



New, Improved, Comprehensive, and Automated Driver's License Test and Vision Screening System

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16. Abstract This one-of-a-kind comprehensive study highlights the importance of automated testing techniques and the significance of vision screening measures other than standard visual acuity testing for assessing all drivers and, in particular, at-risk drivers and older drivers. Non-automated tests tend to be subjective, time-consuming, costly, and heavily reliant on the experience of the examiner. Due to the high collision, injury, and fatality rates of all drivers in the State of Arizona, and the disproportionate number of at-fault older drivers and collision risks in the States of Arizona and Florida, new and automated screening methodologies and vision standards are now needed to promote road safety, predict visual impairment, and evaluate possible restriction or confiscation of driver's licenses. This study demonstrates that environmental factors and manner of collisions increase in collision involvement for drivers between ages 50 to 59 years in both Arizona and Florida. Drivers age 80 to 89 years in both states are most likely at-fault in collisions compared to all other age cohorts. These results are consistent among drivers cited for collision involvement due to visual defects. Our findings, which span an 11- year period from 1991 to 2001, not only apply to Arizona and Florida, two states with some of the largest proportions of older individuals in the United States, but, as our global survey of motor vehicle bureau directors or their representatives of the United States, Commonwealth of Puerto Rico, United Kingdom, Canada, New Zealand, and Australia illustrate, any state, country, province, territory, commonwealth, or nation with an increasing number of older drivers. A pilot study, to follow, ultimately allows for the implementation of effective strategies for screening of visual impairment and eye disease in all Arizona drivers. Snellen acuity, the most widely used vision testing measure, accounts for less than 0.1 percent of the visual field and fails to quantify contrast sensitivity and color vision (Fink and Sadun, 2004), two of several visual parameters needed for safe driving. It is recommended that at-risk and older drivers in Arizona are tested for vision through a newly designed system of measures provided by two automated tests (to test vision condition and function) and one driving simulator (to assess eye status). Hence we integrate it into a larger system and provide additional recommendations as these relate to motor vehicle operation skills and cognition. These automated systems and methodologies may ultimately serve as a prototype of transportation license testing improvements for all other states, countries, and agencies (e.g., aviation, rail, maritime, commercial vehicles, etc.) to follow. Such techniques may also reduce the incidence of fraudulent schemes and issuances of driver's licenses, commercial driver's licenses, and hazardous materials transportation licenses.			
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I dedicate this report to the memory of Max, my grandfather, a pedestrian statistic. May this report serve as a testament to his legacy. He is sorely missed.

This one is for you, Papa.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
<u>LENGTH</u>					<u>LENGTH</u>				
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
<u>AREA</u>					<u>AREA</u>				
in ²	square inches	645.2	square millimeters	mm ²	mm ²	Square millimeters	0.0016	square inches	in ²
ft ²	square feet	0.093	square meters	m ²	m ²	Square meters	10.764	square feet	ft ²
yd ²	square yards	0.836	square meters	m ²	m ²	Square meters	1.195	square yards	yd ²
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi ²	square miles	2.59	square kilometers	km ²	km ²	Square kilometers	0.386	square miles	mi ²
<u>VOLUME</u>					<u>VOLUME</u>				
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft ³	cubic feet	0.028	cubic meters	m ³	m ³	Cubic meters	35.315	cubic feet	ft ³
yd ³	cubic yards	0.765	cubic meters	m ³	m ³	Cubic meters	1.308	cubic yards	yd ³
NOTE: Volumes greater than 1000L shall be shown in m ³ .									
<u>MASS</u>					<u>MASS</u>				
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")	Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
<u>TEMPERATURE (exact)</u>					<u>TEMPERATURE (exact)</u>				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
<u>ILLUMINATION</u>					<u>ILLUMINATION</u>				
fc	foot candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²	cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
<u>FORCE AND PRESSURE OR STRESS</u>					<u>FORCE AND PRESSURE OR STRESS</u>				
lbf	poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

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GLOSSARY OF ACRONYMS

3DAGT	3-Dimensional Amsler Grid Test
AAA	American Automobile Association
AAMVA	American Association of Motor Vehicle Administrators
AD	Alzheimer's Disease
ADL	Activities of Daily Living
ADOT	The Arizona Department of Transportation
AION	Anterior Ischemic Optic Neuropathy
AMD	Age-Related Macular Degeneration
AUS	Australia
AZ	Arizona
CA	Canada
CMV	Cytomegalovirus Retinitis
CPR	Commonwealth of Puerto Rico
DAT	ESRA Dynamic Assessment for Transportation™ (ESRA DAT™)
DETR	Department of the Environment, Transport and the Regions (UK)
DfT	United Kingdom Department of Transport
DMV	Department of Motor Vehicles
DVAT	ESRA Dynamic Vision Assessment for Transportation™
ESRA	ESRA Consulting Corporation
FAA	Federal Aviation Administration
FL	Florida
HIV	Human Immunodeficiency Virus
MIN	minimum
MAX	maximum
MVD	Motor Vehicle Division
NADS	National Advanced Driving Simulator
NHTSA	National Highway Traffic Safety Administration
NZ	New Zealand
PCTL	percentile
PRT	Perception Response Time
RAIR	Relative Accident Involvement Ratio
SAS	Simulator Adaptation Syndrome
SIREN	Simulator for Interdisciplinary Research in Ergonomics and Neuroscience
SSQ	Simulator Sickness Questionnaire
STD	standard deviation
UFOV	Useful Field of View™
UK	United Kingdom
US	United States
USA	United States of America
VACS	Visual Acuity and Contrast Sensitivity Tests
VAPT	ESRA Vision Assessment Procedure for Transportation™

EXECUTIVE SUMMARY

This is the first study of its kind to present new, comprehensive, and automated testing systems with tremendous potential to revolutionize transportation licensing policies and procedures. We offer global survey development and implementation, literature reviews, and a comprehensive study of driving risks commonly associated with aging and disease in two states with significant proportions of older drivers. While the 65 years and older age group accounts for approximately 13 percent of the population of Arizona, it now forms the third fastest-growing population of age 65 years and over in the United States (see Hetzel and Smith, 2001). Similarly, Florida, has a fast-growing and significant population, at 17.6 percent, of age 65 years and older cohorts. Both states rank eighth among the top 10 causes of death through unintentional injuries for the ages 65 to 85 years population. Vehicle traffic accidents represent the largest number of these unintentional injuries and exceed the U.S. average (Centers for Disease Control and Prevention, 2003). Older drivers constitute the fastest growing segment of the driver's licensees. Road safety implications prevail as older drivers, when compared to young or middle-age drivers, reportedly account for a higher number of collisions per distance traveled (Stamatiadis and Deacon, 1995). We effectively address this situation through analyses of the collision data trends and risks of these older drivers, comparison of these results with drivers of all other age groups over an 11-year period (1991 to 2001), and surveys of the driver's license vision test practices of all 50 U.S. States, Commonwealth of Puerto Rico, Canada, Australia, United Kingdom, and New Zealand (henceforth referred to as "other countries"). Use of this information can be applied to develop technologies and measurement criteria for a visual acuity pilot test. Consequently, the results of this comprehensive study may not only benefit the State of Arizona, but also, ultimately, provide a prototype for nationwide transportation license reforms. ADOT is the first agency to commission such a unique, scientific study to promote motorist safety in Arizona and to benefit any country, state, commonwealth, province, territory, or nation with a burgeoning population of older drivers. The new systems and procedures ESRA presents may also reduce the incidence of fraudulent schemes and issuances of driver's licenses, commercial driver's licenses, and hazardous materials transportation licenses.

This report is divided into ten main sections and 22 appendices. Appendices (B,U, V) include Tables and Figures presenting the results of our global survey of directors or their representatives of driver's licensing agencies in the Australia, Canada, Commonwealth of Puerto Rico, New Zealand, United Kingdom, and the United States in the year 2004. Tables and Figures accompany detailed explanations in Appendices B through R where trends and risks of driver collisions, injuries, and fatalities within the States of Arizona and Florida over an 11-year period, years 1991 to 2001, are documented and reported.

First we review recent collision events and how these have impacted older driver licensing issues. We also explore existing literature to highlight some of the possible factors affecting older driver safety, in particular, vision, and the history of studies that relate to driver's license vision testing methods and policies. We find that driver's license vision testing methods and policies vary from state to state and country to country. We determine that a number of states shorten the period between both driver's

license application and renewal vision tests. While this may, in the short term, allow for limited identification of drivers with visual impairments, it fails, in the long term, to significantly improve the actual vision testing process and screen the most at-risk drivers. We also find that major reforms are needed in defining vision standards in order to improve current vision testing methodologies since visual acuity, the most common measurement of ranges of vision loss (International Council of Ophthalmology, 2002), accounts for less than 0.1 percent of the visual field and fails to quantify contrast sensitivity and color vision (Fink and Sadun, 2004). Although the latter constitute two of several visual parameters needed for safe driving, we suggest that these new vision standards incorporate visual acuity measurements. We therefore seek to design a new vision testing procedure through evaluation of the history and application of certain tests and driving simulators. We demonstrate that current vision testing methodologies are inadequate and most driving simulators are limited to research usage. However, we also recommend a vision screening system to study eye conditions, diseases, and functions and how these can benefit any at-risk driver, especially older drivers and drivers with dementia and other neurological conditions that may affect driving performance. We include diagrams of our conceptualized vision test system design, the ESRA Vision Assessment Procedure for Transportation™ (ESRA VAPT™) (Figure 6) and the ESRA Dynamic Vision Assessment for Transportation (ESRA DVAT™) (Figure 7). We also introduce the ESRA Dynamic Assessment for Transportation (ESRA DAT™) (Figure 8), a potentially thorough and cost-effective test of some of the most important features applicable to other areas of transportation. Hence the results of our study may impact driver's license testing procedure, policy, and legislation and the transportation industry overall.

Second, we provide a brief overview of our survey methodology of the driver's license vision test practices. Our global survey (Appendix V) and results are tabulated (Appendices B and U) and described in entirety in the appendices. Although we identify some recent pilot studies carried out at the California Department of Motor Vehicles and the New Mexico Motor Vehicles Division and various reports published through the United Kingdom Department of Transport, our surveys reveal that no comprehensive research or large-scale testing has been conducted over the last decade to validate use of current vision testing methodologies in driver's license bureaus in Australia, Canada, New Zealand, United Kingdom, and the United States. Overall, our data show that all national and international driver's license bureau directors or their representatives (henceforward referred to as "officials") who participated in our study report offer the following broad observations:

- No driver's license bureau offers automated vision testing programs.
- The majority of U.S. states use Optec 1000 vision screening equipment in whole, or in part, for screening drivers at license application or renewal. The other countries surveyed use Optec 2000, a more updated model.
- There are no consistent vision testing approaches or standards in the U.S. driver's license agencies. Each state operates independent of the others. These findings support earlier results described by Demers-Turco (1996) and Peli and Peli (2002).

- Most officials in the United States and in other countries acknowledge that their current vision testing methodologies are either inadequate or inaccurate. This finding confirms conclusions discussed by McCloskey *et al.* (1994) on the topic of vision testing in driver's license bureaus and optometric settings in the United States.
- No vision tests at driver's license bureaus in the United States and other countries include a screening component for glaucoma or Age-Related Macular Degeneration (AMD), two of the fastest growing diseases that can result in vision loss.
- No vision tests at driver's license bureaus in the United States and other countries offer "Dynamic Vision Assessment for Drivers" (ESRA DVAT™) that include responses to ambient light and simulated weather conditions, useful for the vision screening of at-risk drivers, novice drivers, and older drivers.

Third, we briefly discuss some of the ways that collision data are analyzed and how these methods are applied to our study.

Fourth, we evaluate the method of Relative Accident Involvement Ratio (RAIR) to measure and compare the quotient of at-fault drivers of a specific age group to the corresponding number of not-at-fault drivers (no-fault drivers), in the states of Arizona and Florida. RAIR provides us with a rapid and refined method of quantification and comparison of large sets of data, in our case, millions of collisions, between two different U.S. states, over an 11-year period, 1991 to 2001. RAIR also allows us to analyze which drivers, by age cohorts, are most likely to be at-fault in a motor vehicle collision. The data are obtained through databases of two-vehicle accidents. These include the databases of Accident Location Identification and Surveillance System (ALISS) of Arizona and the Highway Safety and Motor Vehicle Department of Florida. The data are acquired through the Arizona Traffic Accident Report and Florida Long Form Traffic Crash Reports provided by law enforcement agents in both states. We investigate the effects of driver age cohorts on collision events and evaluate the impacts of year, lighting, weather, and contributing causes. We highlight our findings as follows:

- The RAIR values for Arizona and Florida drivers typically and graphically appear as bathtub curves. The three distinct areas of the bathtub curve are useful for identifying properties of product life (reliability theory and analysis) and retirement, and, as we show, applying to transportation engineering concepts. (These graphs are merely identified as "U-shape distributions" in other literature.)
- The Wearout Period, a period of increased decline, tends to initiate within the Arizona and Florida driver cohorts at about age 50 to 59 years. Since the onset of the Wearout Period also appears in drivers with corrective lenses restrictions, we suggest frequent vision testing for license renewal applicants at and over age 50 years (every two years) and at and over age 70 years (every year).
- The characteristically long Early Failure Period (often called "Infant Mortality Period" in reliability engineering literature) and high at-fault collision involvement susceptibility we observe among the cohorts age 16 to 19 years in

Arizona and Florida suggests that these drivers require more comprehensive vision testing every two years. Novice drivers may especially benefit from vision status testing through the ESRA DVAT™ due to a lack of experience navigating roads in ambient light and weather conditions.

- We establish a link between drivers with visual defects and collision risk as it relates to environmental and driving performance behaviors.
- Drivers ages 80 to 89 years are about twice as likely to be at-fault when compared to the cohorts ages 16 to 19 years in the following categories of collisions:
 - angle manner of collisions (Arizona, Florida)
 - clear weather-related collision (Arizona, Florida)
 - cloudy weather-related collision (Florida)
 - darkness-related collision (Arizona, Florida)
 - daylight-related collision (Arizona, Florida)
 - fog-related collision (Arizona, Florida)
 - head-on manner of collisions (Arizona, Florida)
 - rain-related collision (Arizona, Florida)
 - rear end collision (Arizona)
 - sideswipe manner of collision (Arizona, Florida)
- Drivers ages 90 years and older are about twice as likely to be at-fault when compared to the cohorts ages 16 to 19 years in the following categories of collisions:
 - head-on manner of collisions (Arizona)
 - cloudy weather-related collision (Arizona)
 - dawn or dusk-related collision (Arizona, Florida)
- Arizona drivers and Florida drivers age 90 years and older with visual defects are about twice as likely to be at-fault in a corrective lenses restriction-related collision than the cohorts ages 16 to 19 years. This seems to demonstrate that these drivers are most likely impacted by dawn and dusk, yet, the shape of these skewed bathtub-shape curves also reveals that various lighting, weather, and manners of collision may also significantly affect vision, especially visual defects.
- Florida drivers age 90 years and older are, according to the highest RAIR values, seven times as likely to be at-fault in collision involvement due to corrective lenses restrictions than drivers age 16 to 19 years (Figures 44, 52, Appendix H). The severity of visual defects in older drivers may account for these extraordinarily higher collision risks.

- Both Arizona and Florida drivers ages 80 to 89 years are about three times as likely to be at-fault in left-turn manner of collisions compared to the drivers age 16 to 19 years in these states.
- Arizona and Florida drivers, age 80 years and over are more likely at-fault in collisions due to corrective lenses restrictions than any other age cohorts (Figures 44 to 52, Appendix H).
- We find that Arizona drivers ages 80 to 89 years are most likely at-fault in collision involvement associated with disregarding traffic signal, driving in opposing traffic lane, following too closely, being inattentive, running stop signs, passing in a no-pass zone, making improper turns and unsafe lane changes. These violations and behaviors may be largely attributed to vision impairments.

Fifth, we report the results of our calculations and analyses of collision rates per 100,000 licensed Arizona drivers on the basis of driver's license restrictions over an 11-year period, from 1991 to 2001. We select drivers ages 25 to 34 years as a baseline since this group surpasses all other age groups with the greatest number of collisions, injuries, and fatalities in both the States of Arizona and Florida. This group is also one of the most populous. We find that Arizona drivers age 75 years and older have significantly higher collision rates than the drivers ages 25 to 34 years. For example,

- Over an 11-year period, from 1991 to 2001, the collision rate, per 100,000 licensed Arizona drivers age 75 years and older, may be as high as seven times the rate for drivers age 25 to 34 years (Figure 82, Appendix B) on the basis of the driver's license restriction "daylight hours".

Sixth, we introduce the Average Individual Risk calculations. These allow us to rank risks and prioritize measures to avert collisions, injuries, and fatalities. We, therefore, determine the following:

- The Arizona driver age groups with the greatest Average Individual Risk of Fatalities include the age 75 years and older cohorts (6.65E-04).
- Arizona drivers in all age cohorts have higher Average Individual Risks of Collisions than Florida drivers.
- Arizona drivers age 75 years and older are, on average, more than four more times as likely to be at an individual risk of collision than Florida drivers of the same age group (Table 95).
- Average Risks of Collisions, Average Individual Risk of Injuries, and Average Individual Risk of Fatalities are highest among Arizona drivers (Table 96).
- We find that the greatest individual risks for Arizona drivers age 80 to 89 years are attributed to: "Pass in No-Passing Zone," "Ran Stop Sign", and "Drove in Opposing Traffic Lane." The greatest yearly individual risk, among these calculated risks is "Pass in No Passing Zone (Table 98).

Seventh, we examine the history and future of vision screening techniques. We highlight the following:

- According to our global survey, no comprehensive studies have been carried out over the last 10 years to validate continued use of the vision testing methodologies currently utilized in driver's licensing agencies. Our extensive literature review confirms this disparity of empirical data.
- We demonstrate the need for a comprehensive and automated vision testing system to include two vision tests and one driving simulator. In combination, these offer what we call ESRA Dynamic Vision Assessment for Transportation™ (ESRA DVAT™), a radical departure from the traditional and inadequate static visual acuity testing techniques in order to comprehensively identify, among others, at-risk drivers.
- The ESRA Vision Assessment Procedure for Transportation™ (ESRA VAPT™) complements the vision testing component of the NHTSA "Model Driver Screening and Evaluation Program" (Staplin *et al.*, 2003a) for a fitness to drive determination. The vision testing component of the NHTSA Model, for example, measures near and far acuity, contrast sensitivity, and visual field loss testing. The ESRA VAPT™ allows for assessment of vision condition and vision function of drivers of all ages. In addition, older drivers and at-risk drivers may be tested for vision status in order to promote safe and longer driving activities.
- We identify the B1Max™ VACS, a fully automated high- and low- contrast visual acuity screen. According to Staplin (2005), the reliability of this procedure is demonstrated by its use as part of the DRIVINGHEALTH® INVENTORY (DHI) tool, which is used for driver evaluations by the Medical Advisory Board of the Maryland Motor Vehicle Administration. It provides a quick and useful screening measure of visual deficiencies that can potentially put an end to mechanical failures and long queues associated with existing vision screening techniques in transportation licensing agencies and medical facilities. This test also powers the Roadwise Review™ home-based assessment tool released by AAA in January 2005.
- The 3DAGT may offer a very fast and effective way to screen drivers for potential or existing brain tumors and eye diseases. Such conditions increase collision risk in drivers. The 3DAGT has been successfully deployed at the Doheny Eye Institute at the University of California since April 2000. However, it requires substantial modifications prior to implementation in any transportation licensing agency, including the Driver's License Bureaus.

Eighth, we also review the history of driving simulators. Fifty-nine different national and international driving simulators are identified in order to select one that may satisfy criteria developed by ESRA for use in its transportation licensing systems and procedures. Recommendations are based on safety and performance records, published

studies, references, and independent testing on older drivers, among other liability concerns. We report the following:

- Some U.S. states, through both private and public educational centers and clinics, offer optional driving assessment sessions. These sessions typically include driving simulator applications, which, according to evaluations available at the Eastern Virginia Medical School (Simpson, 2004) and the University of Virginia (Pinto, 2004), may cost drivers up to \$300 per evaluation.
- These costs are prohibitive and can prevent many drivers, in particular, at-risk and older drivers, from this “hands-on” approach to assessment of vision status skills necessary for driving.
- The addition of a driving simulator, such as the Systems Technology, Inc. models we identify, as part of the system we recommend to ADOT, will allow equal access to all at-risk drivers, regardless of income.
- Driving simulators of the future may be a cost-effective alternative to or supplement to on-road motor vehicle driving skills tests in driver’s license bureau settings. This is a subject that requires extensive research and is beyond the scope of this study.

Ninth, we review the literature on simulator sickness and aftereffects such as flashback effects, Cyberadaptation Syndrome, and Simulator Adaptation Syndrome. We evaluate the histories of simulator sickness studies, the benefits of the Simulator Sickness Questionnaire, and the significance of field of view, flicker, and gender. The incidence of simulator sickness, the impacts of Cybersickness, studies of at-risk drivers, simulator sickness mitigation strategies, future studies, and safety recommendations are also presented.

Last, through development of the ESRA Dynamic Assessment for Transportation™ (ESRA DAT™), we evaluate the potential for automation of other tests, such as cognition, knowledge (written), and operation skills as these may relate to driver’s license tests and other transportation license tests.

The following enhancements are therefore recommended to ADOT:

- Work with local, state, national, and international medical and government agencies to develop a new and comprehensive vision standard to replace the very old and inadequate visual acuity standard for driver’s license issuance and renewal.
- Proceed with an implementation phase of the automated high- and low- contrast visual acuity screen, the B1Max™.
- Initiate a pilot study to include the driving simulator and visual condition tests, as the other parts of the ESRA DVAT™ System as conceptualized (Figure 7). These include the Systems Technology, Inc. driving simulators and the Modified 3DAGT we identify.

- Shorten the periods between driver's license issuance and renewal for vision testing, in particular for drivers age 15 to 19 years (every two years), drivers age 50 to 70 years (every two years), drivers age 70 years and older (every year), and all other drivers (every four years).
- Combine forces with medical agencies and officials, as well as other driver's license bureaus, on developing a method of assessing scores submitted through the three different components of the system (two vision screening tests and one driving simulator) envisaged for the pre-pilot study.

As a low-cost initiative, at a minimum, the State should implement the B1Max™ VACS, a fully high- and low- contrast visual acuity screen in transportation agencies and hospitals. The state should also work with hospitals to implement driving simulators to test the vision status of at-risk patients and others on-site once the driver simulator safety concerns that we identify, among others, are resolved. The modified 3-D Amsler Grid Test (3DAGT) should also be implemented. No independent testings of the ESRA DAT™ System and/ or ESRA DVAT™ System, such as the products we identify were conducted to study for safety concerns. For example, there may be flash images or flashback effects associated with automated testing and driving simulator usage that need to be explored due to safety issues, among others, of drivers and other transportation licensees prior to implementation in any hospital or driver's license bureau setting. These flashback effects may be delayed and occur while driving after driving simulator usage.

It is important to note that the use of the driving simulator(s) we propose in this procedural assessment is not to test driving skills and/ or replace on-road driver's license tests, but to assess vision status and strategy in a simulated driving environment, following a medical assessment referral and/ or evaluation test, as a means of detecting neuropsychologic and neuromotor disorders or as a supplementary measure of screening the vision status of drivers. (Please refer to Figure 6.) Lakshiminarayanan (2000), as we discuss, has linked dementia and Alzheimer's Disease with decreased visual acuity under low luminance.

The driving simulators we identify for possible implementation in the ESRA DVAT™ appear to offer various luminance settings, unlike traditional Snellen eye charts. More importantly, an independent panel of physicians and scientists are needed to determine the length of such simulator tests and the interpretation of these test results. Ideally, these tests need to be conducted and overseen by a licensed medical professional until guidelines are developed to allow for the automatic screening of drivers. In the future, studies and research may allow driving simulators to test driving skills and/ or replace on-road driver's license tests.

