional cues found effective in preventing wrong-way driving by non-impaired may not be effective for the impaired driver. One benefit of our cue-based approach is that it provides a framework for making predictions about which countermeasures are likely to be effective in reaching impaired or disoriented older drivers.

We begin by reviewing prior work on wrong-way driving and crashes on controlled-access interstate highways, giving an overview of driver and environmental characteristics common to wrong-way incidents. Because the wrong-way entry point often cannot be determined from studies of crash reports, our review also includes studies that utilize other data sources, such as camera monitoring of ramps and reviews of incident reports from highway patrol officers, as these studies are most useful in identifying specific features of interchanges associated with wrong-way movements, which we consider to be an indication that a given interchange has a higher risk of being the origination point for a wrong-way crash. Next, we discuss cue-based decision making in the context of wrong-way movements and entries at highway interchanges, discussing conditions under which different cues are more or less likely to be effective in supporting quick and accurate identification of highway entry points. As part of this, we present combined data from studies that conducted camera-based monitoring at interchanges before and after countermeasures were implemented. In addition, because impaired and older drivers are over-represented in wrong-way crashes, we review issues specific to both of those populations, providing a basic overview of the cognitive and decision skills impaired by alcohol use, as well as discussion of how age-related changes in cognitive and sensory abilities put older drivers at increased risk for wrong-way driving. Finally, we make predictions about countermeasures likely to be most effective in reducing wrong-way driving incidents among impaired and older drivers.

Characteristics of Wrong-Way Incidents

Learning about factors associated with wrong-way entries to interstate highways from analyses of archival crash data presents several challenges. First, wrong-way crashes, although severe when they do occur, are uncommon, and estimates suggest that only a small proportion (as low as 1%) of wrong-way movements end in crashes (e.g., Scifres & Loutzenheiser, 1975; Lew, 1971). Because crashes represent only a limited subset of wrong-way movements, conclusions drawn from these cases may not yield broadly generalizable conclusions, though this information does identify the highest-risk populations. A second issue, one especially relevant to the current review, is that it is difficult to determine the wrong-way entry point from crash reports, as it is often unknown how long a driver had been going the wrong way before a crash occurred. In addition, drivers involved in wrong-way crashes are often impaired and so cannot accurately report the point at which they entered the highway. Because many of these crashes occur late at night when there is little traffic, there are typically few, if any, witnesses to wrong-way crashes (e.g., Braam, 2006; Lew, 1971; Michigan Department of Highways, 1968; NTSB, 2013; Scifres & Loutzenheiser, 1975; Tamburri & Theobald, 1965; Zhou et al., 2012; Zhou et al., 2014). For this reason, we also review studies that include data from sources other than reviews of archival crash data, such as field reviews of specific interchanges known to have a history of wrong-way entries, reports provided by highway patrol officers who intercepted wrong-way drivers, interviews of drivers involved in wrong-way crashes, and camera monitoring of wrong-way movements on ramps. Although conclusions drawn from each of these data converge on a few common points, each data source also contributes unique sources of information. Studies of crash reports, interviews with drivers, and reports provided by highway patrol officers provide information about driver characteristics but do not provide detailed information about wrong-way entry points. Camera monitoring of interchanges provides detailed information about the characteristics of interchanges associated with a high risk of wrong-way movements but do not provide information about driver characteristics. Another advantage of camera monitoring studies is that wrong-way movements on ramps are a more sensitive indicator of factors that influence driver decisions leading to wrong-way movements on ramps, which is especially useful in evaluating countermeasures; In some cases, the number of observed wrong-way movements was reduced from as much as 50 to 60 per month to less than five per month (Tamburri & Theobald, 1965; Rinde, 1978). Because only a small proportion of wrong-way movements lead to crashes, changes in crash rates are less appropriate for evaluating the effectiveness of countermeasures.

Driver-related factors. The state of the driver (e.g., under the influence of illicit drugs or alcohol), individual difference characteristics such as age and gender, and a history of reckless driving all appear to be associated with wrong-way incidents and crashes. Each of these factors is discussed in detail next.

Intoxication

One of the most clear and consistent findings from studies of wrong-way driving, including both data from crashes and reports from officers on wrong-way stops that did not lead a crash, is that alcohol and drug impairment is one of the largest single contributing factors in wrong-way incidents. Compared to other drivers, drivers involved in wrong-way crashes are substantially more likely to be intoxicated. Analyses of crash records find that 50 to 70 percent of wrong-way crash reports mention alcohol as a contributing factor, and between 50% and 80% of these intoxicated drivers were reported to have BACs above 0.15 (Braam, 2006; Copelan, 1989; Lew, 1971; NTSB, 2013; Scifres & Loutzenheiser, 1975; Tamburri & Theobald, 1965; Vaswani, 1977a, 1977b; Zhou et al., 2012; Zhou et al., 2014). In wrong-way crashes involving one or more fatalities, some studies find that as many as 80% of at-fault drivers were intoxicated at the time of the crash (Tamburri & Theobald, 1965; Zhou et al., 2012). Studies surveying wrong-way incidents where highway patrol offers stopped a wrong-way driver, many of which do not end in crashes, report lower rates of alcohol involvement. Of the 1,117 cases reviewed by Tamburri and Theobald (1965), 38.2% of wrong-way drivers had been drinking, and of these 22% were judged to be impaired, and 61.8% of these wrong-way drivers had not been drinking at all. Similar data collected by the Michigan Department of State Highways (1968) found that, out of 200 wrong-way driving reports reviewed, around 50% of incidents list alcohol as a contributing factor. Across all crash types, alcohol is reported to be a factor in around 31% of all crash fatalities. An examination of all drivers involved in crashes in 2012 from the FARS database reveals that 46% of drivers involved in wrong-way crashes (following methodology described in Baratian-Ghorghi, Zhou, & Shaw, 2014) on National Highway System (NHS) roads were judged to be under the influence of alcohol, compared to 15% of drivers in non-wrong-way crashes on NHS roadways. The rate of alcohol involvement among drivers who received citations (any type) is higher, 63% of drivers in wrong-way crashes and 27% of drivers in non-wrong-way crashes. The general pattern emerging from studies of both crash reports and reports of wrong-way incidents is that, as incident severity increases, the probability that the wrong-way driver is severely intoxicated increases. This is likely because non-intoxicated drivers typically realize and correct their error before being involved in a crash.

Previous Infractions

Other individual difference characteristics appear to be associated with wrong-way incidents. For example, there is evidence that that drivers involved in wrong-way incidents are more likely to have been convicted of a felony at some time in the past and have received more traffic tickets compared to the general population of licensed drivers (Tamburri & Lowden, 1968; Lew, 1971). Evidence also suggests a long-term pattern of reckless driving for drivers involved in wrong-way crashes; wrong-way drivers are more likely to have had previous traffic violations. In a review of 200 wrong-way incidents, the Michigan Department of State Highways (1968) found that 69% of wrong-way drivers had at least one point violation on their license, compared to 23% who had no points violations. Similar findings are reported by Lew (1971) and Tamburri and Lowden (1968) based on California data. Compared to other drivers involved in highway crashes, wrong-way drivers are more likely to have been involved in crashes prior to the wrong-way incident (Tamburri & Lowden, 1968; Lew, 1971). Drivers involved in wrong-way incidents are also more likely to have been operating a vehicle without a valid license at the time of the incident (Lew, 1971; Michigan Department of State Highways, 1968; NTSB, 2013). A recent report found that 19% of drivers involved in wrong-way crashes did not have a valid license at the time of the crash (NTSB, 2013).

Gender

Drivers involved in wrong-way crashes are two to three times more likely to be male, with estimates ranging from 60 to 81%, which is similar to the rate at which males are involved in other types of fatal crashes (around 70%, NHTSA, 2013). Male drivers involved in wrong-way crashes are more likely to have been drinking than are female wrong-way drivers; in fatal wrong-way crashes alcohol-impaired male drivers outnumber alcohol-impaired female drivers by about 3 to 1 (Baratian-Ghorghi et al., 2014; Brevoord, 1984; Cooner et al., 2004; ITARDA, 2002; Tamburri & Theobald, 1965; Tamburri & Lowden, 1968; Lew, 1971; Zhou et al., 2012; Zhou et al., 2014). Tamburri and Lowden (1968) report that female drivers, although responsible for 21% of wrong-way driving incidents, were at fault in only 10% of wrong-way crashes. Females involved in wrong-way crashes are more likely to be in the 35 to 44 age range, whereas males involved in wrong-way crashes tend to be younger than 35. The trend of disproportionately higher male involvement in wrong-way crashes is also seen in older drivers; in over 65 age group, there is also a higher rate of male involvement in wrong-way crashes compared to females in that age group (ITARDA, 2002; Zhou et al., 2012, Zhou et al., 2014).

Age

Another consistent finding is that older drivers are over-represented among drivers involved in wrong-way crashes. Older adults, particularly those over age 70, tend to be over-represented in wrong-way incidents relative to both their involvement in other types of crashes and relative to the number of licensed older drivers in the population. Tamburri and Theobald (1965) found that drivers over age 70 accounted for 11.8% of all wrong-way incidents examined but only made up 3.8 of all registered drivers in California at the time of the report. A 1968 study by the Michigan Department of State Highways found that older adults' over age 70 made up 6.6% of drivers involved in wrong-way incidents (in a sample of 196) but represented only 2.6% of licensed drivers in Michigan. Despite the overall reduction of wrong-way incidents per vehicle mile traveled over the past 50 years, older adults continue to be overrepresented in wrong-way incidents. In a more recent analysis of wrong-way crashes in the Charlotte, NC area, Braam (2006) found that although drivers age 65 and older made up about 14% of licensed drivers (Federal Highway Administration, 2006) and accounted for only 5% of at-fault drivers in all highway crashes, this group accounted for 17.3% of at-fault drivers in wrong-way crashes. Cooner et al. (2004) report that adults aged 65 and older accounted for 12.7% of drivers at fault in wrong-way crashes, which was higher than their rate of involvement in other crashes. Similar trends are found internationally. Scaramuzza and Cavegn (2007), in an analysis of wrong-way incidents in Switzerland, report that older adults aged 65 and older are more than 7.65 times more likely to be involved in a wrong-way crash compared to their rate of involvement in other types of crashes. In Japan, drivers over the age of 65 accounted for 29% of drivers in wrong-way crashes (ITARDA, 2002).

Why do older adults continue to be overrepresented in wrong-way incidents when overall rates of wrong-way driving have declined significantly? In general, older adults have been found to make more safety-related driving errors, and the frequency of these errors is associated with deficits in cognitive abilities (e.g., Alam & Spainhour, 2008; Anstey & Wood, 2011; Read et al., 2011). Older adults also report more problems with driving-related tasks, such as wayfinding in unfamiliar areas (e.g., Bryden et al., 2013; Read et al., 2011), seeing and understanding road signs (e.g., Scialfa et al., 2005), and the physical demands of maneuvering a vehicle (e.g., reduced muscle strength, difficulty with neck rotation; Anstey et al., 2005). Although older adults are less likely than younger adults to be driving under the influence of alcohol or illegal drugs, older adults are much more likely to have medical conditions that impair their ability to notice and appropriately correct driving errors, such as dementia or adverse reactions to medication (ITARDA, 2002; NTSB, 2013; Zhou et al., 2012). Dementia is a likely contributing factor in many vehicle crashes involving older drivers, one study performed autopsies of older adults killed in vehicle crashes and found that the brains of more than half had physical changes associated with dementia, although most of these drivers had not received a formal diagnosis of dementia prior to their deaths (Johansson et al., 1994). The risk of dementia increases sharply after age 65, while only about 4% of people under age 65 have been diagnosed with dementia, that rate is 11% in those 65 and older, and 32% of those 85 and older (Alzheimer's Association, 2013). Like an intoxicated driver, even if a countermeasure is effective in alerting a cognitively impaired older driver of their error, they may not respond appropriately or quickly enough. Even in the absence of disease, there are significant age-related changes that adversely affect driving ability and may increase older drivers' risk of wrong-way driving. We will discuss issues specific to older drivers, including an overview of how age-related cognitive changes relate to the risk of wrong-way driving, in greater detail in a later section.

Environmental factors. Much work has focused on identifying environmental factors, including weather, lighting conditions, visibility, time of day, and road geometry, that are associated with increased risk of wrong-way driving and crashes. In the 1970s and 80s, several large-scale studies used automated cameras to monitor wrong-way movements on freeway entrance and exit ramps in California, Georgia, and Virginia (e.g., Campbell & Middlebrooks, 1988; Howard, 1980; Lew, 1971; Parsonson & Marks, 1979; Rinde, 1978). Because crashes represent only a small proportion of wrong-way movements, as little as 1% (Scifres & Loutzenheiser, 1975), and entry points frequently cannot be determined from crash reports, wrong-way movements detected by automated cameras are a more sensitive metric of a given interchange's risk of being a wrong-way entry point. Complementing these data are reports from police who intercept wrong-way drivers, as these incidents still occur at a higher rate than do actual crashes, but unlike camera monitoring studies, provide information about driver characteristics.

Studies including data from camera monitoring, police reports, and crash reports all find that wrong-way incidents, particularly those leading to a crash, occur much more frequently at night between 12 am and 6 am on Fridays, Saturdays, and Sundays, a trend primarily driven by alcohol-related incidents (Braam, 2006; Cooner & Ranft, 2008; Cooner et al., 2004; Lew, 1971; Tamburri & Theobald, 1965; Zhou et al., 2014). When wrong-way incidents where alcohol is not a factor are considered separately, they are approximately evenly distributed across days of the week and are more likely to occur in the daytime, at times when there is heavier traffic (Michigan Department of Highways, 1968; Vaswani, 1977a; also see Figure 1). It is common for older adults to avoid driving at night, consistent with this, wrong-way incidents involving older adults are more likely to occur during the day than at night, again peaking at the times of day when there is heavier traffic (Tamburri & Theobald, 1965; also see Figure 2).

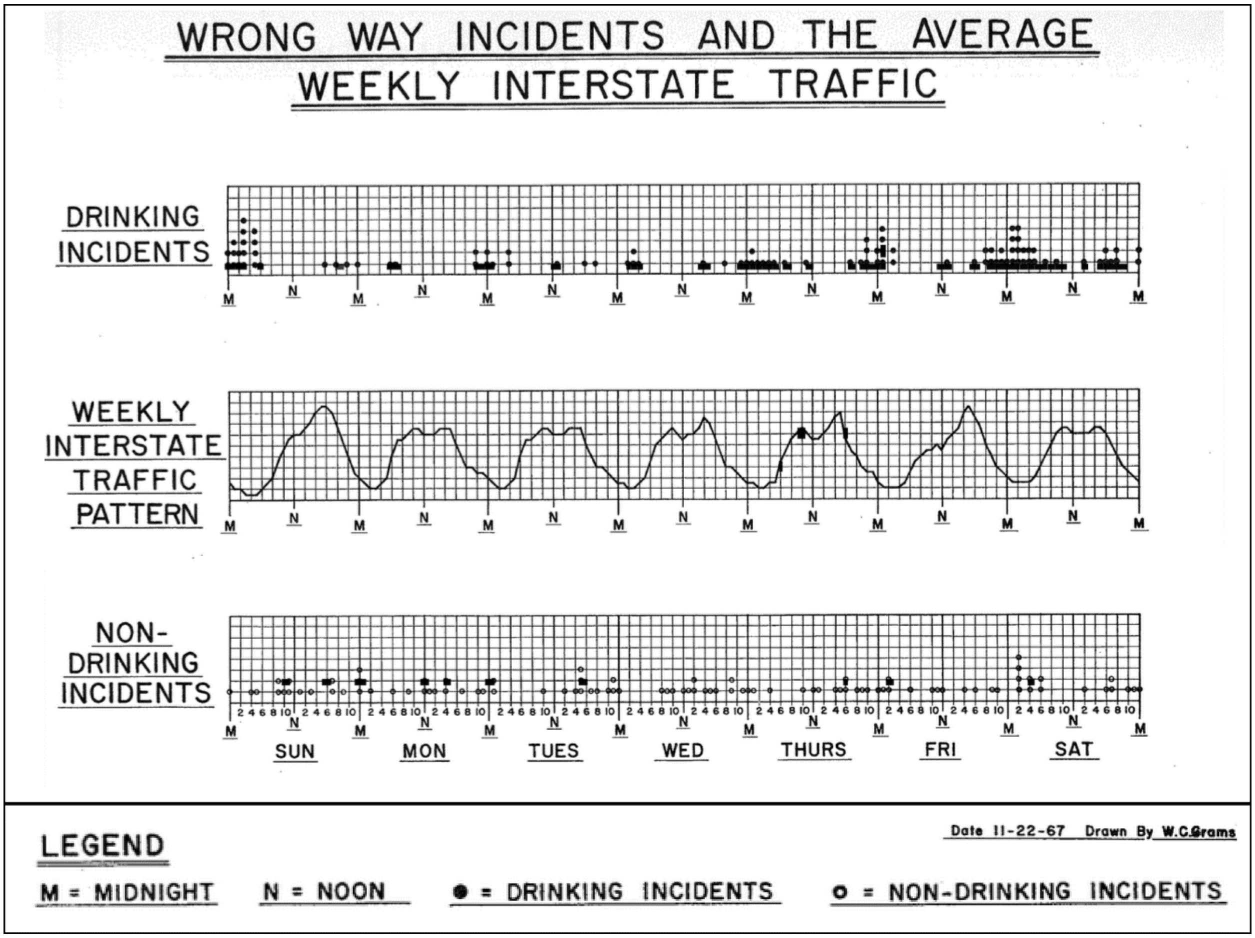

Figure 1. Drinking and non-drinking wrong-way incidents by time of day and day of week (Michigan Department of Highways, 1968). The original figure from Michigan Department of Highways (1968) was enhanced in Adobe Illustrator CC for additional clarity on the labels and captions.

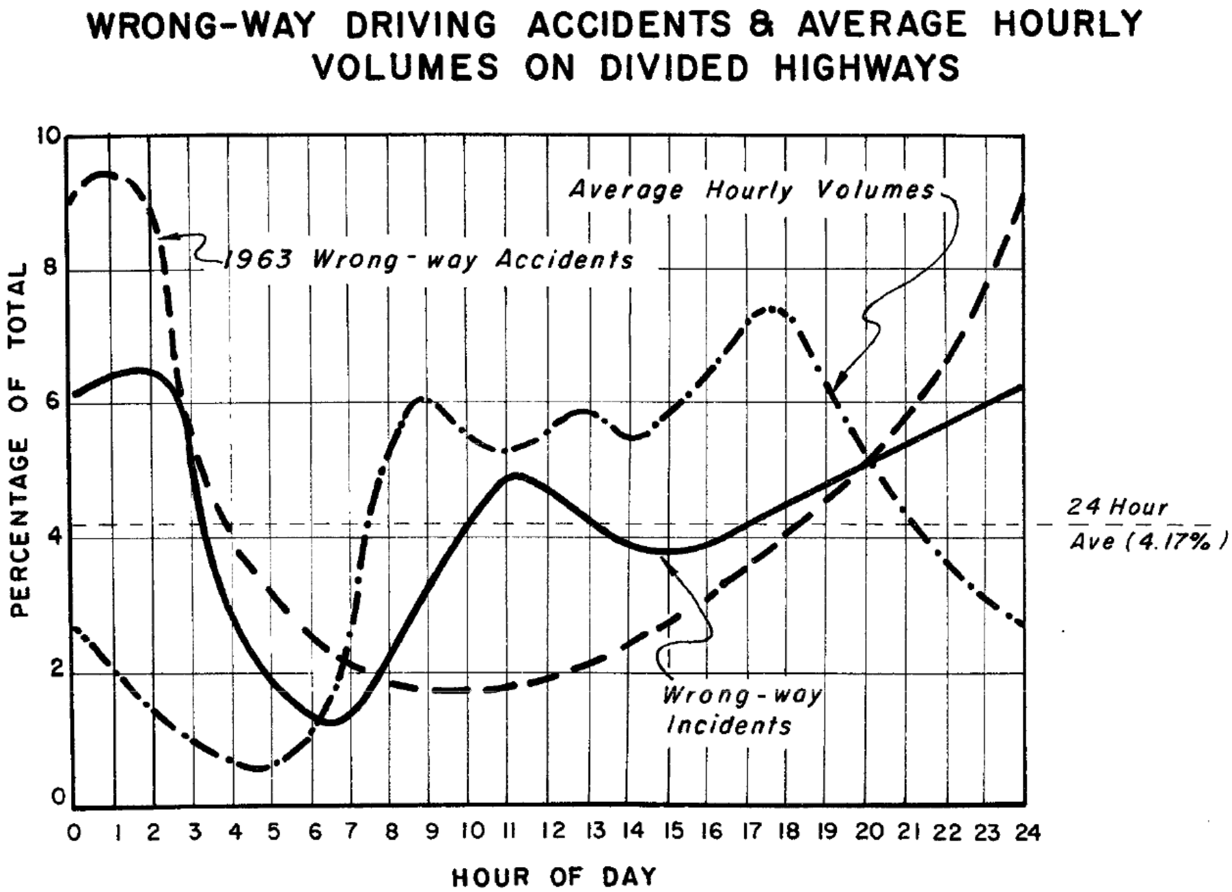

Figure 2. Wrong-way incidents compared to crashes and traffic patterns by time of day.

Visibility conditions have been linked to wrong-way incidents and crashes in several research reports. Although adverse weather conditions can affect visibility, there is no strong evidence that poor visibility due to weather conditions is a major factor in wrong-way driving incidents; most wrong way incidents and crashes, around 80%, occur in clear weather when road conditions are dry (e.g., Braam, 2006; Howard, 1980; Scifres & Loutzenheiser, 1975; Tamburri & Theobald, 1965; Zhou et al., 2014). Visibility distance on roads is related to the severity of wrong way crashes, with fatal and injury crashes more frequent when sight distances are less than 1200 feet. However, this is attributed to longer sight distances increasing the time other drivers have to notice a wrong-way driver and take corrective action (Rinde, 1978). More relevant to identifying interchanges with higher rates of wrong-way movements is the role of visibility in facilitating drivers' ability to "read" the structure of an interchange. For example, if drivers' view of the area surrounding a ramp is blocked by overgrown vegetation or reduced due to a steep grade, this may increase the likelihood of confusion-related wrong-way entries to ramps. In the absence of structural characteristics of the roadway and surrounding terrain that lead to reduced visibility, poor lighting can also contribute to wrong-way movements, both by making it difficult for drivers to infer the interchange's structure and making it more difficult to see signs and pavement markings (Copelan, 1989; Scifres & Loutzenheiser, 1975; Vaswani, 1975a).

The land-use setting in which interchanges are located also relates to the likelihood of wrong-way incidents and crashes. Not surprisingly, wrong-way crashes are more common in densely populated urban areas, as these areas have more traffic and more complex interchanges. Nighttime wrong-way incidents are more likely in these areas both due to the fact that more drivers travel in the area and also because heavy traffic prevents wrong-way entries during the daytime (Copelan, 1989; NTSB, 2013). However, this finding is not consistent across all studies. Scifres and Loutzenheiser (1975) found that wrong-way movements tended to originate from points with low land-use density and in places and times where there is low traffic volume. Similarly, Tamburri and Theobald (1965) found that rural counties tended to have higher than expected rates of wrong-way incidents given their population and vehicle miles traveled for that county (see Figure 3). The authors of both of these studies note that the frequency of wrong-way incidents in less population-dense areas could be elevated due to several factors. First, urban areas are more heavily patrolled by law enforcement, so wrong-way drivers are more likely to be intercepted before there is a collision. Second, while heavy traffic can make navigation more confusing, it also provides an additional cue to the correct direction and path of travel.

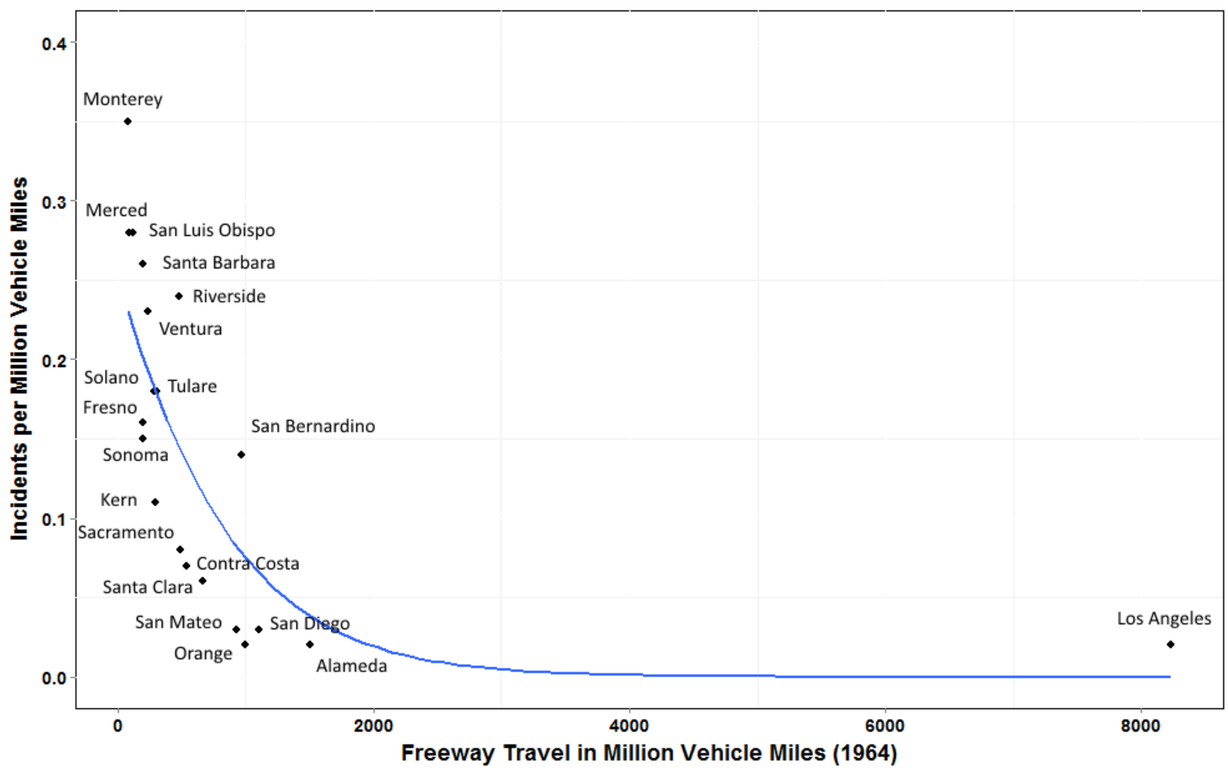

Figure 3. Incidents per million vehicle miles traveled from (Tamburri & Theobald, 1965).

Interchange type. About half of wrong-way entries to controlled-access interstate highways occur at interchanges, while the remaining half of wrong-way entries are accounted for by U-turns (in traffic lanes, from or to on- and off-ramps), or when drivers cross over the median on a divided highway (De Neit & Blokpoel, 2000; Howard, 1980; ITARDA, 2002; Morena & Leix, 2012; Tamburri & Theobald, 1965; Vaswani, 1977b, see Figure 4). A focus of research on wrong-way driving has been to identify interchange types and ramp characteristics associated with high rates of wrong-way movements. Because entry point often cannot be confidently determined from crash reports, much of this work comes from studies that installed motion-activated cameras at a subset of ramps.

There is wide consensus that full cloverleaf interchanges are not conducive to wrong-way movements and are consistently found to have the lowest wrong-way movement and entry rate (e.g., Lew, 1971; Copelan, 1989; Tamburri & Theobald, 1965; Zhou et al., 2012). The low rate of wrong-way entries at cloverleaf ramps is attributed to several design features. First, exit ramps meet the road at flat angles, which makes wrong-way movements difficult and therefore less likely. Second, entrances and exits are always on the right, which is consistent with driver expectations. However, compared to other types of interchanges, cloverleaf interchanges are uncommon, likely due to their higher space requirements, which increase as travel speeds increase because the separation between ramps must also be increased, and their higher cost compared to other interchange types (Garber & Fontaine, 1999).