If the vision testing modifications we identify are implemented and, after the pilot test, proven successful within the State of Arizona, then ADOT will serve as a prototype of vision testing improvements for all other states, countries, and agencies (e.g., aviation, rail, bus, agriculture, etc.) to follow.

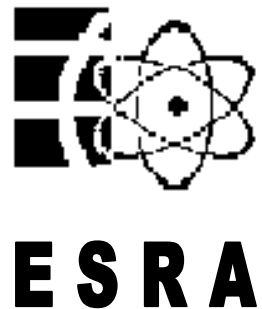
Implementation

The estimated potential benefit of \$45 million per year from implementing the full, three step-improved test is 13 times larger than the estimated \$3.3 million annualized cost of the improved testing system. The magnitude of the benefit compared to the cost creates a strong argument for pursuing a further effort to explore possible implementation of the improved test. Granted, the benefits will not flow directly to ADOT-MVD in the form of funds with which to pay for implementation. Benefits will be dispersed throughout the community in the form of fewer lives lost or damaged by collisions that might have been avoided if more impaired drivers were taken off the roads. Revenues gained and costs avoided will occur in the state's general fund. A case can be made for funding the improved driver testing procedure from these sources.

Note: The benefit/cost estimate was calculated by John Semmens, ADOT, from data provided by ESRA.

The ESRA DAT™ System is developed by:

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INTRODUCTION

Purpose

The objective of this study is ten-fold:

- 1) to evaluate recent literature on cutting-edge automated driver's license testing practices;
- 2) to collect and analyze the collision and fatality data for all drivers in Arizona and Florida;
- 3) to survey key driver's license bureau personnel in all 50 states and in other countries in order to assess the current automated driver's license testing system methodology;
- 4) to synthesize these data as bases for measurement criteria and risk analyses to evaluate the success of a pilot test;
- 5) to present a newly designed experimental visual screening system offering the most potential for a comprehensive and automated driver's license testing system demonstration project in the State of Arizona;
- 6) to demonstrate that a thorough measurement of the visual system is of fundamental importance to motorists everywhere
- 7) to promote highway safety through improved vision screening techniques of older drivers and at-risk visually impaired drivers.
- 8) to evaluate simulator sickness and aftereffects.
- 9) to offer simulator sickness mitigation strategies and suggestions for future studies.
- 10) to introduce the partial and/ or complete automation of other driver's license test components, such as cognition, knowledge (written), and/ or motor vehicle operation/driving skills. Such automation techniques may also benefit other transportation license tests.

Background

While the trends and risks of drivers in the States of Arizona and Florida are calculated and presented, this study shows that older drivers are most susceptible to at-fault automobile collisions when lighting, weather conditions, and select violations are investigated. These paradigms, combined with very high collision, injury, and fatality rates, prove that a completely new vision testing system is needed to screen at-risk drivers. Since we reviewed the driver's license policies, practices, and testing methodologies of the entire United States, Commonwealth of Puerto Rico, Canada, Australia, United Kingdom, and New Zealand, the results of our study not only apply to Arizona and Florida, but to every state, province, territory, nation, or country that seeks to improve safety on its roads and among its motorists. This is the very first study of its kind to identify a systematic approach to driver's license vision testing on the bases of comprehensively studying driver behavior in two U.S. states with a considerable number of older drivers, significant population growth over the last decade, and investigating numerous national and international commercial and research products and components.

Project Overview

Four components define our report: a literature review, a global survey of the directors and their representatives of driver's license bureaus, statistical studies and risk analyses of both Arizona and Florida drivers of all ages, an evaluation of vision screening tests and driving simulators, and the presentation of a newly designed comprehensive and automated vision testing system by ESRA.

The first section contains information gathered largely through on-line searches of books, journals, newspapers, and Internet Web sites. This study includes an extensive bibliography of relevant documentation after the Appendices. The second section describes the underlying process of the global survey of the directors and their representatives of driver's license Bureaus of all 51 U.S. states, Commonwealth of Puerto Rico, all ten provinces and three territories of Canada, six states and two territories of Australia, and all of New Zealand and the United Kingdom. The survey addressed vision testing policies and practices of these bureaus. Results are displayed in the forms of tables and figures. The surveys are included as Appendix B and Appendix V. The third section presents the analyses of collision data for all drivers provided by the Arizona Department of Transportation Traffic Records Section and the Florida Highway and Safety Motor Vehicle Department, for the 11-year period from 1991 to 2001. When possible, we illustrate our results in the Minimum Model Uniform Crash Criteria (MMUCC) standard format. Collision factors, such environmental conditions (lighting and weather), manner of collisions, and violation behavior are illustrated through the application of Relative Accident Involvement Ratios (RAIR) and probabilistic risk analyses of all age groups. We briefly summarize our results after each table and figure in Appendix C.

The fourth section introduces us to the power of Relative Accident Involvement Ratio (RAIR) and its usefulness in determining which drivers, on the bases of age, are most susceptible to at-fault collision involvement with respect to weather, lighting, and manner of collision. The fifth section provides us with an overview of the Arizona driver collision rates over an 11-year period. The sixth section highlights the Average Individual Risk calculations and its application to both Arizona and Florida drivers.

The seventh section covers some of the latest vision test equipment and driving simulators available. We review the histories of these products, highlight some of their strengths and weaknesses, and discuss ways that, as part of a system we design, they may improve safety and ultimately reduce collision risks among all drivers.

Our study supports the initiation of more comprehensive and stringent vision testing methods in order to adequately screen at-risk drivers.

REVIEW OF LITERATURE

Introduction

Vision is the fundamental way we perceive and respond to stimuli all around us. It dynamically involves sight, knowledge and reaction. Sight, a receptive ability, and an acuity measurement, allows one the ability to clearly see a target at a particular distance. Vision is estimated to account for 85 percent to 95 percent of all sensing clues in driving (American Automobile Association, 1991). Low vision often occurs when sight weakens with increasing age. Low vision principally appears in the U.S. population of age 65 years and older cohorts. Although individuals age 80 years and older comprise 8 percent of the population, they constitute 69 percent of the cases of blindness (National Eye Institute, 2004). Low vision results from congenital, genetic, or acquirable factors. The latter may be attributable to age-related deterioration, disease, medication, injury, and/or trauma. While certain diseases and conditions may target specific areas of the eye, trauma may impact all areas of the eye. According to the National Eye Institute (2004), vision disorders constitute the fourth most widespread class of disability in the United States. Vision impairment occurs when glasses, contact lenses, or surgery cannot correct the vision loss. Cataracts, Age-related Macular Degeneration (AMD), glaucoma, and diabetic retinopathy account for the four main causes of visual impairment and blindness in the United States (Desai *et al.*, 2001). Torpey *et al.* (2003) indicate that visual impairment may be caused by both systemic conditions and specific eye conditions. The systemic conditions may include atherosclerotic disease (cholesterol deposits in the eye), cerebrovascular (brain blood vessel) disease or stroke, diabetes, eye infections, hypertension (high blood pressure), Human Immunodeficiency Virus (HIV), and/or vitamin A deficiency. The specific eye conditions may consist of cataracts (clouding of the lens), eye injuries, glaucoma, macular degeneration, and/or tumors (eye-related).

Congdon *et al.* (2003) classify visual impairment according to age-related causes (cataracts, angle-closure glaucoma, open angle glaucoma, Age-related Macular Degeneration), infectious causes (trachoma, onchocerciasis, HIV and HIV-associated infection), nutritional and metabolic causes (vitamin A deficiency, diabetes), refractive error (myopia, hyperopia), and trauma. In order to screen for any one or more of these conditions, regular eye examinations are encouraged.

This study highlights the collision risks and trends of drivers in all age groups in the states of Arizona and Florida. Both states have significant populations of older drivers and are popular tourist and retirement destinations. It seems likely that there are also an additional significant number of older drivers who drive these roads with out-of-state and foreign driver's licenses. Baggett (2003) reports that in approximately 15 percent of accidents involving older adults, for years 1999 to 2001, the driver was not a resident of the state.

The Older Populations of Arizona and Florida

The population age 65 years and over in Arizona jumped 39.5 percent to 667,839 from 1990 to 2000, more than three times the national average. This represented the third largest U.S. population increase, preceded by Alaska (59.6 percent) and Nevada (71.5 percent). In 2000, Scottsdale, Arizona, as a city with a population of over 100,000, contained the ninth highest proportions of a population of age 65 and older in the United States, at 16.7 percent. In mid-2002, the age 65 and older age group accounted for 12.85 percent of the population of Arizona. In Florida, the population of age 65 years and older increased 18.5 percent to 2,807,597. This percentage quantity was almost half of the increase in Arizona at the same time. Yet six cities in Florida constitute the top 10 highest proportions of a population of 65 and older in the United States. (Hetzl and Smith, 2001). From 1990 to 2000, Arizona had an estimated 81.7 percent change in the number of age 85 years and older cohorts; Florida, 57.7 percent. These values were significantly higher than the U.S. national change in the number of age 85 years and older cohorts at 37.6 percent. Florida has more drivers age 90 years and older than any other state (NBC 6 News Team, 2003). The age 65 years and older population in Arizona will be 7.5 times larger 17 years from now than in 1985 (Matthias *et al.*, 1996). By 2025, the United States Census Bureau projects the population of Arizona to reach 6,412,000; Florida, 20,710,000. By 2030, senior citizens will comprise 25 percent of the Pima County, Arizona population (Cañizo, 2003).

It is now estimated that 12.5 percent of all U.S. drivers are age 65 years and older (Farmer, 2004). By 2030, when both “Baby Boomers” and “Generation X” reach retirement age, the percentage of older drivers age 65 years and older is expected to increase to 20 percent. The group born between the years 1946 and 1964 constitutes the “Baby Boomers”. The group born between years 1965 and 1980 defines “Generation X”. Nevertheless, there are approximately 33 million drivers age 65 years and older on U.S. roads and by 2030, the number is expected to climb to almost 100 million drivers (NBC 6 News Team, 2003). According to the Centers for Disease Control and Prevention (2003), the number of fatalities of older drivers on our nation’s road will likely rise as the population of Americans 65 years and older doubles between the years 2000 and 2030 (McCarthy, 2000; Centers for Disease Control and Prevention 2003). At-risk drivers of any age group require frequent and thorough screening for visual status and the impacts of these changes on driving performance, among other areas. According to Ball (2003), visual status often defines the activities of daily living (ADL).

Older Drivers In The News

National and international attention has focused on the implementation and enforcement of stringent licensing and testing procedures for older drivers. These escalated concerns and interests often follow a spate of high-profile collisions involving older drivers and shed light on the need for improved vision screening methods and accelerated driver’s license renewal periods. We define an accelerated renewal period as one where the period between the driver’s license application and renewal or one renewal cycle to the next is considerably reduced. The licensing bureaus consider accelerated renewal periods

as a time for possible intervention strategies during the driver's license issuance and renewal process.

Between 2002 and 2004, several notable older driver involvement collisions occurred in Port Everglades, Florida; St. Petersburg, Florida; Coral Springs, Florida; Santa Monica, California; Southwest Miami-Dade County, Florida (Fred Grimm, 2003); Flagler Beach, Florida; Roseville, Minnesota (Catlin, Bill, 2003); Regina, Canada; Langley, British Columbia (Cooper, 2004); Provo, Utah; Marlborough, Massachusetts and Sydney, Australia (2005).

In most of these cases, it appears that there was either a failure to stop or confusion between use of the accelerator and brake in the motor vehicle. These issues may relate to the visual system. According to LaViola, Jr. (2000), "The visual system tells the subject a variety of information which includes that he/she is moving in a certain direction, accelerating when pressing the gas pedal and decelerating when pressing the brake."

Lundberg *et al.* (1998) suggest that subtle cognitive decrements, instead of dementia, may be significantly linked to risky driving behavior on the bases of collision involvement among older drivers. However, drivers' visual and medical conditions may have also played a pivotal role in these tragedies. Vision loss or impairment, in conjunction with cognitive decrements, may prevent these drivers from making sound and timely decisions of the best action to take when driving an automobile. Mayur *et al.* (2001) report that 92 percent of persons 70 years and older wear glasses. Nearly 69 percent of the cases of blindness occur in the cohorts age 80 years and older (National Eye Institute, 2004). It is possible that improved and frequent vision testing could detect some of these problems or conditions. For example, driving simulator studies merit attention for screening drivers with various forms of dementia. Chronic decrements of mental capacity that may involve progressive deterioration of behavior, memory, personality, thought, and motor functions characterize dementia. Also, certain vision tests are known to associate dementia with contrast sensitivity reduction (Rizzo *et al.*, 1997) and patients' responses to light (Lakshiminarayanan, 2000). Sadun and Bassi (1990) observe optic nerve damage in Alzheimer's disease (AD) patients. This condition may contribute to various forms of glaucoma, central vision loss, peripheral vision loss, side vision loss, or vision loss. Substantial vision loss may occur and AD patients, in particular, may not recognize this difficulty unless adequately screened. As shown in Appendix B, driver's license bureaus are not equipped to screen for eye diseases or any of the visual disorders common in AD.

These implications may also apply to other sectors of transportation—commercial vehicles, trains, and airplanes. Senior pilots occasionally make headline news when their airplanes are involved in a collision. Although the FAA requires commercial airplane pilots to retire prior to age 60 years, private pilots with licenses may fly as long as they have logged the required number of flight hours and passed the required physical and skills tests. No standard comprehensive vision tests and renewal periods exist for pilots. Yet, valid medical certificates are held by more than 3,000 pilots age 80 years and older in the United States (Pensa *et al.*, 2003). Aviation vision tests may include general,

ophthalmoscopic, pupils, and ocular motility examinations. Visual acuity may be tested through application of the Snellen-type charts; Keystone Orthoscope; Bausch & Lomb Orthorator, Titmus Vision Tester; Keystone Telebinocular; Optec 2000 Vision Tester, among others (Federal Aviation Administration, 2003).

Although the genuine cause of these newsworthy injuries and fatalities may never be known, studies must focus attention and resources on improving screening techniques at driver's license bureaus to promote driver safety. Clearly, these recent tragedies create negative stereotypes of older drivers when every driver, in every age group, has the potentiality for risky driving behavior (Appendix B). Rather than focus on possible underlying causes of these collisions, in particular, driver's license vision testing methods, many people and organizations unjustly seek to solely accelerate the frequency of driver's license renewal and testing periods. Others promote participation in short-term driving skill assessment courses. These approaches only create a placebo effect because it is the actual driver's license testing methodology, in conjunction with the frequency of driver's license renewal and testing periods that requires improvements. Once these testing enhancements are in place, the accelerated driver's license renewal periods and short-term driving skill assessment courses serve as supplementary and precautionary safety measures.

Vision Impairment

Vision impairment varies greatly by race and ethnicity. Although approximately 1.98 percent or 2.4 million Americans have low vision, this number is expected to grow by nearly 70 percent by 2020 due to the rise in Americans age 40 years and older (The Eye Diseases Prevalence Research Group, 2004). The 1986 to 1995 National Health Interview Survey reveals a 0.03 percent annual increase in visual impairment rates among U.S. adults between ages 18 to 39 years (Lee, 2004). These rates are significantly higher in third-world countries where resources to tend to health and medical needs are limited.

In the United Kingdom, it is estimated that undetected reduced vision exists in up to half of the older people there. While many of these people have treatable visual problems, they do not have regular optometric examinations. Evans and Rowlands (2004) suggest annual visual screening on people age 75 years and older. Clearly, the percentage of older drivers with correctable visual impairment in the United Kingdom may exceed 50 percent on the basis of driver's license policies and vision screening tests there.

Affected Eye Structures

According to Congdon *et al.* (2003), visual impairments affect a variety of ocular structures. Some of these, in particular the age-related causes (i.e., Age-related Macular Degeneration, angle-closure glaucoma, cataracts, and open-angle glaucoma) are illustrated in Figure 1. Others we shall briefly describe:

●Infectious Causes

- **HIV and HIV-associated infection:**
Choroid, cornea, lacrimal gland, optic nerve, retina.
- **Onchocerciasis:**
Choroid, ciliary body, cornea, iris, macula, optic nerve, retina,
trabecular meshwork
- **Trachoma:**
Cornea, eyelashes, eyelids

●Nutritional and Metabolic Factors

- **Diabetes:**
Lens, macula, optic nerve, retina, trabecular meshwork, vitreous body
- **Vitamin A deficiency:**
Conjunctiva, cornea, retina

●Refractive Error

- **Myopia:**
lens, sclera, retina
- **Hyperopia:**
lens, sclera, retina

Visual Acuity

Visual acuity refers to spatial resolution or the measure of one's vision with respect to clarity, sharpness, or sight ability. This ability results from the coherent focus of light from the region of the cornea on to the retina of the eye (Garcia, *et al.*, 1999). Spatial resolution allows one to discern objects, read text, and interpret symbols and signage. Although these functions are paramount to safe driving practices at any time and anywhere, many drivers are visually deficient due to the aging processes, heredity, medication, or trauma. A driver of any age compromises the safe operation of a motor vehicle when medical or pharmaceutical conditions prevail. Cataracts, diabetic retinopathy, glaucoma, and macular degeneration, among other vision loss conditions (Gottlieb, *et al.* 1997) may weaken color perception, contrast sensitivity, depth perception, glare recovery, or peripheral vision components. Ultimately, these vision impairments elevate the risks of traffic collisions and violations. Visual acuity varies greatly by race and ethnicity. Problems with visual acuity affect more than 2.4 million Americans (1.98 percent) age 40 years and over (Taylor and Mitchell, 2004).

In most states, the measurement of visual acuity, a primary gauge of the extent of functional impairment due to vision loss (National Research Council, 2002), is required to pass a driver's license test. At a standard distance, a patient views the Snellen Eye Chart, a letter chart that is nearly universal in its application to clinical and research usages. The Snellen Eye Chart, developed in 1862 by Dr. Hermann Snellen, a Dutch

ophthalmologist, may today include a series of letters or letters and numbers, with the largest at the top. Snellen-type charts are generally prescribed under ideal conditions (daytime lighting) and the absence of extraneous light sources. According to the National Research Council (2002), the results of this visual acuity test "...are usually expressed in Snellen notation,... the ratio of the test distance to the distance at which the critical detail of the smallest optotype resolved would subtend 1 minute of visual angle." Optotypes refer to the letters, numbers, and symbols that assess the function of different retinal areas.

Although visual loss conditions and visual function deterioration can affect people at any age, these most often impact older drivers as part of the aging process. In both Arizona and Florida, this appears to be most evident through the over-representation of older drivers mostly cited for at-fault traffic collisions and violations. In 2002, among the drivers with any violation, daylight conditions account for the majority of collisions in the age 55 years and older population. The cohorts age 65 years and older constitute the largest percentage of drivers who fail to yield the right of way (Williams *et al.*, 2003). The proportionally higher number of these types of collisions in Arizona suggests that the current visual acuity testing methods for drivers may be inadequate. According to Pitts, visual acuity rapidly declines with increasing age after age 50 years. Studies by Decina and Staplin (1993) reveal the onset of this change at approximately age 45 years. This study demonstrates that an increase in at-fault collision involvement coincides with the drivers, age 50 to 59 years, in both Arizona and Florida. Drivers age 80 to 89 years primarily exhibit the highest Relative Accident Involvement Ratio (RAIR). They are most likely at-fault in collisions, compared to their younger counterparts. These values are in good agreement with those illustrating collision involvement due to visual defects.

Interestingly, some experts argue that visual acuity testing does not provide a comprehensive vision assessment when compared to contrast sensitivity testing, especially with respect to age-related macular degeneration (AMD), cataracts, or glaucoma, optic neuritis, and diabetes, (Meszaros, vol. 29). Eye charts are particularly ineffective because patients can see dark letters through the cataract. Patients may also easily memorize rows of various Snellen acuity charts. Fink and Sudan (2004) show that Snellen acuity, the most widely used vision testing measure, accounts for less than 0.1 percent of the visual field and fails to quantify contrast sensitivity and color vision, two of several visual parameters needed for safe driving. Clearly, there exists a great need for automated visual acuity testing. A fast and effective visual acuity test, such as the B1Max™ combines high- and low- contrast visual acuity screening and offers successful deployment as demonstrated through the widespread distribution of Roadwise Review® through AAA, the largest automobile association operating nationally and internationally.

Charman (1997) discusses the challenges that countries face when setting or seeking to modify visual standards for drivers. These appear to relate directly to the difficulty of defining statistical thresholds of safe and unsafe drivers. Costs of testing and implementing new vision testing standards and other measures of driving performance, aside from vision, pose additional obstacles. While restricted licenses appear to strengthen visual

standards of some drivers, others, especially dementia drivers, go unnoticed due to the inadequate vision testing processes in motor vehicle department settings.

Contrast Sensitivity

Contrast sensitivity defines the ability to detect changes in contrast through resolving gratings of different spatial frequencies at various contrast levels. Contrast sensitivity appears to characterize visual disability in patients with cataracts. It also seems to measure activities of daily living (ADL), the day-to-day ability to perform domestic tasks, in dementia patients (Cormack *et al.*, 2000). McGwin *et al.* (2000) associate decreased contrast sensitivity with left turn driving difficulties. Owsley *et al.* (2001) link severe contrast sensitivity impairment in one eye from cataract to an increase in collision risk. It therefore seems reasonable to assume that contrast sensitivity testing merits implementation in driver's license testing, as suggested by Decina and Staplin (1993).

Color Vision

Color vision, the ability to see and process differences in colors, and perception, the cognitive ability to discern among wavelengths of light, allow the driver to effectively and readily respond to signage and change of traffic signals. A lack of either of these abilities may prove hazardous while driving. According to Staplin (2005), research does not confirm a relationship between color deficiency and collision risk. Also, a minimum of ten minutes per computerized test may be required "...to obtain a reliable measure of color deficiency/blindness where the display quality (of the monitor) must be checked repeatedly to insure precise stimulus properties and a large number of trials is required to be confident of test results..."

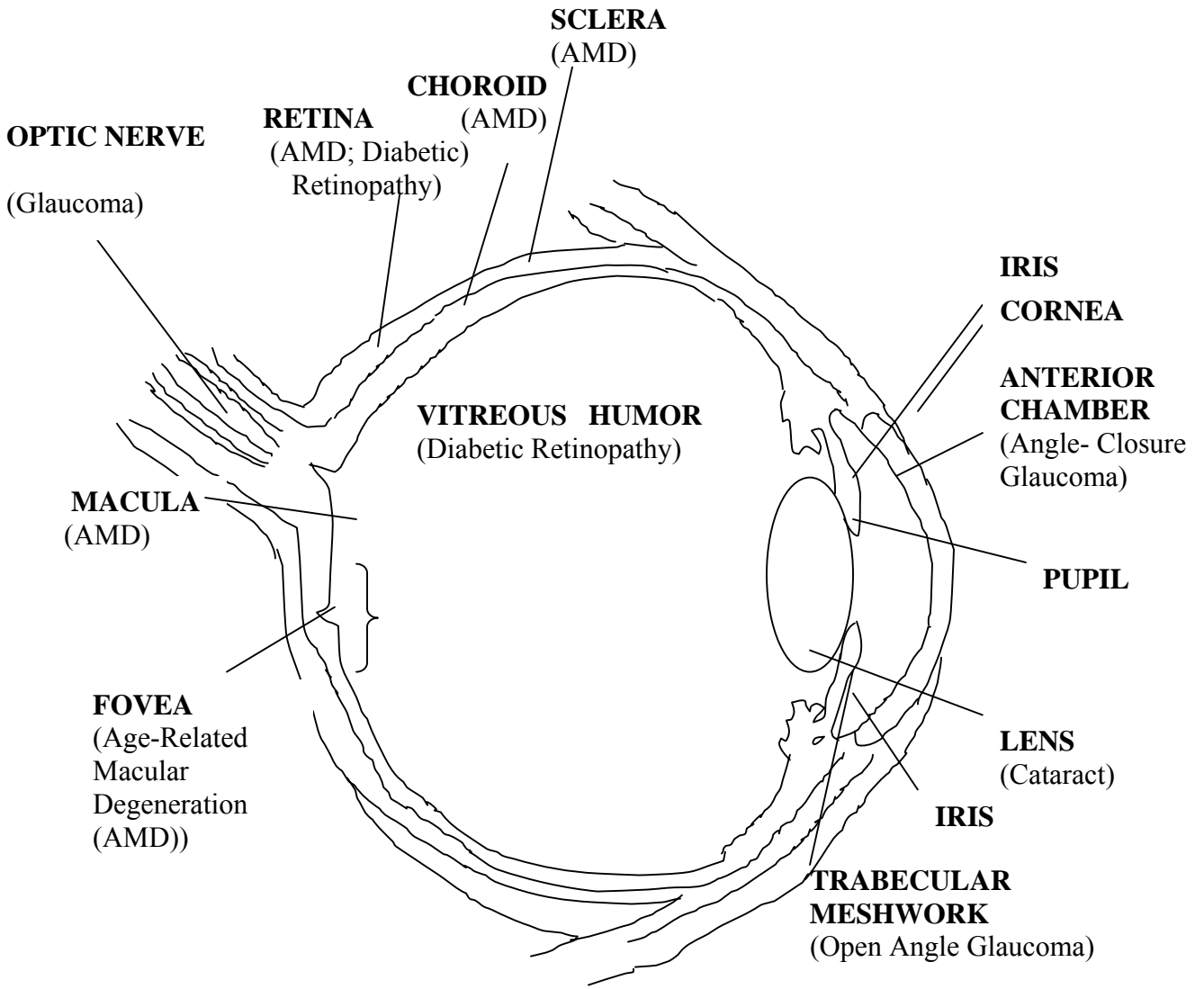


Figure 1. Horizontal section of the human eyeball and some common conditions that may affect it.