Full diamond interchanges, which are the most common type in the United States, are generally considered to be a good interchange design as they do not tend to be confusing to motorists and do not experience a high rate of wrong-way movements (e.g., Copelan, 1989; Lew, 1971; Scifres & Loutzenheiser, 1975). Diamond interchanges are common due to their low cost and because they can be used both urban and rural areas (Garber & Fontaine, 1999). However, there are conditions that increase the rate of wrong-way movements at diamond interchanges, which have led to several studies finding high rates of wrong-way entry at full diamond interchanges (e.g., Copelan, 1989; Lew, 1971; Michigan Department of State Highways, 1968; Tamburri & Theobald, 1965; Scifres & Loutzenheiser, 1975; Zhou et al., 2012; Zhou et al., 2014). The presence of frontage roads near exit ramps, which meet the road at a perpendicular or nearly perpendicular angle, can lead to motorists inadvertently driving down an exit ramp because they believe it is the entrance to the frontage road; poor lighting of the surrounding area can increase the likelihood of such errors. Scifres and Loutzenheiser (1975) reviewed data from 96 wrong-way crashes and were able to determine a likely entry point for 57 of those crashes. They note that wrong-way entries on diamond interchanges, as well as on partial cloverleaf interchanges, tended to occur in areas with low traffic volumes, inadequate lighting, and light land use. Several subsequent studies have reported that problems with wrong-way entries at diamond interchanges can be avoided by ensuring that there is adequate lighting, signage, and pavement markings, but also note that additional channelization measures or geometric changes may be needed at especially problematic locations (Copelan, 1989; Scifres & Loutzenheiser, 1975).

There are several ways in which the basic diamond interchange may be modified. The most common of these is the half-diamond interchange; diamond interchanges may also be combined with other interchange types (e.g., diamond with partial cloverleaf;

see Bonneson et al., 2003). Parsonson and Marks (1979) found half-diamond interchanges to have a higher wrong-way entry rate (3.9 per month). They attribute this to the fact that half-diamonds are incomplete interchanges, which do not allow all directions of movement. This tempts drivers who may have missed their desired entrance ramp to intentionally enter the incorrect ramp to avoid having to drive a long way to the next interchange or waiting to make a safe U-turn further down the roadway. Rinde (1978) also identified half-diamond interchanges as having a higher rate of wrong-way entries (3.86 per month). In an examination of likely wrong-way entry points for a set of wrong-way crashes on Illinois freeways, Zhou et al. (2014) report that the compressed diamond interchange has a higher than expected likelihood of being a point of entry for a wrong-way driver.

Like the diamond interchange, the partial cloverleaf interchange is not typically problematic, as the majority of locations are not thought to have high rates of wrong-way entries, but several studies report higher frequencies of wrong-way movements at partial cloverleaf interchanges compared to other types (Lew, 1971; Howard, 1980; Parsonson & Marks, 1979; Rinde, 1978; Scifres & Loutzenheiser, 1975; Zhou et al., 2012; Zhou et al., 2014). Parsonson and Marks (1979) found the partial cloverleaf ramps to be the most problematic among the 44 ramps observed during the course of their study. One key contributing factor particular to partial cloverleaf ramps is that the entrance and exit ramps are close together, so it is easy for motorists to confuse the two ramps. Parsonson and Marks (1979) recommended that the entrance and exit ramps at these interchanges be widely separated so that signing can be used to eliminate the problems at those partial cloverleaf ramps. However, Campbell and Middlebrooks (1988) that doing this could reduce capacity at those ramps and lead to traffic problems. Further, the space requirements of such a change were also identified as problematic. Instead, Campbell and Middlebrooks (1988) recommend an alternative approach where the two ramps would be combined into a single paved surface and separated with a double-yellow line. Campbell and Middlebrooks (1988) first monitored two ramps that Parsonson and Marks (1979) identified as problematic both before and after this change was implemented. This substantially decreased wrong-way entries at one location, effectively resolving the wrong-way entry problem at that location, but had limited success at a second location.

Several studies have found high wrong-way entry rates at less-common interchange types. Left-side exit ramps have been found to be problematic because drivers may mistake them for entrance ramps, as drivers are more accustomed to exits being on the right side of the highway (Cooner et al., 2004; Copelan, 1989; Howard, 1980; Lew, 1971; Tamburri & Theobald, 1965). Lew (1971) reports, based on camera observations of 122 ramps in California, that left-side ramps had the highest 30-day wrong-way entry rate at 8.69 wrong way moves per month. Left-side ramps also tend to experience more traffic conflicts and crashes (Chen et al., 2011), and some authors have recommended that they be avoided in new construction (Cooner et al., 2004; Copelan, 1989). Trumpet interchanges, which are used when there are three intersecting legs (Garber & Fontaine, 1999) represent only a small proportion of interchanges but have been found to have a higher risk of wrong-way movements (Tamburri & Theobald, 1965).

One important caveat in discussions of the relationship between interchange type and wrong-way movements is that some interchange types are more common than others, and so these types are also over-represented in interchange and ramp monitoring studies. Diamond interchanges are the most common type in the United States, as these are inexpensive to construct relative to other interchange types and can be used in many different land use situations. A survey of traffic engineers across the country by Garber and Fontaine (1999) reports that about 68% of interchanges in the U.S. are diamond interchanges. Partial cloverleaf interchanges were the next most common at 16%, followed by the full cloverleaf, which was reported to account for 8% of interchanges nationally. Further, the types of road and land use areas (i.e. urban, rural, suburban) where each type of interchange is most common systematically vary. Although Garber and Fontaine's (1999) survey results found that diamond interchanges are the most common interchange type in both rural and urban areas, diamond interchanges were an even greater majority of rural interchanges compared to urban (86% vs. 68%). Differences in the conditions under which different interchange designs are favored are likely to also have an effect on the wrong-way movement rate.

Another caveat is that interchanges and ramps observed in camera monitoring studies is often not a random sample of ramps. Instead, because wrong-way movements are known to be uncommon, researchers focus either on ramps already known to have a problem with frequent wrong-way entries or which are suspected to have a problem given some feature of the ramp or surrounding area. Even among the ramps sampled in the limited set of studies available, many observed ramps did not experience any wrong-way movements during the observation period. For example, Lew (1971) notes that several of the interchange categories identified as problematic were strongly influenced by one or two ramps with very high wrong-way entry rates. While it certainly makes sense to focus on problem ramps when an issue is known to be uncommon and severe and research resources are limited, the fact remains that the subset of ramps observed represents a very limited sample of all interstate entrance and exit ramps in only a handful of areas (California, Atlanta, GA, Virginia). As such, it is unknown whether there are other ramps that have frequent wrong-way movements or whether the features of the selected ramps are the same or different from unmonitored ramps. Although it is very likely that the features of problem ramps do, in fact, generalize well to other entrance and exit ramps, one issue with biased sampling is that it is also possible that the results are primarily true of that sample and do not generalize well to the broader population. As will be evident in our discussion of some noteworthy cases from previous studies, many of the most problematic freeway ramps, those that had high rates of wrong-way movements and did not see a reduction in wrong-way movements even after several countermeasures were implemented (some even seeing an increase), were strongly influenced by idiosyncratic factors. Rinde (1978) reports at least some wrong-way activity on each ramp type observed and cautions that the only certain way to determine that a given ramp does not have a wrong-way entry problem is to monitor that ramp (p. 10).

Interchange type may also be influenced by other aspects of the surrounding area, and these factors may have a significant effect on wrong-way entry rates, and these may more strongly influence the rate than characteristics of the interchange design or may interact with interchange design features. For example, the presence or absence of frontage roads influences interchange design and has also been tied to wrong-way entry rates, as wrong-way drivers may confuse ramps for entrances to a frontage road, especially when the frontage road is located near the entrance ramp (Copelan, 1989; Bonneson et al., 2003; Rinde, 1978). Other factors may include proximity to tourist attractions and recreation areas (e.g., parks, stadiums, etc…), which draws more people who are likely to be unfamiliar with the area, or bars, a steep grade that blocks view, or high density of businesses in the area around the ramp, as the visual complexity of the landscape may make it harder to infer the overall structure of the interchange (Ho et al., 2001; Rinde, 1978; Scifres & Loutzenheiser, 1975; Vaswani, 1975b, 1977b). In studies that monitored wrong-way counts before and after countermeasures were implemented, those ramps where many changes still did not substantially reduce wrong-way movements.

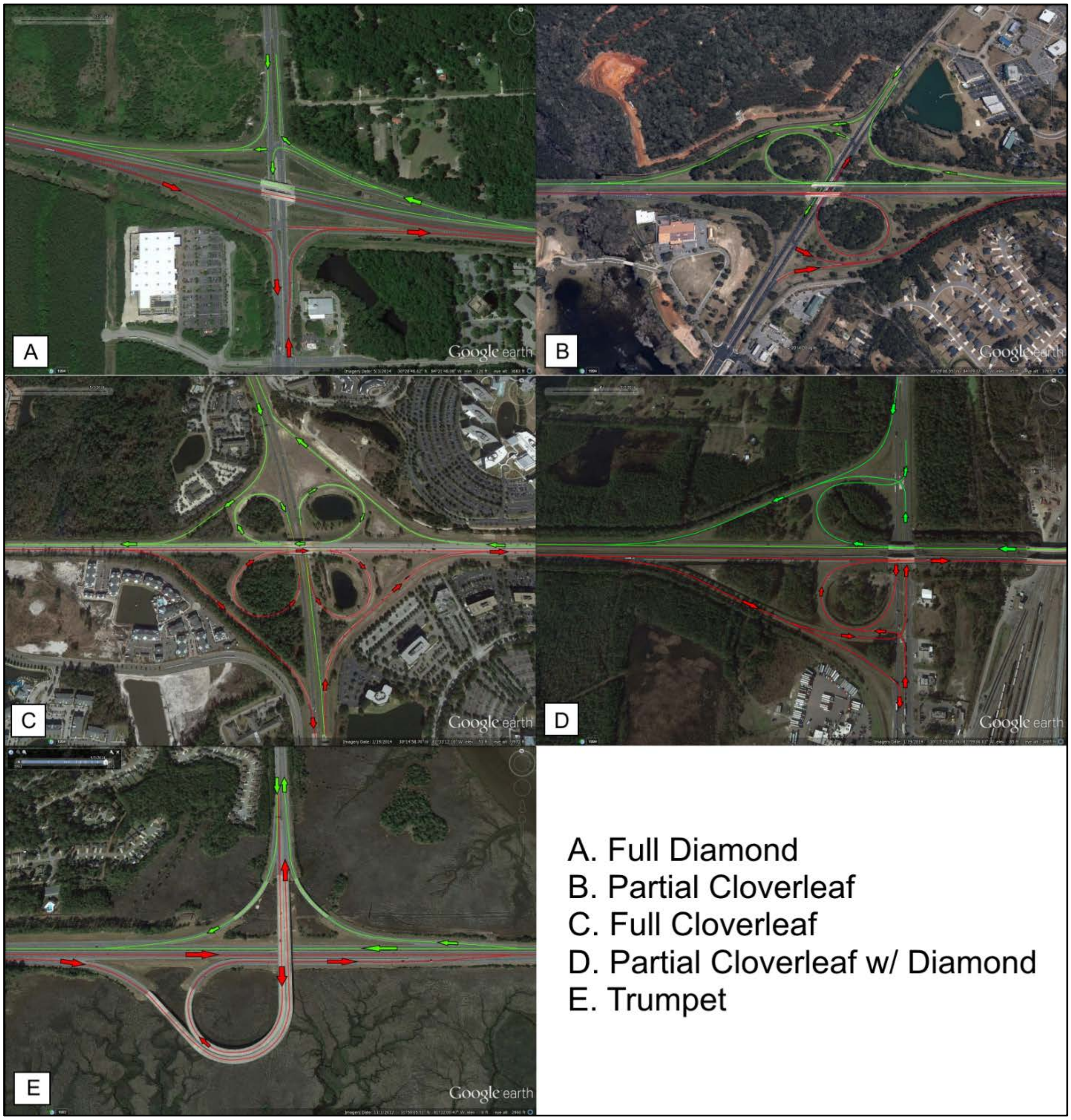

Figure 4. Examples of interchange types.

Cue-Based Decision Making

When faced with complex decisions in situations where time and information-seeking resources are limited, it is not feasible for decision makers to consider all relevant information and the consequences of every conceivable choice. Instead, people often base decisions on only a small subset of the information available. Cues can be defined as units of information that relate to some higher-order property of the environment. For example, arriving at a store in the middle of the day and finding the parking lot completely empty might be a cue suggesting that the store is not open. Much about the built environment is intended to create a cue environment that promotes quick and accurate navigation decisions: Signs are posted and lanes are marked. In the case of driving on public roads, drivers must demonstrate a minimum level of knowledge about relevant rules, signs, pavement markings, and signals before they may legally operate an automobile. Signs, pavement markings, and other traffic-control devices could all be considered cues. Without prior knowledge, there is nothing intrinsic to a painted yellow line that discloses its meaning as a lane delimiter that signals that there is two-way traffic on a given road. Instead, drivers have learned through training and experience that a double yellow lane marking is a consistent and reliable cue signaling this is the case.

Characteristics of cues. Cues in the environment can vary on several dimensions, which in turn affect the degree to which that cue influences decisions. One way in which cues differ is in their diagnostic value or validity, that is, the degree to which a given cue accurately predicts some feature in the environment, future outcome, or expected action. For example, if a green traffic signal is visible when approaching an intersection, this is typically a highly valid and diagnostic cue that it is safe to proceed through the intersection, as traffic on an adjacent cross street will be stopped. In contrast, although the intended meaning of a turn signal is well understood by drivers, it is a less valid cue than a traffic signal, as drivers may signal and then decide not to change lanes or change lanes without signaling. Cues may also vary in their salience, or how readily a cue is noticed. An “out of order” sign over the change slot on a drink machine is a highly salient cue that the drink machine is not working. However, while highly salient cues are often also highly valid, this need not be the case; the machine may have been repaired, but no one has yet removed the sign.

Prioritization of cues. In most decision environments there are multiple cues available, but decision makers typically do not consider all possible cues. Rather, because decision time and cognitive resources are limited, decision makers use a subset of cues. As a result, some cues will influence decisions more strongly than others. Which cues are given priority is determined by decision makers’ knowledge about cues’ likely validity, typically based on past experience, and the salience (ability to attract attention) of available cues. Cues that are known to be reliable and valid, as well as those that are highly salient, are more likely to influence decisions than those that are less reliable or require cognitive effort to use (e.g., require inference). For example, the intent of some types of highway signs is that they should have a stronger influence on behavior than other available cues, while others provide a cue that isn’t available in the absence of the sign (e.g., guide signs). The addition of wrong-way signs to freeway exit ramps has been shown to be a highly effective means of reducing the frequency of wrong-way movements on ramps (e.g., Rinde, 1978). The success of such interventions comes in part from the fact that most drivers have learned that such signs are highly valid and diagnostic cues that they should not enter the freeway at that point. In contrast, if a sign is poorly placed so that drivers cannot easily determine which of several possible locations to which a sign applies, this degrades the sign’s salience, as well as its perceived validity, decreasing the likelihood that drivers will heed the sign’s message.

Decision Maker Characteristics

The salience and diagnostic value of cues, or the ability to make use of multiple cues simultaneously, may differ between individual decision makers. If a person's cognitive and sensory capabilities differ from the norm, or are impaired for some reason, they may not be able to make effective use of a cue that is highly valid and diagnostic for other individuals. For example, the position of the illuminated face within a traffic signal may be a more salient cue than its color for someone with deficient color vision. Because cognitive and perceptual abilities are known to change with age, it is important to consider how these changes may affect both the salience and informational value of relevant cues. Similarly, alcohol and other substance impair one's ability to recognize and make use of cues. In this section we will provide an overview of the types of cognitive skills affected by healthy aging, dementia, and alcohol use and discuss how those changes affect drivers' decision-making ability.

Normative age-related changes. Healthy older adults can be expected to experience normative age-related declines in various cognitive and perceptual abilities, and these declines have the potential to alter the driver's detection and consideration of environmental cues (Boot et al., 2013). That is, the salience, validity, and/or informational conveyance of these cues can be altered or compromised when interacting with an older driver's cognitive and perceptual processes. These difficulties may contribute to the over-representation of older adults involved in wrong-way and other crashes.

<u>Optics</u>. The human eye undergoes various changes before and into older adulthood (Werner et al., 2000; Xu et al., 1997). Lens opacity increases, the cornea thickens, accommodation (focus adjustment at various distances) decreases, depth-perception decreases, and dark- and light-adaption is altered by changes in the magnitude and speed of pupil dilation. A valid cue indicating a wrong-way entrance can lose salience if nearby glare is amplified and extends over the cue's retinal position. In more suitable lighting conditions, the same cue may be salient but can lose its informational value if the driver cannot quickly and effectively focus on it. In perceiving signs and signals, older adults have demonstrated legibility distances at 80% of younger adults' capabilities (Dewar et al., 1997). This means that the information content of a cue may enter the decision process later for older drivers compared to younger drivers.

<u>Attention</u>. Older adults typically perform more poorly than younger adults on multiple measures of visual attention. For example, Useful field of view (UFOV), or the visual area around the point of eye fixation from which information can be extracted, undergoes reduction due to age (Owsley et al., 1991; Ball & Owsley, 1993), and is linked to poorer driving performance (Clay et al., 2005). In situations where a younger driver would not experience difficulty, a decrease in UFOV may delay or prevent information from being gleaned from cues that are too far from the older driver's fixation point. Visual search efficiency also declines with age, partly due to a decrease in older adults' "inhibition of return". That is, older adults have more difficulty preventing attention from returning to locations in the environment that have already been scanned

(Faust & Balota, 1997; Castel et al., 2003; Bédard et al., 2006). Older adults also exhibit greater difficulty than younger adults in preventing their attention from being captured by salient but irrelevant visual distraction (Colcombe et al., 2003). Therefore, less salient cues denoting a wrong-way entrance may be attended to slower by an older driver (or not at all) because his or her attention is captured by more salient but irrelevant cues, and, subsequently, he or she may have difficulty keeping his or her attention from returning to that cue multiple times. Again, changes in attentional control may delay information or prevent information from entering the decision process regarding whether or not an access point to the highway is the appropriate one.

Processing and response speed. Decline in speed of processing is a widely accepted effect of aging (Salthouse, 1996). Notably, basic perceptual, cognitive, and motor processing operations take older adults 1.7-2.0 times longer than younger adults (Jastrzembski & Charness, 2007). In addition to the above-mentioned difficulties, older adults must also contend with a general slowing of processing and response speed amidst an environment that is faster and more easily perceived and navigated by younger drivers. Slower detection and processing of cues may lead to premature decision-making (before all relevant cues have been processed and their meaning extracted) and erroneous actions at wrong-way entrances.

Long-term chronic disease. While increasing age influences perceptual and cognitive abilities, part of the increased risk of older drivers with respect to wrong-way crashes almost certainly can be accounted for by the fact that age is associated with a number of diseases that change abilities and increase crash risk. The probability of experiencing a chronic disease such as diabetes increases with age, and 90% of the population is likely to develop a chronic disease by the age of 65 (Machlin et al., 2008). Non-normative age-related cognitive impairment that includes a variety of forms of dementia are most relevant to wrong-way crashes. These and other disease processes tend to sharply increase the perceptual and cognitive declines observed in normal aging adults. In terms of driving, older adults with some form of cognitive impairment are 3 times more likely to be involved in an at-fault crash (Diller et al., 1999). Not surprisingly, older adults suffering from dementia tend to receive lower driving test scores compared to healthy older adults (Fitten et al., 1995; Hunt et al., 1993), and worse driving performance is associated with greater disease severity (Hunt et al., 1993). Driving performance also tends to decline at a faster rate among those suffering from dementia compared to healthy older adults (Duchek et al., 2003). A variety of perceptual and cognitive abilities are altered in individuals with dementia explaining this increased risk. Those suffering from dementia are also worse at wayfinding, which encompasses knowing where one is, where one desires to go, and how to get there (Passini et al., 1995). This confusion, on top of degraded perceptual and cognitive abilities, may make older adults with dementia especially susceptible to wrong-way crashes. However, individuals with dementia may be aided in wayfinding by clear textual message and unambiguous environmental cues (Blackman et al., 2007; Mitchell et al., 2003). Wrong-way countermeasures, if designed appropriately, may still reduce the risk of this vulnerable population.

Diabetes is another common long-term chronic disease that has been found to exacerbate the decline in cognition that accompanies normal aging. In a meta-analysis of the diabetes and cognition literature, Cukierman and colleagues (2005), found that diabetes tends to lead to worse performance on neuropsychological tests of attention, memory, and processing speed, and is associated with an increased risk of developing dementia. Another meta-analysis also found greater declines in executive functioning and memory in those suffering from type-2 diabetes (Stewart & Liolitsa, 1999). When it comes to driving, those suffering from type-1 diabetes are more likely to be involved in a crash and commit more moving violations than those suffering from type-2 diabetes and healthy control subjects (Cox et al., 2003). Interestingly, the same study found no differences in reported driving mishaps between those suffering from type-2 diabetes and healthy adults. Finally, when diabetics are suffering from hypoglycemia, their driving performance worsens even more (Cox et al., 1993). Cox and colleagues (1993) found that moderate hypoglycemia leads to greater swerving, time over the midline, time off the road, spinning, and compensatory slowing. This highlights the fact that it may not be age specifically that is associated with increased susceptibility to crash, including wrong-way crashes, but age-associated disease processes.

Alcohol impairment. It is well established that alcohol has an adverse effect on cognitive functioning, decision making, sensorimotor coordination, and can lead to riskier decisions (e.g., Fillmore et al., 2009; Fromme et al.,1997; Maylor et al., 1992; Mitchell, 1985). Driving performance suffers even for tasks that are relatively automatic for non-impaired drivers (e.g., lane control). In our cue-decision framework, alcohol impairment has a number of implications. First, reliable, valid, and salient cues indicating that a driver is making an incorrect movement onto a highway may not enter into the decision process at all, or too late to avoid a wrong-way entry or crash. Second, changes in decision processes and risk tolerance may make it more likely that an impaired driver will intentionally proceed with a wrong-way entry or continue a wrong-way highway movement. Third, if cues indicating a wrong-way entry are attended and understood, sensorimotor and response time impairment may make it more difficult for an impaired driver to correct this error and avoid a crash. Next, we turn to specific sensorimotor, perceptual, and cognitive impairments that likely play an important role in increasing susceptibility of wrong-way crashes for impaired drivers.

In many ways, the impairments observed as a result of alcohol intoxication may resemble age-related perceptual and cognitive declines. Similar to the effect of age, alcohol impairment results in a restriction of the Useful Field of View (Dry et al., 2012). Visual acuity and glare recovery for the impaired driver, similar to the older driver, are also negatively affected (Moskowitz et al., 1993). Changes in scanning pattern are evident with intoxication as well, with alcohol discouraging peripheral scanning, resulting in a tunnel-vision pattern of information extraction (Moskowitz et al., 1976). These changes and the visual distortion and blur associated with high levels of intoxication (as are often observed in wrong-way drivers) will decrease legibility distances of signs, signals, and pavement markings. Empirical evidence suggests that alcohol intoxication makes individuals more susceptible to the phenomenon of inattentional blindness (Clifasefi, Takarangi, & Bergman, 2006); highly salient, seemingly obvious visual events are more likely to go unnoticed under conditions of impairment (a pattern similar to increased inattentional blindness with increasing age). This suggests that in some cases, wrong-way countermeasures may be fully within an intoxicated driver's view, or even at the center of vision, yet this information may still not reach awareness. The profound effect of alcohol impairment on visual and attentional functioning likely limits (or delays) the cues entering into the decision process of the impaired driver, increasing wrong-way crash risk.

Within our framework, the risks associated with alcohol impairment extend beyond the failure to notice and extract important environmental cues. After cues have been noticed and their meaning extracted, alcohol impairs how extracted information is processed and how multiple sources of information derived from cues are integrated and responded to. In terms of decision making and response selection, alcohol interferes with the ability to execute planned actions by impairing the inhibition of automatic responses and biasing riskier choices (e.g., Lane, Cherek, Pietras, & Tcheremissine, 2004; Mulvihill, Skilling, & Vogel-Sprott, 1997). Alcohol can also impair working memory processes critical for the maintenance and integration of information derived from environmental cues (e.g., Saults et al., 2007), with this integration process being critical to the formation of an appropriate response. Finally, it is well known that alcohol can impair steering and braking response speed (e.g., Allen et al., 1975; Crancer et al., 1969). Consider two drivers, one intoxicated and one not intoxicated, erroneously entering a highway exit ramp and realizing on the ramp or freeway their error. The non-impaired driver will better be able to maneuver their vehicle as to avoid a crash with an oncoming vehicle and correct the direction of their vehicle. In addition to being more likely to make an incorrect decision to commit a wrong-way entry, impairment to the ability to recognize, correct, and maneuver out of this situation also puts the impaired driver at greater risk.

In sum, there are likely multiple effects of alcohol that contribute to a cascade of failures that explain the over-involvement of impaired drivers in wrong-way crashes. Some of these effects resemble those induced by aging, though for alcohol impairment these effects may be much more severe (except in cases of dementia). This suggests that similar countermeasures may be effective in addressing wrong-way crashes in both of these populations. However, it is also important to note that the context of wrong-way crashes is different for alcohol impaired and older drivers, with most alcohol impaired wrong-way crashes occurring at night and older driver wrong-way crashes occurring during the day. Given these different contexts, it may not always be safe to assume that the same countermeasures effective for alcohol impaired drivers will be effective for older drivers and drivers with dementia. It should be noted that here we focused on alcohol impairment since alcohol is the drug most associated with wrong-way crashes, but impairment by other illicit substances are likely to have similar effects of increasing wrong-way crash risk, and risk is likely exacerbated when more than one substance is involved.

Cue-Based Decision Making as a Factor in Wrong-Way Driving

In many cases, suboptimal decisions can be traced to misleading or ambiguous cues and in others it may be that decision makers did not appropriately interpret available cues. We can think about a non-driving incident as providing a salient example of this. A major contributing factor in the 1979 incident at Three Mile Island, where radioactive gasses were released into the environment, was the presence of a misleading cue: A light though to reflect the state of a valve actually reflected the state of the solenoid controlling the valve. That is, the light was a salient cue that operators typically relied upon because it was known to be valid, but the interface provided no immediate feedback when the validity of that cue was compromised. Most wrong-way movements on ramps and entries to freeways, with the exception of the small proportion cases where wrong-way driving was intentional, can be linked to one or several contributing factors. Work conducted in California, Georgia, and Virginia from the 1960s to 1980s used camera monitoring equipment to identify interchanges with high rates of wrong-way movements and also assess the effectiveness of countermeasures designed to prevent wrong-way entries. Those studies identified a set of common features of problematic interchanges, such as having entrance and exit roads located close together, inadequate signs and pavement markings, confusing or misleading road geometry, and poor visibility. Many of the countermeasures implemented in those studies successfully resolved the wrong-way movement problems at the studied interchanges. The most extensive of these, reported on by Rinde (1978), observed a total of 3,954 interchanges, about two-thirds of the interchanges in California at that time. Out of that sample, there were 257 interchanges identified as problematic (five or more wrong-way movements per month). Countermeasures implemented during the course of the study reduced the wrong-way movement rate for 91% of these problematic interchanges to 2 or fewer per month. In some cases, the wrong-way entry problem was solved by a single change, while at other interchanges the wrong-way movement rate was unchanged or sometimes increased, even after multiple changes that had been successful at other locations.

In this section, we discuss the types of cue environments associated with high and low rates of wrong-way movements on ramps, providing examples from cases presented in past work. In this context, we describe how successful countermeasures reduce the rate of wrong-way entry at a given ramp by changing the structure of cues, such as providing new cues or improving the salience of existing cues. We also present cases from those studies where typically successful countermeasures were not sufficient to resolve a wrong-way entry problem. These cases are interesting because they often have unique, idiosyncratic features that contribute to the problem, and this suggests that something about the cues associated with those features is very likely to invite wrong-way movements at those locations. Finally, we make predictions based on past research about how wrong-way countermeasures could interact with driver characteristics, such as dementia, alcohol impairment, or distraction, to increase the risk of wrong-way movements.

Informative cues are absent. In some cases, an interchange lacks cues that would help motorists more quickly and accurately identify the correct entrance ramp. In the case of diamond and partial cloverleaf interchanges, entrance and exit ramps at some points meet the adjoining roadway at perpendicular (or near perpendicular) angles, and it may not be immediately evident which points are entrance and exit ramps. Several countermeasures have been developed that provide cues allowing drivers to more easily distinguish between entrance and exit ramps. One highly successful countermeasure tested in early studies (e.g., Vaswani, 1977b) is the addition of a stop bar at the terminal point of exit ramps, providing a clear cue that traffic can be expected to approach from the opposite direction. Similarly, painting the left and right road edge lines different colors provides an additional visual cue. Because drivers are accustomed to center lines being painted yellow when there is two-way traffic, seeing a yellow edge line on one's left is a cue signaling that one is traveling in the correct direction (Figure 5). Another currently-in-use countermeasure that provides an additional cue is the use of red-backed reflectors on center lines, as the reflectors would be clearly visible to wrong-way drivers but only visible in the rearview mirror of drivers traveling in the correct direction (Cooner et al., 2004).

Figure 5. A stop bar painted at the terminal of the entrance ramp provides a cue that cars are likely to be approaching from the opposite direction.

The current standard is to include regulatory signs, such as Do Not Enter and Wrong Way at the terminal point of exit ramps. These signs provide a clear cue that not only alerts drivers who have mistakenly entered the ramp, but when clearly visible from the roadway also serve as a cue that prevents drivers from ever mistakenly entering the ramp. For this reason, it is beneficial for such signs to be present both close to the ramp terminal and also further down the ramp. When the use of these sign combinations were not standard practice, adding them at a problematic location was often sufficient to eliminate or substantially reduce wrong-way movements at a location (Parsonson & Marks, 1979; Rinde, 1978).

Another important cue that is sometimes absent and can lead to wrong-way driving is the lack of guide signs or existing signs not being sufficiently informative. This issue was linked to wrong-way movement problems in several cases, especially at interchanges located near a tourist attraction or other point of interest (e.g., Scifres & Loutzenheiser, 1975; Parsonson & Marks, 1979; Campbell & Middlebrooks, 1988). In these cases, wrong-way movements and entries occurred because motorists had either missed their exit or had become lost searching for the freeway entrance. Either out of confusion or frustration, motorists attempted to access the freeway through an exit ramp. Rinde (1978) describes such a case where a split diamond interchange located near a rural recreation area had 12 wrong-way movements recorded during an observation period of 47 days. This problem was resolved by adding “Freeway” signs, an I-5 sign with an arrow, and pavement arrows guiding motorists back onto the highway. Once these changes were made, no wrong-way moves were recorded during the 30-day post-change observation period.

Advance cues, those that signal some future event or state, have been shown to lead to faster decision speed and more accurate choices in laboratory experiments. On roadways, trailblazer signs and advance guide signs give drivers additional time to make driving decisions, such as whether to look for the freeway entrance ramp on the left or right side or to signal that the entrance ramp will be located some distance ahead. Because all drivers, not just older or impaired drivers, can process only a limited amount of information per unit time, advance and trailblazer signage that provide route information can help reduce driver confusion and prevent wrong-way movements on freeway ramps (Copelan, 1989; FHWA, 2014).

In the absence of other information, it is common to refer to the behavior of other drivers to infer the correct direction of movement on a given roadway or to detect the presence of a crossroad ahead. However, although wrong-way crashes and incidents are known to be more common in urban than in rural areas (e.g., NTSB, 2013), Scifres and Loutzenheiser (1975) reported a higher rate of wrong-way entries at diamond and partial cloverleaf interchanges in less densely-populated rural areas. In the absence other traffic, drivers rely more on other sources of information, such as signs and pavement markings, so it may be especially important for these to be reflective or well-lit at rural interchanges.

While helpful for non-impaired drivers, several of the countermeasures described above may be of less value to impaired drivers. Impairment due to alcohol use or dementia compromises the ability to quickly retrieve relevant information and apply it to the current situation. Yellow edge lines, stop bars, and red-backed pavement reflectors require some amount of inference to understand: One has to notice the markings and recall relevant knowledge of what these markings signal about the correct direction of travel. There is the additional concern that, while motorists could state the meaning of these markings if asked, this is not a frequently-accessed piece of information, or drivers may not be aware of the meaning of these at all. One study by Case (1971) found that six out of seven surveyed were not aware that center line reflectors are typically white. However, because red-backed reflectors are in more common use now (Cooner et al., 2004), it is possible that more drivers would be aware of their meaning. Also, even if drivers are not aware of the meaning of any of these markings, their presence, especially if they are brightly reflective and attention-grabbing, may be enough to signal to a driver that something is “not quite right”.

Cue salience. A common problem noted at interchanges with a high rate of wrong-way movements is that cues were present but insufficiently salient. Examples of this include worn or dirty signs that no longer meet retroreflectivity standards, worn pavement markings that are no longer clearly visible, signs that are too small to be clearly visible, or poorly illuminated interchange areas. Rinde (1978) describes the eastbound off-ramp from California SR-90 to Culver Boulevard in Los Angeles, which had an initial wrong-way move rate of 50 per month. This problem was resolved (0 wrong-way moves detected in post-change observation period) by relocating Wrong Way and Do Not Enter signs, which were already present at that location, closer to the intersection and also by lowering the one-way arrows.

There are a number of wrong-way driving countermeasures that have the goal of increasing the salience of cues. These include lowering signs, adding retroreflective tape to sign posts, and using larger signs. More recently, with the development of low cost LED lighting with low energy requirements, it is possible to create signs that illuminate only when a wrong-way driver is present. These signs have the benefit of being highly salient. An additional benefit of such signs is that their ability to capture attention is enhanced because they are not always illuminated. When drivers become familiar with an area, they may habituate to static signs but selectively illuminated signs will still be eye-catching.

Including Wrong Way, Do Not Enter, and One Way signs at the terminal point of exit ramps is common practice, and these signs also provide a cue to drivers that allows them to quickly and easily distinguish between entrance and exit ramps. Several effective countermeasures aim to increase the conspicuity of these signs, such as lowering the mounting height, which makes it more likely headlights will brightly illuminate the signs. While effective, there are some potential drawbacks to this practice (Copelan, 1989, p. 56). Especially in rural areas, a lower sign mounting height means that there is greater risk that signs can be hidden by vegetation around the ramp if it becomes overgrown. Additionally, lower signs could become worn more quickly, as they may be more likely to be struck by road debris from passing vehicles.

Increasing cue salience may be especially important to preventing wrong-way driving by impaired motorists. A more recently-developed countermeasure that could be effective even for impaired drivers are illuminated wrong-way signs, particularly those that are only illuminated when a wrong-way driver is detected. Not only are these signs less dependent on external sources of illumination from cars' headlights (as some impaired drivers may be driving without turning on headlights), their activation is highly likely to draw attention. Interventions that change the salience of one cue relative to another may also be effective in reducing wrong-way entries by impaired drivers. Vaswani (1973) recommends increasing the conspicuity of entrance ramps relative to exit ramps as a way of effectively drawing attention to the correct ramp and away from the incorrect one. Increasing sign conspicuity through the use of larger signs may be especially helpful to older drivers (Copelan, 1989; FHWA, 2014; Friebele et al., 1971).

Cue validity. Cue validity, the extent to which a cue is consistently predictive of some state or outcome is also a likely contributing factor in wrong-way entries at interstate ramps. Ideally, the geometric design of roads afford the correct driver behavior. Part of the very low rate of wrong-way entries at full cloverleaf interchanges may be attributable to the presence of a very valid geometric cue, both entrance and exit ramps meet the road at very flat angles. This means that the action that is easiest for drivers to take also tends to be the correct one. However, there are many instances in which road geometry functions as an invalid cue that encourages incorrect movements, as one cue drivers likely use is whether or not a maneuver is possible: If it possible to turn in a given direction, then that remains as a potential choice. If it is easy to turn down a given ramp, then it is more likely that ramp will be chosen in error. Several successful countermeasures operate by channelizing traffic, encouraging movement in one direction, or make other movements difficult, discouraging drivers from those choices. For example, Vaswani (1974; 1977) recommended eliminating pavement edge flares around exit ramps, as these wider openings make right turns down the ramp easier and so encourage that choice. That is, the wider opening serves as a misleading cue. Current guidelines recommend other countermeasures that have the effect of narrowing the ramp throat as a way of discouraging wrong-way entries (e.g., Cooner et al., 2004; Zhou & Rouholamin, 2014), and ramp monitoring studies where these changes were implemented have shown these changes to be effective in reducing wrong-way driving (Rinde, 1978; Parsonson & Marks, 1979).

Two cases from Rinde (1978) illustrate other types of cue validity issues that, once resolved, resolved wrong-way entry problems at those locations. The first is an interchange near Bakersfield, California that initially had a rate of 15 wrong-way movements per month. Rinde speculates that at least some of the wrong-way moves on that ramp were intentional, as there was an off- but no northbound on-ramp at that location, but part of the problem at that ramp was traced to a confusing guide sign. Although the exit was some distance from Bakersfield, the sign led motorists to mistake the northbound off-ramp for the exit for Bakersfield. After all references to Bakersfield were removed from the sign, no further wrong-way moves were recorded at that location. In the second, the wrong-way movement problem at a partial cloverleaf interchange at Airway Boulevard and I-580 was resolved by changing the lighting at that location. At this location, the exit ramp was brightly illuminated but the entrance ramp was not lit and was nearly invisible from a distance. After changing the lighting so that the entrance ramp was brightly lit, wrong-way movements were reduced from 4 to less than 1 wrong-way movement per month (see also Vaswani, 1973). In this instance, the greater illumination of the exit ramp relative to the entrance ramp seemed to serve as an invalid cue that the more brightly illuminated area is the correct entrance ramp (see Figure 6).

Figure 6. Recent image of the westbound off-ramp of the partial cloverleaf interchange at Airway Boulevard and I-580, near Livermore, CA. Nighttime wrong-way entrances were greatly reduced after lighting changes that increased the visibility of the on-ramp (Rinde, 1978).

The perceived validity of signs as a cue is reduced when drivers cannot determine which road point at a junction to which the sign applies. This can be the case if the sign post is too far to one side or the other or is oriented in such a way that it is visible to drivers to whom the sign is not relevant. In Figure 7, the “Do Not Enter” sign is located some distance to the side of the ramp, where it may not be noticed or a driver may not judge that it applies to that ramp. In this instance, a confused driver would need to travel some distance before encountering the additional wrong-way signs located further down the ramp.

Figure 7. Entrance and exit ramps at a partial cloverleaf interchange, exit 343 on I-10. The Do Not Enter sign is located some distance from the exit ramp and may not be illuminated by drivers' headlights.

Cue validity can also be compromised in situations where there are multiple cues that seem to be in conflict. Zhou and Rouholamin (2014) recommend that sites be inspected to ensure that pavement markings and signs convey consistently, reinforcing the same message (e.g., remain in right lane). The highest wrong-way count of any of the ramps studied by Campbell and Middlebrooks (1988) was located at the interchange (partial cloverleaf) of I-75 and Aviation Boulevard, near Hartsfield-Jackson Airport in Atlanta. The left panel of Figure 8 shows the original signs at that location, which were located at the diverge point for the two ramps. These signs were judged to be confusing because both southbound I-75 and eastbound I-285 were accessed by the same ramp (see Figure 9). When the signs were changed so that two right pointing arrows were used, the wrong-way count at the ramp increased from 55.6 to 65.9 per month. When temporary pavement arrows were placed on both ramps, the wrong-way entry count decreased to 34.1 per month. Campbell and Middlebrooks also recommended that the signs be relocated from the diverge point of the two ramps, which did not allow sufficient decision time for motorists, to further up the ramp and on the right side. At the time of the report, the signs had not been revised or relocated. Figure 9 shows the interchange as it appeared in March of 2013; the signs have been changed so that both have an angled, right-facing arrow, and the sign is now on the right side of the roadway.

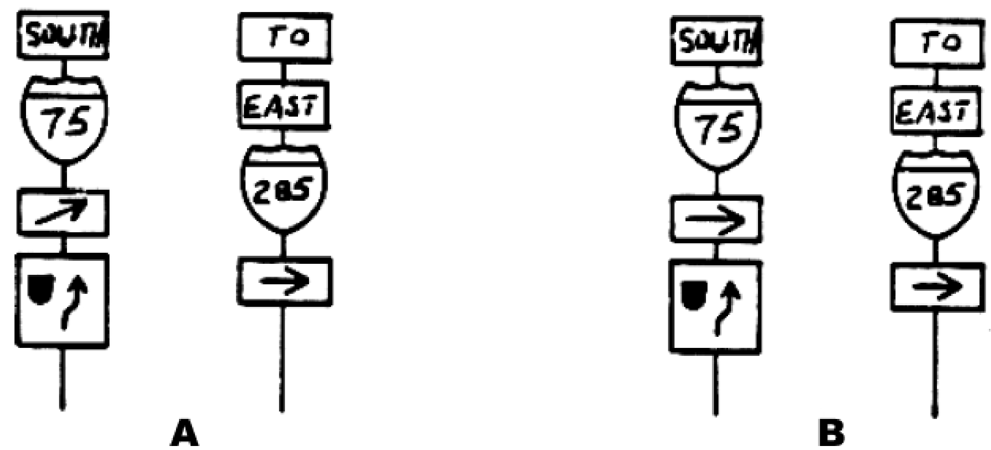

Figure 8. A minor sign change at the interchange (from A to B) at I-75 and Aviation Avenue led to an increased wrong-way count. Pavement markings reduced the wrong-way rate but did not eliminate the problem (Campbell & Middlebrooks, 1988).

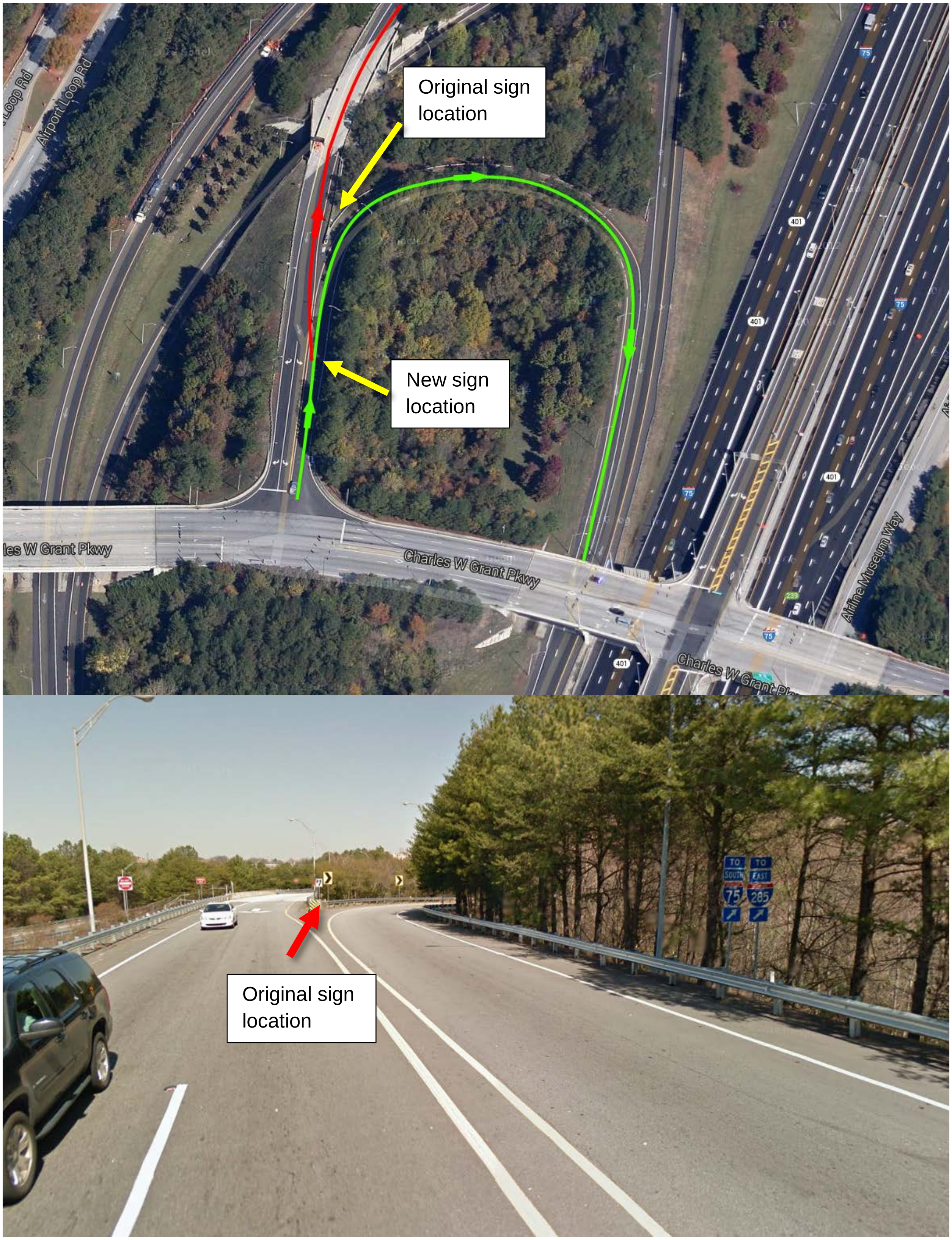

Figure 9. The interchange at I-75 and Aviation, March 2013. The signs have been relocated, as recommended by Campbell and Middlebrooks (1988), and different arrows are used.

Cue reliability. Drivers are more likely to utilize cues appropriately when they are consistent. Several authors mention the importance of consistent application of signage and pavement markings at interchanges. In camera monitoring studies, interchange designs that were uncommon or had some feature that violated driver expectations were also those most likely to experience high rates of wrong-way. Left-side exit ramps are an example of this: Most freeway ramps are located on the right side of the roadway, and drivers are accustomed to this practice. That is, ramp location is a strong cue to drivers, and there is likely a cost associated with violating this expectation. Consistent with this, left-hand ramps have been found in several studies to have high wrong-way movement rates relative to other interchange types (Lew, 1971; Copelan, 1989), and current guidelines recommend against constructing left-side ramps (e.g., Cooner et al., 2004; Zhou & Rouholamin, 2014). Similarly, other less common ramp types have also been identified as problematic in some studies, such as the buttonhook, j-shaped, and trumpet interchanges, and current guidelines recommend against the construction of new ramps of these types (Zhou & Rouholamin, 2014).

Consistent application of standards is also likely to benefit older and impaired drivers. When cognitive resources are limited, people tend to default to habitual behavior. If a cue in the environment is known to have a consistent meaning, then even impaired drivers are likely to respond to them appropriately. Since the early days of interstate highways, a standardized sign set has been adopted across the nation, which likely increases the effectiveness of such signs relative to earlier, non-standardized signing (e.g., Figure 10). Placing signs in consistent locations may also be beneficial, particularly for older drivers, as drivers' expectancies also affect how quickly they can locate and respond to a given sign or signal. For example, it is common for traffic signals to be located above the roadway. However, in some urban areas traffic signals are located on posts placed on one side of the roadway. A driver unfamiliar with this convention may also fail to notice a traffic signal. A study by Borowsky et al., (2008) examined the effect of sign placement on how accurately drivers could detect the presence or absence of a No Right Turn sign. Participants were shown road scenes where a No Right Turn sign on a computer monitor and made a verbal response to indicate whether or not a No Right Turn sign was present in the image. Participants' eye movements were also recorded during the study so that scanning patterns could be examined. Participants were more likely to correctly detect and identify the No Right Turn when it was in the expected location, on the right side of the roadway, than when it was placed on the left side. Because older adults tend to use simpler, less exhaustive visual search strategies (e.g., Bao & Boyle, 2009), placing signs and markings in predictable locations is especially important for older drivers.

Figure 10. The use of standardized signs aids comprehension.

Cue utilization. Some cues are more likely to influence decision outcomes than others. The strength of a given cue comes from a combination of factors. First, the cognitive "cost" of making use of a cue is influential; cues that are less costly to obtain and use often have more influence than those that are more difficult and costly to use. For example, although reliable and valid, making use of the cue that the edge line on an entrance ramp should be on the left side is has a high cognitive cost compared to other cues, such as Wrong Way signs, as it requires both retrieval of information from long-term memory and for the driver to apply that information to the current situation. As discussed earlier, cue salience is an important factor in ensuring drivers will make use of available cues; the more perceptually salient a cue, the less the cognitive cost associated with accessing that cue. For example, brightly lit signs in a dark area have low visual search demands, while brightly lit signs in a busy urban area are more difficult to pick out from the background. The influence of a given cue can also be affected by a decision maker's past experience with that cue. Reliable and valid cues, those that are consistently strongly correlated with some outcome or state in the environment, are also more likely to be strong cues.

However, even when the cue environment is optimal for most drivers, there may be characteristics of individual drivers that influence their ability to make use of available cues or to utilize them appropriately. Due to reduced cognitive resources, older and impaired drivers are more likely to make decisions based on fewer cues and to rely more on the strongest cues in the environment (e.g., Mata et al., 2007; Mata et al., 2012). It may also be more costly for older adults to make use of some cues, as memory retrieval tends to slow with age, older adults require longer to locate and comprehend road signs, and in especially complex visual environments, older adults search speed and efficiency is reduced to a greater extent than younger adults'.

Providing redundant cues is likely to be especially helpful for older drivers and is also likely to benefit all drivers. If multiple cues are present that convey the same information, this increases the probability that drivers will perceive and heed the intended message. For example, Wrong Way signs are often provided on both sides of an entrance ramp, rather than on just one side or the other. Poor memory is also a barrier to cue utilization, as in the case of advance guide signs. Although advance guide signs allow for more decision time so that drivers and move to the correct lane to make their exit, older road users may not be able to recall route information, even after a very brief delay (e.g., Johnson et al., 2002), or may be less confident of recalled information (e.g., Hertzog & Touron, 2011). In addition to making more driving errors in general (Anstey & Wood, 2011), older adults are even more likely to make safety-critical errors when driving in an unfamiliar area or otherwise under heavy cognitive demands (Read et al., 2011). Having additional guide signs available closer to the decision point are likely to increase driver confidence and reduce the likelihood of driving errors.

Especially relevant to the case of older adult wrong-way drivers is the need for countermeasures to provide some scaffolding guiding the correct action after they are made aware of the error. Older adults who have dementia, especially in high-stress situations, may become "trapped" in an action pattern because they cannot construct a series of steps to correct the problem. Two proposed countermeasures that provide some degree of decision support for wrong-way drivers are Goodman's "ears" (Goodman, 1969; Brevoord, 1984; see Figure 11) and the wrong-way derailer (Rinde, 1978; see Figure 12). Goodman's "ears" provide a clear place where the wrong-way driver can turn around safely and return to the roadway. The wrong-way driver is guided into the sand or dirt-filled area by reflectors that should only be visible to wrong-way drivers. Goodman (1969) points out that this approach is beneficial because it minimizes reliance on signs and signals, which is useful in the case of intoxicated wrong-way drivers. Similarly, the wrong-way derailer described by Rinde (1978) uses red-backed reflectors, which would only be clearly visible to a wrong-way driver, to guide the driver off of the road and into the median barrier. Most head-on wrong-way crashes on interstates occur in the left-most lane, as confused or impaired drivers likely believed this was the rightmost "slow" lane. An intervention like the wrong-way derailer could be effective both in capturing attention of a wrong-way driver and efficiently providing them a safe alternative course of action. Rinde (1978) reports this intervention was only tried at ramps, where travel speeds are known to be slower, due to liability concerns if the countermeasure led to injury to the wrong-way driver or other drivers.

Goodman's Ears

Goodman proposes that diamond interchanges should include 'ear roadways' which automatically lead the wrong-way driver back on to the exit road (Figure 32a). Examples of other application of the ear roadway can be seen in Figure 32b. This measure appears to have been rarely used or evaluate. Elsewhere a 'sand pit' is proposed to bring the wrong way driver to a halt (Figure 33).

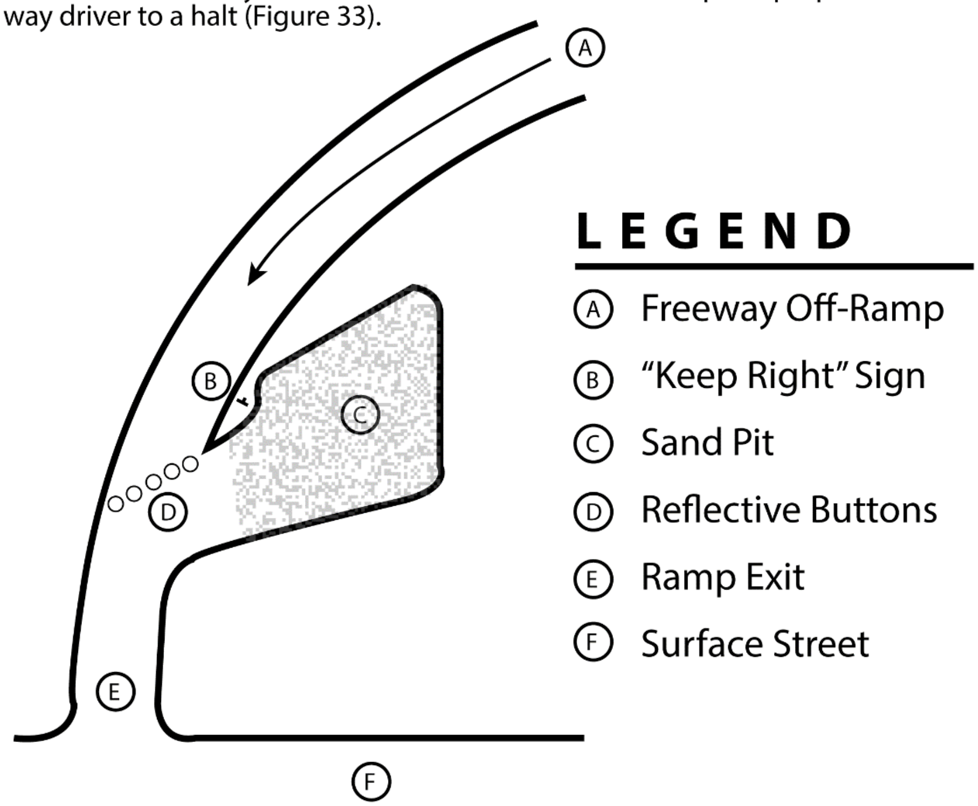

Figure 33. Example showing how the wrong-way driver is guided into a 'sand pit'

Figure 11. This proposed countermeasure includes retroreflective buttons guiding the wrong-way driver to an area where they can safely turn around. The original figure from Brevoord (1984) was enhanced in Adobe Illustrator CC for additional clarity on the labels and captions.