Some Diseases Of The Eyes

Age-Related Macular Degeneration

Age-related Macular Degeneration (AMD) is a progressive disease that affects straight-away, central, vision. It impacts the macular area and fovea, the tissue surrounding the central portion of the retina. (See Figure 1.) This deterioration of the macula area of the retina is called macular degeneration. AMD occurs as nonexudative (or “dry”) AMD and exudative (or “wet”) AMD. The nonexudative, atrophic, or “dry” form is most widespread and appears in nearly 90 percent of all AMD patients (Quillen, 1999). Dry AMD, while fairly damaging, rarely causes severe blindness. However, the exudative, neovascular, or “wet” form of AMD is most destructive. Irreversible impairment to the cones and rods, two types of photoreceptors responsible for the visual response to light, result when hemorrhaging, leaking fluid, or scarring of abnormal blood vessels that grow from the choroids, a layer of high vascularity located between the retina and the sclera, into the macula region occur.

Each year, approximately 200,000 people per year are inflicted with AMD (Oliwenstein, 2002). Approximately 1.47 percent of U.S. citizens at age 40 years and older, or more than 1.75 million, are affected by neovascular AMD. By 2020, this number is expected to jump by 50 percent to 2.95 million U.S. individuals. According to the Eye Diseases Prevalence Research Group (2004), AMD significantly increases with age. AMD occurs in more than 15 percent of white women age 80 years and older. Smoking appears to increase the risk of AMD by as much as 15 percent. Although it is the leading cause of severe vision loss among Americans age 65 years and older, studies show that only 30 percent of American adults are familiar with AMD (Oliwenstein, 2002). Owsley *et al.* (1998) has linked AMD with injurious collisions by older drivers.

Cataract

Cataract primarily accounts for low vision among white, black, and Hispanic persons. Congdon *et al.* (2004) estimates that 17.2 percent of all American adults age 40 years and older have cataract in either eye and 5.1 percent have pseudophakia/aphakia. Cataracts affect nearly 50 percent of the population of age 75 years and older. By 2020, the incidence of cataracts is expected to jump nearly 46.8 percent to 30.1 million Americans age 40 years and older; pseudophakia/aphakia, over 50 percent.

Since cataracts cloud the lens of the eyes, the condition impacts color perception and glare. It may also create diplopia, double vision. McCloskey *et al.* (1994) reports a 1.2 fold increased risk of injurious collisions among older drivers with diplopia. Surgical removal of the cataracts may correct vision and allow these at-risk drivers to continue safe driving practices. Owsley *et al.* (1999) report a study on Alabama driver’s licensees, ages 55 to 85 years, with and those without cataracts. Those with cataracts are 2.5 times more likely to have at-fault collision involvement in the prior five years and four times more likely to report driving difficulties. Carroll *et al.* (2002) evaluates the impacts of various levels of cataract-related glare on older drivers’ identification of highway signage

in darkness. Fewer signs are correctly identified at all luminance levels with and without glare for subjects with significant and early cataracts.

Glaucoma

Glaucoma is a condition characterized by an elevated internal ocular pressure, an alteration of the visual field, and an optic neuropathy relating to a loss of nerve cells within the optic nerve (Hitchings, 2000). It causes severe loss of vision and peripheral vision. It fades images and reduces contrast. Early detection of glaucoma is key to intervention. This disease advances so slowly that most patients are unaware of any vision loss until progression occurs (Peli and Peli, 2002).

Glaucoma triggers blindness in an estimated 1.5 million people in India (Markandaya, *et al.*, 2004). Glaucoma now affects 2.2 million Americans at age 40 years and older. Although it is the most common form of blindness among Hispanics, it is the fastest-growing eye disease among Hispanics age 65 years and older. It is expected to impact 3.3 million Americans by 2020 (National Eye Institute, April 12, 2004). Glaucoma is often tested through glare recovery, a test designed to measure the time it takes a patient to recover from the viewing of flashing bright lights, or glare. Early glare research (Wolf, 1960; Brancato, 1969; cited in Corso, 1981) shows that older adults require longer recovery time and increased brightness to discern objects.

McCloskey *et al.* (1994) has associated a 1.5 fold increased risk of injurious collision among older drivers with glaucoma. Owsley *et al.* (1998) has determined that glaucoma and restricted useful field of view, serve as strong and independent predictors of collision-related injuries for Alabama drivers ages 55 to 87 years. Useful field of view, measured binocularly, defines a visual information extraction area that functions in a single glance without eye or head movement (Roemaker *et al.*, 2003). This spatial area allows visual stimuli detection in a variety of situations (Roemaker *et al.*, 2000).

Hu *et al.* (1998) argue that glaucoma is the only medical condition that links older drivers, particularly males, with increased collision risk. Although they claim that high collision rates are not associated with commonly studied medical conditions, it is possible that a number of these medical conditions are not adequately screened in driver's licensing bureaus. Therefore, the connections may inadvertently appear less than obvious.

The most common form of glaucoma is open-angle glaucoma, an insidious form that remains seemingly inconspicuous until severe and permanent peripheral vision is evident. This disease impacts the trabecular meshwork and optic nerve of the eye. (See Figure 1.) In children, it also disturbs the sclera (Congdon, *et al.*, 2003). Approximately 1.86 percent of American adults age 40 years and older are now affected with open-angle glaucoma. Open-angle glaucoma may appear in three times as many blacks than whites. By 2020, this disease is estimated to rise by 50 percent to 3.36 million American adults (Friedman *et al.*, 2004).

Low, normal tension glaucoma occurs when normal to low ocular pressure exists. A lack of blood circulation in the eye reduces sight, causes loss of peripheral vision, and damages the optic nerve. The angle-closure glaucoma affects the anterior chamber and optic nerve of the eye.

Hemianopsia

Hemianopsia results from optic nerve degeneration. This may relate to injury, trauma, tumors, and other contributing causes that may reduce sight, contrast, photophobia, peripheral vision loss, and color vision change.

Optic Atrophy

Optic nerve degeneration defines optic atrophy that may relate to injury, trauma, tumors, and other contributing causes. This may reduce sight, contrast, photophobia, peripheral field loss, and color vision changes.

Refractive Error

Refractive error describes the inability of the eye to properly focus images on the retina. Refractive error occurs as myopia (nearsightedness, shortsight), hyperopia (farsightedness, long sighted) and astigmatism. An individual with myopia has the ability to see near objects clearly but not in the distance. An individual with hyperopia has the ability to see objects in the far distance but may not see near images clearly. Astigmatism results in a blurred image through an inability of the cornea to properly focus an image onto the retina. Contact lenses, eyeglasses, or refractive surgery often correct myopia and hyperopia.

Refractive errors primarily cause visual impairment and blindness in the developing world (Congdon et al, 2003). Kempen *et al.* (2004) determined that 33 percent of Americans and Western Europeans and 20 percent of Australians age 40 years and older are affected by refractive errors. Cheng *et al.* (2003) observed that an increase in prevalence of refractive errors, specifically myopia, astigmatism, and anisometropia, significantly increased with age in Chinese adults age 65 years and older in Taiwan. Myopia appears to be common in East Asia. Wong *et al.* (2000) determined that there exists an overall prevalence of refractive errors, in particular, myopia, in 38.7 percent of 2,000 Chinese residents, age 40 to 79 years, in Singapore. This rate is nearly double the rate observed in Caucasians and Blacks of similar age cohorts.

Infectious Disorders of the Eye

Various communicable diseases of the eye are prevalent in regions of destitute throughout Africa, Australia, the Middle East, and Southeast Asia. Not only do many inhabitants of these areas lack adequate medical facilities and care, if any, but also effective sewage and potable water, among other factors. As a result, poor hygiene, an agent for disease, is very widespread.

Chlamydia Trachomatis

Chlamydia trachomatis, a bacteria, causes trachoma, an eye infection, that, when left untreated, may lead to blindness or chronic scarring. Although trachoma occurs globally, it is rarely found in the United States except in impoverished areas where poor hygiene and crowded living conditions exist. The National Institute of Health (2004) indicates that affected individuals with trachoma can transmit this disease through direct contact with eye or nose-throat secretions, contaminated objects (e.g., clothes or sheets), and through infected flies.

Onchocerciasis

Onchocerciasis, commonly called River Blindness because it occurs along rapidly flowing rivers and streams, affects 17 million people worldwide. According to the Centers for Disease Control (2004), female black flies (*Simulium*) transmit a disease produced by the prelarval and adult stages of nematodes, parasitic worms, *Onchocera volvulus*. More than 25 global nations, including the central part of Africa, host Onchocerciasis. The bite of certain species of these black flies, among other infections, can cause ocular lesions that can lead to blindness. Symptoms may not appear for months or years until after exposure.

Human Immunodeficiency Virus, HIV

Human Immunodeficiency Virus, HIV and HIV-associated infection, may lead to secondary infection, in particular, cytomegalovirus (CMV) retinitis. This infection, which may advance to blindness, if untreated, tends to affect the eyes of patients during the late stages of AIDS. Highly active antiretroviral therapy may account for the significant decrease of these incidences in the developed world since the 1980s (Congdon, 2003).

Nutritional And Metabolic Factors

Diabetic Retinopathy

Diabetic retinopathy impacts people with diabetes, a disease defined by a lack of production or use of insulin by the human body. It results in central vision loss and occurs when blood vessels leak fluid within the eyes. It affects vision through the retina and vitreous humor. (See Figure 1.) Among middle-aged Americans, diabetic retinopathy is the leading cause of new blindness (Quillen, 1999). It also results in vision loss in older populations. This disease adversely impacts night vision. Some studies suggest that this disease may contribute to collision risk in older drivers (McGwin, Jr., *et al.* 1999). In the developed world, diabetic retinopathy is a primary cause of blindness and visual impairment in adults less than age 40 years (Congdon, 2003). Diabetic retinopathy is prevalent in 4.1 million adult Americans age 40 years and older. As the population ages, diabetic retinopathy may eventually pose a public health threat as more people develop diabetes mellitus (DM) and face possible vision loss (Kempen *et al.*, 2004). Diabetic retinopathy may affect 7.2 million Americans by 2020 (National Eye Institute, April 12, 2004).

Vitamin A Deficiency

Vitamin A deficiency stems from a lack of essential vitamins in a balanced diet. Patients with vitamin A deficiency may experience dim light or poor night vision (night blindness). Dietary intervention and treatment are necessary to prevent blindness. In some developing countries, especially where malnutrition is widespread and medical services are limited, Vitamin A deficiency accounts for childhood blindness.

Ocular Trauma

Trauma to the eyes often result from assaults, sports, or occupational injuries. Ocular trauma may lead to monocular blindness. Nearly 500,000 blinding ocular injuries occur both globally and annually (Congdon, 2003). Ocular trauma affects any part of the eye.

Alzheimer's Disease, Dementia, and Driving

Alzheimer's disease, the most common primary dementia in the United States, characteristically impacts memory and visuospatial, linguistic, and executive functions (Lee, 2001). Alzheimer's disease and dementia also pose potential problems for drivers who may not be able to see, judge, and process information as normal drivers would. Uc *et al.* (2004) report that drivers with mild AD are most likely to make incorrect turns, commit more navigation errors, and make more at-fault safety errors in an instrumented vehicle equipped to record and assess driver speed, steering, braking, and acceleration. Impairments in early AD include but are not limited to: object localization and recognition, reading, route finding, visual attention, and visuospatial abilities. Similarly, dementia sometimes proves hazardous to drivers who may lose their sense of time or direction. While there are various stages and varieties of dementia, it is necessary to screen drivers because conventional vision testing methods and self-screening assessments may not easily detect this condition. Drivers with dementia may not recognize the symptoms and, hence, may lack the ability to acknowledge that they have dementia and cease driving, if necessary.

Since 1980, Alzheimer's disease has more than doubled to approximately 4.5 million Americans. By 2050, it is estimated that the incidence of Alzheimer's disease will jump to 11.3 million to 16 million Americans (Herbert, 2003). Although rare and hereditary forms of Alzheimer's disease may appear in the age 30s and 40s cohorts (Bird *et al.*, 1989), the greatest risk factor is increasing age. Alzheimer's disease appears in nearly 10 percent of all cohorts age 65 years and older and approximately 50 percent of all cohorts age 85 years and older (Evans, 1989). Pritchard *et al.* (2004) report that between 1979 and 1997, the incidence of dementia, primarily Alzheimer's disease, trebled among adult (age 45 to 74 years) neurological deaths in Australia, Canada, France, Germany, Italy, Japan, Netherlands, Spain, United Kingdom, and the United States. Environmental toxins and pollutants may account for these concomitant upsurges. As long as people with dementia have a mortality rate 3.5 times higher than the general population rate (as cited in Pritchard *et al.*, 2004), we can assume that collision risks among these drivers will also increase.

Hopkins *et al.* (2004) estimate that the number of dementia drivers in Ontario, Canada will increase three fold between 2000 and 2028 to approximately 100,000. Among those aged 65 years and older, the overall dementia prevalence rate is estimated at 8.7 percent in 2000. The at-risk dementia drivers are approximated to constitute only one-half of all dementia patients. Hopkins *et al.* urge driving policy and screening test reforms to weed out dementia drivers, especially of the Alzheimer's type, who may continue to drive well into a disease that persists 8 to 10 years after the onset of symptoms. They note that physicians, through Section 203 of the Ontario Highway Traffic Act, are required to report patients who have medical conditions that may negatively impact their driving performances. Yet, these physicians are not trained to detect dementia drivers or other at-risk drivers.

According to the Florida At-Risk Driver Council (2004), mild to moderate dementia drivers constitute more than 20 percent of all 242,480 drivers age 85 years of age and older for the fiscal year 2002 to 2003. This leads to the question of whether a similar proportion of drivers are now on Arizona roads, since both states are characterized by similar population growth, percentages of older adult cohorts, and climate. It is possible that a number of dementia drivers may account for the high collision, injury, and fatality rates that are observed in Arizona.

Wolf (2004) notes that it is estimated that more than 500,000 drivers with Alzheimer's disease now hold Florida driver's licenses and there is no system available to screen or monitor these kinds of drivers.

Janke and Eberhard (1998) of the California Department of Motor Vehicles and the National Highway Traffic Safety Administration (NHTSA) sought to create a battery of non-driving tests and road tests to identify elderly drivers with dementia or other aging-related medical conditions. These tests were included in a pilot study and reviewed on the bases of detection of driving performance and functional impairment. By 2002, the University of Iowa Hospitals and Clinics installed driving simulators to study licensed drivers who were Alzheimer's disease patients. It was determined that 33 percent of all of these drivers were involved in simulated collisions due to inattention or slow reaction time (Rizzo, 2002).

Although cognitive function maladies generally define degenerative dementias, there are several studies that document sensory, particularly visual, decrements in these patients. While some research fails to link visual acuity changes as gauged by the traditional Snellen eye chart, Cormack *et al.* (2000) cite a number of studies that relate impaired visual acuity and visual hallucinations in patients with Alzheimer's disease. They also refer to studies that clearly document color vision, contrast sensitivity, stereoacuity, and visual acuity impairments in dementia patients. Other studies document a link between decrements in visual acuity and contrast sensitivity with Alzheimer's disease and other dementia patients (Mendez, *et al.* 1990; Lakshiminarayanan, 2000; Cormack *et al.*, 2000). Decreased visual acuity under low luminance has also been associated with dementia patients, including those with Alzheimer's disease (Lakshiminarayanan, 2000). Yet,

traditional Snellen type charts are often unable to detect Alzheimer's disease and dementia since these tests are typically conducted in normal light conditions.

Driving simulators are therefore supplemental methods of screening these at-risk drivers because they may offer ambient weather and light conditions as part of the process of Dynamic Vision Assessment for Transportation (DVAT™). The simulation of these conditions, all that contribute to the environmental factors as described, e.g., in the Haddon Matrix (Haddon, 1972), may ultimately improve our vision screening methods, especially of at-risk drivers and, possibly, dementia drivers. (In transportation engineering studies, the Haddon matrix serves as a framework for injury prevention identification. Events occur within a certain time sequence, as defined by the matrix.) Driving simulators may also weed out drivers with strokes and other neurological disorders, including Parkinson's disease, a progressive, neurodegenerative disease characterized by tremor and impaired muscular coordination that affects more than 500,000 Americans (National Institute of Neurological Disorders and Stroke, 2004) and has doubled in incidence between 1979 and 1997 (Pritchard *et al.*, 2004). Also, contrast sensitivity testing and other traditional vision testing methods of dementia patients tend to be time-consuming and challenging.

It is important to note that diagnosis of a neuropsychologic or neuromotor disorder does not imply driving impairment. However, in some cases, these diseases, especially in advanced stages, may disallow the safe operation of motor vehicles. Most physicians may not know how to identify these diseases in their patients without the use of specialized equipment or actual driving observations. Ott *et al.* (2005) report that a clinician's assessment alone "...may not be adequate to determine driving competence in those with mild dementia." Hence driving simulators may prove especially useful for such assessments, especially when the incidence of dementia is expected to jump 400% over the next twenty years (Whitmer *et al.*, 2005).

Some Driver's License Vision Testing Policies: An Overview

In order to better understand the vision testing processes at driver's license bureaus in Arizona, Florida, and the United States, it is necessary to evaluate the vision testing policies in these places as well as in other countries. A number of these places are identified in our global survey (Appendix B).

Driver's license renewal policies are a fundamental part of the vision screening program. These policies serve to weed out drivers who may cause harmful collision events. In light of recent studies by Owsley *et. al* at the University of Alabama in Birmingham that show, for example, how driver refresher training courses for older drivers do not reduce older driver-involved collisions (Owsley, *et al.*, 2004), the driver's license renewal policies provide an even greater role for promoting safety on roads.

Arizona

In Arizona, a driver's license is valid until age 65 years. Any person age 65 years and older who renews by mail must submit a vision test verification form, provided by the Motor Vehicle Division (MVD), or certification of an applicant's vision examination, conducted no more than 3 months earlier. Visual acuity testing is required for driver's license renewal every 12 years until age 65 years. After age 65 years, testing is required every five years. Drivers age 70 years and older are not allowed to renew their driver's licenses by mail.

According to Arizona Administrative Code, Title 17, section R17-4-502, 2002, in the State of Arizona, an examination is required when the license applicant indicates that a visual condition has either developed or modified "...that may constitute a disqualifying medical condition." This, however, only considers the driver who discloses a visual disorder, among other possible conditions. Many drivers, especially dementia drivers, are unaware of these possible visual disorders and, therefore, continue to drive without adequate assessments.

Florida

For a number of years, Florida law permitted drivers at any age to go without vision testing for as long as 18 years (Clark and Kripalani, 2003). In January 2004, a law was enacted in Florida to require drivers age 80 years and older to submit to a vision test at either driver's license bureaus or licensed physicians. Test results are now required for renewal. Alternative means of transportation, public awareness, and safer approaches to allowing older drivers to remain on the road are also vigorously pursued.

Field of vision measurements are only used in the State of Florida when submitted by ophthalmologists or optometrists.

United States

In the United States, driver's license application and renewal procedures vary from state to state. There may be age-based assessments (medical, road, vision, and/ or written tests) and frequencies of renewal periods. There may also be requirements for in-person, computer-based, or post mail renewals.

Several studies point to a lack of uniform vision screening standards and testing in the United States (Demers-Turco, 1996; Peli and Peli, 2002). Each state motor vehicle bureau operates independently. According to Decina *et. al* (1997) vision screening apparatus availability, ease of test administration, and medical opinion consensus generally govern the current U.S. vision standards and testing methods. The impetus to modify vision testing methods stems from years of survey and research, most recently through several studies commissioned by the NHTSA (Staplin *et al.*, 2003a, 2003b, 2003c). A survey by the American Association of Motor Vehicle Administrators (AAMVA) and the National Highway Safety Administration (NHTSA),

“AAMVA/NHTSA Survey of States/Provinces on Model Driver Screening/ Evaluation Program”, reveals that eighty-five percent respond favorably to possible modifications incorporating dynamic visual acuity, contrast sensitivity, and low luminance acuity (Staplin *et al.*, 2003a).

Only 26 percent of all U.S. states require frequent vision testing for older drivers through shorter license renewal periods or in-person renewals. These include Arizona, California, Colorado, Florida, Hawaii, Idaho, Indiana, Iowa, Kansas, Missouri, New Mexico, and Rhode Island. Driver reexamination is prohibited on the basis of age in Maryland, Minnesota, and Nevada. Ageism with respect to driver’s licensure is against the law in Massachusetts. Shipp *et al.* (2000) support comprehensive vision testing for at-risk drivers at driver’s license renewal.

Approximately half the U.S. drivers age 85 years and older do not meet motor vehicle bureau vision standards (Susman, 1999). This is a great concern, along with the increasing lack of health insurance in the United States. While laws require drivers to possess driving insurance, and most U.S. states require motorists to possess liability insurance for vehicle registration or rental purposes, personal health insurance coverage is optional. In 2003, approximately 15 percent, or 43 million, of the U.S. population was uninsured. These people, of all ages, lacked private, public, government, state, or military health insurance plans, among other possible types of coverage. This value is slightly higher than the 14 percent of the population estimated to lack health insurance coverage in 2001 (U.S. Department of Health and Human Services, 2004). Yet, the American Public Health Association (2004) reports that in some or all of the years 2002 to 2003 more than 80 million Americans lacked health insurance. The states of Arizona and Florida are ranked among the highest rates of uninsured in the U.S. because nearly one out of every three of the total population under age 65 years in these states were uninsured during this time period.

Consequently, millions of American drivers may not have access to regular or periodic vision examinations in a medical setting. McCloskey *et al.* (1994) suggest that for insured Americans, optometrists do not routinely administer sophisticated vision tests that may identify high-risk older drivers. In Oregon, effective June 1, 2004, a Medically At-Risk Driver Program requires a mandatory medical reporting process (through certain physicians and health care providers) of persons age 14 years and older who have severe and uncontrollable functional and/or cognitive impairments that are likely to impact the person’s ability to safely operate a motor vehicle. However, Oregon House Bill 3071, while helpful for the drivers who carry health insurance, does not seem to address drivers who lack it. This law also functions on the premise that the physicians and health care providers are adequately equipped and/or trained to assess drivers for these functional and/or cognitive impairments, particularly those that adversely impact vision.