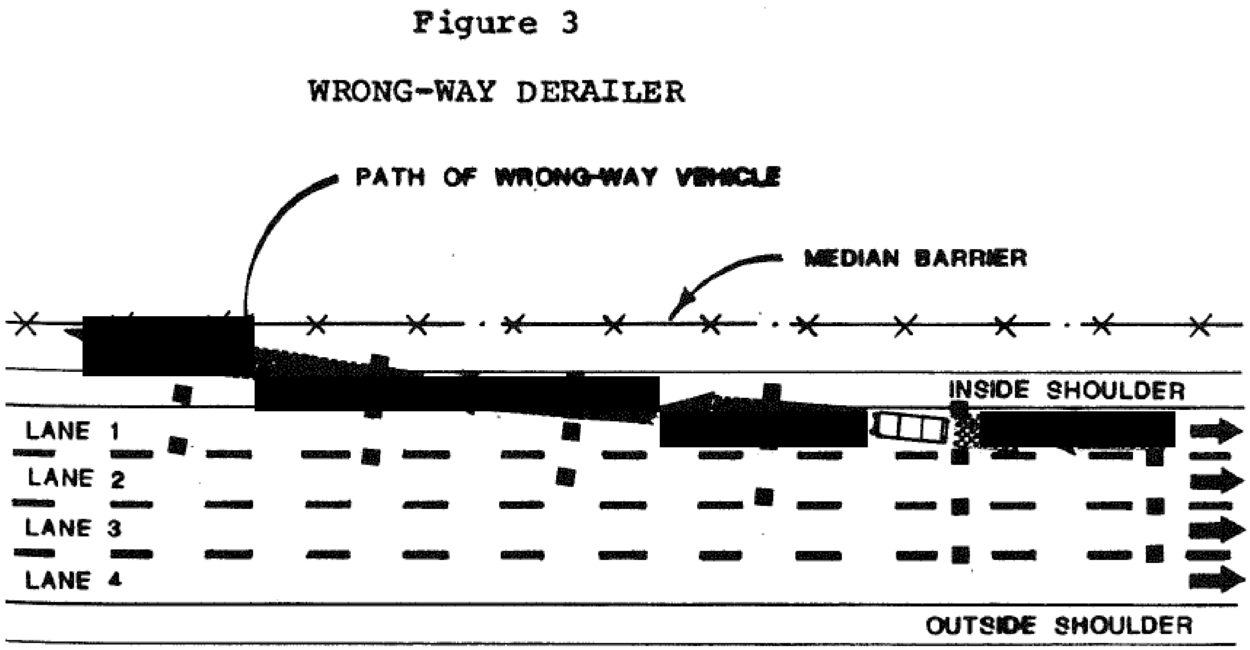

Figure 12. Diagram of wrong-way derailer described in Rinde (1978). Figure reproduced from Rinde (1978), page 31.

Multimodal cues could be another way to increase the likelihood that impaired drivers will notice and heed warnings. Tamburri and Theobald (1965) report that a warning sign that also included lights and a loud alarm reduced the frequency of wrong-way entries at one ramp in the Sacramento area by 54%, with 89% of drivers who activated the sign taking corrective action. However, this countermeasure, though effective, was not found to be a practical option: The noise from the sign drew complaint from residents in the surrounding area, as false activations triggered by drivers making illegal U-turns (intentional wrong-way drivers who weren't at risk of entering the freeway in the wrong direction) were frequent.

A more subtle example of multimodal cues would be internally illuminated or LED-bordered signs (e.g., Cooner et al., 2004) in combination with rumble strips that are minimally noticeable to right-way drivers but are noisy if driven over in the opposite direction (e.g., Rinde, 1978, p. 33). In this example, a highly salient sign combined with a tactile cue, rumble strips, could provide a strong enough message to reach even an impaired driver but would be less likely to be disruptive to residential areas near a ramp.

Analysis of Archival Data

In this section, we present a statistical analysis of archival data compiled from studies that monitored the number of wrong-way movements on highway entrance and exit ramps. Our goal was to determine whether data from these studies provide information about which classes of cues and problems with the cue environment might have the strongest effect on wrong-way movement rates on ramps. For example, if the geometric design of ramps is a stronger cue than signage, then we would expect for countermeasures that change road geometry to have a stronger effect on wrong-way movement rates than sign revisions. For this analysis, we created a data file based on information (typically notes from site visits and drawings of ramps) taken from four published reports: Rinde (1978), Parsonson and Marks (1979), Howard (1980), and Campbell and Middlebrooks (1988). In many cases, complete information was not available in the report, as summaries of site visits and changes were not consistent in what information was included. For example, sometimes an author would simply say that sign revisions were made but did not specify which signs had been changed or in what way they had changed. In some cases, it was possible to fill in missing information from other sources. For example, in some cases the type of area in which a ramp was located was not noted in the report (e.g., urban, rural) but could be determined from other information. For this, we focused on ramps where the study authors had reported wrong-way movement counts from both an initial baseline period and after changes had been made to the ramp. A complete list of coded items is provided in Appendix A, as well as a note on our procedure for filling in missing data.

Reports varied in the metric reported, with some providing both counts and per month averages and others providing per month averages or counts only. This also sometimes varied within the same report. Because the number of days for which interchanges were observed varied considerably, from 14 to 365 days, all counts were converted to the average number of wrong-way movements per month. Cases where counts were reported but not observation duration were excluded from the data set, as these would be difficult to interpret without knowing the length of the observation period.

Interchange type. Interchange type was provided in most field visit reports. The terminology used was not consistent between reports or even at times within the same report, so the data file included a large number of ramp categories. To facilitate analysis, some of the ramp types were combined into a single category based on similar geometric characteristics of ramps. Appendix B lists both the initial categories and the combined categories, as well as the number of ramps in each category for the initial and combined categories. Figure 13 shows a summary of the average wrong-way moves per month for each interchange type included in the data set. As is evident in Figure 13, elevated median wrong-way movement rates for interchange types identified as potentially problematic is strongly influenced by a few especially individual ramps with especially high rates of wrong-way movements.

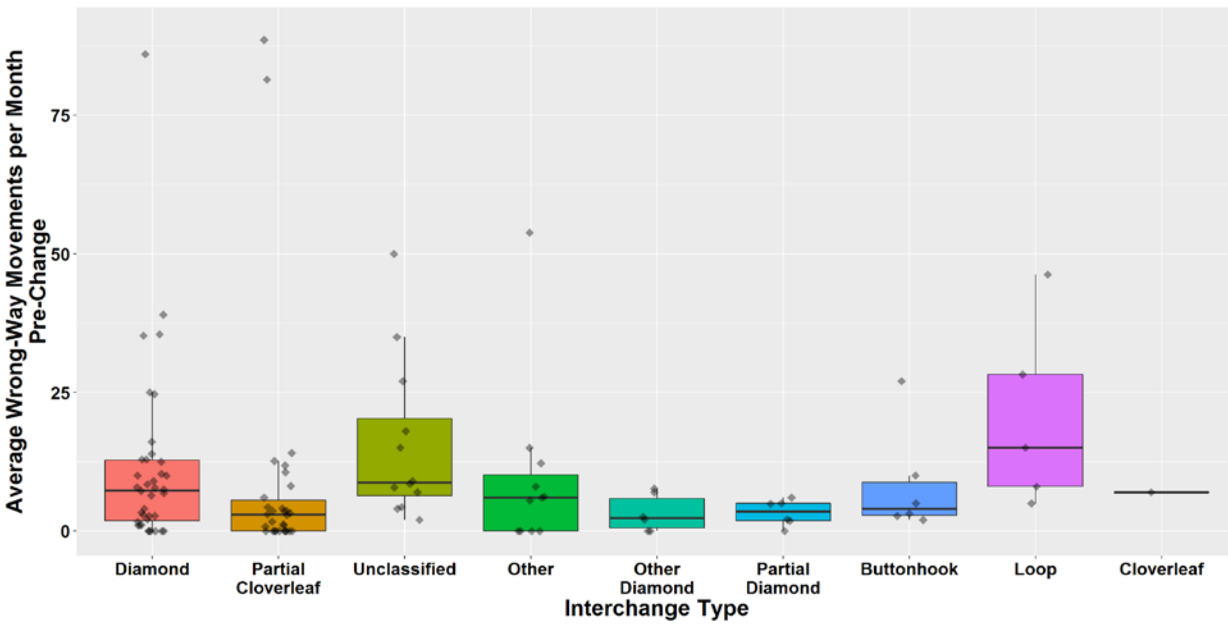

Figure 13. Average wrong-way moves per month by ramp type during the pre-change monitoring period. Dark line shows the median for each interchange type, and the points in the foreground show values for each individual ramp.

Due to the large number of interchange categories and the small number of observations for some categories, statistical comparisons were not made between all interchange types. Rather, we compare only the two most common interchange types, diamond (*n* = 38) and partial cloverleaf (*n* = 30). The median per-month wrong-way movement rate before countermeasures were implemented was compared between diamond (*Median* = 7.35) and partial cloverleaf (*Median* = 2.95) interchanges using Mann-Whitney's U test. This test was selected because it is less influenced by extreme outliers and does not require the same rigid assumptions about the distribution of data required by other common statistical tests. In this data set, diamond interchanges were found to have a very slightly but statistically difference between the two interchange types such that initial wrong-way movement rate for diamond interchanges was higher than that for partial cloverleaf interchanges, $U = 734$, $Z = 2.04$, $p = .04$, $r = .06$. Note that elevated rates of wrong-way movements were also seen for the "unclassified" and loop categories (medians of 8.75 and 15, respectively).

Figure 14 shows the average wrong-way moves per month for the post-change period. Substantially fewer cases in the data set had complete data from the post-change period. In many instances, the author would note that "wrong-way movements were significantly reduced at this location" but did not give a specific count. There were post-change counts available for 21 ramps at diamond interchanges and 12 ramps at partial cloverleaf interchanges. As in the pre-change period, the median number of wrong-way movements per month for diamond interchanges was slightly higher (*Median* = 3.3) than what was observed at partial cloverleaf interchanges (*Median* = 1.55), but this difference was not significant, $U = 169$, $Z = 1.61$, $p = .11$. Due to the small number of partial cloverleaf interchanges with post-change data, there may not have been sufficient power to detect post-change differences, but the general pattern of data at post-change follows what was observed for the pre-change period. At least in the current data set, diamond interchanges appear to be slightly less responsive to implemented countermeasures, as there were more cases with high post-change counts for diamond interchanges. An additional caveat here is that all of the interchanges included in the current data set were selected for observation because there was a known or suspected wrong-way movement issue at those locations.

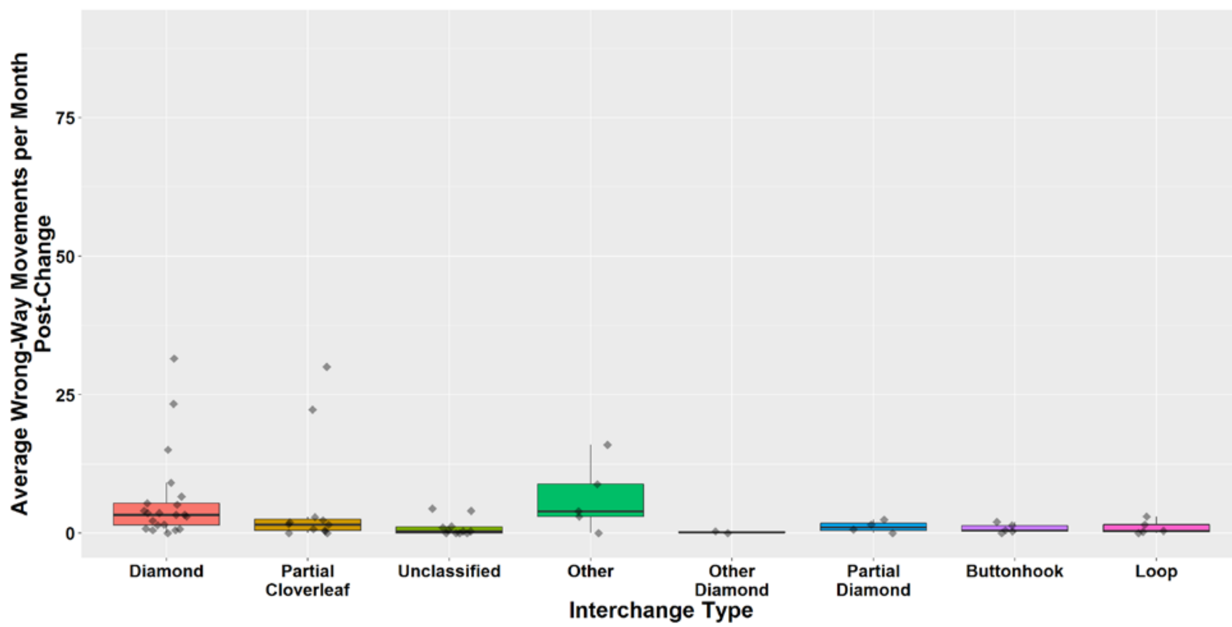

Figure 14. Average wrong-way moves per month by ramp type during the post-change monitoring period. Dark line shows the median for each interchange type, and the points in the foreground show post-change counts for each individual case.

Ramp location and wrong-way movements. Ramp location was coded as either urban, rural, suburban, or unspecified. The suburban category was not specified in any single report but was added later based on inspections of the area around those ramps that could be confidently located in Google Maps based on information provided in reports. Some ramps were located in areas with moderate to heavy residential land use in the surrounding areas but did not have any businesses or points of interest nearby. If it could be confidently determined that the housing in the surrounding area was present at the time of the report, then this case was coded as “suburban”.

The distribution of wrong-way movement averages by location is shown in Figure 15. As can be seen from the image, the variability in wrong-way movement rates differed substantially by location, though the median number of wrong-way movements for each location category was similar. There were also significantly more urban cases (n = 28) than either rural (n = 11) or suburban (n = 11); location was not mentioned and could not be determined in 65 cases. Because of this, as in the previous analyses, only nonparametric tests were used for statistical comparisons, as these do not make strong assumptions about the distribution of data.

When all four interchange categories were compared using a Kruskal-Wallis test, there was a large difference in median wrong-way movement rates between ramps (medians are show by the horizontal line in the boxplot in Figure 15), $\chi^2(3, N = 115) = 22.84$, $p < .001$, which was driven by the “Not Specified” category. This is likely because report writers tended to give fewer details for ramps with lower wrong-way movement rates. When only urban, suburban, and rural ramps were compared, there was no difference in the median wrong-way movement rate between areas, $\chi^2(2, N = 50) = 1.06$, $p = .59$. Across all locations, the median wrong-way movement rate was 5 per month. In Figure 15, extreme values occur more frequently at urban interchanges, but this trend was not statistically significant, likely due to the large difference in the number of valid cases for each interchange type.

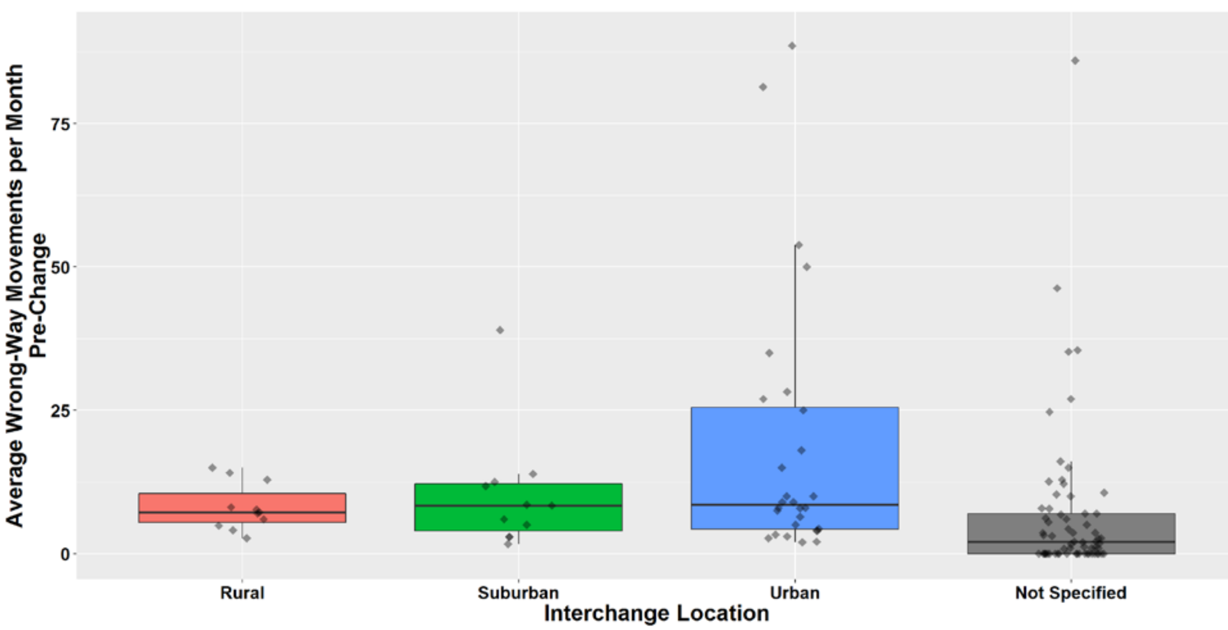

Figure 15. Average wrong-way moves per month by ramp location during the pre-change monitoring period. Dark line shows the median for each interchange type, and the points in the foreground show values for each individual case.

Features associated with high initial rates of wrong-way entry. Other features of interchanges, such as having businesses or points of interest (e.g., airports, shopping malls, parks) in the surrounding area are likely to be associated with rates of wrong-way entry. In the current data set, this information was not reliably available and could not be reliably determined from other sources. As a result, no formal statistical analyses were done on these factors. However, it is of note that the two most extreme cases in the urban category were both near the Atlanta airport, which even in the late 1980s was a very busy airport, making it likely to draw drivers unfamiliar with the area. Similarly, other extreme cases were located near stadiums and large shopping malls. These locations were a focus of study because, even if the probability of a wrong-way entry was low given the number of vehicles traveling through that location on a daily basis, due to the high traffic, this would present more opportunity for a wrong-way incident to occur.

Were changes more effective in some locations? All of the 64 cases that included both pre-change and post-change wrong-way movement data had some type of countermeasure implemented, either changes in signage, addition of pavement markings, addition of traffic signals, or some other intervention. For this reason, it is not possible to test whether the frequency of wrong-way movements may fluctuate over time, even in the absence of changes. In at least one case (Campbell & Middlebrooks, 1988), there were instances where wrong-way counts initially increased after a change was made but resolved over time as local drivers became familiar with the new design. Another valid question is whether countermeasures were more or less likely to be effective at a given location or type of interchange. To examine this, we computed the percent change in wrong-way movement rates for each case with valid pre- and post-change data and compared these rates using a Kruskal-Wallis rank sum test. There was a slight, but not statistically significant, tendency for urban locations to show a larger proportional reduction in wrong-way moves per month, there were also more cases in urban locations and these were more likely to have had higher initial counts. There were three cases where there was an increase in incidents between pre- and post-change, all of which were different types of interchanges. Because all of these were cases with a smaller number of initial wrong-way movements, it is likely these cases represent mean regression or measurement error and not a true increase (see Figure 16).

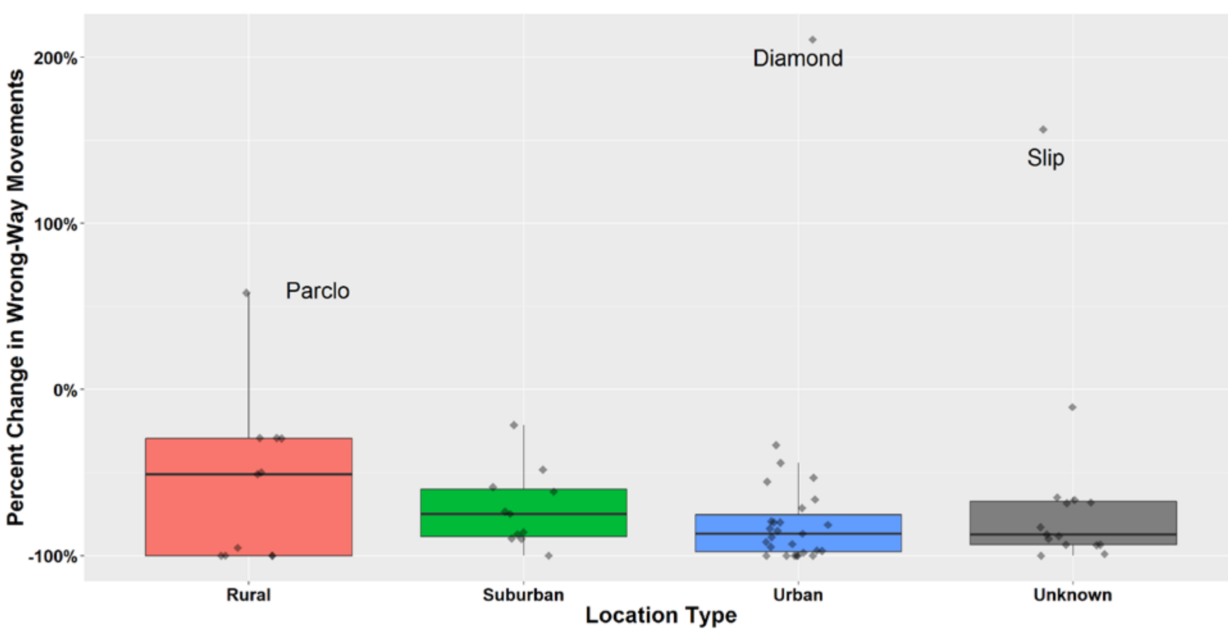

Figure 16. Percent change in wrong-way movements by interchange location.

Which changes had the strongest effect on reducing wrong-way movements? In several reports where field visits were conducted, authors note that while some features of interchanges are consistently linked to higher rates of wrong-way movements, there was no single countermeasure or set of countermeasures that consistently eliminated wrong-way driving at a location (Rinde, 1978; Parsonson & Marks, 1979; Campbell & Middlebrooks, 1988). In the current data set we coded whether changes were made to regulatory or warning signs, pavement markings, geometric design of the ramp area, or some other type of change not included in any of these categories (e.g., installation of new traffic signal).

First, we examined the number of changes, collapsed across types of change, made at interchanges (see Figure 17). In general, cases with higher wrong-way counts were more likely to receive multiple interventions, as three or more changes were coded for the cases with the highest wrong-way counts. Next, we looked at whether any change category led to a significantly greater reduction in wrong-way counts (see Figures 18 – 21). No specific type of change was tied to a significantly higher or lower average reduction in the rate of wrong-way movements per month. This is possibly due to the conditions at each ramp being somewhat unique to that ramp, so different interventions were likely to be effective in each case. Also, because changes were often implemented simultaneously, it is impossible to distinguish between interventions that were more or less effective, or whether certain combinations of changes were more effective than others. In a few cases changes were made one at a time and researchers reported counts following each change, but this was done for only a few extreme cases, so no formal analyses were conducted. Table 1 gives the number of ramps at which each type of change was made.

Table 1. Changes made and number of ramps at which each type of change was made.

Type of Change	Change Made	Change Not Made
Guide and Directional Signs	39	25
Regulatory Signs	42	22
Pavement Markings	40	24
Road Geometry	18	46
Other Change	9	55

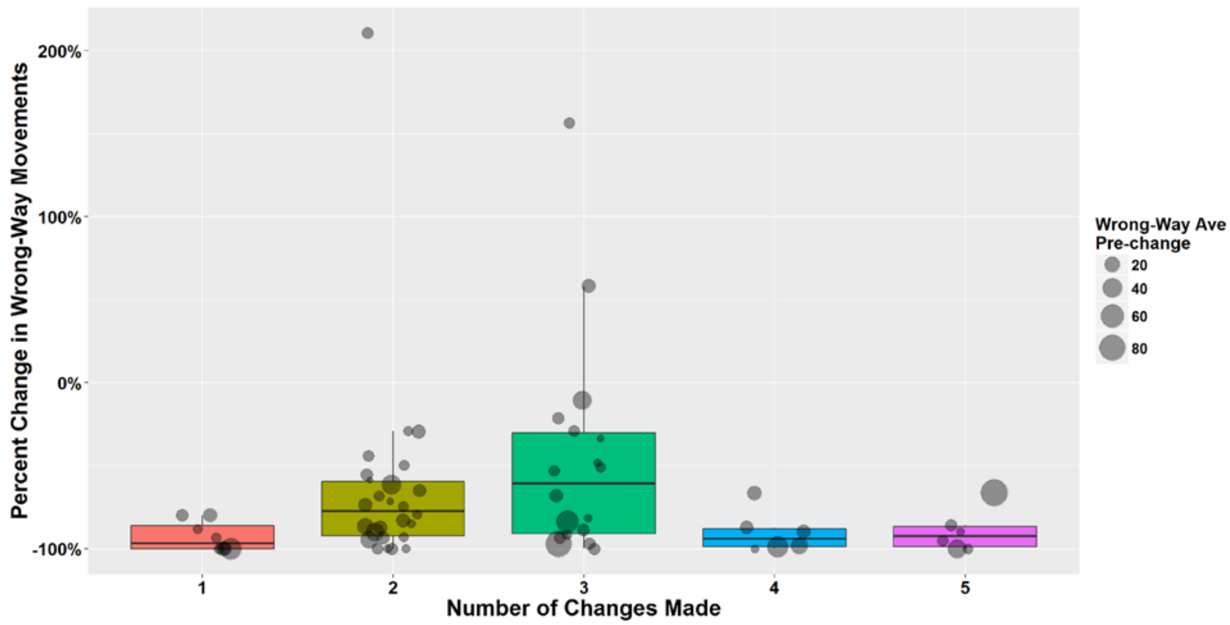

Figure 17. Percent change in wrong-way movements by number of changes made (categories could include different types of changes). Point sizes show the number of wrong-way movements per month during the baseline observation period.

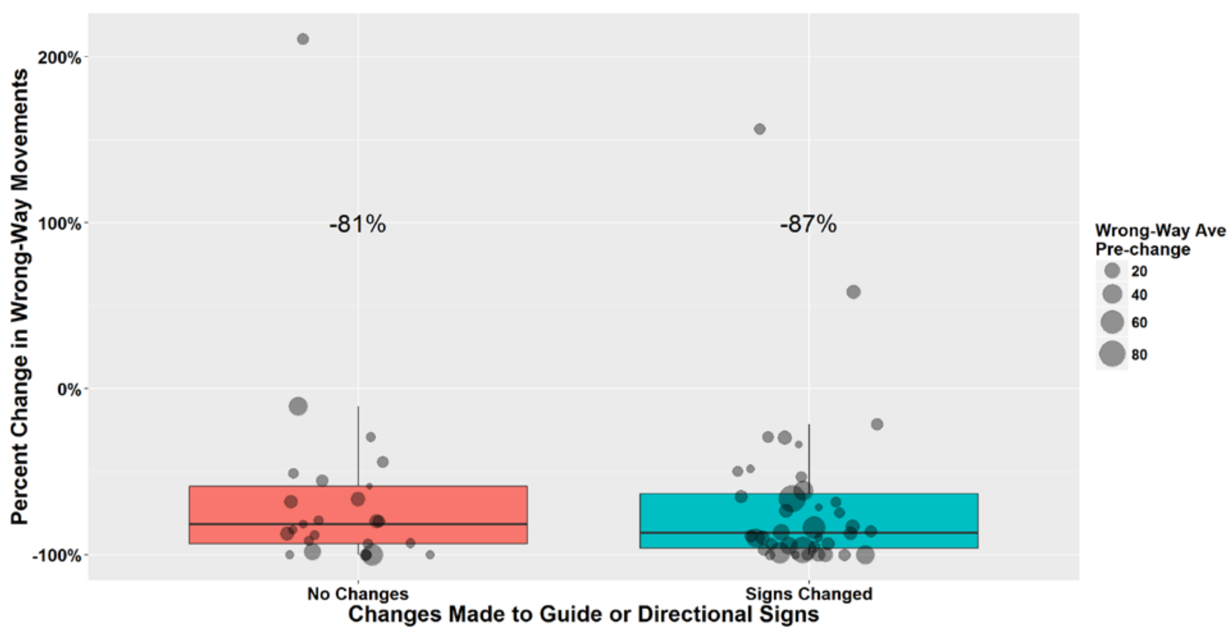

Figure 18. Percent change in wrong-way movements by whether or not changes were made to guide or directional signs. There was a slightly greater reduction in wrong-way movements when guide signs were changed, but this difference was not statistically significant.