Therefore, millions of drivers on our roads may not have been screened for eye disease or impairment. These drivers may not have access to regular or periodic vision examinations in a medical setting. The onus then falls onto the state driver’s license bureaus to adequately screen all drivers, including the uninsured, for visual impairments.

A recent survey commissioned by the DOT indicates that 63 percent of the AAMVA member respondents support the privatization of some driver's license qualification assessments (Staplin *et al.*, 2003a). However, these activities are not explicitly defined. One cost-effective strategy devised to alleviate this burden of responsibility on all driver's license bureaus is the possible completion of all vision testing and certifications through driver insurance programs (Semmens, 2004). This way, vision tests could be conducted at each annual motor vehicle insurance renewal period and, via a computer network, presented to driver's license bureaus through an on-line program to reduce paperwork and additional staffing concerns. Queues would also be shortened due to the numerous vision testing offices and satellite locations.

A number of studies address collision risk and driver's license renewal policies. Overall, the link appears to be weak due to inadequate vision testing mechanisms and the dire need to improve these methods and obtain empirical data to institute new vision test processes at all driver's license bureaus. Shipp *et al.* (2000) note the limitations associated with existing vision tests as a means of screening functional visual impairments. They also support status quo maintenance, mandatory vision testing for driver's license renewal, uniform and stringent vision screening requirements, comprehensive eye examinations by ophthalmologists or optometrists, and mandatory vision testing for initial and renewing driver's license applicants as ways of addressing the projected increase in at-risk visually impaired drivers in all U.S. states.

Levy *et al.* (1995) associates lower collision-related fatality risks of drivers aged 70 years and older with state-mandated visual acuity tests and U.S. driver's license renewal policies. Dobbs *et al.* (1998) shows that driver's license removal criteria are ineffective in North America on the bases of a road driving study and the identification of clinically-impaired older drivers through hazardous error associated with driving, positioning, and turning of motor vehicles. Shipp (1999) demonstrates that several factors, including a lack of a vision test at license renewal and a high population density escalate the likelihood of older driver fatalities. Rock (1997) does not associate collision, licensure, or fatality rates of older Illinois drivers, from years 1987 to 1989, and 1995, with accelerated renewal periods for older drivers and road test removals for drivers under age 75 years. According to Owsley *et al.* (2003), collision risks increase among visually impaired older drivers who satisfy the legal licensing requirements. On the basis of years 1990 to 2000 U.S. data, Grabowski *et al.* (2004) does not associate frequent license renewal, in-person renewal, state-mandated vision, and road tests with fatality rates among drivers age 65 to 74 years and 75 to 84 years. However, lower fatality rates are linked with in-person license renewal among the older drivers.

Furthermore, Rock (1997) discusses the impacts of sweeping reforms on collisions, fatalities, collision rates, and licensure rates in Illinois older drivers' license renewal requirements. The changes include road test elimination for ages 69 to 74 years and reduction in length of license terms and renewal requirements (from four to two years) for ages 81 to 86 years and one year for ages 87 years and older. No benefits are reported

through these changes, including the administration of vision tests at driver's license renewal. These results may be expected when the testing methods are ineffective and unchanged.

Australia

By 2051, the proportion of adults age 65 years and older is expected to reach 24.2 percent in Australia (Langford et al., 2004). Researchers and driver's license officials have taken a very proactive role in developing new standards and assessment methods to adequately screen at-risk and older drivers throughout Australia. Some of these results have been reported by Fildes (1997), Fildes *et al.* (2001), Charlton et al. (2001), Andrea *et al.* (2002), Langford *et al.* (2004), among others.

Fildes (1997) reports that by the late 1990s, age requirements for license renewals existed in nearly 75 percent of Australia except for Northern Territory and Victoria. Fildes also notes that annual vision tests, for all ages, were required in approximately 50 percent of Australia, including Australian Capital Territory, New South Wales, South Australia, Tasmania, and Western Australia. Interestingly, in Western Australia, as of 2000, regulations require licensed drivers at 75, 78, and 80 years, and every year to 84 to have an eyesight test and medical form completed by a doctor. Licensed drivers at age 85 years and every year after are required to complete a practical driving assessment in addition to the completion of an eyesight test and medical form (The Government of Western Australia, Road Safety Council, 2000). In South Australia, an annual medical assessment is required for drivers aged over 70 years to retain their license. Although annual driving tests are not required, referrals are sometimes issued according to a physician's discretion (Hunt, 2005).

Keeffe *et al.* (2002) reveal that while older drivers tend to refrain from or limit their driving, many visually impaired drivers remain on the roads in Australia. Although it is demonstrated that no difference in likelihood for collision exists between people with good vision than those with visual acuity less than 20/40 (6/12), it is estimated that only 2.6 percent have vision less than that required for driver's licensure. This study supports the need for improved vision testing, standards, and policy in Australia.

In 2003, the parliamentary Road Safety Committee of Victoria, Australia released a report with several recommendations for older drivers. Those included compulsory license renewal vision testing, routine medical evaluations, mandatory medical testing for licensing drivers age 80 years and over, and the shortening of the license renewal period from 10 to 5 years for drivers age 65 years and older, among other recommendations. Victoria is the only state in Australia that offers vision testing only to driver's license applicants. All other states provide vision testing at the driver's license renewals (Lennon and Leunig, 2003).

Langford *et al.* (2004) evaluate various older driver's licensing procedures through older driver fatal and serious injury collision involvement rates across all Australian states. They report that Victoria lacks a mandatory driver assessment program yet has the lowest

older driver collision rate per number of driver's licenses issued. Hence they conclude that older driver safety benefits do not appear to be linked to various age-based mandatory assessment procedures. As this report demonstrates, however, there are many collision factors, apart from the denominators of per population and per number of licensed drivers issued that require extensive review and analysis. These may include but are not limited to the same RAIR analyses we conducted in our report.

Additionally, some recent studies do not link collision rate with driver's license vision testing practices (Hull, 1991). Clearly, this may be attributed to the ineffectiveness and inadequacy of these testing methods not only in Australia, but other countries as well. For example, our research shows (Appendix B, Table 2) that 75 percent of Australian states solely utilize

Snellen-type eye charts as a means of visual acuity and vision testing of drivers. Fink and Sadun (2004) show that the most common measurement of ranges of vision loss (International Council of Ophthalmology, 2002), visual acuity, defines less than 0.1 percent of the visual field. Failure to measure contrast sensitivity in driver's license vision tests directly and adversely impacts driver safety.

Not only are new national and international comprehensive vision measurement standards needed, but also improved vision testing methods. Once these changes are in effect, we may observe a stronger link between driver's license vision testing, initial and renewal driver's license procedures, and types and rates of collisions and collision involvement across Australia and elsewhere.

United Kingdom

In the United Kingdom, it is estimated that the cohorts age 60 years and older constitute 20 percent of the population. By 2031, they will form 30 percent of the population (United Kingdom Department of Transport, 2002). Meanwhile, these older drivers are two to five times more likely to die or suffer serious injury in any collision due to increased frailty (Holland, *et al.*, 2003).

Since 1935, the basic U.K. visual requirement for driver's license applicants remains the number plate test, which involves reading in daylight a number plate with symbols three inches (79.4 mm) high at a distance of 67 feet (20.5 m), with or without corrected lenses, at a nominal binocular Snellen acuity of approximately 6/15 in meters or 20/50 in English units. Self-declaration of the ability to pass is required on all driver's license applications and verified at driving test time. No additional tests are required until age 70 years yet over the years, the U.K. visual standards have been deemed inadequate due to seemingly higher vision test standards in many other countries and suggestions that many current drivers could not pass the U.K. number-plate test. Contrastingly, Davison and Irving (1980) report that possible age-related visual acuity decrements appear in drivers as early as ages 40 to 44 years when they fail to achieve mean U.K. Snellen acuity levels. Such findings seem to support studies in the United States by Decina and Staplin (1993) that reveal the onset of this change at approximately age 45 years. Others have expressed

concerns about the lighting conditions, lack of standardization, symbol design, etc. Meanwhile, younger drivers appear to contribute most to collisions in the United Kingdom. Misinterpretation of road signs may account for the disproportionate number of maneuvering errors among older drivers (Charman, 1997).

Although many concerns remain about the U.K. driver's license requirements, Charman (1997), whose study was commissioned by the United Kingdom Department of Transport (DfT), does not recommend changes in current driver's license requirements due to the lack of a single test or combination of tests to effectively screen at-risk drivers without disqualification of safe drivers. However, Currie *et al.* (2000) challenge the effectiveness of the Snellen acuity chart and, on the bases of analyses of patients and questionnaires to health care professionals, deem it a poor predictor of one's ability to meet the required driving visual standard in the United Kingdom. These findings appear to be supported by Schneck *et al.* (2002), especially as they relate to older drive, contrast sensitivity, and low luminance conditions.

Unsurprisingly, most medical and health care professionals lack the time, resources, and training to provide any more than basic screening to assess an unwell or medicated driver's fitness to drive. In the United Kingdom, many doctors are not familiar with laws governing assessment of drivers. The burden of responsibility lies primarily on the driver and the Driver Vehicle Licensing Authority (DVLA) to determine whether a patient is fit to drive (Holland *et al.*, 2003). License review for fitness to drive is required at age 70 years, and subsequent frequency of license review is every 3 years. A minimum horizontal field of 120 degrees is required by the European Union Directive and recommended in the United Kingdom (Charman, 1997).

Interestingly, according to the DfT (1995), Australia, Canada, New Zealand, and the United States all have higher fatality rates per 100,000 population than the United Kingdom.

New Zealand

In New Zealand, older drivers at ages 75, 80 and every two years thereafter are currently required to renew their driver's licenses. While medical certification is a requirement for these drivers, an on-road driving test is also compulsory from age 80 and every two years thereafter. An eyesight examination or certificate is required for license renewals.

Canada

An overview of the testing policies of Ontario is presented. The reader is referred to Canadian Ophthalmological Society, specifically for recommendations on vision standards for driving in Canada. Ontario requires at-fault drivers age 70 years and older to take a vision test, a general knowledge test and a road test. The age 80 years and older drivers are required to take a vision test and a general knowledge test, in addition to a skills refresher course every two years (Lazaruk, 2004). Hopkin *et al.* (2004) indicate

that the road test component was likely removed for these cohorts due to increases in associated expenses and numbers of drivers age 80 years and older. The screening process also appears to be inadequate because it can neither detect dementia drivers nor drivers in the early stages of dementia. Hence other at-risk drivers are also ineffectively screened.

The number of Ontario drivers age 65 years and older are estimated to increase fivefold in the 42-year period between 1986 and 2028, to approximately 2.5 million drivers. Drivers age 80 years and older constitute the fastest growing age group of drivers in Ontario. In just 10 years, the number of Ontario drivers age 80 years and older jumped 152 percent to 115,709 drivers in 1997. Tasca *et al.* (2000) report that collision risk is higher among drivers age 80 years and older compared to drivers age 70 to 79 years cohorts in Ontario, Canada. Hence Canada, and in particular Ontario, face many of the same challenges as Arizona and many other U.S. states and other countries (Hopkins *et al.*, 2004).

Vision Testing: Self Versus Other

Self-assessment of visual impairments is risky because some drivers may not wish to reveal their medical limitations or may not be aware of their visual impairments. Nevertheless, road safety is compromised. Ball (2003) reports that questionnaire research reveals that standard clinical measures do not adequately identify visual difficulties in older adults and that "... older adults are sometimes totally unaware of their visual problems."

Ideally, licensed medical officials should administer comprehensive vision testing on-site at driver's license bureaus. Since this would prove to be a very costly endeavor for most, if not all, driver's license bureaus, then an effective on-site vision testing exam or process is needed to discourage bias and to promote driver safety. Annual comprehensive eye examinations are crucial for eye disease prevention or detection.

It is possible that no one has been able to demonstrate a strong link between visual acuity and collision risk because of the following:

- Visual acuity scores are not comprehensive assessments of driver vision.
- The lack of empirical data governing the effectiveness of driver's license bureau vision testing machines precludes other possible inferences.

Burg conducted one of the earliest large-scale studies involving vision screening methodology in 1968. On the basis of 3-year driving records, visual performance, and other characteristics of a sample size of $n > 17,000$ California driver's license applicants, he determined that driving accidents and convictions were most closely associated with dynamic visual acuity, static acuity, field of view, and glare recovery.

Field Of Vision Testing

The visual field measures the ability to see objects at a distance. It quantifies peripheral vision, commonly referred to as side vision, the visual processing of objects and movements outside of the direct line of vision. Most U.S. states require a visual field of 100 degrees or more, along the horizontal dimension for driving (Peli and Peli, 2002). Others require decipheral vision testing for commercial drivers.

According to McCarthy (2004), 62 percent of the U.S. states test a driver's license applicant's field of vision in addition to visual acuity. These states include Arkansas, California, Florida, Georgia, Hawaii, Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Nebraska, Nevada, New Hampshire, New Mexico, New York, North Carolina, North Dakota, Ohio, Oregon, South Carolina, South Dakota, Virginia, Washington, Wisconsin, and Wyoming. However, only 26 percent of all U.S. states require frequent vision testing for elder drivers through shorter license renewal periods or in-person renewals. These include Arizona, California, Colorado, Florida, Hawaii, Idaho, Indiana, Iowa, Kansas, Missouri, New Mexico, and Rhode Island. Driver reexamination is prohibited on the basis of age in Maryland, Minnesota, and Nevada. Ageism with respect to driver's licensure is against the law in Massachusetts.

Again, these field of vision tests, while necessary, are neither comprehensive nor automated.

Older Versus Younger Drivers

Fragility and injury susceptibility, account for the disproportionate number of older drivers killed in motor vehicle collisions (Li, *et al.*, 2003). Cognitive, motor, sensory, and visual abilities also weaken due to age-related processes and diseases. Cognitive skills, sensory and motor capabilities, and reaction time tend to decrease as driver age increases. Hence there are susceptibilities to collisions due to physical impairments, medication usage, and perceptual lapses. Medication can impair visual and driving performance. While young drivers may have a greater involvement in collisions associated with alcohol and narcotics, older drivers, especially the elderly, are more likely to be involved in medication-related collisions than their younger counterparts. These perceptual lapses include, but are not limited to failures to acknowledge signs or signals or to yield the right of way. These factors tend to contribute to a rise in injury-related collisions and left-turn collisions. Wood (1994) suggests that older drivers may experience difficulty performing simultaneous tasks due to increases in reaction times, psychomotor slowing, and cognition changes associated with attention and recognition, in addition to reduced visual performance. Visual performance decrements are associated with age (Shipp *et al.*, 2000). Many older drivers suffer with other possible age-related ailments, including arthritis. These can affect neck and arm movement. In addition to visual problems, these ailments could pose safety problems for drivers, especially when experiencing blind spots. The potential for incidents involving blind spots always exists when driving, particularly when changing lanes. A number of interesting studies describe

the differences between older and younger drivers with respect to collision risks. Others define PRT, Perception Response Time, and gauge driver performance by measuring the length of time between the appearance of a threat in the driver's field of view and the start of braking. PRT is often used to quantify older driver performance.

According to Evans (1998), a significant number of fatalities include very young and very old unlicensed drivers. Many older drivers continue to drive even when their licenses are revoked. Evans also determined, on the basis of collision rate involvement, that very old U.S. drivers face an increased fatality risk. Licensing a 20-year-old appeared to pose a greater risk to motorists than licensing older drivers up to age 80 years.

Dobbs *et al.* (1998) cited several studies that report that drivers 16 to 24 years have higher collision rates than drivers 75 years and older. Ryan *et al.* (1998) determined that among Western Australian drivers, collision involvement was as high for the age 75 years and older cohorts as for the age 25 years and younger cohorts. Stutts *et al.* (1998) examined data from 3,238 North Carolina driver's license renewal-seeking applicants age 65 years and older and linked cognitive test performance with crash risk. Cook *et al.* (2000) determined that Utah drivers age 70 years and older were more than twice as likely to have a crash involving a left-hand turn and more than likely to be killed than Utah drivers between the ages of 30 and 39 years. McGwin Jr *et al.* (2000) determined that decreased visual acuity and contrast sensitivity among drivers between 55 and 85 years of age accounted for high risk driving conditions.

According to Margolis *et al.* (2002), there is a considerable increase in motor vehicle collision and fatality rates per mile driven for drivers age 75 years and older. Claret *et al.* (2003) examined all 220,284 collisions between vehicles with four or more wheels in Spain during the period from 1990 to 1999 and found that male drivers age of 74 years and over posed the greatest risk of causing collisions. The onset of this trend was most noticeable for drivers after the age of 50 years. In the age 55 years and older U.S. cohorts, motor vehicle collision was identified as the second leading cause of death due to injury (University of Alabama-Birmingham Department of Ophthalmology Driving Assessment Clinic. 2003).

Medications for heart disease, stroke, arthritis, among other ailments, are identified with at-fault Alabama drivers aged 65 years and older who were involved in collisions. (McGwin Jr, 2000) Medication, clearly, can also affect the vision, motor, and cognitive abilities of drivers. Mortimer and Fell (1989) report that U.S. drivers, in 1983, age 65 years and older were involved in more fatal collisions at night than the drivers age 25 to 65 years and fewer collisions than the drivers under age 25 years. At-risk Alabama drivers, age 55 years and older, are associated with useful-field-of-view size constriction, visual sensory impairment, and/or cognitive weakening (Owsley, 1994). Owsley *et al.* (1998) reports that when useful field of view is reduced 40 percent or more in older drivers, they are 20-times more susceptible to injurious collisions. Several studies link collision involvement with useful field of view (Goode *et al.*, 1998, Owsley *et al.*, 1998).

Older drivers are more inclined to collisions associated with, among other factors, approaching traffic, failure to yield, left turns, inattention, intersections, and stop signage (Planek and Fowler, 1971, Keltner and Johnston, 1987; McGwin and Brown, 1999, Zhang *et al.*, 2000). Wallace and Eberhard (1995) call for revisions to driver's license renewal procedures and testing for older drivers on the basis of increased motor vehicle collision risks among drivers age 68 years and older after a study in a rural community in Iowa, from 1985 to 1989. Zhang *et al.* (2000) provide an analysis of collision-related factors involving drivers age 65 years and older between 1988 and 1993 in Ontario, Canada. Some increased risks of fatalities and injuries are associated with failing to yield right-of-way, disobeying traffic signs, snowy weather, and medical/physical conditions, especially for drivers age 75 years and older. Snowy weather increases fatal-injury collision risk by 60 percent for drivers age 65 years and older.

Baggett (2003) found that, when compared to younger drivers, older Arizona drivers tend to have more angle collisions, left-turn collisions, and accident involvements during daylight hours. Griffin III (2004) sought to link fragility, illness, left turns, and perceptual lapses to driver age. He analyzed Texas collision data over a 25-year period and linked older drivers with fragility, illness impairment, perceptual lapses, and left turn collisions. He determined that fragility, particularly for the cohorts age 85 years and older, tends to result in 3.72 times as many crash-related deaths as the 55 to 64 year old groups.

Matthias *et al.* (1996) determined on the basis of data for years 1984 to 1988 that Arizona drivers age 70 years and older were nearly twice as likely to be cited for improper turning as all other drivers combined. For Arizona drivers age 65 years and over, left-turn collisions constitute a significantly larger proportion of total collisions than for any other age cohorts. These findings are consistent with Staplin *et al.* (1997). Their focus group discussions with older drivers revealed that left turn maneuverability was the most challenging aspect of driving-related complexities at intersections.

A recent study conducted by Dr. Matthew Baldock at the University of Adelaide reports that the number of collisions among older drivers was lower than younger drivers in South Australia because the older drivers tend to avoid driving in rain, darkness and heavy traffic, among other adverse conditions (Hunt, 2005).

Although most driver's licenses are renewed every eight years in Wisconsin, recent state legislation, such as 2005 Assembly Bill 43, includes a proposal for a law to require a vision test that is passed every three years for drivers ages 75 to 84 years. Drivers age 85 years and over would be required to pass vision and traffic-knowledge tests every two years. Vision tests may be administered through optometrists, ophthalmologists, physicians, and local Department of Motor Vehicle sites. According to a recent amendment to this proposal, a restricted license, with consideration of distance, routes, and time of day, may be issued to some older drivers through the Department of Motor Vehicles.

Meanwhile, there is a growing movement in New Zealand, led by Grey Power. This independent organization operates to protect the rights of people age 50 years and older and to eliminate “humiliation and stress” that older drivers, especially drivers age 80 years and over allege to face through driver’s license testing (Stuff, 2004). Recent proposals call for an end to the controversial practice of driver testing of drivers over age 80 years in lieu of a family group conference (Cousins, 2005).

In New Zealand, according to the Land Transport NZ (2002), both community referrals and computer-based tools were being reviewed as possible means to assess older drivers. Another form of further assessment, such as a practical driving test or medical examination, was considered for older drivers who failed a screening test, or who failed an assessment.

As of April 2005, legislation has been proposed by the government of New Zealand to abolish the age-based on-road driving tests. However, an optional on-road test, in certain circumstances, has also been proposed. The Driver Licence Amendment Rule is expected to be signed and implemented in early 2006. One proposal includes the establishment of a new conditional older driver license that would permit older drivers the option of obtaining either a full license (for travel in and out of a local area) or a conditional license (for local area travel only). An easier on-road test may accompany conditional licenses. Another proposal allows older drivers 80 years and over to operate either an automatic or a manual vehicle, as opposed to an automatic vehicle only.

Similarly, many U.S. state driver’s license bureaus, senators, and legislators, seek to modify driver’s license policy and renewal procedures, amid charges of ageism, especially among older drivers. Alternative transportation methods are encouraged and, through federal and state grants, some forms of public transportation and subsidized cabs are promoted. Some insurance companies, special interest groups, and medical officials offer special driver education programs and driver insurance discount incentives to assist senior drivers with self-assessment tools to determine whether they should continue driving. However, these strategies, while praiseworthy, are insufficient because, on the bases of our studies, current driver’s license testing and vision screening mechanisms are both inadequate and infrequent. For example, while Wisconsin Assembly Bill 43 appears laudable, it appears to assume that current vision testing methods are strong measures of driving ability. It also does not include proposals for screening the vision and neuropsychomotor competence of drivers of other ages, especially due to concerns associated with dementia, Alzheimer’s disease, among others. These proposals seem to target older drivers and do not account for drivers in other age groups. New Zealand, like the USA and other countries, illustrates a U-shape distribution with respect to collision-related injuries and distance driven. Dementia, although primarily associated with older people, occurs in people of all ages, particularly the middle-aged. In the United Kingdom, recent estimates show that at least 20,000 middle aged people with dementia require special support (Whalley, 2003). Yet, no new and effective methods of screening drivers, irrespective of age, in particular for vision and neuropsychomotor conditions (i.e., dementia), appear to be proposed or implemented.

SURVEY OF DRIVER'S LICENSE BUREAU DIRECTORS OR THEIR REPRESENTATIVES

As part of our project to determine if the current vision testing practices in the State of Arizona require enhancement, a comprehensive survey on the visual acuity testing methods of drivers was developed. Questionnaires were faxed or e-mailed to the directors of all driving licensing agencies of all 50 U.S. states, Commonwealth of Puerto Rico, Canada, New Zealand, the United Kingdom, and Australia from January 28 to April 16, 2004. Some officials were telephoned for follow-up interviews. We received responses from 100 percent of all national and international driver's license bureau directors or their representatives. Our aim was to review and learn about the policies and practices of other driver's licenses bureaus within the United States and overseas in order to provide a recommendation on a suitable comprehensive automated driver's license testing system to ADOT. The results of this survey are presented in Appendix B of this report.

Our visual acuity survey covers all 50 U.S. states and the Commonwealth of Puerto Rico, all 10 provinces and 3 territories of Canada, all of New Zealand, all of the United Kingdom, and the 6 states and 2 territories of Australia. The provinces of Canada include Newfoundland and Labrador, Nova Scotia, Prince Edward Island, New Brunswick, Québec, Ontario, Manitoba, Saskatchewan, Alberta, and British Columbia. The territories of Canada include Nunavut, Yukon, and Northwest Territories. Nunavut constitutes nearly one-fifth of Canada's land mass yet has the smallest population. Approximately 85 percent of the 28,000 residents of Nunavut are Inuit, an indigenous people formerly called Eskimos. The states of Australia include New South Wales, Queensland, South Australia, Victoria, Tasmania, and Western Australia; the territories, Australian Capital Territory and Northern Territory.

ANALYSIS OF COLLISION DATA

Introduction

Consequences from traffic collisions include injuries, fatalities, *and/or* property damage. In order to ultimately design an all-new pre-pilot vision test for ADOT, it is necessary to consider the histories, modes, and trends of collisions between states. In this study, the states of Arizona and Florida are selected. In addition to descriptive statistics, risks for undesired events are estimated using some very basic risk concepts and risk analyses through statistical data we obtained through ADOT Motor Vehicle Crash Statistics Unit, Traffic Records Section, ADOT Motor Vehicle Division, and Florida Department of Highway Safety and Motor Vehicles.

Methodology

The trends and risks of the drivers of the states of Arizona and Florida are gauged with data from the Accident Location Identification and Surveillance System (ALISS) of Arizona and the Florida Highway Safety and Motor Vehicle Department of Florida

databases. The data stem from the Arizona Traffic Accident Report and Florida Long Form Traffic Crash Reports provided by law enforcement agents in both states. All data are processed through special coding and programming developed by ESRA Consulting Corporation in Matlab 6.0, Release 13. All tables are produced in Microsoft Excel; all statistical figures, Matlab.

Where values are calculated based on the number of licensed drivers (hereafter referred to as “licensees”) in the states of Arizona and Florida, linear regression techniques are used to obtain the numbers of licensed drivers in the State of Arizona for years 1991 to 1996. In most exercises, we eliminate 15-year-old drivers from these analyses and calculations due to the Graduated Driver’s license Program that took effect in Arizona in 1996.

The Framework

The Haddon Matrix provides us with an epidemiological framework for injury assessments through environmental, human, and vehicular factors (Haddon, 1972). This allows us to ultimately define the likelihood and significance of injuries, for example.

Table 1. The Haddon Matrix (Songer, T., 2004).

	HUMAN	VEHICLE	ENVIRONMENT
PRE-EVENT			
EVENT			
POST-EVENT			

We can evaluate a collision sequence through pre-collision, collision, and post-collision events. However, in our study, we are primarily interested in the pre-collision event and how it relates to driving or human factors and the environment. Vehicle maintenance, failure, design, speed, and illumination all influence the vehicle factor. The driving or human factor includes age, alcohol, fatigue, gender, driving experience, training, legislation, and penalties. Road, traffic, and weather conditions constitute environmental factors (Rodrigue *et al.*, 2004; Songer, 2004).

Rodrigue *et al.* (2004) indicate that direct observation, induced measurements, and survey techniques are the three widely accepted modes of exposure data collection. Exposure, a scale factor, defines the quantity of collisions in the numerator of a ratio. It simplifies the process of comparing data from two states by eliminating variables such as size and motor vehicle mileage.

Thorpe (1964) pioneered the induced exposure method to allow for a variety of risk comparisons. This led to calculations of Relative Accident Involvement Ratio (RAIR), refined by Stamatiadis and Deacon (1997), whereby each motor vehicle collision consists of an at-fault (responsible) driver and not-at-fault (not responsible) driver.

COMPARISON OF RELATIVE ACCIDENT INVOLVEMENT RATIO (RAIR) OF COLLISIONS OF ARIZONA AND FLORIDA DRIVERS, YEARS 1991 TO 2001

In the year 2000, 76 percent of all traffic fatalities involving older drivers included another vehicle (U.S. DOT, 2000.) The propensity of these fatal collisions, and many others that transcend driver age, reinforces the need to evaluate, among other factors, the impact of roadway lighting and other features of driver vision, perception, and performance. When these collisions occur at night, they may be attributable to a driver's inability to notice delineation, warnings, and other possible road safety controls. Night severely restricts driver's visual range to about 262 feet (80 meters) and impacts a driver's ability to discern details and steadily react to stimuli (Hollnagel and Källhammer, 2003). Adverse weather conditions affect pavement markings. At night, any quantity of ice, snow, or water can cause pavement markings to appear nearly indiscernible. Interestingly, however, dry pavement accounts for 81 percent of fatalities during both day and night times (Opiela *et al.*, 2003). As a result of this growing interest in at-fault collision involvement studies, and its underlying causes, the calculations and applications of the Relative Accident Involvement Ratio (RAIR) are presented. In order to achieve a representative sample of drivers from both Arizona and Florida, nine age groups are selected: 16 to 19 years, 20 to 29 years, 30 to 39 years, 40 to 49 years, 50 to 59 years, 60 to 69 years, 70 to 79 years, 80 to 89 years, and 90 years and older.

RAIR measures the likelihood of involvement in a collision. It is a ratio of the number of at-fault drivers of a certain age group divided by the total number of at-fault drivers to the number of not-at-fault drivers of a certain age group divided by the total number of not-at-fault drivers. RAIR stems from the pioneering work of Thorpe (1967) and Carr (1970). Its applications are valuable in many transportation engineering studies and analyses. Stamatiadis and Deacon (1995) utilized RAIR to study collision-related trends among drivers on the bases of age cohorts and gender.

According to Stamatiadis and Deacon (1995), accident propensity, a term used to describe RAIR calculations, is sometimes applied to measures of the ratio of accident involvement quantity to the miles of travel. Since these tend to lack accuracy because of the need for exogenous travel estimates, the RAIR approach seems most practical when direct exposure estimates are unfeasible or lacking.

As shown by Chandraratna *et al.* (2002), we define RAIR as follows:

$$RAIR_{i,j} = \frac{\frac{D1_{i,j}}{\sum \sum D1_{i,j}}}{\frac{D2_{i,j}}{\sum \sum D2_{i,j}}}$$

Where:

i = type of drivers

j = type of conditions

$D1_{i,j}$ = number of at-fault drivers of driver type i for type j conditions.

$D2_{i,j}$ = number of not-at-fault drivers of driver type i for type j conditions.

RAIR values greater than 1.0 denote a driver group more likely to be at-fault in motor vehicle collisions. RAIR values less than 1.0 designate a driver group that is less likely to be at-fault (Robertson and Aultman-Hall, 2001).

Over (1998) addresses the possibility that the classification scheme of at-fault and no-fault drivers may be open to gender bias. He also encourages the indication of the type of collision because some drivers are more susceptible to severe consequences than others.

In order to compare millions of collisions involving Arizona and Florida drivers during the years 1991 to 2001, data were compiled in Microsoft Excel format. Programs in Matlab 6.0, Version 13 were developed and ran to divide and analyze at-fault and no-fault drivers in each type of collision and state. The literature was reviewed on at-fault driver calculations and predictions.

Interestingly, Robertson and Aultman-Hall (2001) used RAIR to quantify the effects of dry, wet, and snowy/slushy roads on Kentucky drivers age 65 years and older who were involved in collisions. They determined that these drivers, when compared to drivers younger than age 65 years, were more likely to be at-fault when roads were dry. Wood and Troutbeck (1992) found possible connections between reduced contrast sensitivity and at-fault motor vehicle collisions.

However, Owsley and Ball (1993) determined a correlation between Useful Field of View (UFOV), the visual information extraction area that functions in a single glance without eye or head movement, and at-fault motor vehicle collisions. A study of drivers in Vancouver, British Columbia in 1986 indicated more at-fault automobile collision involvement among drivers age 55 years and older than drivers age 36 to 50 years (Cooper, 1990). In Germany, while accident involvement of drivers age 65 years and older is low, the percentage of at-fault drivers is high. In 1989, however, drivers age 70 years and older represented the largest percentage (71.3 percent) of at-fault drivers as compared to drivers under age 30 years at 56.7 percent (Schlag, 1993).

Bathtub Curves

Bathtub curves are usually associated with product failure and reliability engineering. These curves illustrate an expected failure rate of, for example, an electronic component, with respect to time. Three regions define the bathtub curves: Early Failure Period (sometimes called the Infant Mortality Period, the High Initial Failure Rate, or the Burn-in Failure), Intrinsic Failure Period (also referred to as the Stable Failure Period) and Intrinsic Failure Rate, or Useful Life Period, and the Wear-out Failure Period. The Useful Life Period is sometimes called the Chance Failure or Random because it exhibits random failures of the product.

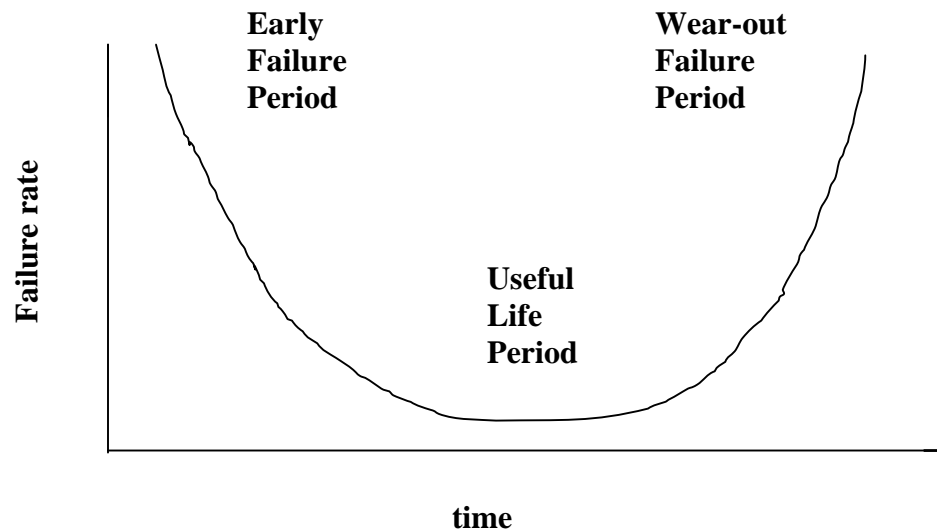


Figure 2. The Bathtub Curve

The failure probability density function illustrates the type of behavior shown in a bathtub curve:

$$f(t) = b\theta(\theta t)^{b-1} \exp[-(e^{\theta t})^b \cdot \theta t^b - 1] \text{ for } b > 0, \theta > 0, t \geq 0$$

where:

b = shape parameter,

t = time,

and θ = scale parameter

$R(t)$, the component reliability function, as an approximate fit, is defined as:

$$R(t) = \exp[-(e^{\theta t})^b - 1]$$

$h(t)$, Hazard rate, which explains probability of failure changes over the lifetime of the component (Modarres, *et al.* 1999), is represented by:

$$h(t) = \frac{f(t)}{R(t)} = b\theta(\theta t)^{b-1} e^{(\theta t)^b}$$

Interestingly, many of our RAIR graphs 30 to 43, Appendix G, appear in the shape of bathtub curves up until the age 80 to 89 years cohorts, where the Wearout Period tends to end and retirement, in most cases, begins. This may be expected because older drivers are most vulnerable to collision-related injury or death due to frailty associated with older age. Similarly, fatigue causes deterioration of mechanical and electrical components and susceptibility to external stresses. Design or defects of a product sometimes contributes to brittle behavior of a material. Therefore, in order to maximize safety of both people and products, it is necessary to seek to minimize these stress factors. In traffic-related collisions, these may be due to visual, cognitive, or motor impairments, or any combination thereof, of the drivers. Through improvements to driver's license testing methods, we may have an edge on screening at-risk drivers. Through a follow-up medical evaluation, these drivers may seek possible remedies to continue to drive or consider alternative methods of transportation.

However, it is possible that the sudden drop this study observes within the majority of these RAIR figures, following the ages 80 to 89 years cohorts are due to random fluctuations, missing data, or changes in policy or driver behavior. George (2000) explains that nonparametric failure rate functions may describe this "premature wear out and retirement" because no family of distribution functions fits these failure rate functions. Retirement follows the onset of the Wearout Failure Period and causes failure rate functions to decrease.

Unreported collisions may also reduce failure rate functions and occur late in product life, or, in our study, late in driver life. Interestingly, a similar decline is observed immediately after the ages 75 to 79 years cohorts in Western Australia, through driver collision involvement by age, on the basis of rates per 100 million kilometers driven (Ryan and Legge, 1998).

According to the Information Technology Laboratory of the National Institute of Standards and Technology (2004) empirical evidence demonstrates that repairable systems can also be illustrated by bathtub curves when the ordinate is the Repair Rate or the Rate of Occurrence of Failures (ROCOF). However, some but not all devices may illustrate this type of general shape. For example, only 72 percent of United Airlines commercial aviation equipment tends to follow infant mortality rates (Smith, 1992). Different components, like different kinds of human populations, exhibit varying levels of behavior associated with stresses. Hence the three regions may differ according to variables, populations, and time.

Bathtub curves are quite familiar in the literature, especially as these apply to certain product life analyses in reliability engineering. However, these are typically referred to as U-shape distributions in transportation engineering studies and are often associated with one distribution skewed relative to the other. Burg was one of the first to characterize traffic-related collisions in the form of U-shaped (or bathtub-shaped) curves. Burg (1967) and Hills and Burg (1977) showed that the measured visual performance of drivers progressively declined after about age 45 years. It was fairly constant until that age. The U-shaped curve was represented for all types of collisions when the collision rate was plotted on the ordinate and age cohorts were plotted on the abscissa. Young and adult drivers demonstrated significantly higher collision rates. Yet, noticeable increases in collision risk beginning at about age 50 years were evident. Hills and Burg (1977) also identified collision risk, with respect to static or dynamic acuity, in drivers age 54 years and older. In Australia, where drivers age 70 years and older are estimated to comprise 14 percent of Australian fatalities by 2005, a skewed bathtub curve now defines the relative risk of driver fatality per million kilometers traveled. However, the random period appears considerably shorter and the onset of the Wearout Period begins at ages 45 to 49 years. High levels of involvement in a fatal collision are apparent for ages 17 to 20 years and ages 75 to 79 years (Australian Transportation Safety Bureau, 1996).

Similar U-shaped or bathtub curves appear in various traffic violations per 100,000 miles among California driver age cohorts (State of California Department of Motor Vehicles, 1982.) In 1990, U.S. drivers ages 16 to 19 years had the highest collision rate and U.S. drivers age 75 years and older had the highest fatality rate. The fatality rate per 100 million miles, was represented as a U-shape or bathtub curve, where drivers ages 16 to 19 years had the second highest rate of fatalities followed by a decrease. An increase in fatality rate per 100 million miles was evident among the age 55 to 59 years cohorts. Collision rates per million miles were highest for drivers age 16 to 19 years and second highest for drivers age 75 years and older (Massie, *et al.*, 1995). Kim (1996) showed, in the form of a U-shaped distribution, that males ages 15 to 24 years and females age 65 years and older were most likely at-fault in collisions in Hawaii from 1986 to 1993.

Odds of fault were placed on the ordinate, age cohorts on the abscissa. Driver fatality rates, on the bases of age and gender, in 1996, demonstrated that the cohorts age 85 years and older and the cohorts age 16 years constituted the highest fatality rates per 100 million vehicle miles traveled (U.S. DOT, 2000). A bathtub curve illustrated these rates.

In the United Kingdom, however, a different shaped curve emerges: Half of a U where male and female novice drivers are most accountable for collisions. However, the ordinate posts self-reported accident liability, and the abscissa indicates age. (DETR, 2000.) A bathtub curve is observed when accident involvements per year per 1,000 drivers, on the bases of fatal and serious accident liabilities by driver age group (ages 50 years and older) and gender, are illustrated (Maycock, 2002).

To the best of our knowledge and research, there exist no studies that have associated trends in RAIR with bathtub curves. However, in order to identify trends in Figures 30 to 44, it is useful to consider the various regions of the bathtub curves as bases for measurement since our figures, in one form or another, tend to take on the bathtub curve in appearance. More importantly, all of these figures appear to demonstrate the very start of the Wearout Failure Period for both Arizona and Florida begins at approximately age 50 to 59 years. Drivers with visual defects involved in automobile collisions in both states, as shown in Figure 43, seem to have bathtub curve features similar to those of environmental conditions and manner of collisions, especially dawn or dusk lighting conditions as shown in Figure 42. This finding establishes a link between collision involvement and visual defects. This finding also underscores the need for ambient lighting changes and/ or contrast sensitivity testing during vision testing.

Additionally, our RAIR values, especially for the drivers age 80 years and older, are in very good agreement with those computed for Michigan drivers by Stamadiatis and Deacon (1998). Their trends of observed effect of driver age on RAIR also follow a bathtub curve, or U-shaped distribution, as do our RAIR results.

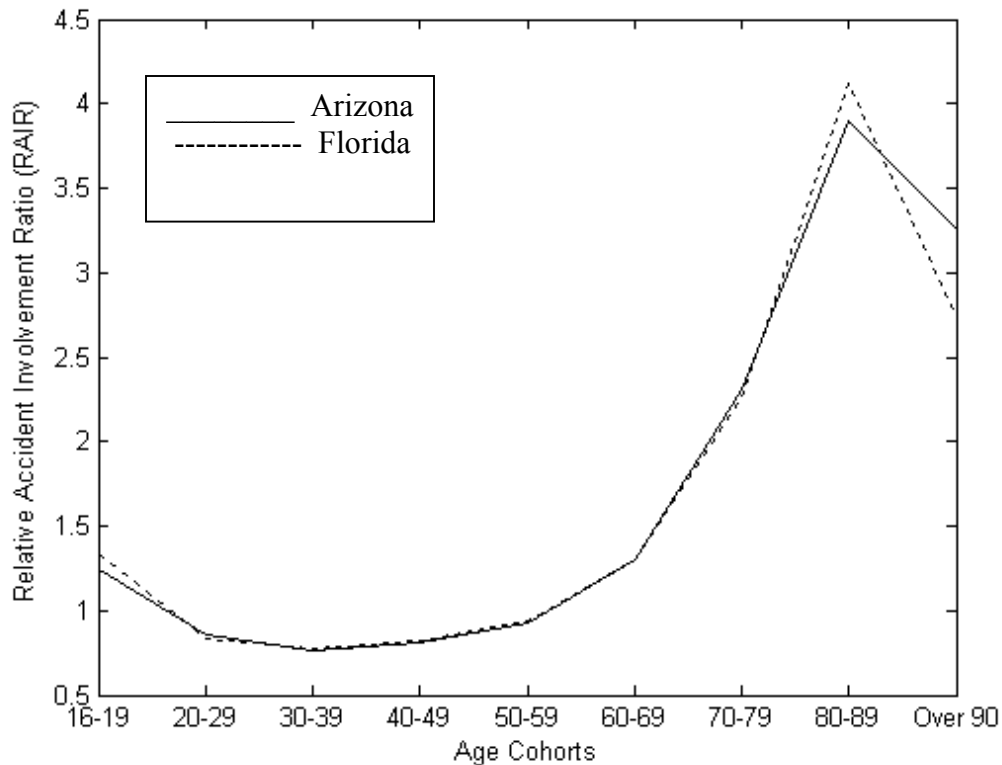


Figure 3. Comparison of Left Turn Manner of Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

According to Figure 3, the Early Failure Period is very short. While both Arizona and Florida drivers feature the onset of the Wearout Period at about the cohorts age 50 to 59 years (RAIR~ 1), a peak occurs among the cohorts age 80 to 89 years (Arizona RAIR ~ 3.9; Florida RAIR~ 4.25) and retires. Drivers age 16 to 19 years are three times less likely to be involved in collisions due to left turns than drivers age 80 to 89 years. Notice how the RAIR values of both Arizona and Florida drivers age 80 to 89 years surpass those of any other age group for left-turn manner of collisions. The results of this study are somewhat in agreement with the findings described by Chandraratna *et al.* (2002). The general shape of our RAIR for left turn collisions by driver age group appears to be considerably similar except for the component of age 89 years and older cohorts. Although the RAIR values for the ages 16 to 19 years are the same, the RAIR for the age 80 years and older Kentucky cohorts are approximately double the RAIR values of Arizona and Florida drivers. Chandraratna *et al.* suspect that left turns at intersections may account for these discrepancies among older drivers.

Appendix G includes detailed results and analyses of RAIR values of collision risks associated with environmental factors. Our most interesting RAIR findings are summarized on the following pages.

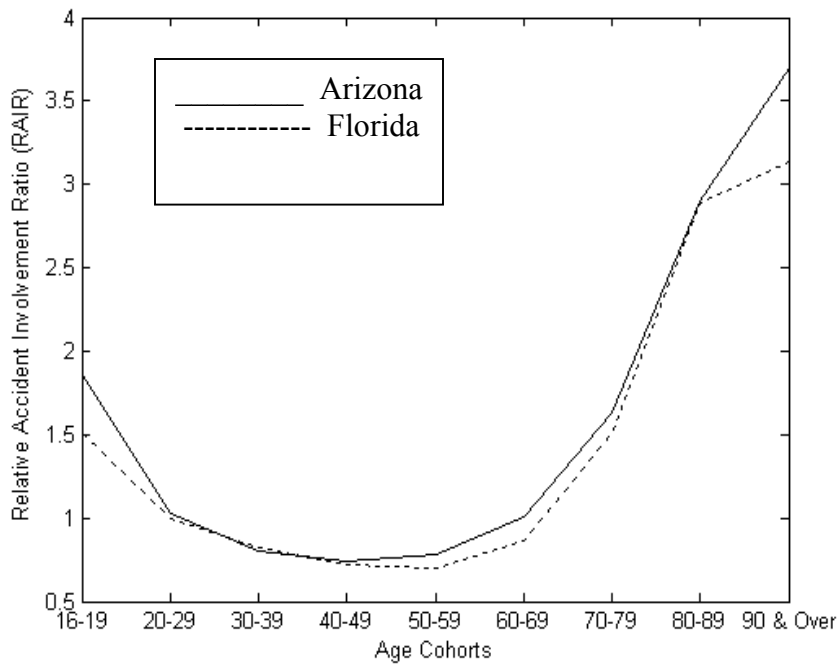


Figure 4. Comparison of Dawn or Dusk Related Collisions Among Drivers in Arizona and Florida for Years 1991 to 2001

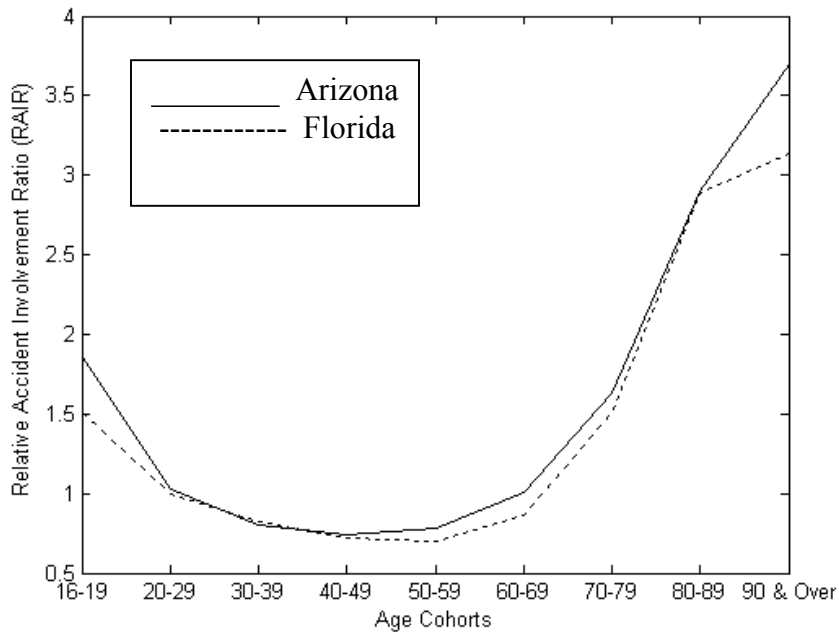


Figure 5. Comparison of Collisions Among Drivers with Visual Defects in Arizona and Florida for Years 1991 to 2001

- The relative involvement of dawn or dusk-related collisions among both Arizona and Florida drivers are evaluated. Arizona drivers (RAIR~3.6) and Florida (RAIR~ 3.1) drivers age 90 years and older are about twice as likely to be at-fault in a dawn or dusk-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.8; Florida RAIR~ 1.5). The onset of the Wearout Period begins at ages 50 to 59 years for both Arizona and Florida drivers (Figure 42, Appendix G).
- The relative involvement of corrective lenses-related collisions among both Arizona and Florida drivers are observed. Arizona drivers (RAIR~3.6) and Florida (RAIR~ 3.1) drivers age 90 years and older with visual defects are about twice as likely to be at-fault in a corrective lenses-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.8; Florida RAIR~ 1.5). The onset of the Wearout Period begins at ages 50 to 59 years for both Arizona and Florida drivers (Figure 43, Appendix G).
- Drivers ages 80 to 89 years in Arizona (RAIR ~ 3.5) are about twice as likely to be at-fault in angle manner of collisions compared to the Arizona drivers age 16 to 19 years (RAIR ~ 1.5). Similarly, the drivers ages 80 to 89 years in Florida (RAIR ~ 3.25) are about twice as likely to be at-fault in angle manner of collisions compared to the Florida drivers age 16 to 19 years (RAIR ~ 1.5), as shown in Figure 30, Appendix G.
- Drivers ages 80 to 89 years in Arizona (RAIR ~ 1.8) are about 1.5 times as likely to be at-fault in backing manner of collisions compared to the Arizona drivers age 16 to 19 years (RAIR ~ 1.25). Similarly, the drivers ages 80 to 89 years in Florida (RAIR ~ 2.15) are about twice as likely to be at-fault in backing manner of collisions compared to the Florida drivers age 16 to 19 years (RAIR ~ 1.2), as shown in Figure 31, Appendix G.
- Drivers ages 80 to 89 years in Florida (RAIR ~ 3.25) are about twice as likely to be at-fault in head-on manner of collisions compared to the Florida drivers age 16 to 19 years (RAIR ~ 1.5). However, the drivers 90 years and older in Arizona (RAIR ~ 2.85) are about 1.5 times as likely to be at-fault in head-on manner of collisions compared to the Arizona drivers age 16 to 19 years (RAIR ~ 1.9), as shown in Figure 32, Appendix G.
- Drivers ages 80 to 89 years in Arizona (RAIR ~ 3.8) and Florida (RAIR ~ 4.15) are about three times as likely to be at-fault in left-turn manner of collisions compared to the drivers age 16 to 19 years in Arizona (RAIR ~ 1.25) and Florida (RAIR ~ 1.45), as shown in Figure 33, Appendix G.
- Florida drivers ages 16 to 19 years (RAIR~ 2) are more likely to be at-fault in a rear end collision due to higher RAIR values than the cohorts ages 80 to 89 years (RAIR~ 1.9). Contrastingly, Arizona drivers age 80 –89 years (RAIR ~ 2.19) are more likely to be at-fault in a rear end collision due to higher RAIR values than the cohorts ages 16 to 19 years (RAIR~ 1.95), as shown in Figure 34, Appendix G.
- Arizona and Florida drivers age 80 –89 years are about twice as likely to be at-fault in a sideswipe manner of collision due to higher RAIR values than the cohorts ages 16 to 19 years (RAIR~ 1.5), as shown in Figure 35, Appendix G.