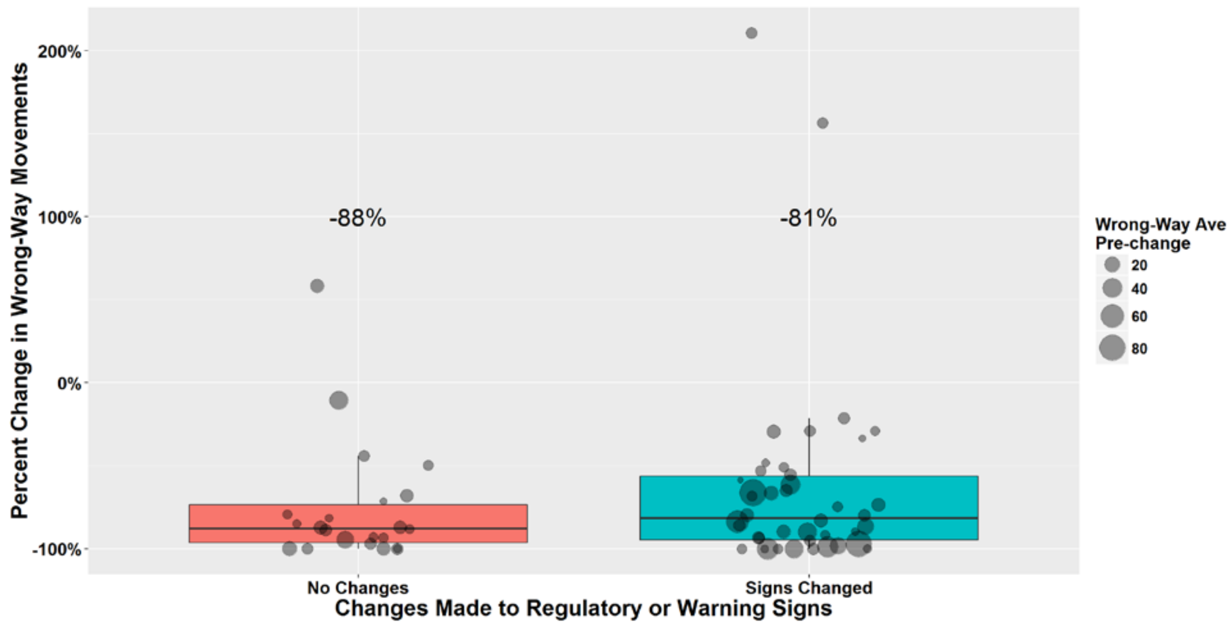

Figure 19. Percent change in wrong-way movements by whether or not changes were made to regulatory or warning signs. There was a slightly greater reduction in wrong-way movements when regulatory signs were not changed, but this difference was not statistically significant.

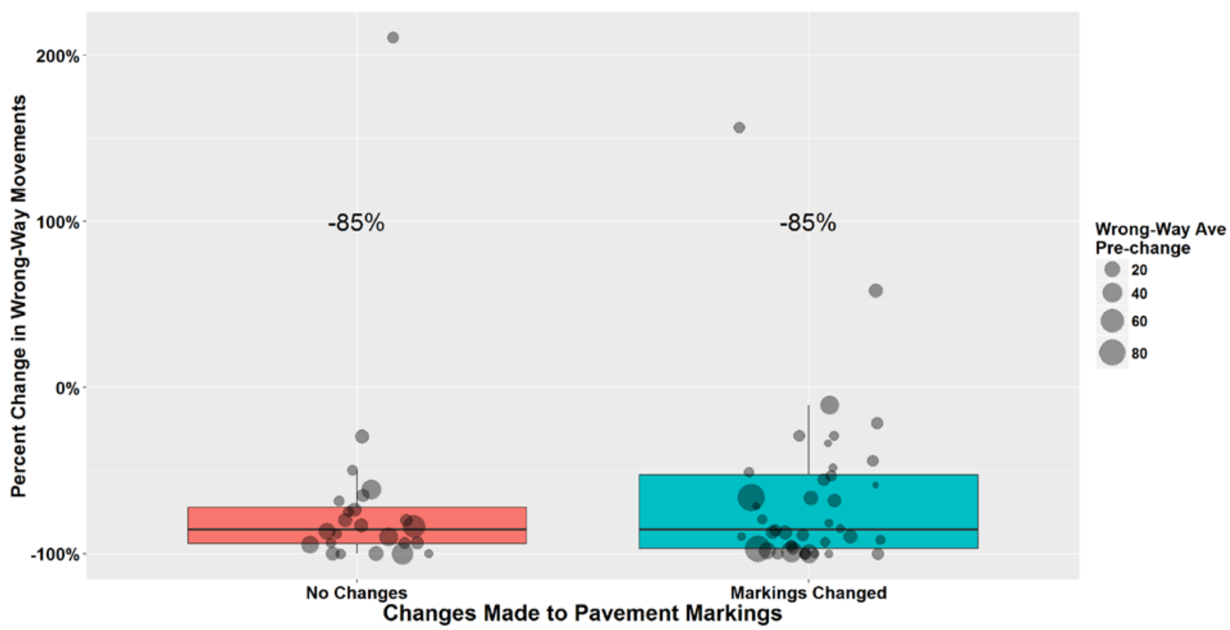

Figure 20. Percent change in wrong-way movements by whether or not changes were made to pavement markings. The percent reduction in wrong-way movements was identical between locations where pavement markings were changed compared to those where no changes were made to pavement markings.

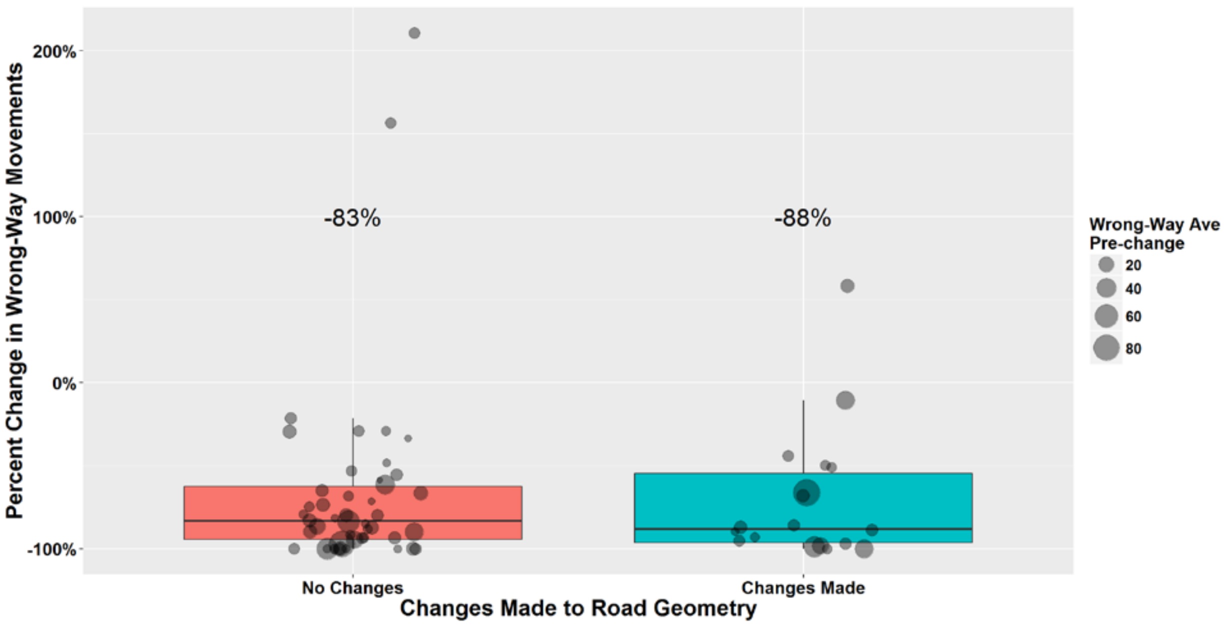

Figure 21. Percent change in wrong-way movements by whether or not geometric design changes were implemented at a ramp. Geometric changes were the least common type of change made, likely because this is likely the most expensive types of change made.

Summary

Data presented in four reports that conducted camera-based monitoring ramps were coded and combined into a single data set. Overall, there was no single feature of ramps, among those mentioned in the reports that strongly predicted either very high wrong-way movement rates or were significantly less responsive to remediation measures. Across all interchange types, there were examples of ramps with high rates of wrong-way movements in nearly all categories. This suggests that, as several authors mention, there are idiosyncratic features of individual ramps that have wrong-way movement counts. Although some interchange designs were found to have higher average wrong-way movement counts, it is difficult to draw clear conclusions from this because there are systematic differences in the types of locations where certain types of interchanges are located (e.g., all buttonhook interchanges in the data set were in urban areas), and there were also substantially more diamond and partial cloverleaf interchanges included in the data set, as these are the most common types of interchanges.

There are several caveats that limit the generalizability of these analyses. First, the number of cases with complete data was small (n = 65), and measurement error in the counts was likely high. This is because wrong-way movements are known to be infrequent overall, so more than 30 days of observation, which was the most frequent observation period, to get a reliable count. In addition, there were many cases with missing data, and in some cases the missing data was due to a systematic reason (e.g., less detail provided for less problematic ramps).

Another caveat is that many of the observed interchanges were selected for observation because they were known to have higher than average rates of wrong-way movements. Several reports note that most interchanges observed, about 73% to 85% of ramps observed (not all of which are included in this data set, as they were not included in the reports) had 2 or fewer wrong-way movements per month (Tamburri & Theobald, 1965; Campbell & Middlebrooks, 1988; Copelan, 1989). Another caveat is that some data are incomplete, so even if a feature is not noted, it may have still been present at the interchange. At best, these summary statistics can only tell us about features that were associated with higher rates of wrong-way movement in a population of ramps already known to have a higher risk of wrong-way movements.

Concluding Remarks

Our review of the literature found that a number of individual difference variables, environmental variables, and roadway characteristics appear to influence wrong-way highway entrances, movements, and crashes (see Table 2). One of the biggest challenges of understanding wrong-way crashes is their relative rarity (however, their severity warrants attention and the investigation of effective countermeasures). Our analysis was informed by crash reports, but was supplemented by police reports and monitoring of wrong-way entries. Alcohol intoxication appears to play one of the biggest roles in this often fatal type of crash. These impairment-related crashes tended to occur during weekends and late at night. Older, non-alcohol impaired drivers tended to be involved in wrong-way crashes during the day. It was noted that the effect of alcohol on perceptual and cognitive abilities sometimes resembles the effect of age on these same abilities. This might imply that countermeasures effective at reducing the risk of one group might also reduce the risk of the other. However, this assumption deserves further observational and empirical scrutiny.

Table 2. Driver and environmental characteristics associated with wrong-way driving.

Driver Characteristics	Environmental Characteristics
High BAC (often > 0.15) or evidence of illegal drug use	Nighttime, between 12 am and 6 am (peak between 3 and 4 am)
Male	Weekend (Highest rate on Saturdays)
Older drivers (> 70)	Urban area
More traffic violations	Clear weather
More likely to have prior felony convictions	Poor visibility (lighting or due to terrain/roadway structure)
More likely to be operating vehicle without license	Frontage road near ramp
	Left-side ramp, diamond, and partial cloverleaf interchanges

We framed the problem of wrong-way crashes in a cue-decision framework in which multiple cues are weighted and combined to influence the decision of whether or not one of several ramps is the correct way to access the highway. Individual difference characteristics such as age and intoxication influence the degree to which cues and countermeasures intended to prevent wrong-way movements are attended, and these individual differences also modulate the ability to extract the correct meaning from these cues. Our framework identified two decision points: the first related to wrong-way entries, and the second to the continued movement on the ramp and highway once a wrong-way entrance has been initiated. Environmental cues and countermeasures have the opportunity to inform better decisions at each of these decision points (Figure 22). In addition to providing support for the correct decision, it may be important to provide drivers the opportunity to correct their actions when the incorrect decision has been made.

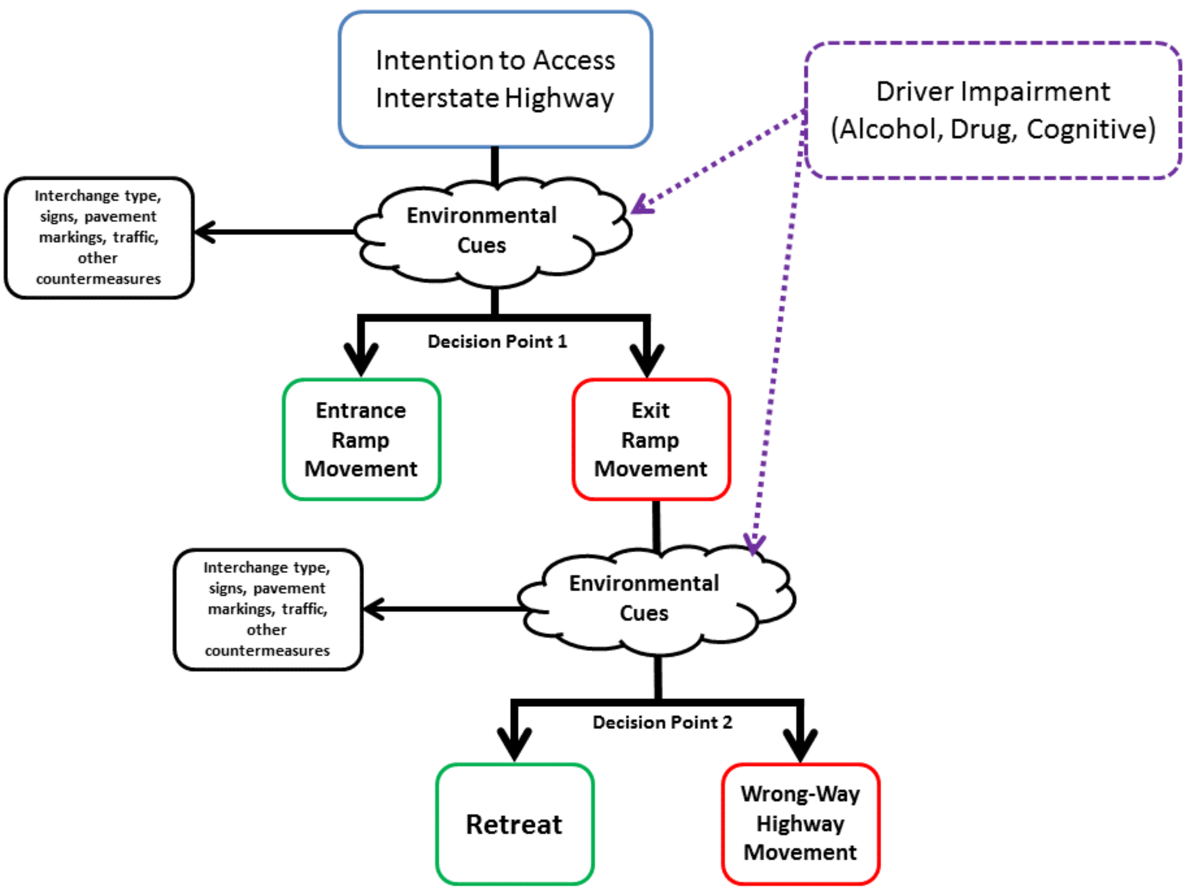

Figure 22. Our conceptualization of the decision making process related to wrong-way entries and crashes, based on the literature.

An archival analysis synthesized previous findings and examined specific interchanges and countermeasures most associated with reduced wrong-way entries. However, this analysis painted a complex picture. There was no clear association between specific countermeasures implemented and the reduction of wrong-way entries. There was no clear relationship between the number of countermeasures implemented and the reduction of wrong-way entries. This may suggest that idiosyncratic factors unique to particular interchanges are driving wrong-way entries at some locations, and that observation periods of some previous studies may not have been long enough to get a reliable estimate of wrong way entries before and after the implementation (or lack of implementation) of one or more countermeasures. Analyses are further complicated by the fact that problematic interchanges tended to be the ones studied, and more and specific types of countermeasures tended to be implemented at the most problematic interchanges. This may present a biased picture of which interchange types are most problematic, and also the effectiveness of implemented countermeasures.

Given these limitations, simulator studies may help address potential solutions to wrong-way entries more thoroughly. If idiosyncratic features of problem interchanges are driving specific wrong-way crashes, these interchanges might be modeled and imported into a driving simulator. Younger drivers experiencing real or simulated intoxication, as well as older drivers, might be asked to drive this interchange in the simulator. The presence and number of existing and experimental countermeasures might be implemented to observe the effect of these countermeasures on sensitive measures of driving performance and attentional allocation, and if wrong-way movements do occur, participants can explain the confusion that occurred and the factors that went into their decision process. Within our cue-based decision framework, we can use simulated driving performance to determine which cue or set of cues is most influential in aiding in correct decisions. As evident from the references discussed within this review, wrong-way crashes have been a persistent problem for over half a century. Much more work needs to be done to ensure that wrong-way crashes become even more rare then they are now, and new approaches and efforts may be needed to reach this goal.

Chapter 3. Task 2 - Simulator and Lab Tasks to Identify Effective Countermeasures to Prevent Wrong-Way Crashes.

In our earlier review we took the perspective that drivers' decisions to enter the interstate at a given point could be framed as a cue-based decision. Road geometry, pavement markings, guide or warning signs, and the behavior of other traffic are all cues that drivers may consider when deciding which of the available highway entry points is the correct one, and the goal of most countermeasures is to provide additional, unambiguous information that helps drivers quickly and accurately distinguish between entrance and exit ramps. Age and drug/alcohol impairment limit the drivers' ability to detect and effectively process these cues. Within this framework, more salient cues and a greater number of cues are expected to provide impaired drivers and drivers experiencing age-related perceptual and cognitive decline with additional information, or information that is more likely to be noticed and processed, to aid in the decision regarding the correct point of entry.

Two experiments were conducted to explore the possibility that wrong way entries can be reduced through the application of additional cues. A laboratory decision task presented participants with pictures of entrance and exit ramps for short periods of time. The duration of the image was controlled to simulate a single glance. The question posed was what countermeasures best predict correct ramp categorization. A second driving simulator task asked drivers to take an entrance ramp on the left to a destination city. Countermeasures were manipulated to explore whether wrong way entries might be reduced by increasing the number and salience of countermeasures present. Other measures of performance were explored that might be predictive of confusion such as vehicle speed, lane deviation, and braking behavior near an exit ramp. Younger and older adults were tested in this simulator task. Younger drivers drove nighttime scenarios given that this is the time in which most younger adult wrong-way crashes (WWCs) occur. Further, half of the younger adult sample experienced simulated impairment. These participants wore goggles that distorted vision and were also asked to engage in a cognitively demanding secondary task while driving. Older drivers drove daytime scenarios as most older adult WWCs occur during daytime. More details regarding each of these studies and their results are described in the next sections.

Ramp Decision Task

Method

Materials

A total of 589 images of entrance and exit ramps were collected from Google Street View. These included images of ramp locations reviewed in the Statewide Wrong Way Crash ramp study (n = 61), as well as images selected to be representative of diamond or partial cloverleaf interchanges where the ramp terminal end meets the adjoining road at a right angle or near-right angle. Cloverleaf interchanges were excluded because these are known to have a very low rate of wrong-way entries. We also excluded partial cloverleaf interchanges where the entrance and exit ramps were very close together, as both the entrance and exit ramps would have been visible in the image, making it difficult to convey to participants which ramp they should respond to during the task.

This initial set of 589 images was reviewed to eliminate images that were not good candidates for inclusion in the current study. The most common reasons for excluding an image include excessively blurry or poor quality images, images that were taken from too close or too far away for all relevant features to be visible, critical features (e.g., signs) were occluded or partially occluded, or the image was a duplicate of an image already included in the set. After this initial review, the final image set consisted of 464 images, including 255 entrance and 209 exit ramp images. The ramps' features varied considerably, with ramps from 33 different states represented in the final image set.

The screen captures in the final image set were then cropped to a uniform size (1280 x 860 pixels). To the extent possible, images were cropped so that the ramp appeared at or near the center of the image (see Figure 23). Next, three independent raters coded key countermeasure and environmental features for each ramp image. Examples of the features coded include the presence or absence of warning signs, the number of each type of warning sign present, the presence or absence of pavement markings, as well as the approximate condition of pavement markings (see Appendix C for a complete listing of elements coded for each image).

Figure 23. Entrance ramp at SR1 and Birchwood Loop Road, Anchorage, AK (Source: Google Street View, image date: September, 2011).

Participants

A total of 138 participants completed the laboratory task (85 younger adults, 51 older adults). They also gave information about their health and driving history (questionnaire content is provided in Appendix D. Of these, 16 were excluded from final analyses, including 8 participants (all younger adults) who were pilot participants in a preliminary version of the task, and 8 who were excluded due to incomplete data, failure to follow instructions, or experimenter error (3 older, 5 younger). The final sample consisted of 120 participants (see Table 3 for a summary, also see Appendix E for complete questionnaire results).

Table 3. Lab study participant information.

Age Group	Mean Age (SD)	Gender (M / F)
Younger (n = 80)	22.6 (2.6)	32 / 48
Older (n = 40)	71.8 (6.5)	20 / 20

Procedure

Participants were instructed that they would be viewing a series of highway entrance and exit ramp images taken from Google Street View, and that their task would be to indicate whether or not each image was of an entrance ramp. This design was chosen because it would be more similar to drivers' actual task. That is, drivers must search for entrance ramps, and need only identify exit ramps for the purpose of avoiding them. Following the task instructions, participants completed eight practice trials before beginning the main task, which consisted of 464 trials (each ramp image in the set was displayed once). Each trial began with white screen with a cross in the center, which was displayed for 500 ms. Immediately following the fixation cross, the ramp image was displayed for 200 ms. Finally, a white screen with the text "Was the previous image an entrance ramp?" and prompts reminding participants of the response keys. Participants indicated their choice by pressing one of two keys on the keyboard. Although the ramp image was displayed only briefly on each trial, participants were allowed to take as long as they wished to enter their response.

Results

The critical performance measure was the accuracy of participants' responses to the question "Is this an entrance ramp?" Exit ramps that consistently receive accurate "no" responses should be the least likely to be mistaken for an entrance ramp (correct rejections). Entrance ramps that are difficult to identify, as well as those frequently mistaken for exit ramps, could also pose a problem because drivers would continue to search for what they believe to be the correct entrance ramp, increasing the likelihood that they would mistakenly drive onto an exit ramp.

Response Accuracy

The proportion of correct responses given was calculated for each of the 464 ramp images included in the task. Average accuracy across all ramp images ranged from a low of 16.1% to 100% (ramp images correctly classified by all participants). Across all ramps, the distribution of average accuracy showed significant negative skew (i.e. high accuracy for most images). The median accuracy across the sample was 89.5% (*Mean* = 87.5%, *SD* = 0.10), with 75% of ramps showing average accuracy of 84.7% or better.

While overall accuracy across all ramps was good, average accuracy did differ significantly between entrance and exit ramps, $F(1,462) = 12.27$, $p = .001$, $d = .33$, 95% CI [0.14, 0.51], such that average accuracy was better for exit (*Median* = .92) than for entrance ramp images (*Median* = .88, also see Figure 24)[1].

However, despite the overall better accuracy in recognizing exit ramps, more specifically, recognizing that they were not valid entrance ramps (as per the task instructions), performance on exit ramp trials showed more variability than did performance for entrance ramp images. Average accuracy for individual entrance ramp images ranged from .44 to .98, while average accuracy for individual exit ramps ranged from .16 (below chance performance) to 1.0 (i.e. none of the 120 participants misidentified that ramp image). The points shown in Figure 24 show accuracy for those ramps showing the poorest performance.

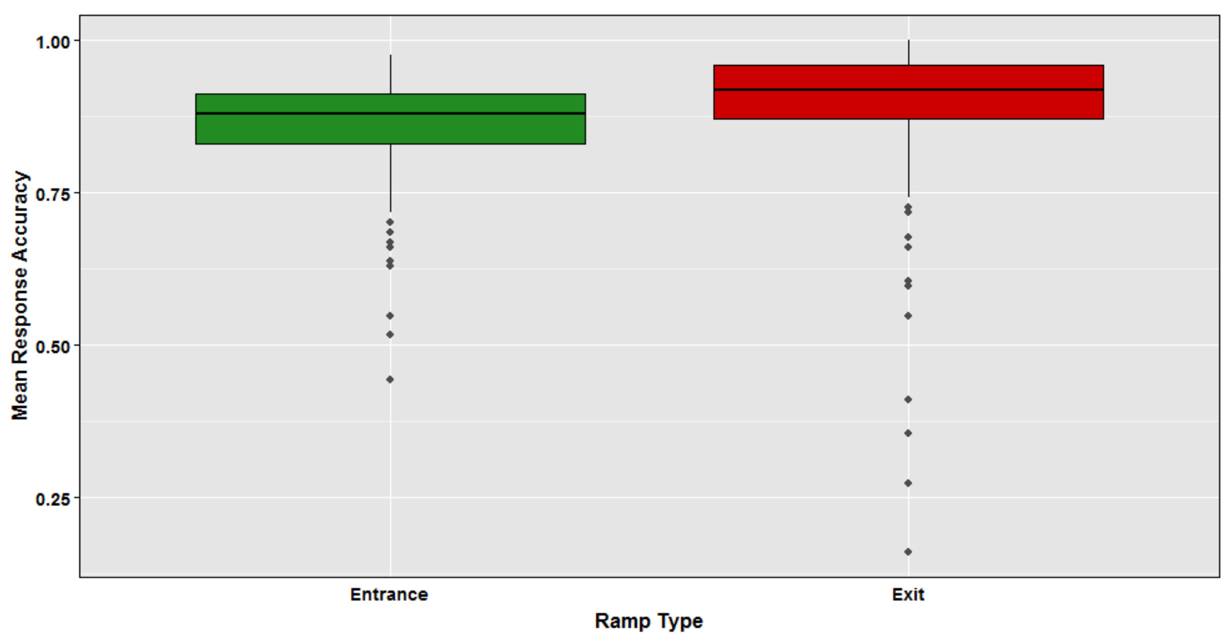

Figure 24. Boxplot showing average accuracy by ramp type.

[1] Because the distribution of accuracy was severely negatively skewed, values were arcsin transformed. Statistical tests are based on transformed values.

Response Accuracy by Countermeasures Present

As described in the materials section, the presence or absence of key features of entrance and exit ramps was recorded for each image used in the current study. Our goal was to determine which features were most strongly related to performance, in particular, identifying those features that could be seen as either “risk factors” for a given ramp becoming a wrong way entry point or as protective, in that those features were associated with a very low error rate for that image.

<u>Signs</u>

The first ramp feature we examined was the type of signs present in the image. Because different types of signs are used at entrance than at exit ramps (with the exception of one-way signs), we note whether the ramp images included in an analysis are all of one type or the other, or whether ramps of both types are included.

<u>Wrong-way</u>: There were four exit ramps with average accuracy below chance (50%). In all four of these images, no wrong-way signs were visible in the image. Because there were so few ramps with below-chance performance, we also examined ramps where average performance was below the 25^{th} percentile (less than 85%). There were 41 exit ramps with average accuracy below 85%, and of these, all 41 images did not have a wrong-way sign visible in the image[2]. These results suggest that wrong-way signs serve as critical cue allowing drivers to quickly and accurately identify exit ramps.