- Arizona (RAIR~ 2.45) and Florida (RAIR~ 2.75) drivers age 80 to 89 years are about twice as likely to be at-fault in a clear weather-related collision than the cohorts ages 16 to 19 years, as shown in Figure 36, Appendix G.
- Florida (RAIR~ 2.75) drivers age 80 to 89 years are about twice as likely to be at-fault in a cloudy weather-related collision than the cohorts ages 16 to 19 years (RAIR~ 1.75). Arizona (RAIR~ 2.95) drivers age 90 years and older are about twice as likely to be at-fault in a cloudy weather-related collision than the cohorts ages 16 to 19 years (RAIR~ 1.75), as shown in Figure 37, Appendix G.
- Florida (RAIR~ 2.55) and Arizona (RAIR~ 2.35) drivers age 80 –89 years are about twice as likely to be at-fault in a rain-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.8; Florida RAIR~ 1.9), as shown in Figure 38, Appendix G.
- Florida (RAIR~ 2.6) and Arizona (RAIR~ 2.6) drivers age 80 –89 years are about twice as likely to be at-fault in a fog-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.55; Florida RAIR~ 1.85), as shown in Figure 39, Appendix G.
- Florida (RAIR~ 2.8) drivers age 80 to 89 years and Arizona (RAIR~ 2.65) drivers 90 years and older are about twice as likely to be at-fault in a daylight-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.75; Florida RAIR~ 1.75), as shown in Figure 40, Appendix G.
- Florida (RAIR~ 2) drivers and Arizona drivers (RAIR~1.9) age 80 –89 years are about equally as likely to be at-fault in a darkness-related collision as compared to cohorts ages 16 to 19 years (Arizona RAIR~ 1.5; Florida RAIR~ 1.4), as shown in Figure 41, Appendix G.
- Arizona drivers (RAIR~3.6) and Florida (RAIR~ 3.1) drivers age 90 years and older are about twice as likely to be at-fault in a dawn or dusk-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.8; Florida RAIR~ 1.5), as shown in Figure 42, Appendix G.
- Arizona drivers (RAIR~3.6) and Florida (RAIR~ 3.1) drivers age 90 years and older with visual defects are about twice as likely to be at-fault in a corrective lenses-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.8; Florida RAIR~ 1.5), as shown in Figure 43, Appendix G. This seems to demonstrate that these drivers are most likely impacted by dawn and dusk, yet the shape of these skewed bathtub-shape curves also reveals that various lighting, weather, and manners of collision may also significantly affect vision, especially visual defects.
- Arizona and Florida drivers age 80 –89 years are about twice as likely to be at-fault in a sideswipe manner of collision due to higher RAIR values than the cohorts ages 16 to 19 years (RAIR~ 1.5).

DESCRIPTIVE STATISTICS AND CALCULATED RISKS OF VIOLATIONS/BEHAVIOR-RELATED COLLISIONS IN THE STATE OF ARIZONA, YEARS 1991 TO 2001

The collision rates per 100,000 licensed Arizona drivers on the basis of driver's license restrictions over an 11-year period, from 1991 to 2001 (Appendix R) are calculated. Drivers ages 25 to 34 years are selected as a baseline since this group surpasses all other age groups with the greatest number of collisions, injuries, and fatalities in both the states of Arizona and Florida (Appendix C and Appendix D). This group is also one of the most populous. The following are determined:

- The collision rate of licensed Arizona drivers age 75 years and older, may be as high as twice the rate of drivers ages 25 to 34 years (Figure 82, Appendix B) on the basis of any one of the following:
 - corrective lenses
 - failed to yield right of way
 - made improper turn

These findings support Wick and Vernon (2002). They indicate that higher rates of citations, collisions, and at-fault collisions characterize some groups of visually impaired non-commercial drivers. Collision risks are seemingly greater among drivers with higher levels of impairment and restriction.

- The collision rate of drivers Arizona drivers age 75 years and older, may be as high as three times the rate of drivers age 25 to 34 years on the basis of any one of the following:
 - automatic transmission
 - left outside mirror
 - full hand controls
- The collision rate of Arizona drivers age 75 years and older, may be as high as seven times the rate of drivers age 25 to 34 years on the basis of "daylight hours" driver's license restrictions.

COMPARISON OF AVERAGE INDIVIDUAL RISKS OF COLLISIONS, INJURIES, AND FATALITIES OF ARIZONA AND FLORIDA DRIVERS, YEARS 1991 TO 2001

Risk calculations are often used to quantify radioactive releases and predict nuclear power reactor accident sequence frequencies (McCormick, 1981). Risk methodologies are also useful as a method of ranking risks and prioritizing measures to prevent collisions. In order to manage the underlying causes of traffic-related collisions, injuries, and fatalities, it is necessary for us to identify, estimate, and evaluate the risks associated with these events. Calculations of Average Individual Risk of collisions, injuries, and fatalities of Arizona drivers and Florida drivers allow us to initiate this process. In order to obtain a representative sample of all age cohorts, in accordance with Minimum Uniform Car Crash Criteria (MUCC), ages 16 to 19 years, 20 to 24 years, 25 to 34 years, 35 to 44 years, 45 to 54 years, 55 to 64 years, 65 to 74 years, and 75 years and older, are observed. These results are tabulated in the Appendix Q.

According to the American Institute of Chemical Engineers (2000), we define Average Individual Risk as:

$$IR_{AV} = \frac{\sum_{x,y} IR_{x,y} P_{x,y}}{\sum_{x,y} P_{x,y}}$$

Where

IR_{AV} = average individual risk in the exposed population (yr^{-1})

$IR_{x,y}$ = individual risk at location x, y (yr^{-1})

$P_{x,y}$ = number of people at location x, y

On the basis of these calculations, our study shows the following:

- Arizona drivers in all age cohorts have higher Average Individual Risk of collisions than Florida drivers.
- The greatest Average Individual Risk of collision, Average Individual Risks of Injury, occur among both Arizona ($1.14E-01$) and Florida drivers ($6.71E-02$) age 16 to 19 years. This may be due to inexperience, high speeds, and, possibly, alcohol and narcotics.
- Arizona drivers age 75 years and older are more than four more times as likely to be at Average Individual Risk of collision than Florida drivers of the same age group.
- The greatest Average Individual Risk of injury occurs among both Arizona and Florida drivers age 16 to 19 years.

- Arizona drivers age 75 years and older are more than four times as likely to be at an Average Individual Risk of Injury than Florida drivers of the same age group.
- Arizona drivers age 75 years and older are more than four times as likely to be at an Individual Risk of injury than Florida drivers of the same age group.
- The Arizona driver age groups with the greatest Average Individual Risk of fatalities include: age 75 years and older cohorts (6.65E-04).
- The Average Individual Risk of fatalities among Florida drivers is highest among age 16 to 19 years cohorts (2.41E-04). According to Table 2, this quantity warrants public spending to control the hazard.
- Arizona drivers age 75 years and older are more than 3.3 times as likely to be at an Average Individual Risk of Fatality than Florida drivers of the same age group.
- According to the Thresholds of Annual Fatality Risk Levels (Table 2, below), the Average Individual Risk of fatalities may encourage people to control these safety hazards.

Table 2. Thresholds of Annual Fatality Risk Levels According to Otway and Erdmann

Annual fatality Risk level, yr⁻¹	Conclusion
10 ⁻³	This level is unacceptable to everyone. Accidents providing hazard at this level are difficult to find. When risk approaches this level, immediate action is taken to reduce the hazard.
10 ⁻⁴	People are willing to spend public money to control a hazard (traffic signs/ control and fire departments). Safety slogans popularized for accidents in this category show an element of fear, i.e., “the life you save may be your own”
10 ⁻⁵	People still recognize the risk. People warn children about these hazards (drowning, firearms, poisoning). People accept inconveniences to avoid the risk, such as avoiding air travel. Safety slogans have precautionary ring: “never swim alone, “ “never point a gun,” “never leave medicine within a child’s reach.”
10 ⁻⁶	Not of great concern for the average person. People aware of these accidents but feel that they can’t happen to them. Phrases associated with these hazards have element of resignation: “lightning never strikes twice,” “an act of God”
10 ⁻⁷	Acceptable risk of death to an individual from nuclear power plant accidents.

H. J. Otway and R. C. Erdmann, 1970, *Nuclear Engineering Design*, **13**, 365, as cited in McCormick, p.370.

In addition to our global surveys of officials of driver's license bureaus, statistical studies and risk analyses are generated to determine the possible impacts of vision impairments on collision trends among drivers of various age cohorts in two states with increasing older driver populations. This study seeks to identify cutting edge vision testing equipment that offers improvement over the current vision testing techniques. Comprehensive studies, surveys, and literature reviews are performed. When testing equipment is not identifiable, testing methods previously perceived as "off the beaten track" in driver's license bureaus are considered: computer automated vision screening and driving simulators.

REVIEWS OF VISION TESTS AND DRIVING SIMULATORS

Introduction

In order to establish criteria for new testing methods it is necessary to evaluate currently available and emerging new tests. Accordingly, evidence of these findings is presented and designs and recommendations of a comprehensive automated driver's license test system, that includes vision screens and a driving simulator, are provided.

The History and Future of Vision Tests

The current vision standards for driver's licenses that U.S. states follow are not based on strong empirical evidence through driving performance, vision tests, and safety record. These primarily stem from antiquated visual standards established through Black *et al.* (1937), a 1925 report approved by the American Medical Association, and widespread implementations and modifications of the Snellen Eye Chart of the 1860s. These standards are typically approved by recommendations from medical, highway, safety, and government agencies. While the Snellen type of test remains solely in use in New York, all other U.S. states, according to our survey, complement this test through the use of vision screening equipment. These allow officials to test both potential and licensed drivers, depending on the state's rules and regulations, for less than 0.1 percent of the visual field (Fink and Sadun, 2004). Nevertheless, the following is proposed:

- Ranges of vision loss, as prescribed by the International Council of Ophthalmology (2002), should not only be based on visual acuity.
- Quantification of visual standards that account for other ocular features, in addition to visual acuity, are direly needed to improve safety and vision, both on and off the roads.
- New visual standards may also allow for a smooth transition of automation technology in transportation agencies and medical facilities.

As we ride the Information Superhighway, the need for automated vision testing in all driver's license bureaus prevails. A new system may allow for cost-saving measures associated with testing apparatus, staffing, paperwork, and space. Future vision tests, in addition to those we describe in this chapter, may allow for instant assessments anywhere a driver accesses the Internet, especially with the advent of biometrics and computer network designs to accommodate these features, among many others. Biometrics may allow the measurement of one physical or behavioral characteristic unique to an individual. Physical characteristics include the face geometry, fingerprint, hand geometry, iris, and/or retina. Behavioral characteristics include an individual's voice and/or signature.

In the United Kingdom, the climate seems very favorable for such possibilities due to implementation of the new national identity card scheme underway there (United Kingdom Home Office, November 2003). The use of web-based or Internet-based automated vision testing at private homes and in other public locations other than a

driver's license bureau office seems likely due to the plans for biometrics within the UK card scheme.

Interestingly, the case in favor of new vision standards and vision testing techniques was adequately addressed on the basis of a large-scale study (n= 30,000) conducted in Canada. Collision risk among Quebec drivers age 70 years appeared to be the same for those with static acuity below U.K. and European standards (6/12 to 6/15 in meters) as opposed to those with better acuity (Gresset and Meyer, 1994).

Vision Screening Tests

A number of vision testers are reviewed, including many of the devices currently in use at driver's license bureaus in the United States and overseas. These are confirmed through live observations and/ or literature reviews. A number of vision screening and/ or testing devices are highlighted in Table 99 of Appendix S. Interestingly, there is a dearth of empirical evidence demonstrating the effectiveness of each vision testing product in use at all of the United States driver's license bureaus we contacted. Also, these vision screening machines are severely limited by their static conditions and inability to screen driver's licensees for both potential eye diseases and vision loss conditions. Although some companies plan to expand their lighting and testing options, these machines completely lack the capability to dynamically simulate driving conditions. Many are not computer automated and therefore burden officials with extra time and paperwork to score and record driver licensee's test results. Many officials express concerns about cheating and the memorization of material on current driver's license vision testing techniques. Unlike the written knowledge driving tests, which are primarily automated, none of the vision screening equipment at the driver's license bureaus is currently available on-line, in or out of the bureau offices. It is, however, possible that these vision screening machines fill voids in clinics, schools, and hospitals for very rudimentary vision screening purposes. However, to the best of our knowledge, there are absolutely no independent and large-scale scientific studies to continue to support their use at ADOT- MVD. The results of our survey of all driver's license bureaus in the United States, the Commonwealth of Puerto Rico, Australia, Canada, United Kingdom, and New Zealand clearly support these findings. Nevertheless, in an effort to curtail the high number of collisions, fatalities, and injuries in the State of Arizona, a revolutionary approach to improve vision screening tests is essential.

It is important to note that Decina *et al.* (1990) conducted one of the largest studies on the use of the vision screening machine called the Optec 1000. A pilot vision screening test of 12,710 Pennsylvania licensed drivers was performed at the time of license renewal. Specifically, an Optec 1000, equipped with contrast sensitivity, horizontal visual fields, and static visual acuity tests was used. Decina *et al.* (1990) suggested that contrast sensitivity impairments appear to indicate the highest collision risk among drivers age 65 years and older. They determined, through an extensive literature search, that there was a weak link between vision screening test failure and driving record. More importantly, they determined that more than 50 percent of the licensees who failed the vision

examination were unaware that they were afflicted with vision problems such as cataracts, glaucoma, macular degeneration, and outdated corrective lenses.

Szlyk *et al.* (1991) sought to improve vision screening methods after identifying limitations in the Keystone and Titmus vision screeners through tests among patients with retinitis pigmentosa and other central field defects. Decina and Staplin (1993) identified a combination of contrast sensitivity, horizontal visual field, and visual acuity tests as an alternative vision screening tool for drivers. These measures appeared to relate directly to collision risk for drivers ages 66 to 75 years and age 76 years and older. They later indicated that they did not associate a relationship between collision involvement and visual acuity or horizontal visual field measures.

In the mid- to late- 1990s, the California Department of Motor Vehicles and the NHTSA took a proactive approach to improving driver's license testing methods. Several pilot studies were conducted. Hennessy (1996) reported that two of five experimental vision tests, the Pelli-Robson Low-Contrast Acuity Test and Perceptual Reaction Time (PRT) Assessment, the latter that measures visual information processing speed, were considered for a large-scale statewide study in California. In 1998, Janke and Eberhard (1998) conducted a series of driving and non-driving tests through the California Department of Motor Vehicles and NHTSA in an effort to identify older drivers with dementia or other age-related medical conditions. The vision testing component included angular motion sensitivity, dynamic contrast sensitivity, dynamic high-contrast acuity, static contrast sensitivity, static high-contrast acuity, Useful Field of View, etc.

Most recently, Hitchcock *et al.* (2004) utilized the Optec 1000 and the hand held version to demonstrate that that visual acuity alone may not be sufficient for neurobehavior test paradigms because their subjects, with corrected to normal visual acuity, had varying contrast sensitivity scores. They cautioned about conclusions concerning the Optec 1000 and the hand held version for the use of contrast sensitivity assessments. While both tests provided similar and previous derived contrast sensitivity functions, the contrast sensitivity scores were dissimilar and a slight learning effect appeared to impact most measurements. Differences in spatial frequency scores were attributed to differences in design characteristics affecting viewing.

Our telephone conversation with a representative at Stereo Optical (April 19, 2004) yielded the following information: The Optec 1000 is primarily a driver's license bureau instrument, with limited capability, designed to measure acuity, with four tests and two slides. The Optec 2000 is more functional and includes 12 tests, 150 different slides, and a depth perception feature. There is an Optec 2000 with peripheral tests. Additional charges apply to an Optec 2000 with remote control capability. Both the Optec 1000 and the Optec 2000 provide day luminescence level. The Optec 6500 provides daytime and nighttime lighting conditions and high and low glare features. No dawn, dusk, or weather conditions are provided in Optec tests.

Also, through an on-line search (Clark, 2001; Scheeres, 2001) and interview with Jeffrey Stewart (2004) of VisionRx, we determined that the State of New Mexico driver's license

bureau conducted a pilot study, for approximately six months in 2001 (Perry, 2004), involving a fully automated visual acuity testing device developed by VisionRx.

However, it appeared as if the focus of the study was ease of possible transition from non-automated to automated vision testing mechanisms as opposed to the scientific collection of data to support further study or implementation of the product. There were no published or independent studies conducted.

Some other vision testing products are also worth mentioning. These include the Useful Field of View (UFOV®), a test developed by Owsley and Ball that allows for a measure of one's ability to promptly process and react to several targets. The Useful Field of View is a test of visual attention performed and scored on a computer. It measures visual attention skills, processing speed, and sensory function. UFOV primarily quantifies one's visual selective attention (Owsley, *et al.*, 1998) and complements the cognitive screening process (Myers, *et al.*, 2000). Rizzo *et al.* (1997) suggest the UFOV among other off-road tests, to assist licensing authorities in the recertification process of impaired drivers. Its effectiveness as a possible neuropsychological evaluation tool may allow it to assess driving risk. Although UFOV may be used to measure driving performance and visual attention skills, in some studies, it has not linked collision status with drivers (Schneider, 2002). Nevertheless, Schneider suggests the possible use of UFOV for a pre-recovery assessment of patients with head injuries to predict their driving ability. He notes that the UFOV may be sensitive to different types and severities of brain dysfunctions. However, Ball *et al.* (2003) report that the UFOV is strongly connected with at-fault motor vehicle collisions. Also, Rinaldi *et al.* (2002) indicate that tests such as the UFOV adequately predict driving performance on the low fidelity simulation task. As of January 2005, the UFOV is incorporated in the AAA Roadwise Review™, where it provides a quick and effective measure of visual information processing speed.

A battery of cognitive tests and physical measures for older drivers (ages 55 to 96 years) has been designed and reviewed through the Maryland Department of Motor Vehicles and NHTSA. Although many different vision tests are available, as identified in our comprehensive survey and discovered through our extensive literature review, only one currently meets the specifications of the ESRA DAT™ requirements.

According to the Stereo Optical website, the distance and near testing capabilities of the Optec 6500 may include acuities, color perception, depth perception, low vision E, fusion, lateral and vertical phorias. The Titmus Vision Screeners, for another example, are portable. Manufacturers and distributors claim these products occupy a small space area and are administrable in under five minutes. Most offer a small and limited group of test slides. All offer daylight features. However, they are susceptible to mechanical failure, fatigue, and breakdown. They also are not fully automated.

In January 2005, the American Automobile Association (AAA) released Roadwise Review™, a CD-ROM incorporated the DRIVINGHEALTH® INVENTORY (DHI) tools (of TransAnalytics LLC) that assess head/ neck flexibility, high contrast visual acuity, leg

strength and general mobility, low visual acuity, Useful Field of View, visualization of missing information, visual search, and working memory of drivers. These eight functional areas are considered the most likely predictors of collision risk, as validated by the National Highway Traffic Safety Administration and the National Institute of Aging.

This computer-based screening program is available to non-members and is offered at significant discount to non-members. Many libraries and senior centers will offer free use of the CD-ROM. Roadwise Review™ is not fully automated because an assistant is required to make measurements as the driver takes the test. However, Roadwise Review™ offers one of the best tools available for self-assessment.

The PreView PHP Preferential Hyperacuity Perimeter™ (PHP), a commercially available product designed for early detection and monitoring of Age-related Macular Degeneration (AMD), is developed by Notal Vision Ltd. and distributed through Carl Zeiss Meditec, Inc. According to the technical specifications of the PHP, it tests the central visual field- 14 degrees- through use of a “dot deviation signal flashed across macular loci” (Carl Zeiss, 2004).

While the PHP may potentially fit into a part of the eye disease component of the ESRA DAT™, we are unable to recommend it at this time on the following grounds: It is not fully automated. A clinician is required for instruction and testing. A stylus is required for a patient to touch a screen where distortion in the lines is perceived to appear. The PHP is chiefly designed as a monitoring instrument for patients who have already been diagnosed with AMD. Driver’s license bureaus do not have a system in place to monitor progression of AMD over time in driver’s licensees or applicants. The PHP is not designed as a screening tool for AMD. The diagnostic procedure also takes about twenty minutes or longer to complete rather than the “rapid test time- five minutes per eye” extensively documented in its marketing literature (Kent, 2003; Carl Zeiss, 2004). This product is, ideally, developed for use by clinicians- not driver’s license personnel. This product has never been proposed for any transportation licensing application (via publication or other materials). No studies have been conducted that associate its usage, for transportation licensing, with reduced collision risk. The record of safety, liability, and performance of the PHP, as these relate to transportation licensing applications, is, therefore, currently unknown. However, for medical settings, the PHP appears to show potential for effective monitoring of wet AMD (Loewenstein *et al.*, 2003; Preferential Hyperacuity Perimeter (PHP) Research Group. 2005.).