<u>Do Not Enter</u>**:** Do Not Enter signs were clearly visible in 194 out of 209 exit ramps included in the task. The number of Do Not Enter signs visible ranged from 0 to 3. Three out of the four ramp images with below chance accuracy had no visible Do Not Enter sign and one had two visible Do Not Enter signs. This pattern was less evident among the 41 images with average accuracy below 85%; only 9 out of the 41 did not have any visible Do Not Enter sign. The remaining low-accuracy images were approximately evenly divided between images with one (n = 15) and two (n = 17) visible Do Not Enter signs.

<u>One Way</u>**:** One Way signs differ from the two other sign types examined because they are not unique to either entrance or exit ramps, though they are more commonly seen at exit ramps. Of the 464 ramp images in the current study, 145 exit ramps had at least one visible One Way sign, and 27 entrance ramps had at least one visible One Way sign. All four of the exit ramps with average accuracy below 50% had either one or two visible One Way signs. The single entrance ramp with below 50% accuracy did not have a One Way sign present. When ramp images with accuracy below 85% were examined,

[2] This does not mean that there were NO signs of a given type present, just that they were not visible in the image. If a given ramp was very wide or signs were placed at a greater distance from the ramp terminal, then they may not have been visible in the cropped image.

there was a clearly different pattern for entrance than for exit ramps. In total, there were 88 entrance ramps with average accuracy below 85%, and for 79 of these there was no visible One Way sign present. For exit ramps, the images with below 85% accuracy were approximately evenly distributed across images with none (n = 12), one (n = 16), and two (n = 13) One Way signs visible. Because entrance ramps included in the current study tended to have fewer signs and special features overall compared to exit ramps, it is possible that the presence of One Way signs is a stronger cue for identifying entrance ramps. Although exit ramps may have One Way signs, this is much less common than for entrance ramps, so it is not surprising that drivers may not rely on One Way signs to identify exit ramps.

<u>Freeway Entrance</u>: Of the 255 entrance ramps in the image set used, there were 225 with no freeway entrance signs visible, 15 with one, and 15 with two freeway entrance signs visible. There was a single entrance ramp with average accuracy below 50%, and that was an image that had no visible freeway entrance signs. However, there was no evidence that average performance differed significantly between entrance ramp images with freeway entrance signs and those with no freeway entrance signs visible.

<u>Pavement Markings</u>

<u>Stop Bar</u>: For each exit ramp image, coders indicated the degree to which a stop bar was visible at the end of the ramp. Coders' ratings ranged from 0, which meant that no stop bar was visible in the image, to 5, which meant that the stop bar was bright and had minimal visible wear. Of the 209 exit ramp images included in the study, 19 had no visible stop bar, and the remaining 190 exit ramp images had visible stop bars with ratings ranting from 1 to 5. The most common rating was 3 (n = 81), which indicated that a stop bar was clearly visible and had moderate wear. Because so few exit ramp images did not have stop bars, it cannot be determined whether the presence or absence of a painted stop line significantly relates to performance accuracy. There were also no clear differences in performance between stop bar visibility categories. However, the four exit ramp images that had below chance average accuracy were rated as having very worn stop lines: 2 received ratings of 1 and 2 received ratings of 2.

To estimate the degree to which the presence and condition (i.e. visibility) of the painted stop bar affected image classification accuracy on exit ramp trials, we also conducted an one-way ANOVA predicting arcsine transformed response accuracy from stop bar visibility ratings (higher numbers indicating darker, more visible stop bars in the image). For this analysis, because there were only three images where the stop bar was rated 5 (the highest rating), only those images where the stop bar received a rating between 0 and 4 were retained (n = 206). There was no evidence that stop bar conspicuity strongly affected response accuracy on exit ramp trials, $F(4,201) = 1.20$, $p = .31$.

<u>Directional Arrows</u>: Painted directional arrows were visible in 130 out of the 209 exit ramp images, and the remaining 79 exit ramp images had no visible directional arrows, or the directional arrows were completely worn away and no longer visible. When performance was compared between the 130 exit ramps with directional arrows and the

79 ramps that did not have visible directional arrows, there was no evidence of any significant difference, $F(1,207) = 1.59$, $p = .21$, $d = -0.18$, 95% CI [-0.46, 0.10].

Traffic Signals

Traffic signals were visible in many of the ramp images used in the current study (see Table 4). It is possible that the presence of traffic signals may serve as a cue disclosing whether a given ramp is a valid entrance ramp.

Table 4. Presence of visible traffic signal by ramp type.

	Entrance	Exit
Traffic Signal Visible	134	108
No Traffic Signal Visible	121	101
Total	**255**	**209**

To test for possible effects of the visible traffic signals on performance accuracy, average accuracy was compared between entrance and exit ramp images with and without visible traffic images. There was strong evidence that performance on images with visible traffic signals differed from those that did not have visible traffic signals, but this factor interacted strongly with ramp type, $F(1,460) = 56.14$, $p < .001$. Follow-up tests of the interaction revealed that average performance tended to be poorer for entrance ramp images with visible traffic signals, $F(1,253) = 46.64$, $p < .001$, $d = 0.86$, 95% CI [0.60, 1.12]. However, performance on exit ramp images tended to be better when there was a traffic signal visible, $F(1,207) = 18.83$, $p < .001$, $d = 0.60$, 95% CI [0.32, 0.88] (see Figure 25).

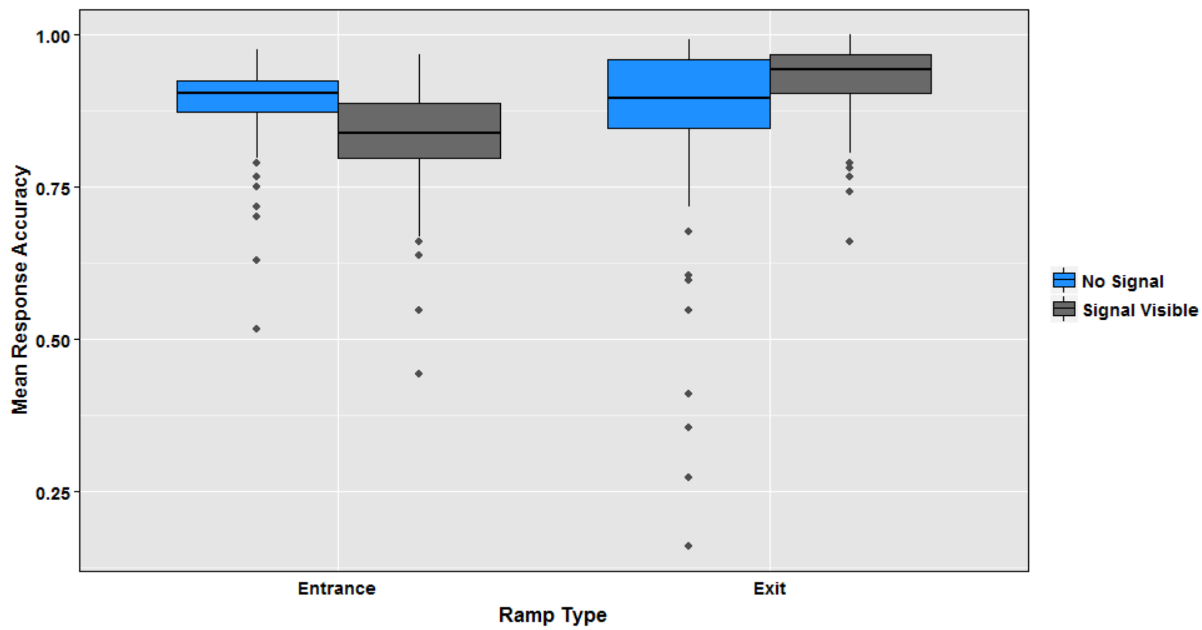

Figure 25. Mean accuracy by presence of visible traffic signal and ramp type.

Vehicle Presence

One very salient and diagnostic cue disclosing whether a given ramp is an entrance or exit ramp is the presence of other vehicles on the ramp. During late night and early morning hours, when wrong-way crashes are most likely to occur, this is also a time when few other vehicles are on the road.

The number of vehicles present in the current set of ramp images ranged from 0 to 20. Table 5 shows the counts for each total number of vehicles present by ramp type. When average accuracy was compared between images with and without vehicles present, there was evidence of significantly better performance on ramp images where at least one vehicle was visible on the ramp, $F(1,462) = 6.87$, $p = .01$, $d = .52$, 95% CI [0.34, 0.71].

Table 5. Number of vehicles present in ramp images by ramp type.

<table>
<tr><th></th><th colspan="2">Entrance</th><th colspan="2">Exit</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>No other vehicles visible</td><td>136</td><td>136</td><td>55</td><td>55</td></tr>
<tr><td>1 or 2 vehicles</td><td>77</td><td rowspan="6">119</td><td>65</td><td rowspan="6">154</td></tr>
<tr><td>3 or 4 vehicles</td><td>29</td><td>29</td></tr>
<tr><td>5 or 6 vehicles</td><td>4</td><td>23</td></tr>
<tr><td>7 or 8 vehicles</td><td>4</td><td>13</td></tr>
<tr><td>9 or 10 vehicles</td><td>3</td><td>11</td></tr>
<tr><td>11 or more</td><td>2</td><td>13</td></tr>
<tr><td>Total</td><td colspan="2">255</td><td colspan="2">209</td></tr>
</table>

Further analyses provided evidence that the presence of vehicles on the ramp more strongly related to performance on exit ramp images than entrance ramp images, as there was a significant interaction between ramp type and vehicle presence, $F(1,460) = 42.52$, $p < .001$. First, performance on entrance was poorer when vehicles were present in the image, $F(1,253) = 14.24$, $p < .001$, $d = .47$, 95% CI [0.22, 0.73], while performance on exit ramp images benefitted from the presence of vehicles on the ramp and did so to a greater degree, $F(1,207) = 24.63$, $p < .001$, $d = .78$, 95% CI [0.46, 1.10] (see Figure 26).

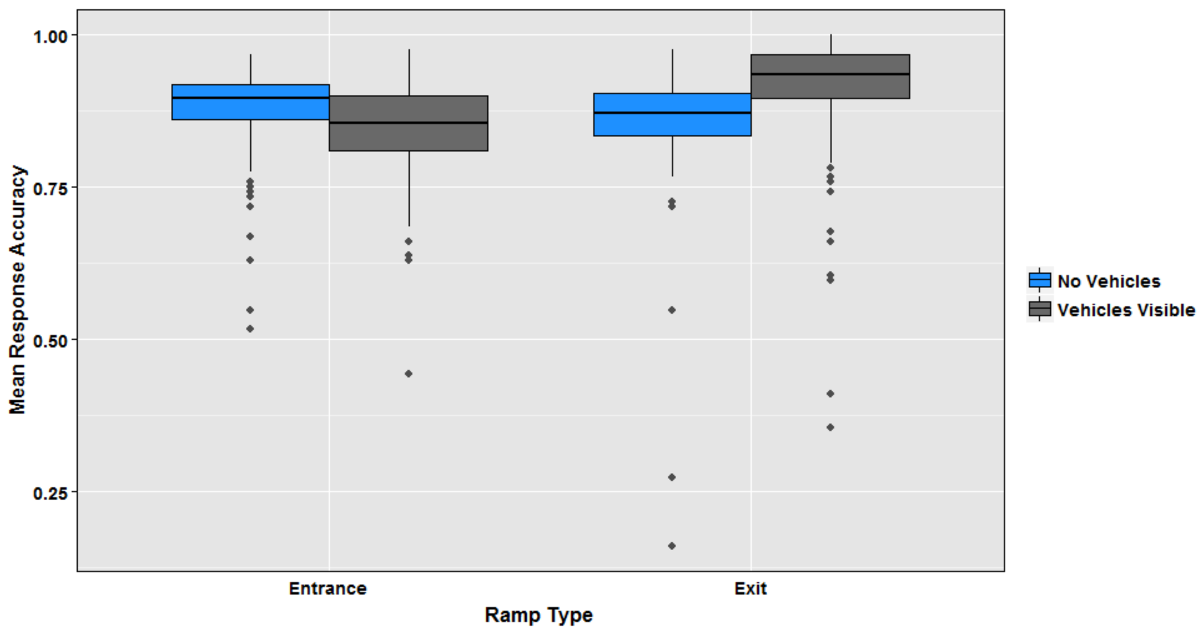

Figure 26. Mean response accuracy by ramp type and vehicles present.

<u>Total Countermeasures Present</u>

Because the ramp images included in the current study varied considerably in which specific countermeasures were present, we conducted additional analyses that examined differences average accuracy across ramp images as a function of the total number of countermeasures present, rather than the specific countermeasures. To do this, a composite score was computed for each ramp based on the total number of each countermeasure type present at that ramp. For each of the countermeasures listed in Table 6, a given ramp was given a count of 1 if that countermeasure was present in the image and a count of 0 if it was not. Note that only features that vary between ramps are included in the composite score, as there were some features (e.g., painted edge lines) that were present in all ramp images.

Table 6. Coding categories included in composite countermeasure score and the number of ramp images where each was present.

Countermeasure	Exit (n = 209)	Entrance (n = 255)
Do Not Enter signs at ramp end	194	0
Do Not Enter signs further down ramp	10	0
Wrong-Way signs at ramp end	12	0
Wrong-Way signs further down ramp	154	0
One-Way signs at ramp end	145	27
One-Way signs further down ramp	1	0
Freeway Entrance signs at ramp end	0	30
Freeway Entrance signs further down ramp	0	0
Pavement Marking: Stop Bar	190	0
Pavement Marking: Directional Arrows	130	4
Pavement Marking: Painted Median	113	102

In general, entrance ramps had fewer countermeasures present than did exit ramps, as the only countermeasures found at entrance ramps were one-way signs, freeway entrance signs, painted medians, and directional arrows. Table 7 shows the distribution of composite scores for both entrance and exit ramps.

Table 7. Number of ramps with a given composite score by ramp type.

Total Countermeasures	Exit (n = 209)	Entrance (n = 255)
0	0	112
1	0	124
2	3	18
3	33	1
4	64	0
5	67	0
6	41	0
7	1	0

There was weak evidence that the total number of countermeasures present related strongly to average response accuracy for a given ramp image when considering entrance and exit ramps together. Overall, there were no clear trends when mean performance for each of the 464 ramp images was examined as a function of the number of countermeasures present (see Figure 27). Because MUTCD guidelines dictate that certain signs be present at exit ramps, many of the ramps had the same number of countermeasures present and no exit ramps had fewer than two countermeasures present. For entrance ramps, many ramp images had none of the countermeasures included in our composite measure.

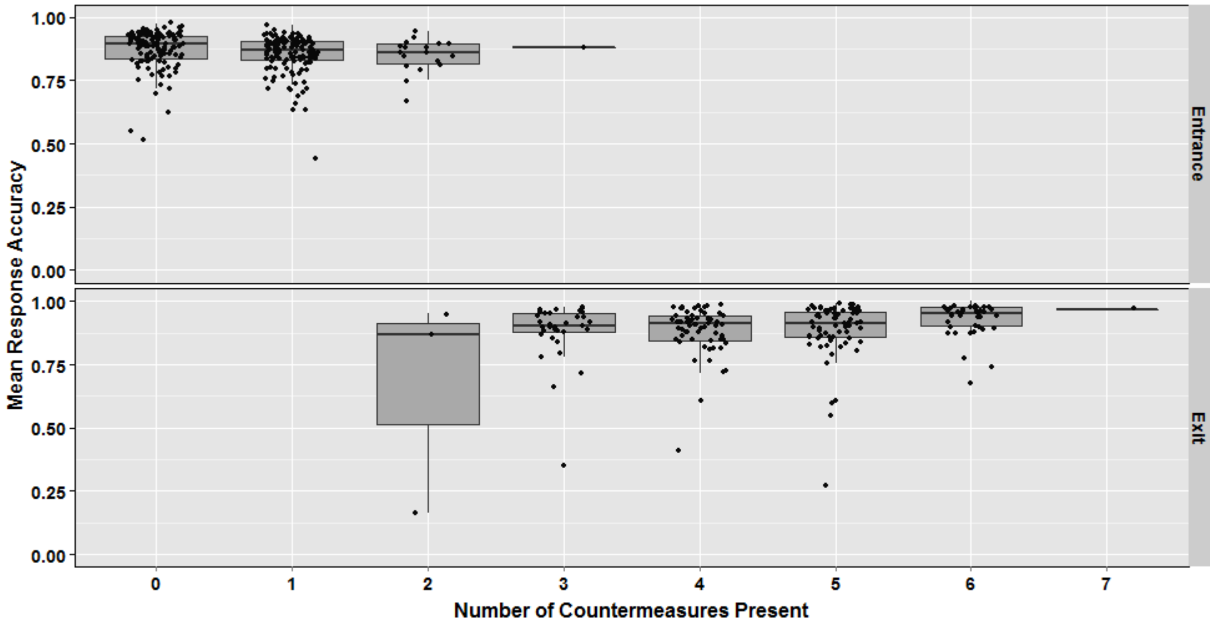

Figure 27. Average response accuracy by total number of countermeasures present and ramp type.

Because entrance and exit ramps differed so substantially in the range and frequency at which coded countermeasures were present, performance on entrance and exit ramps was examined separately. For exit ramps, the number of countermeasures present ranged from 2 to 7, with most ramps having either 4 or 5 total countermeasures visible in the image. Because very few ramps had fewer than 3 or more than 6 countermeasures, only those ramps with between 3 and 6 countermeasures visible were included in the analysis (n = 205). The overall test comparing all groups revealed that performance did in fact differ as a function of the number of countermeasures visible in each image, $F(3,201) = 3.27$, $p = .02$ (see Table 8
). Pairwise follow-up tests found no differences in performance between ramp images with 3, 4, or 5 countermeasures visible $F < 1$. However, when ramp images with 6 visible countermeasures were compared to those with 3, 4, and 5 countermeasures, performance was better for images with 6 countermeasures (M = .93, n = 41) than for those with fewer countermeasures (M = .89, n = 164), $F(1,203) = 9.55$, $p = .002$, $d = .30$, 95% CI [0.04, 0.56].

For entrance ramps, the number of countermeasures present ranged from 0 to 3, with most ramps having either 0 (n = 112) or 1 (n = 124) countermeasure present. When entrance ramps with no countermeasures were compared with those with 1 countermeasure, entrance ramps with one countermeasure present tended to have slightly poorer average accuracy than those with no visible countermeasures, $F(1,234) = 5.28$, $p = .02$, $d = 0.54$, 95% CI [0.18, 0.89]. This may be because one of the most consistent features of entrance ramps in the current study is that entrance ramps tend not to have many visible features. Instead, exit ramps tend to have several signs and are more likely to have pavement markings, such as a painted stop bar and directional arrows. These results suggest, at least to some extent, that the presence of signs and other visible countermeasures at highway entrance ramps might make it more difficult to distinguish them from exit ramps. If entrance ramps are less quickly and confidently identified, then this could increase the likelihood of driver confusion.

Table 8. Median response accuracy by ramp type and number of visible countermeasures.

Total Countermeasures	Exit (n = 209)	Entrance (n = 255)
0	NA	0.90
1	NA	0.87
2	0.87	0.86
3	0.90	NA
4	0.91	NA
5	0.91	NA
6	0.95	NA
7	NA	NA

Age Differences

In the next set of analyses we consider individual differences in performance on the lab task. Of special interest is whether participants of different ages differ in overall task performance, as well as whether any of the key image features identified in the previous analyses affect performance more or less for older compared to younger participants. To examine this, we conducted a mixed-effects logistic regression analysis where age group, ramp type, and key ramp features were used to predict response accuracy on a given trial. Analyses were conducted using version 3.1.2 of the R statistics programming language and version 1.1.7 of the lme4 package (R Development Core Team, 2014; Bates, Maechler, Bolker, & Walker, 2014).

First, we examined item response accuracy as a function of fixed effects of ramp type (entrance vs. exit) and age group (younger vs. older) with random intercepts for each subject[3]. Across participants in both age groups, performance for exit ramp images was better than for entrance ramp images, with errors 1.37 times, 95% CI [1.29, 1.44] as likely on entrance ramp trials as on exit ramp trials, z = 11.71, p < .001. On a given trial, older adults were 3.04 times, 95% CI [2.42, 3.83], more likely to make an error than were younger adults, z = 9.57, p < .001. The degree to which the probability of giving a correct response differed between entrance and exit ramp trials was similar between younger and older adults.

Next, we evaluated the effect of the number of countermeasures present on response accuracy overall and for each age group. These analyses parallel those presented in the previous section. Because the features and countermeasures representative of

[3] A model including the ramp type by age group interaction was not a better fit than a model with each factor entered individually, so the model with two fixed effects was retained.

entrance and exit ramps differed, these analyses were conducted separately for entrance and exit ramps.

Again, a mixed-effects logistic regression analysis was used to examine the effect of the total number of countermeasures present, age group, and the interaction between these two factors on response accuracy. For entrance ramps, as in previous analyses, there was a significant difference in response accuracy between older and younger adults, with older adults making 3.15 times, 95% CI [2.29, 4.34] as many errors as younger adults on entrance ramp trials, $z = 7.10$, $p < .001$. There was evidence of a weak effect of the number of countermeasures present on error rate. The error rate for entrance ramps tended to *increase* as the number of countermeasures present increased, $z = -3.61$, $p = .0003$, OR = .87, 95% CI [0.81, 0.94]. There was no evidence that the effect of the number of countermeasures on response accuracy for entrance ramps varied between older and younger adult participants, $z = .30$, $p = .76$, OR = 1.02, 95% CI [0.91, 1.13].

A different pattern was observed for the effect of the number of countermeasures on response accuracy for exit ramps. As was the case for entrance ramps, response accuracy differed between older and younger participants, though to a slightly lesser extent than for entrance ramps, $z = 4.23$, $p < .001$, OR = 2.71, 95% CI [1.71, 4.30]. In contrast to what was observed for entrance ramps, the error rate *decreased* when more countermeasures were present in an image, $z = 4.86$, $p < .001$, OR = 1.16, 95% CI [1.09, 1.22]. As was the case for entrance ramps, there was no evidence that the association between the number of visible countermeasures in an image and error rate differed between younger and older adults, $z = 1.0$, $p = .32$, OR = 1.04, 95% CI [0.96, 1.14].

Number of Warning Signs Present

We also examined whether the number of warning signs present at a ramp terminal related to response accuracy in the laboratory task. For this analysis, we examined three different signs: Wrong Way, Do Not Enter, and One Way.

Wrong Way

Very few exit ramps had Wrong Way signs posted at the ramp terminal. Out of 205 total exit ramp images, 193 did not have any Wrong Way signs at the ramp terminal, 11 had two Wrong Way signs posted, and 1 had three. Instead, it was much more common for Wrong Way signs to be posted some distance down the ramp. This was the case at 153 out of the 205 ramp images included in the current study. To determine whether the inclusion of these additional signs benefitted response accuracy, a mixed-effects regression analysis was conducted where age group (younger, older), the presence or absence of an additional Wrong Way sign, and the interaction between these two factors were used to predict response accuracy. The inclusion of Wrong Way signs further down the ramp benefitted younger adults' performance, $z = 4.55$, $p < .001$, OR = 1.36, 95% CI[1.19, 1.55] but did not to relate to performance for older adults, $z = -1.03$, $p < .30$, OR = 0.93, 95% CI [0.82, 1.06].

Do Not Enter

The number of visible Do Not Enter signs at exit ramp terminals ranged from 0 to 3. Note that an exit ramp included in one of the stimulus images may have indeed had a Do Not Enter sign posted, but this may or may not have been visible in the image used in the study (e.g., if the ramp was very wide, all signs may not be visible). A mixed-effects logistic regression was used to determine whether the number of visible Do Not Enter signs related to response accuracy, as well as whether this relationship differed between age groups. The number of visible Do Not Enter signs benefitted response accuracy for both older and younger adults; as the number of visible Do Not Enter signs increased, so too did response accuracy. However, younger adults, $z = 18.75$, $p < .001$, OR = 2.21, 95% CI [2.03, 2.40], benefitted to a greater degree than did older adults, $z = 8.25$, $p < .001$, OR = 1.44, 95% CI [1.32, 1.57].

One Way

The number of One Way signs present at exit ramp entrances ranged from 0 to 4. As before, a mixed-effects logistic regression was used to examine the relationship between the number of visible One Way signs and response accuracy, as well as whether this differed between older and younger participants. There was no evidence that the number of One Way signs was related to response accuracy for exit ramps overall or for either age group.

Distinctive Features of Entrance and Exit Ramps

Upon completing the lab task, participants were asked to indicate which features they felt were most representative of exit and entrance ramps. Responses to this open-ended question were then coded by three independent raters who indicated whether or not each response included some mention of each of the features included in our ramp image coding scheme (e.g., presence of Do Not Enter sign, vehicles on ramp).

The most commonly mentioned image feature, by a large margin, was the presence of vehicles on the ramp. This feature was mentioned by 94 out of 120 participants with respect to entrance ramps and 97 out of 120 participants with respect to exit ramps. This suggests that the presence and behavior of other vehicles is a cue drivers frequently use to determine whether a given ramp is a valid highway entrance. The frequent mention of other vehicles is consistent with our previous analyses, as the presence or absence of vehicles was found to be strongly related to response accuracy for both entrance and exit ramps.

Following the presence of other vehicles, the next most frequently mentioned feature was the presence of traffic signals, and this feature was mentioned much more frequently for entrance ramps (52/120) than for exit ramps (14/120). Consistent with our previous analyses, this feature is also one found to significantly relate to response accuracy for both entrance and exit ramps.

Participants also frequently mentioned signs (any type of sign) as being diagnostic of whether a given image had depicted an entrance or exit ramp. A total of 37 out of 120 participants mentioned signs as a distinctive feature of entrance ramps. Signs were mentioned at about the same rate, 36 out of 120, as being a feature representative of exit ramps. Specific signs were mentioned much less frequently. Freeway entrance signs, which were the only signs used only at exit ramps were only mentioned by 6 participants as being critical in helping to identify entrance ramps. Guide and route signs were mentioned much more frequently, by 13 participants for entrance ramps. Guide and route signs were not mentioned very often with respect to identifying exit ramps, only 2 participant responses mentioned route and guide signs in their responses.

Directional arrows were mentioned as a diagnostic cue for both entrance (n = 44) and exit ramps (n = 32). Pavement markings were not frequently mentioned in participant responses. Only 6 participants mentioned pavement markings of any kind as helping to identify entrance ramps, and 10 mentioned pavement markings as helping to identify exit ramps.

For entrance ramps, the position of the ramp or angle at which it met the adjoining road was an important cue. This feature was mentioned by 30 out of 120 participants with respect to entrance ramps, but only 11 out of 120 mentioned it for exit ramps. No other geometric features of ramps were mentioned.

Perhaps the clearest difference between participant’s description of features representative of entrance ramps compared to those representative of exit ramps is whether it was meaningful for a feature to be present or absent. For entrance ramps, 34 out of 120 responses mentioned that it was the absence of a feature (e.g., no signs, no stop bar) that disclosed that a given ramp was an entrance ramp. For exit ramps, the presence of a feature was more diagnostic of whether a ramp was an exit ramp. Only 4 out of 120 participants mentioned the absence of a feature being an important in identifying exit ramps. Table 9 shows the total number of participants mentioning each of the features coded.

Table 9. Total number of participants mentioning a feature by ramp type.

Feature	Exit	Entrance
Vehicles present	97	94
Traffic signal	14	52
Do Not Enter Signs	0	3
Wrong Way Signs	16	0
One Way Signs	3	3
Guide / Route Signs	2	13
Freeway Entrance	0	6
Signs Nonspecific	36	37
Stop Line	13	1
Directional Arrow	32	44
Painted Edge Line	6	2
Pavement Marking Nonspecific	10	6
Angle / Position of Ramp	11	30
Absence of Feature	4	34

Driving Simulator Task

Method

Materials

A NADS MiniSim high-fidelity driving simulator developed by The National Advanced Driving Simulator lab at the University of Iowa (Iowa City, IA) was used for the study (Figure 28). The NADS MiniSim incorporates a dashboard with a virtual instrument cluster, steering wheel; accelerator and brake pedals; and three 42" plasma displays that gives the driver a 180° horizontal and 50° vertical field of view of the simulated environment. Each display has a resolution of 1360 x 768 pixels and a refresh rate of 60 Hz.