Furthermore, a comprehensive visual field test, the Three-Dimensional Computer Automated Threshold Amsler Test, also called the 3-D Amsler Grid Test (3DAGT), developed by Fink *et al.* (2003), has great potential to screen and evaluate numerous people for vision impairment over the Internet and in space. As an automated computer-based diagnosis system (Fink, 2002), it may offer patients on earth a very extensive examination when compared to traditional visual field tests. In space, the 3DAGT may provide an autonomous onboard physician to astronauts. Since April 2000, more than 200 patients have been examined with the 3DAGT at the Doheny Eye Institute in the Keck School of Medicine at the University of Southern California (Fink *et al.*, 2003). In

2004, the 3DAGT has accurately evaluated, characterized, and monitored scotomas, regions of reduced or loss of vision within the visual field, in 25 AMD patients and 41 eyes (Nazemi, *et al.*, 2004).

The 3DAGT was based on an Amsler grid-like pattern developed by M. Amsler in 1947 to assess visual function in the central 10 degrees of vision. Wall and Sadun (1986) later improved this perimetric method through the design of threshold level measurement techniques. Fink *et al.* (2000) generated a three-dimensional computer automated threshold form of Amsler grid testing as we now know it.

The 3DAGT, when modified, may provide quick and easy automated testing of visual field conditions in various kinds of transportation agencies, including a driver's license bureau setting. A touch-sensitive examination screen (or a regular monitor used in conjunction with a computer mouse) is used to test the visual conditions of patients. Patients cover one eye and, while positioned a fixed distance away from a computer, trace the missing field of vision areas on an Amsler Grid, while focusing on a "varying fixation marker" (Fink *et al.*, 2003, Nazemi, *et al.*, 2004). Different grayscale levels are provided when different degrees of contrast of the Amsler Grid are displayed. These tests offer high angular resolution of 1 degree, rather than the conventional 6 degrees. It may take up to five minutes to test each eye (Fink and Sadun, 2004). Internet-based results are recorded and provided via a three-dimensional illustration and characterization of the scotoma and central hill-of-vision. These are linked to a database for analysis and diagnosis. The 3DAGT successfully detects and screens patients for AMD, anterior ischemic optic neuropathy (AION), central or branch retinal artery occlusions, detached retina, glaucoma, ocular hypertension, and optic neuritis. Several genetic impairments and various types of brain tumors are also identifiable (Tindol, 2000; Fink *et al.*, 2003). These are all conditions that adversely impact driving performance if not readily detected by conventional vision testing equipment.

In the meantime, the depth, extent, location, shape, and slope of any visual field defect can be identified by the 3DAGT in the form of a three-dimensional map. The 3DAGT may eventually allow for the identification of binocular scotomata through binocular visual field data (Fink, 2004). According to our research, the 3DAGT is the only such product to successfully screen for these diseases and to produce independent testing and peer-reviewed publications of its findings.

However, ESRA is aware of crucial modifications of the 3DAGT that are needed prior to deployment at driver's license bureaus and other transportation agencies.

According to Lawrence Gilbert, Senior Director, Office of Technology Transfer, California Institute of Technology (2004):

"The California Institute of Technology (Caltech) understands that Dr. Wolfgang Fink, Caltech, with your (Sandy Straus) assistance at ESRA Consulting Corporation, intends to modify the "3-D Computer-Automated Threshold Amsler Grid Test", to present to the

Motor Vehicle Division (MVD) of the State of Arizona, for driver's license vision testing, if selected to proceed with this project.

Contingent upon selection on behalf of the Motor Vehicle Division, Caltech intends to enter into a contractual agreement with Dr. Wolfgang Fink, Caltech, including your (Sandy Straus) involvement at ESRA, to create a company to provide products that will enable the development of the technology for this project, and possibly, in other countries and U.S. States."

Vision Screening Methods in Other Settings

The controversy surrounding the effectiveness and variation of vision screening methods appears to extend beyond the driver's license bureau agencies and into the U.S. preschools. There appears to be a lack of evidence to support which of the 11 most widely used screening tests adequately detects vision problems in children less than 5 years of age (National Eye Institute, 2004). These studies are of interest because, for example, Stereo Optical, which manufactures the Optec vision screeners, the most commonly used vision testing devices in the U.S. driver's license bureaus, also supplies preschool vision screening equipment, specifically the Random Dot E Stereoacuity Test and the Stereo Smile Test II. According to our comprehensive national and international survey of driver's license bureau directors, nearly 79 percent of all U.S. Motor Vehicle Bureaus, 33 percent of all driver's license bureaus of the Provinces and Territories of Canada, and 12.5 percent of the driver's license bureaus of Australia, incorporate Optec, in whole or in part, in their vision screening test processes. In the Vision in Preschoolers Study, however, it remains unclear which of the 11 screening tests adequately detects visual acuity impairment independently or in conjunction with other tests (National Eye Institute, 2004).

Following our extensive review of vision testing equipment, we identify the following automated vision test for implementation in the ESRA DVAT™ System (Figure 7):

RECOMMENDED VISION SCREENING EQUIPMENT

Table 3. Model and Special Features of Vision Screening Equipment

B1Max™ VACS

- Fully automated.
- Rapidly provides high- and low- contrast visual acuity screening in 5 minutes or less.
- Prevents cheating.
- Relates measured acuity to collision risk.
- Presents screening instructions in English and Spanish.
- Local and Network capabilities
- Cost-effective
- Ready for deployment
- Currently powers AAA Roadwise Review™ in national and widespread use.
- may be highly recommended based on the performance of the DrivingHealth® Inventory (DHI) during multiple years of scientific study as a tool used for driver evaluations by the Medical Advisory Board of the Maryland Motor Vehicle Administration.

We also identify our conceptualized version of the 3-D Computer-Automated Threshold Amsler Grid Test (3DAGT), appropriately called the Modified 3DAGT. This version potentially screens any visual disease or injury that affects the central visual field, including glaucoma and AMD of transportation licensees and applicants. Since a prototype of the Modified 3DAGT does not yet exist, we are unable to recommend it for the implementation phase at this time. An automated vision condition test is envisaged as part of the ESRA Dynamic Vision Assessment for Transportation (ESRA DVAT™).

The 3DAGT test, while outstanding, currently requires significant modification and simplification necessary to employ in a driver's license bureau setting and/ or any transportation agency where the testing of applicants and licensees are involved. According to Dr. Wolfgang Fink (2004), this could take up to eight months to complete with the assistance of ESRA. Not only does it lack certain features in need of development, but it also necessitates specific modifications and reductions in time to test each driver's licensee's or applicant's eyes.

The 3DAGT also requires complete automation for vision testing at and away from driver's license bureau sites, simplification for layman usage and scoring, test fraud prevention mechanisms, and linkage to agency databases for record storage and retrieval, especially as these relate to score updates. The Computer-based 3D visual field testing

with peripheral fixation points, according to U.S. Patent #6,578,966 (June 17, 2003, by Fink and Sadun) and U.S. Patent #6,769,770 (August 3, 2004, by Fink and Sadun), appears to be developed as a visual field test for patients in the presence of or through visual field test result interpretations by clinicians. The output, as illustrated, in Figures 1, 9, and 11 of these published patent documents, for example, is far too complex for a layman in a transportation licensing agency to interpret or understand.

Yet, automation and networking capabilities, combined with essential modifications and developments of the 3DAGT, should not require the assistance or interpretation of results after the screening process. Therefore, neither clinicians nor driver's license bureau staff members should be required to oversee and interpret any results. Such staffing would prove neither cost-effective nor beneficial to any transportation agency. However, the 3DAGT is identified based on its successful performance, strong record of publication, and uniqueness. The modified 3DAGT, as envisaged by ESRA, has the potential to significantly transform vision testing for all transportation licensees and applicants.

Modification details of the 3DAGT, devised by ESRA Consulting Corporation, are beyond the scope of this report.

Table 99 of Appendix S includes an overview of many vision screening devices, including the B1Max™ and 3DAGT. It also includes an overview of the vision attention/ cognition test, UFOV®.

DRIVING SIMULATORS: YESTERDAY AND TODAY

From the Past to the Present

The driving simulators of today are products of research tools initiated in the early 20th century. These driving simulators, while largely employed in automotive industry, government, space, military, and academic research fields, in addition to the novice driver and recreational computer markets, among other fields, are also utilized in the medical sector for both research and patient recovery applications. In this chapter, we not only examine the history of driving simulators, but also consider these simulators as a possible testing mechanism in the driver's license bureaus.

Driving simulators were initially developed to assess the skills and competence of public transit operators in the early 1910s. Over the next four decades, mockup automobiles were equipped with devices to test drivers' responses to various stimuli. In some cases, mechanical moving scenes or filmed road scenes were shown. By the 1960s, a number of automobile manufacturers, automobile insurance companies, military agencies, universities, and aerospace companies used film approach simulators for studies involving a variety of visual displays (Decina, *et al.*, 1996). However, concerns about automobile safety and collision rates resulted in the development of driving simulator within the United States and overseas. Case *et al.* were among the first to study performance variables of older and younger drivers in 1970. By 1983, the Federal Highway Administration (FHWA), Human Factors Laboratory, Highway Driving Simulator (HYSIM) was developed as a fixed-base driving simulator, complete with an actual and highly equipped motor vehicle, to conduct a battery of studies ranging from hazard mitigation to human factors. The Swedish National Road and Transport Research Institute (VTI) Driving Simulator, fitted with a sophisticated motion system, and the Daimler-Benz (now DaimlerChrysler) Simulator, soon followed. In the Netherlands, driving simulations were successfully used to assess visual attention and analysis of drivers at about this time (Ponds *et al.* 1988; Brouwer *et al.*, 1991). It was during the 1980s when the surge in popularity of video games and personal computers with improved imagery coincided with advanced interactive driving simulation. These led to complex yet even more realistic driving simulators, complete with imagery, traffic settings, automobile dynamics (e.g., braking or steering reactions), real-time features, and advanced mockup vehicles by the 1990s.

Charman (1997) cites a number of research studies that incorporate driving simulators and the significant correlation between these tools and on-road conditions. He also notes that the use of driving simulators for vision testing of drivers "...remains unproven". Clearly, no national or international driver's license bureau we surveyed in Australia, Canada, New Zealand, United Kingdom, and the United States implements driving simulators for driver's license vision testing purposes. Ideally, these are places where very large numbers of licensees could easily be studied. Nevertheless, a pilot study incorporating this technology, through ADOT, may serve as a prototype for this possible new and emerging vision testing area. These findings allow us to focus our attention on driving simulators and eliminate virtual reality, wearable forms of simulation, and

military, truck, and flight simulators from our review. Some software programs seem to merit attention. However, since these do not quite have “the look and feel” of a motor vehicle, these types of simulation were eliminated from further review.

Saluäär, *et al.* (2000) devised a scheme of classification of simulators as low-level, mid-level, and high-level. Low-level simulators are associated with personal computers, pedals, and steering wheels. Mid-level simulators generally include a mockup automobile and projection screens linked with a personal computer for data collection and study. High-level simulators are more advanced and sophisticated simulators. They usually include or exceed the design of mid-level simulators and may have a Stewart platform or hexapod for support of movement and orientation of the mounted automobile.

The low-level simulators are among the most popular due to widespread use in driver education, medical establishments, rehabilitation settings, and academic projects. Some, low-level simulators, however, are associated with high costs due to size and proprietary features. The mid-level simulators are growing in popularity in government and academic environments due to their seemingly realistic simulations of the “driver experience,” complete with sounds and visual images that are unrivaled in other types of experimental tests. High-level simulators require sophisticated hardware, software, and structural components. Due to the steep costs associated with these types of driving simulators, they are almost all exclusively available at universities, government agencies, and research centers at major automobile manufacturers. The National Advanced Driving Simulator (NADS) at the University of Iowa is an example of a high-level simulator.

Our Internet search yielded 59 different driving simulators from Australia (3 percent), Canada (2 percent), France (8 percent), Germany (14 percent), Japan (3 percent), Korea (2 percent), Netherlands (5 percent), New Zealand (2 percent), Norway (2 percent), South Africa (2 percent), Spain (3 percent), Sweden (3 percent), United Kingdom (7 percent), and United States (42 percent). (See Appendix C.) Only 2 percent of these simulators were not identified with any country or nation. We sought criteria specified in the ESRA DAT™ and literature review. Approximately 81 percent of the driving simulators reviewed in this study were designed exclusively for research purposes. The remaining 19 percent were comprised of novice driver driving simulators, among other non-research applications.

A number of research driving simulators, particularly those within German and Korean universities and institutes, incorporate the Stewart Platform. This consists of a platform, one triangular face of an octahedron. The base, the opposing triangular face, connects to the platforms by six struts of the octahedron. These struts allow for positioning the platform in six degrees of freedom. Platform orientation and position vary. An actual motor vehicle is typically fitted with measuring devices, linked to a computer for data collection and analyses, and various road images are projected onto large screens within the dome-like structure. Stewart platforms allow for the simulation of low frequency accelerations. While valuable to traffic safety research efforts, the Stewart Platform cannot be placed in a driver’s license bureau. However, such simulators can be used in carefully controlled experimental studies.

Interestingly, vision and motion measurements are typically hallmarks of high-level driving simulators, as opposed to the more mainstream mid-level driving simulators. NADS of the University of Iowa is a high-level simulator due to its numerous advanced features. Many of the driver education driving simulators are geared toward novice drivers whereas the rehabilitation and recovery driving simulators, in use at some hospitals and clinics, are geared toward ill or older drivers. This demonstrates the need for a driving simulator to bridge the gap between age groups and provide low-cost and effective vision and skill assessments. Many driving simulators now actually have “the look and feel” of motor vehicles because they may either be part of actual vehicles or offer a sophisticated combination of aerodynamic structural designs and graphic features.

Driving simulators are now used to assess the visual and physiological effects of fog on driving behavior. Fog reduces visibility and results in numerous motor vehicle collisions. Different densities of fog can be simulated to measure drivers’ visual performance and speed. Studies show that driving speed increases as fog density increases because many drivers mistakenly feel as if they are slowing down (Snowden, Stimpson, and Ruddle, 1998). In addition, these simulators are better equipped to measure real-world driver performance and behavior than they ever were before. For example, some driving simulators offer ambient light and weather conditions. Other simulators, such as those created through Systems Technology Inc., also offer a strong record of peer-reviewed and independent studies of successful poor visibility and testing features of their STISIM driving simulators. The STISIM models, in widespread use in more than national and international academic and industrial settings, including various clients in Arizona, also offer simple self-customization features of different driving scenarios that allow driver’s license bureau personnel the flexibility they require. Moreover, these driving simulators may also serve the dual purpose of screening at-risk drivers and providing an on-the-spot educational tool to the public on how they may exercise caution in order to drive safely on our nation’s roads.

Furthermore, the amount of time for testing is also an issue of concern due to the long queues that are now common in many medical facilities and driver’s license bureaus. Long periods of testing involving driving simulators, particularly those capable of providing comprehensive assessments, may also increase the likelihood of an examinee experiencing a flashback effect or other aftereffect associated with simulator sickness.

According to Johansson and Nordin (2002), a driver’s field of vision require simulations of landscapes, roads, signage, vehicles, etc. on the visual screen of a driving simulator. Visual screens are dependent upon several factors, including acuity, display size, frame rate, resolution, and transport delay. The visual system is imperative to the driving simulator since it supplies visual information to the driver.

Research, Training, and Screening Usage

Driving simulators are usually designed for three purposes: Research, Training, and Screening. Such designs involve criteria that vary according to application.

Nearly every driving simulator in use today originated from research simulators within the military, government, academia, and automotive industries. Driving simulator research devices are generally utilized for empirical, investigative, and experimental usage. The majority of simulators today, as our study shows, appear to be utilized for research purposes.

Driving simulator training devices, however, are used for educational purposes. These are generally targeted toward novices and/ or secondary school students. Such simulators may be used on a daily, weekly, monthly, or yearly basis depending on the curricula developed by instructor(s) and/ or an agency. Driving simulator training models are educational tools used to gauge the performance of the student. Such devices may prove especially useful if our recommendation for accelerating the periods between driver's license issuance and renewal are accepted by legislation.

In the State of Florida, however, there are currently some proposals through the Florida Senate Transportation Committee (Long, 2005) for the possible use of driving simulators to test the skills of some traffic school students. (Traffic schools typically serve to promote safety, among other purposes, to motorists with traffic violation records.) These driving simulator devices may be used to improve student's performance through training but should not be deemed as a screening measure unless collision risk and record are safely and adequately documented and associated with such driving simulator usage. This has not been done to date by any entity worldwide. The distinctions between simulators need to be made because training devices cannot substitute for screening devices, or vice versa, unless there has been widespread independent testing and documentation to support such applications and nomenclature. Performance on simulators has not been directly correlated with on-road performance to date.

Furthermore, driving simulator screening devices are primarily used for detecting conditions or impairments that traditional tests cannot. Such devices are based on many years of published studies, results, and trials. For example, driving simulators are now used in research environments to detect or monitor dementia in drivers. Since the incidence of dementia is expected to jump 400% over the next twenty years (Whitmer, 2005), driving simulator screening devices may prove indispensable for transportation license screening purposes.

Driving simulators used for research, training, and screening purposes fill a niche that may otherwise not be available through conventional experimental and testing methods. Further studies must be conducted to enable usage for mass distribution. All driving simulators, irrespective of design, application, and frequency of usage, require safety and liability concerns to be addressed due to driving simulator sickness and other possible aftereffects.

SIMULATOR SICKNESS AND AFTEREFFECTS

What is simulator sickness?

Simulator sickness, or cybersickness, defines possible maladies associated with simulator usage. These include but are not limited to aviation, marine, military, and driving simulators. These feelings of nausea or discomfort occur in some subjects who use driving simulators. Simulator sickness may be triggered throughvection, perceived motion, which occurs as a result of a disparity between visual and vestibular perceptual clues (Kennedy *et al.*, 1998). For this reason,vection is sometimes defined as a visually-induced deceptive body motion. While early studies relate primarily to military applications, the widespread use of simulators today allow for further investigations. Kennedy and Fowlkes (1992) characterize simulator sickness as "polysymptomatic", because several symptoms are at play, including blurred vision, cold sweating, concentration difficulty, confusion, drowsiness, eye strain, head fullness, nausea, pallor, and vomiting. Additional symptoms of cybersickness may include ataxia (postural disequilibrium or a lack of coordination), disorientation, dryness of mouth, fullness of stomach, headache, and vertigo (LaViola, Jr., 2000). Since there appear to be several rather than one single source of these symptoms, Kennedy and Fowlkes (1992) define simulator sickness as "polygenic". Since there are so many factors that cause cybersickness, LaViola, Jr. (2000) reports that "...there is no foolproof method for eliminating the problem."

Simulator sickness is sometimes classified as a form of motion sickness that may result from abrupt changes in movement or while the body's orientation is relatively fixed yet exposed to moving visual scenes. Cybersickness differs from motion sickness in that visual stimulation, rather than vestibular stimulation, can trigger cybersickness.

Military studies laid the groundwork for modern simulator development and research activities. Crampton and Young (1953) associated motion sickness with video displays. Havron and Butler (1957) linked flight simulators with motion sickness-like symptoms. Miller and Goodson (1960) reported motion sickness in a helicopter.

There are three controversial theories that govern simulator sickness. These include the cue conflict theory, the poison theory, and the postural instability theory. The cue conflict theory arises from a sensory mismatch between what is expected versus what actually occurs in the simulator. The poison theory evolutionarily relates simulator sickness to the experience of poison or intoxication. The postural instability, unlike the sensory conflicts, defines the decreased ability to stabilize one's postural motion. The interested reader is encouraged to explore Mollenhauer (2004) for characteristics of these theories, discussions of visual and vestibular systems, and simulator design factors that impact simulator sickness.

Aftereffects

Simulator sicknesses are often characterized by aftereffects. Stanney and Kennedy (1998) document significant and lasting aftereffects, particularly disorientation, elevated nausea levels and oculomotor disturbances following virtual environment exposure. Stanney, *et al.* (1998) warn of the hazards of disturbed locomotor and postural control following virtual environment exposure. They also cite perceptual-motor disturbances of concern. Recent studies show that three major aftereffects include postural equilibrium, fatigue and drowsiness associated with the Sople Syndrome, and oculomotor changes such as eyestrain (Kennedy, *et al.*, 1997). Stanney *et al.* (1998) cite aftereffects that include disturbed vestibulo-ocular reflex (VOR) function, flashbacks, illusory climbing and perceived inversions of the visual field, increased risk of adverse adaptations to subsequent normal environments, postural disturbances, reduced complex psychomotor flexibility, and reduced motor control turning sensations. Kellog, *et al.* (1980), Kennedy *et al.* (1987) and Regan and Ramsey (1994) report aftereffects, such as the disorientation of subjects, for several hours after simulator usage. Gower and Fowlkes (1989) document aftereffects that persist for days.

Kolasinski (1996) suggest that the lingering effects of ataxic decrements, operational consequences of simulator sickness, among other delayed aftereffects, triggered through use of virtual reality systems, are of special concern.

Flashback Effects

Flashback effects may result from simulator exposure. These effects may be characterized by flash images or flashbacks that appear, following driving simulator usage. Lackner and DiZion (2003) describe this phenomenon, characteristic of flight simulator exposure, as a consequence of the adaptation process. Head and body movements are associated with "...unusual and inappropriate patterns of sensory feedback." Several studies underscore the susceptibility of some simulator users to flashback effects, as a type of aftereffect that may not be immediately obvious until hours or days after a simulator session. Kolasinski (1996) refers to this phenomenon as delayed flashbacks.

Baltzley *et al.* (1989) report that some cases of ataxia and unsteadiness persist for more than 6 hours and, even longer than 12 hours. Flashback effects are a potentially greater risk to driving simulator users because these effects last longer. Baltzley *et al.* (1997) note the unique incidences of flashback effects and coping mechanisms developed by the pilots themselves that tend to mask the extent of post simulator effects. Hence, flashbacks pose a safety risk through navigation activities (Kennedy *et al.*, 1992).

Past studies document significant health and safety concerns associated virtual environments due to visual flashbacks, disorientation, and disequilibrium that occur up to 12 hours after a simulator session (Kennedy *et al.*, 1995). However, a lack of flashback studies, as these relate to driving simulator usage among all age groups, disallows quantification of such aftereffects. For these reasons, further studies are needed and conservative approaches, what we call "flashback effect management", are required.

Cyberadaptation Syndrome and Simulator Adaptation Syndrome

The transition between the virtual environment and the real environment is filled with different responses to different simulator users. This transition may be accompanied by varying degrees of simulator sickness. According to Lackner and DiZio (2003), virtual environments and the aftereffects that occur on the return to the normal environment are characterized by “full set of behavioral, psychological and physiological changes.” Cyberadaptation Syndrome, or Simulator Adaptation Syndrome, may describe this journey and its characteristics.

Stanney and Salvendy (1998) report that Simulator Adaptation Syndrome (SAS) underscores the need for standard measurement approaches and sensorimotor discordance identification that trigger this reaction to driving simulators. Simulator Adaptation Syndrome (SAS) creates autonomic symptoms, such as nausea, in some drivers of driving simulators. According to Rizzo *et al.* (2003), these may be due to a broad range of simulator displays, devices, technologies, and scenarios- all that may present a drawback to testing if not properly monitored and reviewed.