Figure 28. NADS Minisim at Florida State University.

Diamond Interchange

Participants completed scenarios that involved a custom build simulator tile. This tile depicted a diamond interchange similar to the one found at the junction of I-75 and University Parkway in Sarasota, Florida (Google Maps: https://goo.gl/maps/x9RLw). This was an interchange identified in an analysis by the Statewide Wrong Way Crash Study as a problematic interchange associated with WWCs. Two sets of countermeasures were associated with this tile. One set included the minimum countermeasures described by the MUTCD (Figure 29). The second set was based on a proposed new minimum recommended by the analysis provided by the Statewide Wrong Way Crash Study. (Figure 30).

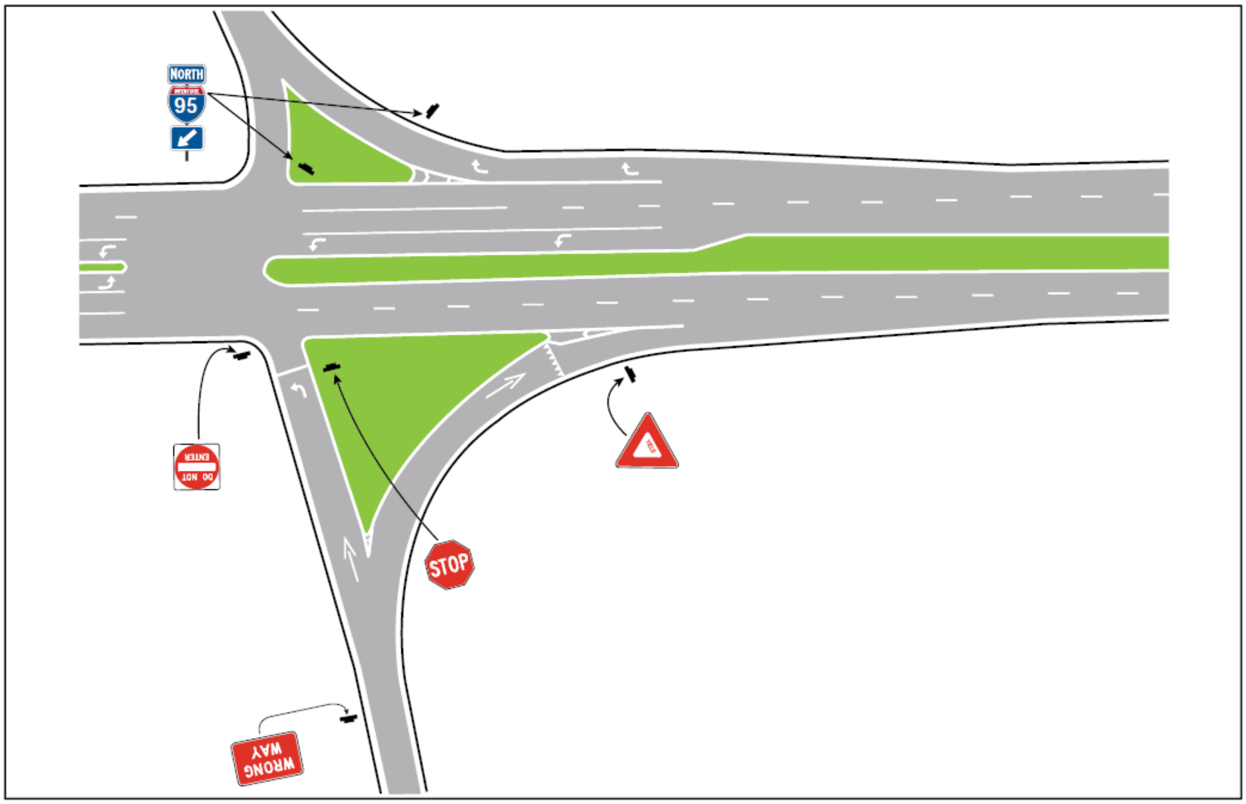

Figure 29. Minimum countermeasure condition.

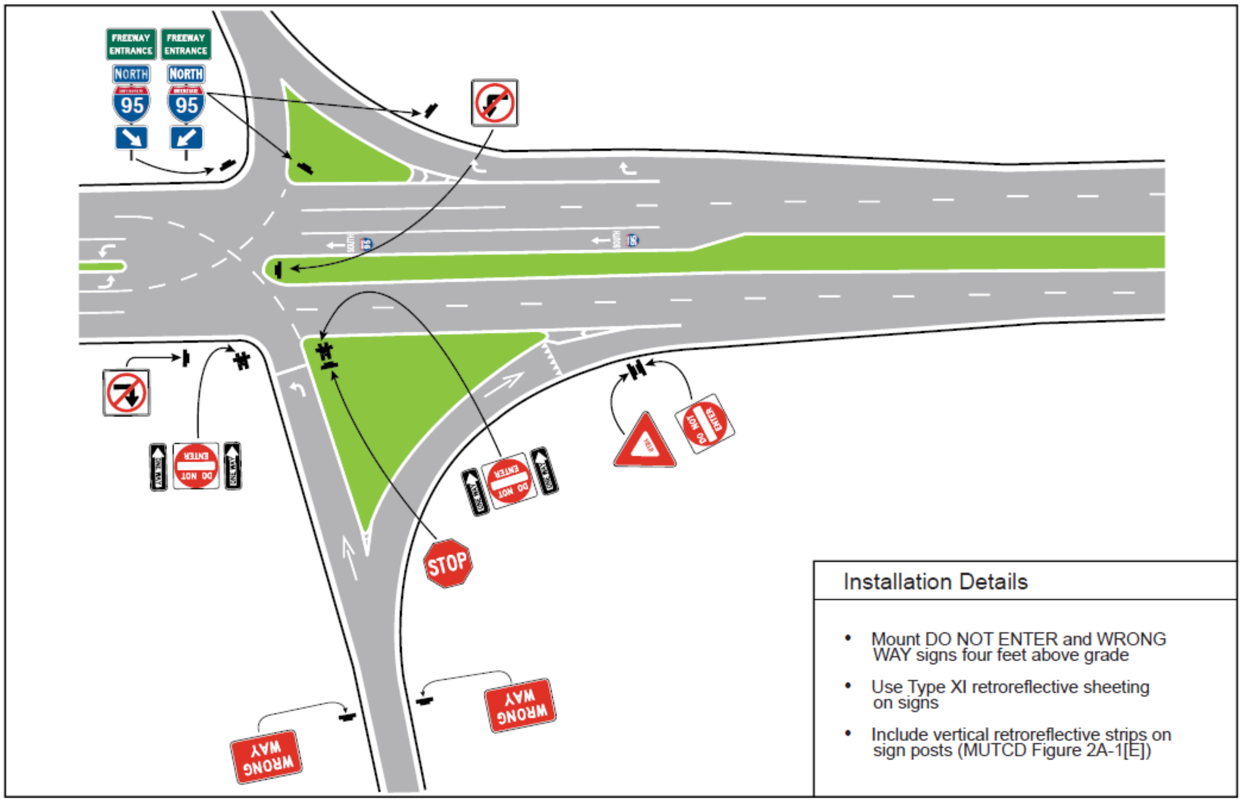

Figure 30. Basis for enhanced countermeasure condition.

Important features to note are that the enhanced countermeasure condition included multiple Wrong Way signs identified in the lab-based task as an important cue for exit ramp classification. Do Not Enter signs were oversized in this condition and lowered. Turn restriction signs were implemented (No Left Turn near the exit ramp on the left). Vertical red retroreflective strips were included on all signs associated with exit ramps in the enhanced countermeasure condition. Figures 31 - 38 depict what these measures looked like within the simulator during daytime and nighttime scenarios. The enhanced countermeasure condition also included large overhead Wrong Way signs and pavement shields in left-turn lanes indicating the highway number with forward arrows.

Figure 31. Driver view in the simulator of the minimum countermeasure condition.


Figure 32. Driver view in the simulator of the minimum countermeasure condition (exit ramp).

Figure 33. Driver view in the simulator of the enhanced countermeasure condition.

Figure 34. Driver view in the simulator of the enhanced countermeasure condition (exit ramp).

Figure 35. Driver view in the simulator of the minimum countermeasure condition (entrance ramp).

Figure 36. Driver view in the simulator of the enhanced countermeasure condition (entrance ramp).

Figure 37. Driver view in the simulator of the minimum countermeasure condition at night (exit ramp).

Figure 38. Driver view in the simulator of the minimum countermeasure condition at night (exit ramp).

Simulator Task

After a short unrelated practice scenario participants were asked to drive Eastbound and Westbound in the scenario of interest (once in each direction). Older adult participants (*N* = 40) all drove in a day-time variant of the scenario, while younger adults (*N* = 80) all drove in a night-time variant of the scenario. This is consistent with the time of day most associated with WWCs by each group. Half of the younger adult group participated in an impaired/dual-task condition described later. This created three groups: Older Adult, Younger Adult Impaired, and Younger Adult Unimpaired. The four possible scenarios were: Eastbound with minimum countermeasures, Eastbound with enhanced countermeasures, Westbound with minimal countermeasures, and Westbound with enhanced countermeasures. Initial direction of travel (East or West bound) and first countermeasure encountered were varied between participants.

Drivers were given a direction of travel (i.e., North on the highway), and travel destination (i.e. Lansing) at the beginning of the scenario, but no further instructions were given. The appropriate exit was on the left. Road signs cued drivers to their destination. Minimal ambient traffic was present. The behavior of other vehicles was anticipated to serve as a strong cue regarding ramp type and our aim was to have participants primarily influenced by countermeasures rather than traffic. The scenario was programmed to terminate once the participant travelled on either of the wrong-way ramps (one on the left, one on the right), or if they drove straight without making the appropriate left ramp entry (i.e., this was a situation in which participants missed the opportunity to turn on all ramps). In order to best characterize the influence of wrong way countermeasures on driving behavior the scenario was divided into sub-region Areas of Interest (AOIs, see Figure 39). We anticipated that driver behavior measures of confusion would manifest near a ramp that would allow a wrong way entry. As such, the two main regions of interest for this scenario were the 64 feet before (purple) and after (green) the stop bar in advance of the exit ramp on the left where drivers could make a wrong-way entrance. In some analyses, we focus on a sub-region of the “after” AOI directly adjacent to the exit ramp (blue).

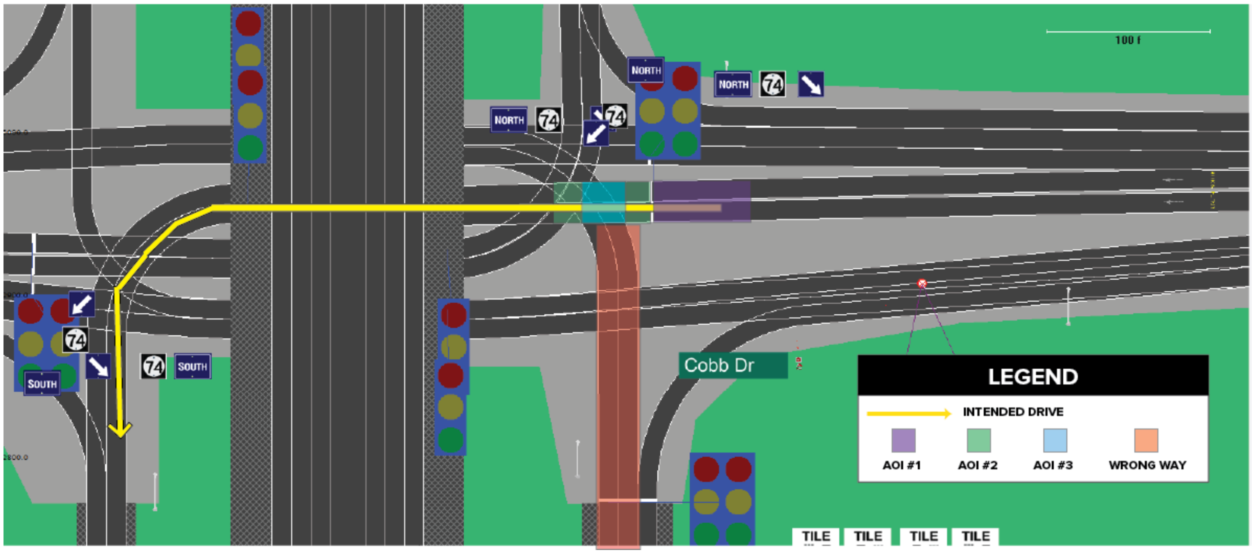

Figure 39. Depiction of areas of interest leading up to the exit ramp (shaded in orange). The yellow arrow represents the path to make a right way entrance.

Impaired Condition

In order to simulate the experience of drug/alcohol impairment in younger adults, a dual-task paradigm was used in combination with goggles that distorted vision (http://fatalvision.com/single-goggle-kit-360.html). The dual-task paradigm (similar to the Auditory Continuous Memory Task; Veltman & Gaillard, 1998) auditorily presented drivers with a stream of letters (1 digit per 0.5 - 1.0 seconds; randomly determined in intervals of 0.1), and participants were asked to report the number of target letters (the letter A) they heard immediately at the conclusion of the driving scenario. Practice trials were given to participants seated in the simulator prior to beginning the drive to ensure that they understood the nature of the task. The dual-task automatically began after the participant reached 20 mph in each scenario. Participants in the impaired condition completed both scenarios (minimum and enhanced) under conditions of impairment.

Results

Wrong Way Entries

Across both countermeasure conditions, approximately 13% of participants proceeded straight through the scenario without turning onto an entrance or exit ramp. Tables 8 and 9 provide more detail about drivers' turning decisions as a function of group and countermeasure condition. In the analysis of wrong way entries all data were considered (regardless of whether the wrong way occurred with a left or right turn). However, due to the differing behavior of participants, we focus primarily on participants who followed instructions (exited left toward their destination city) in later analyses examining subtle potential indicators of confusion (e.g., speed, braking).

In total, four wrong-way entries were observed. Statistical significance is difficult to achieve when analyzing the frequency of very low probability events (a characteristic of wrong-way crashes) unless sample sizes are extremely large. However, for all drivers, a chi-square test revealed a significantly greater number of wrong way entries in the minimum countermeasure condition compared to the enhanced countermeasure condition, X^2 (1) = 4.07, p < .05. This result must be interpreted with caution given the small number of observations within each cell. To correct for this, Fisher's Exact Test is recommended, and with this conservative correction the 2-sided test fails to reach statistical significance (p = .12). A Monte Carlo simulation further explored the likelihood that all four wrong-way events would occur in the minimum countermeasure condition by chance. Two sets of data (minimum, enhanced; N =120 each) were created by randomly sampling without replacement from the observed data set (4 wrong-way events, 236 non wrong-way events) for a total of 5,000 iterations. By chance alone the likelihood that all four wrong-way events would fall within the minimum countermeasure condition was low (p = .061). Overall data indicate a trend for fewer wrong-way entries within the enhanced condition. Consistent with previous reports, wrong-way entries did not occur in the young adult unimpaired condition. Two wrong-way entries occurred within the older adult sample, and two occurred within the impaired younger adult sample.

Table 10. Turning behavior of all participants in the minimum countermeasure condition.

Minimum	Exited Left		Did Not Exit Left	
	Left-Turn Wrong Way	Right Way	Missed all exits	Right-Turn Wrong Way
Younger	0	38	2	0
Younger (Impaired)	2	32	6	0
Older	1	31	7	1
Total	3	101	15	1

Table 11. Turning behavior of all participants in the enhanced countermeasure condition.

Enhanced	Exited Left		Did Not Exit Left	
	Left-Turn Wrong Way	Right Way	Missed all exits	Right-Turn Wrong Way
Younger	0	38	2	0
Younger (Impaired)	0	32	8	0
Older	0	34	6	0
Total	0	104	16	0

Minimum Speed

If participants thought they needed to turn sooner (using the exit ramp rather than the entrance ramp further down the road), a reasonable behavior would be for participants to reduce their speed in anticipation of the turn. Slower speeds might also represent general uncertainty regarding where to go. To ensure comparability across participants, we only included participants in the following analyses who followed directions (exited toward the appropriate city on the left). Recall that we created two primary areas of interest surrounding the exit ramp on the left (64 feet before the stop bar of the interchange and 64 feet after). Minimum speed data were entered into an ANOVA (Analysis of Variance) with Countermeasure Condition (minimum vs. enhanced) and Area of Interest (AOI Before, AOI After stop bar) as within-participant factors, and Risk Status as a between participant factor (Older Adults & Impaired Younger Adults vs. Non-Impaired Younger Adult). Previous literature suggests that younger unimpaired drivers are unlikely to experience confusion. We also anticipated a potential effect of the first countermeasure configuration participants encountered. If enhanced countermeasures are effective at indicating where to go (past the first ramp on the left and under the overpass to the entrance ramp), participants might remember this solution even when the countermeasures were minimal during the next scenario. For this reason, First Countermeasure (Enhanced First vs. Minimum First) was included as an additional between-participant factor in the ANOVA.

This analysis revealed a main effect of Countermeasure Condition ($F(1, 79) = 10.73$, $p < .01$). Estimated marginal means are reported (Figure 40). Across the two areas of interest, average minimum speed was 33.89 MPH in the minimum condition and 36.43 MPH in the enhanced condition. This is consistent with greater confusion/uncertainty in the minimum condition. However, Countermeasure Condition interacted with First Countermeasure observed ($F(1, 79) = 8.10$ $p < .01$). The source of this interaction was that there was little difference in minimal speed when participants experienced the Enhanced Condition first (35.79 vs. 36.12 MPH for minimum and enhanced countermeasures, respectively) and larger differences when participants experienced the minimal condition first (32.00 vs. 36.74 MPH). Having initially experienced enhanced condition cues and successfully navigated the entrance ramp appears to have influenced performance in the later scenario featuring minimal countermeasures. Note that although we counterbalanced direction of travel (east bound vs. west bound), the correct "solution" was the same for both scenarios: drive past the signal, under the overpass, and turn left. In general, results support that speed may serve as an index of ramp confusion, but that familiarity regarding the correct location of a ramp may play an important role as well. Risk Status did not significantly interact with any other variable (all interaction term p values $> .23$).

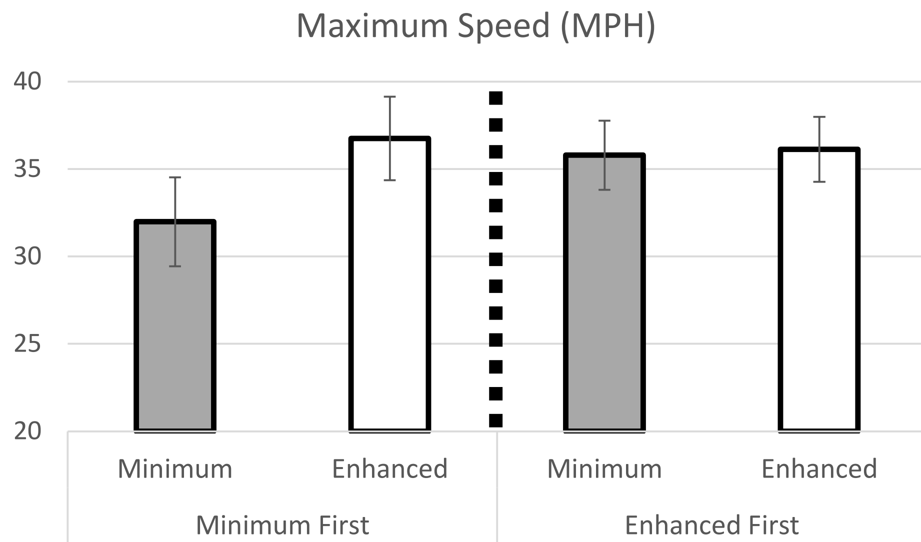

Figure 40. Minimum speed data across two areas of interest as a function of countermeasure configuration *and which countermeasure configuration participants encountered first. Error bars represent 95% confidence intervals.*

A cleaner comparison that avoids the difficulty of interpreting countermeasure effects in the presence of interactions with presentation order is to compare participants only on the first countermeasure condition they encountered (a strictly between-group comparison). A MANOVA was conducted including minimum speed data from both areas of interest and including Risk Status as a covariate. This revealed a significant effect of countermeasure type (Wilks' $\lambda = .91$, $F\ (2, 82) = 4.11$, $p <. 05$). Before the stop bar (AOI Before), participants exposed to minimum countermeasures reached lower minimum speeds (31.30 vs. 36.06 MPH, $F(1, 83) = 7.54$, $p < .01$). The same was true for the area of interest after the stop bar (30.66 vs. 35.30 MPH, $F(1, 83) = 8.22$, $p < .01$).

Overall, participants reached lower speeds near an opportunity to make a wrong-way entrance when countermeasures were minimal. This pattern may represent a behavioral measure of confusion. Since Risk Status did not interact with countermeasure effects, effects appear to be similar regardless of age or simulated impairment. Average speed was also explored as a predictor of confusion. Identical analyses were performed as the ones described previously with similar results. Lower average speeds were associated with the minimal countermeasure condition. This is not surprising given the extremely high correlation between average speed and minimum speed ($r = .996$).

Next braking response and lane deviation were examined as potential predictors of confusion. To preview results, these driving metrics did not appear to strongly differentiate between Minimum and Enhanced conditions.

Braking Response:

Braking response was also explored as a potential measure of confusion. Braking in advance of or near an exit ramp might signal either confusion or intent to turn onto an exit ramp. We chose to analyze braking response as the maximum force applied to the brake pedal near the exit ramp on the left. Maximum brake force data were entered into an ANOVA with Countermeasure Condition (minimum vs. enhanced) and Area of Interest (AOI Before, AOI After stop bar) as within-participant factors, and Risk Status as a between-participant factor (Older Adults & Impaired Younger Adults vs. Non-Impaired Younger Adult). Countermeasure order (minimum vs. enhanced first) was also included as a between-participant variable. The only significant effect observed was an Area of Interest by Countermeasure condition interaction ($F(1, 79) = 5.37$, $p < .05$). This pattern was different compared to differences observed in minimum speed (in general, lower minimum speeds were observed in both areas of interest). Figure 41 depicts these data. The source of this interaction appeared to be similar maximum brake force applied before and after the stop bar in the minimum condition (2.09 vs. 2.43 pounds of force for Before and After AOIs, respectively), but increasing maximum brake force after the stop bar for participants in the enhanced condition (0.96 vs. 3.52 pounds of force). A shift in the distribution of maximum brake force to closer to the interchange may serve as an index of less confusion, though interpretation is not as clear as with speed measures. The area of interest in this latter AOI (after the stop bar) includes the area adjacent to the exit ramp on the left. Thus another interpretation might be that participants were breaking to turn *onto* the exit ramp in the enhanced condition. Disambiguating these possibilities is necessary before suggesting maximum brake force as a means of measuring wrong-way confusion. It should also be noted that on average, participants were going faster during this second AOI in the enhanced condition, which may necessitate greater braking in preparation not for a wrong-way entrance, but a right-way entrance.

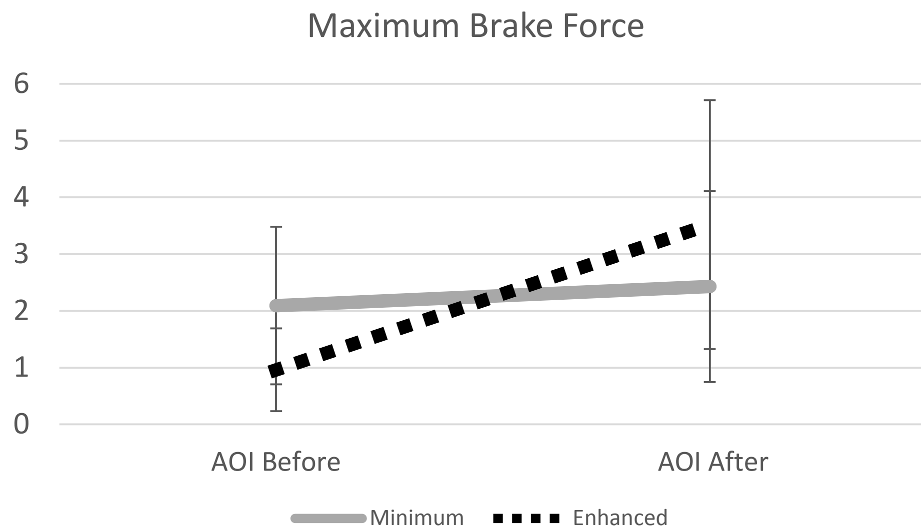

Figure 41. Maximum brake force (in pounds of force) as a function of AOI (before and after the stop bar leading up to the exit ramp on left) and countermeasure type. Error bars represent 95% confidence intervals.

Lane Deviation:

Finally, deviation within one's own lane may also be an indicator of confusion or uncertainty in advance of an exit ramp. A confused driver might steer toward then away from the exit ramp, initially thinking the exit ramp was an entrance ramp and then rejecting it. Data representing variability (*SD*) in lane deviation were entered into an ANOVA (Analysis of Variance) with Countermeasure Condition (minimum vs. enhanced) and Area of Interest (AOI Before, AOI After stop bar) as within-participant factors, and Risk Status as a between participant factor (Older Adults & Impaired Younger Adults vs. Non-Impaired Younger Adult). This analysis revealed no effect of Countermeasure ($F(1, 79) = .59$, $p = .44$). Countermeasure did not significantly interact with any other variable (all p values > .058). The trend for a Countermeasure by First Countermeasure interaction ($F(1, 79) = 3.70$, $p = .058$), though not significant, suggested a pattern of less lane variability in the Minimum condition after having first received enhanced countermeasures (Table 12).

Table 12. SD in lane deviation (in feet) as a function of countermeasure condition and countermeasure order.

				95% Confidence Interval	
CM First	**Countermeasure**	**Mean**	**Std. Error**	**Lower Bound**	**Upper Bound**
ENH	Minimum	.186	.041	.104	.268
	Enhanced	.368	.067	.235	.500
MIN	Minimum	.375	.053	.269	.481
	Enhanced	.297	.086	.127	.468

We conducted a more focused analysis on only the section of roadway adjacent to the exit ramp on the left (see blue region of Figure 39). If confusion has an influence on lane deviation it is likely to occur here. This analysis suggested that countermeasure type did have an effect, but an order effect similar to what was observed with the speed measure was also present. This analysis revealed a significant Countermeasure Type by Countermeasure Order interaction ($F(1, 82) = 6.44$, $p < .01$). Figure 42 indicates lower lane variability in the enhanced condition, but only if participants encountered the minimum condition first. Having experienced the enhanced measure first may have influenced subsequent driving behavior. No interaction was observed with risk status (all interaction term p values > .18).

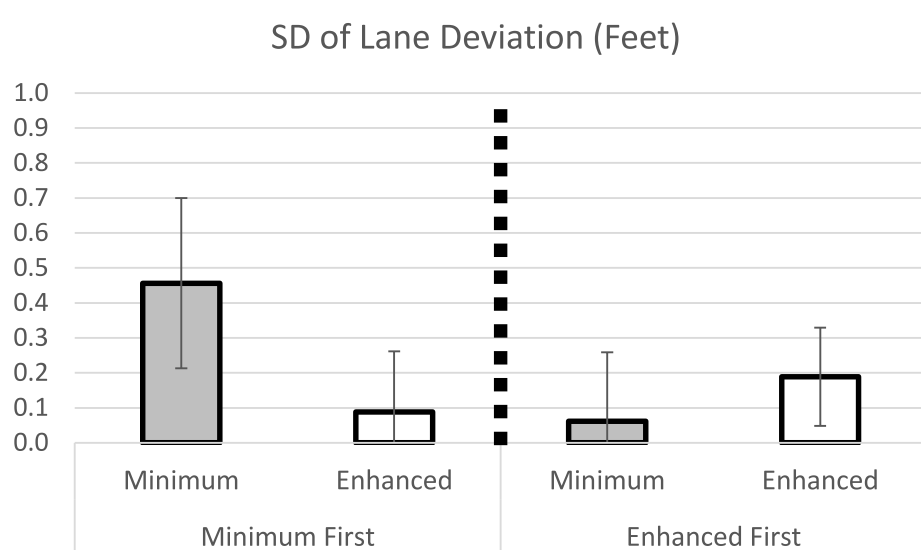

Figure 42. For all participants, variability in lane position adjacent to the exit ramp on left as a function of countermeasure configuration and which countermeasure configuration participants encountered first. Error bars represent 95% confidence intervals.

Individuals who made a wrong-way maneuver exhibited extreme lane deviation because they exited their lane to take the exit ramp. However, Figure 43 depicts lane deviation scores when these individuals are removed from analysis. The general pattern of results remains unchanged.

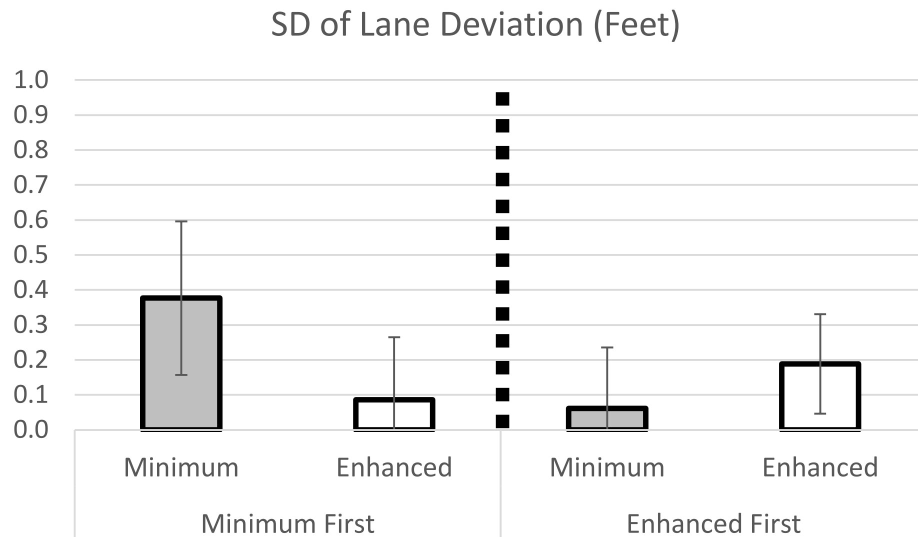

Figure 43. For only participants who did not engage in a wrong-way maneuver, variability in lane position adjacent to the exit ramp on left as a function of countermeasure configuration and which countermeasure configuration participants encountered first. Error bars represent 95% confidence intervals.

Verbal Reports

To better understand the decision making process, a subset of participants were asked to think-aloud as they drove the scenario while their verbalizations were recorded. Half of the older participants and half of the younger adults in the unimpaired condition provided think-aloud reports during the driving task. As was done for the free-response questions asked following the lab task, independent raters coded participants' verbal reports to indicate the number of times each participant mentioned a given feature or cue (e.g., signs, pavement markings, presence of other vehicles). Then the total number of times each feature was mentioned was compared between age groups and countermeasure conditions.

Participants very infrequently mentioned any specific type of sign. Across all 40 participants (20 younger, 20 older) for which verbal reports had been collected, no participant mentioned Do Not Enter, Wrong Way, One Way, or Freeway Entrance signs at any point during either scenario. Two younger adults, one in the minimum countermeasures condition and one in the enhanced condition, mentioned guide/route signs. Instead, participants were far more likely to make a nonspecific comment about signs (i.e. not specify the sign to which they are referring). These types of comments were no more frequent among younger (n = 19) than older (n = 12) adults, X^2 = 1.58, p = .21, nor did they differ across countermeasure condition (enhanced: n = 16, minimum: n = 15, X^2 = .03, p = 86.

Participants mentioned neither specific pavement markings nor any general comment about pavement markings in their verbal reports. No participant mentioned stop lines, directional arrows, pavement shields indicating route, or any other specific type of pavement marking. There were also no instances of participants mentioning specific geometric features of the roadway (e.g., angle at which ramp meets the roadway).

Similar to the results from the representative features questions that followed the lab task, several participants did mention the presence of other vehicles and traffic signals, this too was infrequent in the verbal reports. In total, there were 6 instances of participants having mentioned the presence of other vehicles (Younger: n = 2, Older: n = 4). Across both age groups, there was no evidence that the frequency at which other vehicles were mentioned in the verbal reports varied between the enhanced and minimum countermeasure conditions (Minimum: n = 4, Enhanced: n = 2).

Although also infrequent (n = 10), participants in the simulator study mentioned traffic signals in their verbal reports. There was no evidence that the tendency to mention traffic signals differed between age groups (Younger: n = 6, Older: n = 4), $X^2 = .40$, $p = .53$. The frequency at which traffic signals were mentioned in verbal reports also did not differ between countermeasure conditions (Minimum: n = 6, Enhanced: n = 4), $X^2 = .40$, $p = .53$.

If participants are uncertain, verbal reports should be more likely to contain general statements of confusion (e.g., “Where am I going?”). Participants’ verbal reports contained 19 instances of statements indicating confusion. The frequency of these statements did not differ between age groups (Younger: n = 10, Older: n = 9), $X^2 = .05$, $p = .82$, or countermeasure condition (Minimum: n = 8, Enhanced: n = 11), $X^2 = .47$, $p = .49$.

Conclusions

Simulator studies and lab-based decision studies appear to be promising methods to understand factors that contribute to decisions regarding highway entry points. In general, a greater number of countermeasures did appear to make a difference in judging correct highway entry points, consistent with the recommendations of the Statewide Wrong Way Crash Study. Simulator studies also reveal that vehicle speed, braking behavior, and lane deviation may serve as additional subtle measures of confusion. However, contrary to predictions, verbal reports did not provide additional insight into the decision process of drivers navigating interchanges.

Chapter 4. Summary of the Studies

Benefit of the Project

This project has provided relevant data to aid the formulation of policy and recommendations. Some of the findings with relevant policy implications are:

Task 1: Literature Review & Decision Model Development

A theoretical model developed based on the review of the literature on wrong-way entries, crashes, and wrong-way drivers suggests that enhancing countermeasures can be an effective means of reducing wrong-way entries and crashes. Comparisons of field studies to determine the most effective countermeasures is challenging due to idiosyncratic differences between studied interchanges. Driving simulator and lab-based studies are advantages as they can manipulate countermeasures and hold all other factors constant to better understand countermeasure effectiveness.

Task 2: Lab and Simulator Tasks

Lab and simulated studies suggest that increasing the number and diversity of countermeasures present at interchanges can reduce confusion regarding highway entry points. The driving simulator study suggests that there may be subtle behaviors indicative of confusion that can be used in future studies of wrong-way countermeasures. This is an important finding as wrong-way entries are relatively rare events.

Specific Recommendations Based on Study Findings

1) Problematic interchanges would likely benefit from an increase in the number and diversity of countermeasures to prevent WWCs. This report presents initial empirical evidence that the new minimum set of countermeasures proposed by the Statewide Wrong Way Crash Study, which increases the salience of countermeasures and the number of countermeasures at interchanges, may decrease confusion regarding the correct highway entry point.

2) The driving study presented here represents promising evidence that simulators can be used to investigate wrong-way entries and confusion. In addition to whether or not a wrong-way entry occurs, more sensitive metrics of speed, braking behavior, and lane deviation are available. We recommend further simulator studies with larger samples to provide additional evidence for the efficacy of specific countermeasures. Here we compared two sets of countermeasures, but future studies may link decreased confusion to specific individual countermeasures (e.g., larger Do Not Enter signs). It is possible that one or a few of the additional countermeasures in the new proposed minimum have the most impact in reducing confusion, with other countermeasures having little or no effect. Eyetracking may also reveal the specific cues that aid in the decision process. Cost savings might be achieved by better understanding, out of the set of countermeasures implemented, which are responsible for decreased confusion.

3) In our review, alcohol and drug impairment appear to be the largest risk factor associated with WWCs. Efforts should be continued with respect to reducing impaired driving.

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Appendix A. Variables coded in the archival data analysis.

Variable	Description
Interchange type	Ramp type. Taken directly from description in reports.
Wrong-way movements pre-change period	Number of recorded wrong-way movements per 30-day period before any changes were implemented.
Wrong-way movements post-change period	Number of recorded wrong-way movements per 30-day period after all changes had been implemented.
Number of days observed (pre/post)	The number of days the camera monitoring system was set up at a given ramp. If the count given in the report was a 30-day average, the value for this variable was assumed to be 30.
Frontage road*	Whether or not a frontage road was present in the area around the ramp (0 or 1). This information was taken from the descriptions in reports.
Location*	Whether the ramp was located in a urban, rural, or suburban area. The suburban category was added and applies to ramps that were located in an isolated residential area.
Businesses*	Whether or not businesses were present in the area around the ramp (0 or 1). In several cases the description of a ramp mentioned that some wrong-way movements were due to drivers confusing the ramp for the entrance to a nearby gas station or restaurant.
Nearby Attraction / Point of Interest*	Whether the ramp was near any major attraction or point of interest (0 or 1). This category would include any special location that is likely to be associated with an increased number of motorists present who are unfamiliar with the area, such as tourist attractions, large shopping malls, or recreation areas. For example, one interchange reviewed was near Sea World, San Diego and another was near Dodgers Stadium (both of these would have been present at the time the report was published).
Change to regulatory signs	Whether changes were made to regulatory signs around the ramp (0 or 1). Changes may include adding signs, relocating signs, or taking some measure to increase the conspicuity of these signs. Regulatory signs in this context would have the function of

	warning motorists away from a given entry/exit point or alerting them that they are traveling in the wrong direction.
Changes to guide or directional signs	Whether changes were made to guide or other directional signs around the ramp (0 or 1). These changes may include adding signs, relocating signs, or taking measures to increase the conspicuity of these signs. These signs would all have a common function of making motorists more confident they are headed toward their intended destination.
Changes to signs, unspecified	The report mentions making changes to signs, but does not specify the type of change made (0 or 1).
Changes to pavement markings	Whether or not pavement markings were added to the ramp (0 or 1). This would include directional arrows
Changes to road geometry	Whether changes involved altering the structure of the road at the entrance or exit ramp. This would include changes such as adding a median or divider, widening or narrowing the lane, or adding/removing/moving a lane
Other changes	Changes not captured by any of the above categories (0 or 1). Examples of this category include adding traffic signals to the interchange and making lighting changes. In most cases, the type of change coded in this category occurred only once in the data set.
Changes made	Whether or not any change was made to the ramp or surrounding area. In some cases, a site visit revealed no obvious problems, so no changes were implemented. For these cases, an initial wrong-way movement count was provided, but in no instance was a second observation period was conducted.

* Missing data: In order to maximize the number of cases with complete data, we filled in information about the interchanges from supplementary sources. In some instances it was possible to locate a given ramp on Google Earth/Maps based on information provided in the reports. We then used historical information to determine whether or not key features of the interchange and surrounding area were present at the time the report was published. For example, in some cases we used Google Maps images to determine if a ramp was in a rural, urban, or suburban area. If the area surrounding a ramp was rural in recent images, it was assumed that was also a rural area in the late 1970s. If a ramp was found to be located in a major city (e.g., Los Angeles, Sacramento, San Diego), it was coded as urban. Suburban locations were determined by checking (on www.zillow.com) whether houses surrounding the ramp were constructed prior to the time the report was published. In many cases reports explicitly mention whether points of interest are present in the area near an interchange (e.g., “ramp was located near a popular state park”), but this information was not reliably included. In some cases, data from Google Maps allowed us to determine whether there was some point of interest near a ramp. In one instance, an interchange at Stadium Boulevard in Los Angeles, CA (Rinde, 1978) was found to be

near Dodger’s Stadium, which opened in 1962. This case was coded as having a nearby attraction/point of interest. Data was not added unless clear supporting evidence could be found.

Appendix B. Ramp categories included in the archival data file.

Original Interchange Type	Number of Ramps	Combined Category	Number of Ramps
Diamond	50	Full Diamond	50
Half Diamond	7	Partial Diamond	10
Partial Diamond	1		
Quarter Diamond	2		
Split Diamond	5	Other Diamond	7
Modified Diamond	1		
Left Hand Diamond Off Ramp	1		
Diamond w/ Cloverleaf	2	Partial Cloverleaf	31
Partial Cloverleaf w/ Buttonhook	1		
Partial Cloverleaf	28		
Cloverleaf	1	Cloverleaf	1
Buttonhook	6	Buttonhook	8
Four Lane Buttonhook	1		
Hook Ramp	1		
Loop Ramp	2	Loop	8
Isolated Loop	1		
Loop	1		
Loop Off Ramp	1		
Skewed Loop, Partial Interchange	1		
Partial Interchange, Loop Ramp	1		
Partial Loop Off Ramp	1		
Isolated Off Ramp	3	Other	16
Slip Ramp	3		
Scissors	2		
Irregular	1		
Unusual Configuration	4		
Four Way Stop	1		
Incomplete Interchange	1		
Five-Legged Intersection	1		
Unclassified	32	Unclassified	32
TOTAL:	**163**		**163**

Appendix C. Categories Coded for each Ramp Image.

Ramp Type	Entrance
	Exit

Location	Rural	
	Suburban	
	Urban	

Terrain	Flat	
	Hills	
	Mountains	

	0	**1**	**2**	**3**	**4**
Vegetation	None or very little vegetation. Includes urban and also desert areas	Grass only, grass short, no trees or shrubs near ramp but may be visible in the distance	Grass, some shrubs, grass may be taller but is not overgrown	Dense vegetation around ramp area. Trees growing close to ramp.	Overgrown vegetation near ramp. Tall grass and shrubs that have not been maintained

Time of Day	Daylight
	Dusk/Dawn
	Night

Weather	Clear
	Cloudy/Overcast
	Rain

	1	2	3
Number of Lanes	Ramp has only a single lane, no additional lanes meet or feed in to ramp	Ramp has 2 lanes at terminal end. Need not have multiple lanes further up ramp.	Ramp has 3 or more lanes at terminal end. Need not have multiple lanes further up ramp.

Shoulder / Curb	Flush shoulder, no curb
	Curb and gutter, no sidewalk
	Curb and gutter w/ sidewalk

Ramp Curved or Straight	Curved
	Straight

Highway visible from ramp	Yes
	No

Lighting	Will not be included. No convenient way to code. All daytime images.

Do Not Enter	Number at ramp end	Count; 0 indicates entrance ramp
	Size	Standard, Oversized, NA (entrance ramp)
	Mounting Height	Standard, Lower, NA (entrance ramp)
	Retroreflective strips on sign post	Yes, No, NA (entrance ramp)
	Additional signs further down ramp	Yes, No, NA (entrance ramp)

Wrong Way	Number at ramp end	Count; 0 indicates entrance ramp
	Size	Standard, Oversized, NA (entrance ramp)
	Mounting Height	Standard, Lower, NA (entrance ramp)
	Retroreflective strips on sign post	Yes, No, NA (entrance ramp)
	Additional signs further down ramp	Yes, No, NA (entrance ramp)

One Way	Number at ramp end	Count; 0 indicates entrance ramp
	Size	Standard, Oversized, NA (entrance ramp)
	Mounting Height	Standard, Lower, NA (entrance ramp)
	Retroreflective strips on sign post	Yes, No, NA (entrance ramp)
	Additional signs further down ramp	Yes, No, NA (entrance ramp)

Freeway Entrance	Number at ramp end	Count; 0 indicates exit ramp
	Size	Standard, Oversized, NA (exit ramp)
	Mounting Height	Standard, Lower, NA (exit ramp)
	Retroreflective strips on sign post	Yes, No, NA (exit ramp)
	Additional signs further down ramp	Yes, No, NA (exit ramp)

Route/Guide Signs (e.g. I-95, cardinal direction)	Number at ramp end	Count; 0 indicates exit ramp
	Size	Standard, Oversized, NA (exit ramp)
	Mounting Height	Standard, Lower, NA (exit ramp)
	Retroreflective strips on sign post	Yes, No, NA (exit ramp)

	Additional signs further down ramp	Yes, No, NA (exit ramp)

Other signs (e.g. construction, point of interest, exclude business, advertising, or any non highway sign)	Number at ramp end	Count; 0 indicates no other signs present
	Size	Standard, Oversized, NA (no other signs)
	Mounting Height	Standard, Lower, NA (no other signs)
	Retroreflective strips on sign post	Yes, No, NA (no other signs)
	Additional signs further down ramp	Yes, No, NA (no other signs)

Pavement markings							
	Stop Bar	**0**	**1**	**2**	**3**	**4**	**5**
		Exit ramp but no evidence a stop bar was ever present	Heavy wear, stop bar almost completely worn away	Heavy wear, parts of stop bar no longer visible	Moderate wear, stop bar still visible	Clearly visible but some wear	Freshly painted, minimal wear
	Crosswalk	**NA**	**1**	**2**	**3**	**4**	**5**
		No crosswalk, no evidence of one ever having been present	Heavy wear, crosswalk almost completely worn away	Heavy wear, parts of crosswalk no longer visible	Moderate wear, crosswalk still visible	Clearly visible but some wear	Freshly painted, minimal wear
	Painted curb edge line	**NA**	**1**	**2**	**3**	**4**	**5**
		No curb edge line, no evidence of one ever having been present	Heavy wear, curb edge line almost completely worn away	Heavy wear, parts of curb edge line no longer visible	Moderate wear, curb edge line still visible	Clearly visible but some wear	Freshly painted, minimal wear
	Painted median	**NA**	**1**	**2**	**3**	**4**	**5**
		No painted median, no evidence of one ever having been present	Heavy wear, painted median almost completely worn away	Heavy wear, parts of painted median no longer visible	Moderate wear, painted median still visible	Clearly visible but some wear	Freshly painted, minimal wear
		NA	**1**	**2**	**3**	**4**	**5**

	Directional arrows (includes wrong-way arrows and turn direction arrows)	No directional arrows, no evidence of one ever having been present	Heavy wear, directional arrows almost completely worn away	Heavy wear, parts of directional arrows no longer visible	Moderate wear, directional arrows still visible	Clearly visible but some wear	Freshly painted, minimal wear
	**Coded NA if category did not apply (e.g. stop bar on entrance ramp)						

Other traffic control devices	Signal controlled intersection at ramp junction?	yes/no
	Pedestrian signals	yes/no

Image-specific features	Vehicles present on ramp	yes/no
	Number of vehicles present on ramp	Count
	Cross street visible	yes/no
	Vehicles present on cross street	yes/no
	Number of vehicles present on cross street	Count
	Blur on sign faces	yes/no

Appendix D. Questionnaire Set.

Wrong Way Crash Research Questionnaire

Participant Number: ________
Assessor Initials: ________
Date: ________

<u>Demographics Questionnaire:</u>

Gender: ☐ Male ☐ Female Date of Birth: ___/___/_____ Age: _____

1. What is your highest level of education?

- ☐ Less than high school graduate
- ☐ High school graduate/ GED
- ☐ Vocational training
- ☐ Some college/ Associate’s Degree
- ☐ Bachelor’s Degree (BS, BA)
- ☐ Master’s Degree (or other post-graduate training)
- ☐ Doctoral Degree (PhD, MD, EdD, DDS, JD, etc.)

2. Current martial status (check <u>one</u>)

- ☐ Single
- ☐ Married / Unified
- ☐ Separated
- ☐ Divorced
- ☐ Widowed
- ☐ Other (please specify) ___________________________

3. Do you consider yourself Hispanic or Latino?

- ☐ Yes
- ☐ No

3a. If “Yes”, would you describe yourself as:

- ☐ Cuban
- ☐ Mexican
- ☐ Puerto Rican
- ☐ Other (please specify) ______________________

4. How would you describe your primary racial group?

- ☐ No Primary Group
- ☐ White Caucasian
- ☐ Black/ African American
- ☐ Asian
- ☐ American Indian/ Alaska Native
- ☐ Native Hawaiian/ Pacific Islander
- ☐ Multi-racial
- ☐ Other _______________

5. In which type of housing do you live?

- ☐ Residence Hall/ College dormitory
- ☐ House/ Apartment / Condominium
- ☐ Senior housing (independent)
- ☐ Assisted living
- ☐ Relative's home
- ☐ Other (please specify) ________________________________

6. Is English your primary language?

- ☐ Yes
- ☐ No

6a. If "No", what is your primary language? ________________________

7. What is your primary mode of transportation? (Check one)

- ☐ Drive my own vehicle
- ☐ A friend or family member takes me to places I need to go
- ☐ Transportation service provided by where I live
- ☐ Use public transportation (e.g., bus, taxi, subway, van services)

Health Information

1. In general, would you say your health is:

☐	☐	☐	☐	☐
Poor	Fair	Good	Very good	Excellent

2. Compared to other people your own age, would you say your health is:

☐	☐	☐	☐	☐
Poor	Fair	Good	Very good	Excellent

3. How satisfied are you with your present health?

☐	☐	☐	☐	☐
Not at all satisfied	Not very satisfied	Neither satisfied or dissatisfied	Somewhat satisfied	Extremely satisfied

4. How often do health problems stand in the way of your doing things you want to do?

☐	☐	☐	☐	☐
Never	Seldom	Sometimes	Often	Always

5. Do you currently wear corrective glasses or contacts?

☐ Yes ☐ No

5a. If yes, what do you currently wear?

☐ Glasses ☐ Reading
☐ Bifocals ☐ Contact Lenses
☐ Trifocals ☐ Other _______________

Simulator Sickness Questionnaire

For each symptom, please circle the rating that applies to you RIGHT NOW.
Please complete even if you have no symptoms

SYMPTOM	RATING			
General discomfort	none	slight	moderate	severe
Fatigue	none	slight	moderate	severe
Headache	none	slight	moderate	severe
Eye strain	none	slight	moderate	severe
Difficulty focusing	none	slight	moderate	severe
Salivation increased	none	slight	moderate	severe
Sweating	none	slight	moderate	severe
Nausea	none	slight	moderate	severe
Difficulty concentrating	none	slight	moderate	severe
“Fullness of the head”	none	slight	moderate	severe
Blurred vision	none	slight	moderate	severe
Dizziness with eyes open	none	slight	moderate	severe
Dizziness with eyes closed	none	slight	moderate	severe
Vertigo	none	slight	moderate	severe
Stomach awareness	none	slight	moderate	severe
Burping	none	slight	moderate	severe

Other (please describe)

Phone Survey

It is very important that you answer the following questions honestly.

1. Do you own a cellular phone (please circle below)?

YES NO

2. If you answered YES above, is your phone a smartphone?

YES NO DON'T KNOW

3. Did you bring a cell phone to the lab with you today (please circle below)?

YES NO

4. If you answered YES above, where was your phone while you were completing the experiment tasks (driving simulator, computer-based tasks)?

A. In my pocket

B. In my purse/backpack in a different room from the one where I completed the experiment

C. In my purse/backpack in the same room where I completed the experiment

D. Other. Explain: ____

5. If you answered YES above, what alert setting is your cell phone **currently** set to (please circle below)?

SILENT

VIBRATE

RING

RING AND VIBRATE

PHONE IS OFF

OTHER (please describe below)

____

6. What kinds of notifications does your cellular phone receive? Notifications refer to any message (auditory,vibrate,visual) that alerts you to some event (circle all that apply).

Voice calls   text messages   emails   instant messages

Social media   games   other non-game applications

Digit Symbol—Coding

1	2	3	4	5	6	7	8	9
—	⊥	⊐	∟	⊔	○	Λ	×	=

Sample Items

2	1	3	7	2	4	8	2	1	3	2	1	4	2	3	5	2	3	1	4

5	6	3	1	4	1	5	4	2	7	6	3	5	7	2	8	5	4	6	3

7	2	8	1	9	5	8	4	7	3	6	2	5	1	9	2	8	3	7	4

6	5	9	4	8	3	7	2	6	1	5	4	6	3	7	9	2	8	1	7

9	4	6	8	5	9	7	1	8	5	2	9	4	8	6	3	7	9	8	6

2	7	3	6	5	1	9	8	4	5	7	3	1	4	8	7	9	1	4	5

7	1	8	2	9	3	6	7	2	8	5	2	3	1	4	8	4	2	7	6

Appendix E. General Health Questionnaire Results.

Age Group and Gender

	Male	Female	Total
Older	19	20	39
Younger	28	46	75

Education

	Younger	Older	Total
Did not complete high school	0	0	0
High school graduate / GED	3	3	6
Vocational training	0	2	2
Some college / Associate's degree	49	12	62
Bachelor's Degree	17	11	28
Master's degree or other post-graduate	5	5	10
Doctoral degree (PhD, MD, EdD, DDS, JD)	0	6	6

Race / Ethnicity

	Younger	Older	Total
White / Caucasian	47	37	85
Black / African American	6	2	8
Asian	5	0	5
American Indian / Alaska Native	0	0	0
Native Hawaiian / Pacific Islander	1	0	1
Multi-racial	9	0	9
Other	1	0	1
No primary group	5	0	5
Prefer not to respond	0	0	0

Do you consider yourself Hispanic / Latino?

	Describe self as…	Younger	Older	Total
Yes	**Cuban**	3	0	3
	Mexican	2	0	2
	Puerto Rican	1	0	1
	Other	10	0	10
	Prefer not to respond	2	0	2
No	**NA**	56	39	96

Marital Status

	Younger	Older	Total
Single	70	5	76
Married / Unified	2	20	22
Separated	0	2	2
Divorced	0	6	6
Widowed	0	6	6
Other	2	0	2

Housing

	Younger	Older	Total
Residence Hall / College dormitory	5	0	5
House / Apartment / Condominium	67	39	106
Senior housing (independent)	0	0	0
Assisted living	0	0	0
Relative's home	0	0	0
Other	2 (Sorority House)	0	2

Is English your primary language?

	My primary language is…	Younger	Older	Total
Yes	**English**	63	38	101
No	**Chinese**	1	0	1
	Dutch	1	0	1
	German	0	1	1
	Spanish	8	0	8
	Telugu	1	0	1

What is your primary mode of transportation?

	Younger	Older	Total
I drive my own vehicle	70	39	109
A friend or family member takes me to places I need to go	2	0	2
Transportation service provided by where I live	0	0	0
I use public transportation	2	0	2

In general, would you say your health is:

	Younger	Older	Total
Poor	0	0	0
Fair	2	5	7
Good	26	14	40
Very good	27	16	43
Excellent	19	4	23

Compared to other people your own age, would you say your health is:

	Younger	Older	Total
Poor	0	0	0
Fair	4	4	8
Good	29	9	38
Very good	23	19	42
Excellent	18	7	25

How satisfied are you with your present health?

	Younger	Older	Total
Not at all satisfied	0	0	0
Not very satisfied	6	5	11
Neither satisfied nor dissatisfied	4	4	8
Somewhat satisfied	41	20	61
Extremely satisfied	23	10	33

How often do health problems stand in the way of your doing things you want to do?

	Younger	Older	Total
Never	30	9	39
Seldom	35	19	54
Sometimes	8	9	17
Often	1	2	3
Always	0	0	0

Do you currently wear corrective lenses or contacts?

	I wear…	Younger	Older	Total
Yes	Glasses	30	9	39
	Bifocals	1	8	9
	Trifocals	0	3	3
	Reading	2	7	9
	Contact Lenses	31	2	33
	Other	0	7	7
No	NA	33	8	41