Factors of Simulator Sickness

Kolasinski (1996) cite several factors associated with simulator sickness, including age, degree of control, duration of task, field of view, gender, and lag. Kennedy *et al.* (1997) identify the following five classes of determiners of simulator sickness as equipment and technical system factors; user characteristics, duration of time in the simulator; simulator usage schedule and kinematics. LaViola, Jr. (2000) cites display and technology issues, position tracking error, lag, and flicker as several contributing factors to cybersickness in virtual environments. Some individual factors, as discussed, include age, gender, illness, and position in the simulator. The time between the subject beginning an action and the action occurring in the virtual environment defines lag. According to Pausch *et al.* (1992) delays in lag can result in cybersickness. Nevertheless, proper control of imagery, movement, field of view, and timing, among other factors, of driving simulator sessions may reduce the likelihood of simulator sickness.

Simulator Sickness Studies

Baltzley *et al.* (1989) report that from 6 to 62 percent of military pilots experience simulator sickness. Regan and Price (1994) and Cobb *et al.* (1998) identify simulator sickness symptoms of eyestrain, headache, nausea, and malaise after 10 –20 minutes of virtual reality exposure in non-pilots. Kennedy *et al.* (1995) reveal that 30percent to 50 percent of 2,000 flight simulator testees experienced simulator sickness, such as Sopite Syndrome, characterized by fatigue or drowsiness, following a simulator session. They conclude that there exist major safety implications, particularly for elderly persons, who may be exposed to driving simulators. Although rates are dependent on the type of simulator, Gillingham and Previc (1996) document simulator sickness in 40 percent to 70 percent of pilot trainees following use of high-quality military flight simulators. Kennedy *et al.* (1997) cite reports of simulator discomfort from United State Navy pilots and the United States Air Force where simulator sickness could be detected in almost all

simulators. Baltzley *et al.* (1997) note that simulator studies of United States Coast Guards in training over several weeks led to the conclusion that unsteadiness and postural disequilibrium are the post effects that prompt the greatest safety concerns. Stanney *et al.* (1998) cite several studies where 80 percent to 95 percent of participants in a number of virtual environment studies reported adverse symptoms, and 5 percent to 30 percent experienced symptoms severe enough to end participation. Kennedy *et al.* (2001) estimate, on the basis of a large sample study, that 10 to 20 percent or more testees will exit a simulator session after a few minutes due to simulator sickness.

The Simulator Sickness Questionnaire

In 1965, Kennedy and Graybiel (1965) developed a motion sickness questionnaire that, following several modifications, formed the foundation for today's simulator sickness questionnaires.

The Simulator Sickness Questionnaire (SSQ) quantifies simulator sickness and divides the symptoms according to disorientation, nausea, and oculomotor discomfort (Kennedy, *et al.*, 1993). It allows for the monitoring of simulator performance with data from a computerized SSQ. The questionnaire provides a more valid index of overall simulator sickness that distinguishes it from motion sickness. The SSQ more accurately identifies the basis of simulator sickness.

Stanney *et al.* (1998) report that, while this questionnaire was originally designed as an assessment tool for aircraft simulator system subjects, it allows subjective symptomatology assessments and scores on simulator sickness subscales. SSQ scoring is based on factor analytic models (Kennedy *et al.*, 1992).

Field of View and Flicker

Conflicting findings suggest that wide field of view may not greatly impact the susceptibility of cybersickness. Although Lestienne *et al.* (1977) report intense sensations of motion sickness with a wide field of view, Anderson and Braunstein (1985) document similar findings with a reduced field of view. Although the intensity of simulator sickness may be independent of screen size or number of screens of a driving simulator, Hettinger and Riccio (1992) associate vection with wide field of view displays.

Allen *et al.* (2003) conducted a pilot study of novice drivers using different driving simulator system configurations, including a single monitor desktop, three-monitor "wide field of view" desktop, and a cab with a wide field of view projection. Their objective was to show that a personal computer-based driving simulator system could be used in both research and non-research settings. Approximately 91.7 percent of the participants did not report any discomfort. Single monitor displays demonstrated the highest number of surpassable speed limits. The lowest number of surpassable speed limits, on average, were shown by Wide Field of View Desk Top, composed of three computer monitors. Approximately 2.8 percent indicated that the simulator systems made them feel queasy. These symptoms did not appear to be influenced by increasing display field of view.

Jeng-Weei *et al.* (2002) reports that the rate of nausea decreases when many clouds are used as an independent visual background. This may be due to the naturalness and stableness associated with clouds.

Edwards *et al.* (2003) associate large field of view, e.g., 150 degrees, with simulator sickness. Therefore, field of view, speed settings, and time duration of the driving simulator test may limit simulator sickness. Johansson and Nordin (2002) demonstrate that a lack of synchronization between the visual and motion systems also contributes to simulator sickness (Johansson and Nordin, 2002).

Sparto *et al.* (2004) report that wide field of view devices result in greater simulator sickness. They urge safety testing prior to any use in a clinical setting. However, they show that 69 percent of subjects did not experience simulator sickness symptoms when a wide field of view environment was used to gauge self-reported tolerance to movements. They theorize that reduced exposure time, display device type, content and nature of task, and significant rest breaks between trials may all influence susceptibility to simulator sickness.

Kennedy *et al.* (1988) link vection with increasing retinal periphery stimulation. McCauley and Sharkey (1992) relate driving simulation motion and stimuli to vection. LaViola, Jr. (2000) notes that the complexities of the visual system account for many more vection-related physiological factors. These may be evident during driving simulation when the optical flow patterns of traffic, structures, and roads travel past the examinee's periphery. Wider field of views may also increase the susceptibility to flicker, which can cause eyestrain and other cybersickness symptoms.

There appears to a tradeoff associated with 1-screen and 3-screen simulators. While the 3-screen models may provide more realistic views, they may also consume more space and induce more cases of simulator sickness among subjects.

In order to reduce simulator sickness and improve task performance, there are effective image resolution requirements in aviation training simulators at the Federal Aviation Administration (Mollenhauer, 2004). It is unclear now, based on our literature review, whether there are such requirements exist in any government agencies as these relate to driving simulators due the various applications.

Gender

In several studies, females are more likely than males to report higher simulator sickness ratings (Reason and Brand, 1975; Kennedy *et al.*, 1995; Rinalducci *et al.*, 2002; Allen *et al.*, 2003; Edwards *et al.*, 2003; Rizzo *et al.*, 2003). This finding may also relate to the size of the field of view, which may be larger among females.

Incidence of simulator sickness

The incidence of simulator sickness varies from application to application. In driving performance studies, Rinalducci *et al.* (2002) shortened driving simulator tests to prevent simulator sickness. However, approximately ten percent of participants from three different age groups reported simulator sickness and were unable to continue testing. Lee *et al.* (2003) determined that approximately 9 percent of the participants in their study experienced “simulator sickness,” although a very short and mild degree of dizziness after completing the driving simulator session. Yet, this did not affect their performance. According to Edwards *et al.* (2003), simulator sickness prevented forty percent of recruited older participants from completing their study. They indicated that some participants complained about disorientation, dizziness, and nausea, while others were observed in bouts of sweat and paleness that led to increased head movement, repeated swallowing, and vomiting.

Impacts of Cybersickness

There appears to be a lack of research on cybersickness and the impacts of freedom of movement or control necessary to “...minimize the adverse effects of human-virtual environment interaction” (Stanney *et al.*, 1998). Little or no control over simulator movements may account for the susceptibility of crewmembers and pilots to sickness (Reason and Diaz, 1971; Casali and Wierwille, 1986). Although user-initiated control may impact symptoms of simulator sickness (Stanney and Hash, 1998), Rizzo *et al.* (2003) investigate whether driver SAS initiate poor control of a simulator vehicle or if vehicle control is weakened by SAS.

Studies of At-Risk Drivers

Rizzo *et al.* (2003) evaluated the effects of SAS on driver performance of at-risk older drivers, including patients who were diagnosed with Alzheimer’s disease and stroke. Feelings of discomfort accounted for an early simulator drop out rate of 21 percent of the 164 drivers. Body temperature increase, dizziness, light-headedness, nausea, and nervousness were correlated with high levels of discomfort scores through questionnaires provided to drivers immediately after driving simulator usage. These findings were in good agreement with earlier studies by Kennedy *et al.* (2001). Furthermore, Kolasinski (1996) suggests identification, training, and warnings as methods to reduce simulator sickness in at-risk users.

Simulator Sickness Mitigation Strategies

Mitigation strategies vary among simulator users. Some try conventional approaches while others incorporate various devices.

LaViola Jr. (2000) suggests sitting, rather than standing, in a virtual environment may decrease cybersickness symptoms because it would diminish postural control. He further describes ways to reduce cybersickness, including the use of motion platforms, direct

vestibular stimulation, rest frame usage, and an adaptation program. However, there appears to be a tradeoff with the adaptation program, which, while helpful in the virtual environment, seem to increase the likelihood of aftereffects and flashbacks due to an increase in exposure time, among other factors.

Mollenhauer and Romano (2002) incorporate the application of the ReliefBand®, as a simulator sickness mitigation device. Patients who experience nausea from pregnancy, chemotherapy, and motion sickness sometimes use the ReliefBand to impart a mild electrical stimulation to combat nausea. According to the ReliefBand website (2005), the ReliefBand Device should always be used under medical supervision. There are also risks to pacemaker users who may experience interference through use of the device.

Clearly, use of ReliefBand, and/ or any device that imparts electrical simulations, introduces a whole new set of possible liability issues, especially for transportation licensing agencies, among others, due to the possible side effects to different people.

Future Simulator Sickness Studies

While military studies have contributed to simulator sickness studies for more than five decades, the popularity of driving simulators today, in educational, research, and public distribution, merits further review and studies. According to Kolasinski(1996), “...longer-lasting effects, especially those such as flashbacks and ataxia, pose a safety risk to both users of simulators and to others... It is important that ataxia, as well as sickness, be investigated because... of the many possible liability issues surrounding widespread use of such systems.” She states that such sicknesses threaten the use and application of driving simulator products due to liability concerns.

A lot of the available literature relates directly to the novice, particularly, aviation trainees. These studies generally, fail to target older simulator users and those at-risk. Such users may have special needs and reactions that need to be addressed. There is, therefore, a need for further studies on the flashback effect, especially as these relate to older and at-risk drivers, among others. Kennedy *et al.* (1995) suggest that for future research, simulator exposure time should be carefully recorded in order to assess its impact on aftereffects. Stanney *et al.* (1998) also recommend studies of “...delayed effects from virtual experiences.... in order to ensure the safety of users once interaction with a virtual world concludes.”

According to Kennedy *et al.* (1997), “Formal information exchange programs should be instituted to not only aid industry in reducing product liability punitive awards, but it is in the best interest of the public.”

At the Seventh International Conference on Human Computer Interaction in 1998, a special committee underscored the importance of measurement approaches, standardization, and identification of sensorimotor discordances of aftereffects. Many national and international organizations continue to meet to review and discuss simulator safety mechanisms, among other driving simulator issues.

SAFETY RECOMMENDATIONS

While driving simulators appear to offer a cost-effective alternative to screening all drivers, there are liability issues that every agency needs to consider prior to implementation, application, or use of driving simulators for transportation license testing purposes.

Kennedy (1995) proposes certification tests to avoid the accidents that can result from simulator aftereffects, especially when driving, flying, or roof repair. He warns "... simulator operators, developers, and manufacturers could be liable" since "an individual may be injured as a result of simulator exposure". According to Kennedy *et al.* (1997), there now exists, from virtual environments to real-world settings, "the transfer of maladaptive cognitive and/or psychomotor performance.... with, as yet, unknown adverse legal, economic, individual, and social consequences." Kolasinski and Gilson (1998) conclude that simulator sicknesses and aftereffects "...pose severe safety risks and raise serious liability issues." Surveys of ten simulators at six different Naval and Marine Corps site yield that simulator sickness, especially within flight simulators, occurs "...during maneuvers that do not occasion them...." Hence, Kennedy *et al.* (1989) recommend monitored and restricted activities, such as driving, immediately after simulator sessions due to safety concerns.

Similarly, Stanney *et al.* (1998) recommend that following simulator sessions, "...bans on driving, roof repair, or other machinery use.... may be necessary." They warn that the subjects who feel less affected or ill when they exit such simulator sessions may, in fact, be at greatest risk of simulator sickness and/ or its aftereffects, as documented by Kennedy *et al.* (1995). Such concerns led to grounding policies at the Navy and Marine Corps after simulator flights (Kennedy *et al.*, 1989, LaViola, Jr., 2000).

Stanney *et al.* (1998) further note "Of equal importance is ensuring the health and welfare of users who interact with these environments....If the human element in these systems is ignored or minimized, it could result in discomfort, harm, or even injury. It is essential that VE developers ensure that advances in VE technology do not come at the expense of human wellbeing." They also warn of the negative social implications and impacts resulting from the user's misuse of the virtual environment (VE) technology.

It is very likely that a little simulator sickness discomfort may be a small price to pay to weed out at-risk drivers. These drivers pose a risk to themselves as well as to other motorists. However, driver safety and health cannot be compromised at the expense of driving simulator usage. As long as driving simulators are integrated in the driver's license testing process, as we propose, then the comfort and safety of all subjects must be ensured.

Although driving simulator usage poses a safety concern, we suggest that transportation agencies and medical facilities have examinees sign waivers, indemnification, and release of liability waivers and not drive, fly, and/ or perform roof repair, and/ or operate any machinery until at least 72 hours have elapsed following a simulator test session to

reduce the possibility of potential liability for any possible aftereffects, flashbacks, and/or simulator sicknesses that some subjects may experience. We also urge these agencies to implement driving simulators with long histories of success, implementation, safety testing, and usage as these relate to both novice *and* older drivers. These should be documented through numerous independent and peer-reviewed publications over the last ten years in several different subject areas. Although many factors may account for simulator sickness and its aftereffects, age appears to be among these aspects. As age increases, susceptibility of motion sickness rapidly rises (Gahlinger, 1999). Hence older drivers may be more susceptible to simulator sicknesses and discomfort. Older drivers may have special needs that not all driving simulators provide. Transportation may need to be arranged for driving simulator testees. A panel of independent scientists and physicians should work closely with these agencies to monitor such progress and performance.

We strongly recommend that transportation agencies and medical facilities have examinees sign waivers, indemnification, and release of liability waivers and not drive, fly, and/or perform roof repair, and/or operate any machinery following all other automated forms of testing. Since these may not incorporate simulation, and the effects, if any, may be very short, a team of independent physicians and scientists should determine the appropriate amount of time to refrain from such activities.

Ideally, a pilot test phase should be implemented to determine the feasibility of driving simulator usage for any transportation license testing purposes.

RECENT AND CURRENT DRIVING SIMULATOR RESEARCH

Increases in both driving simulator and on-road driving collisions have been linked to peripheral vision weaknesses (Keltner and Johnson, 1992; Szlyk *et al.*, 1992; Szlyk *et al.*, 1993). Several studies document use and application of driving simulators as a viable option for driver safety analyses. Some studies focus exclusively on dementia drivers. Lundberg (2003) divides these dementia driving studies into two categories: those that relate to collision involvement or driving difficulty and those that are geared toward driving performance predictability.

Szlyk *et al.* (1993) used driving simulators to assess driver safety in visually impaired and non-impaired drivers with juvenile macular dystrophies. Szlyk *et al.* (1995) used an interactive driving simulator to measure compromised vision and visual field loss of drivers of all ages and visual conditions. They successfully identified weaker driving skills, increased eye movements, and slower simulator driving speeds in drivers age 50 to 83 years than the drivers age 19 to 49 years, through an 8-minute driving simulator session. They also associated collision risk with compromised vision and visual field loss. Several subjects were diagnosed with AMD, hemianopsia (when one or both eyes are characterized by blindness in one half of the visual field), among other disorders and diseases.

Decina *et al.* (1996) conducted a useful study of existing simulators for improving the safety training of novice drivers, primarily younger drivers. They determined that high costs and limited accessibility of driving simulators were a deterrent for novice training applications. Although they found that the majority of driving simulators were employed for research and training purposes, Decina *et al.* (1996) suggested a type of network setup "...enabling simulators in remote locations to share scenarios, instructions, and scoring..."

Rizzo *et al.* (1997) utilized the Iowa driving simulator to observe strong predictors of collision in drivers with Alzheimer's disease (AD) and drivers without dementia. Visual and cognitive test scores were used to determine collision susceptibility in drivers with mild dementia. No visual acuity differences, apart from a slight reduction in static spatial contrast sensitivity were observed in the drivers with AD. Yet, several poor neuropsychological measures were apparent in the mild to moderate dementia group of AD drivers. Approximately 29 percent of the AD drivers engaged in the driving simulator study experienced collisions. These findings, among others, led Rizzo *et al.* to support the idea that some AD drivers with mild dementia "...remain fit drivers and should be allowed to continue to drive." According to Rizzo *et al.* (1997), simulated collision avoidance scenarios "...provide demonstrations of driver behavior that cannot be obtained any other way. The simulator record can be compared to that of the black box flight recorder from a downed aircraft, yet no one is injured." Owsley *et al.* (1998) associated collision risk and poor performance in a driving simulator with significant binocular visual field loss.

The University of Michigan Transportation Research Institute driving simulator consists of a mockup of a car based on network of Macintosh computers and, among other things, a 33 degree horizontal and 23 degree vertical field of view. In an effort to assess the visual demand of drivers in three age groups (18 to 24 years, 35 to 54 years, and 58 to 68 years), Tsimhoni and Green (1999) illustrate that the radius of curvature creates a higher visual demand, the proportion of time a road is visible, among the driver cohorts ages 58 to 68 years.

Westlake (2000) supports the use of driving simulator assessments and advanced vision tests, among other approaches to effectively predict collision involvement through these types of cognitive and perceptual tests. Szlyk *et al.* (2002) promotes the use of driving simulators as screening tools for dementia drivers. Szlyk *et al.* indicates that driving simulators also allow the potential to identify neuropsychological tests that provide driving performance predictability. Ball (2003) cites driving simulator performance studies that are associated with useful field of view. Lee *et al.* (2003) encourage the use of driving simulations as an initial screening tool for at-risk drivers through their successful study to assess the driving performance of drivers ages 60 to 88 years. They show that the simulated driving assessment results were in good agreement with the on-road assessment results. These assessments identify decrements associated with cognition, and medical, peripheral vision, and sensory conditions. Hence such tests may also be used to study the driving performance of patients with AD. Ball and Owsley (2003) and Duchek *et al.* (2003) support evaluation and more frequent reevaluation of drivers with mild and very mild stages of dementia of the Alzheimer type.

In the Netherlands, driving simulators, specifically, the mockup of a car positioned before a 165-degree by 45-degree projection screen, continue to prove effectiveness in evaluation of the impacts of visual field defects on the driving performance of driver cohorts ages 37 to 86 years (Coeckelbergh *et al.*, 2002). An experienced driving examiner from the Dutch Driver's License Authority (Centraal Bureau Rijvaardigheidsbewijzen, or CBR) verifies these results through a standard road test for drivers who do not satisfy the vision requirements for driving.

At the University of Iowa Hospitals and Clinics, the Simulator for Interdisciplinary Research in Ergonomics and Neuroscience (SIREN) was set up to assess at-risk drivers through a mockup of a car equipped with a 150-degree forward view and a 50-degree rear view. Studies targeted patients with AD, drowsiness, old age, Parkinson's disease, sleep apnea, or traumatic brain injury (Rizzo, 2002). SIREN varied elevation, roadway type, roadway surface conditions, signal control, and visual environment to optimally test driver performance.

Currently, two major studies, among many worldwide involving driving simulators, are underway at the University of Iowa and Harvard University. At NADS at the University of Iowa, researchers seek to validate a vision test for simulated driving performance tests (Galluzzo, 2004). However, this study is limited to contrast sensitivity testing. At the Schepens Eye Research Institute at Harvard Medical School, research is now in progress to study driving in visually impaired patients using driving simulators. Dr. Eli Peli and

his team of researchers are building specific scenarios using a simulator from FAAC Incorporated of Ann Arbor, Michigan. After more than 3.5 years of various phases of development, data collection is planned for July 2004. According to Dr. Peli, the FAAC simulator "...appears to provide abilities to create scenarios and really analyze data" (Peli, 2004). Although the basic driving simulator tool is in use for driver training programs at several different government agencies (FAAC Incorporated, 2004), at this stage, it does not seem to be marketable for or applicable to driver's license vision testing. Meanwhile, some clinics in Florida already use DriveAble®, a driving simulation used to measure on-road driving skills, and medical and cognitive weaknesses (Florida At-Risk Driving Council, 2004; Jenks, 2004).

Presently, a study is in progress at the National Advanced Driving Simulator (NADS) at the University of Iowa in an effort to validate a vision test for simulated driving performance tests (Galluzzo, 2004). However, this study is limited to contrast sensitivity testing. At the University of Queensland in Australia, touch screens are being developed to detect older motorists who are suffering from the early signs of Alzheimer's. These two-hour tests, including road simulation, are planned for full-scale implementation in General Practitioner surgeries and health centers within three years (Atkinson, 2004).

Drive Safety, Inc. of Utah develops a number of driving simulators for national and international usage, especially in the research and development areas. They also perform safety tests of other driving simulator products. While Drive Safety, Inc. publishes their list of driving simulator users in the private and public sector, they do not disclose the names of the companies whose driving simulator products they test. According to private communication with Drive Safety, Inc. (2004), there are substantial fidelity concerns that their team of scientists and psychologists identify.

Furthermore, Hopkin *et al.* (2004) support driving simulators, among other assessment techniques, in order to research and implement adequate screening mechanisms for dementia drivers and other at-risk drivers in Ontario, Canada, and elsewhere. They cite studies that show dementia drivers are two to five times more susceptible to collision involvement.

Ideally, the driving simulator could be used to supplement current vision testing assessments of at-risk or high-risk drivers to screen those who require further medical evaluations. Since driving simulators have contributed to safety improvements on our roads and in our automobiles, they can and should be considered for use in driver's license testing practices. Also, Roenker *et al.* (2003) discuss administration and scoring anomalies in road tests that are less prevalent in driving simulators due to computerization.

Following a thorough review of many interesting driving simulator products, as tabulated in Table 100 of Appendix T, we identified the best simulators on the basis of results of a questionnaire ESRA developed. Although respondents requested confidentiality of their

questionnaire responses, these questions included but were not limited to the following on their driving simulator product(s):

- Complete references and contact information
- Safety testing such as flashback effect studies
- Identification of any special features or unique functions
- Complete bibliographic information of any published or peer-reviewed studies on any driving simulator products.
- Amount of time required to complete tests.
- Instant scoring mechanisms.
- Network capabilities.
- Bilingual capabilities.
- Full automation.
- Cost of each unit, customization, warranties, training, shipping, etc.
- Discounts.
- Availability and Applicability.

Following a questionnaire developed by ESRA, and, as tabulated in Table 100 of Appendix T, an extensive review of national and international driving simulators, we identify the following three simulators for implementation in the ESRA DVAT™ System (Figure 7):

RECOMMENDED DRIVING SIMULATORS

Table 4: Models and Special Features of Driving Simulators

Model and Special Features
<p>Systems Technology, Inc. STISIM Drive™ Model E-01 Driving Simulator (1-screen with cab) STISIM Drive™ Model E-02 Driving Simulator (1-screen desktop) STISIM Drive™ Model E-03 Driving Simulator (3-screen with cab) STISIM Drive™ Model E-04 Driving Simulator (3-screen desktop)</p> <ul style="list-style-type: none"> • numerous self-customization driving scenarios. • 1 or 3 screen display models. • driver behavior tests. • Networking capabilities. • PC Windows capabilities. • ideal for vision status tests as part of the ESRA DAVT™ and ESRA VAPT™. • ambient and simulated light and weather conditions. • simulation similar to visibility and contrast reduction due to fog, rain, and snow. • based on very strong record of publication (more than 50 peer-review studies). • Recent peer-reviewed and published studies on older drivers include : Bolstad, 2000; Bolstad, 2001; Freund, <i>et al.</i>,2002; Hassanein <i>et al.</i>,2003,; Lee, 2002; Lee <i>et al.</i>, 2003. • international applications. • associated with STISIM users and applications at more than 66 national and international universities and medical institutions, 33 companies, and 13 U.S., foreign, and state agencies. • clients include Arizona Department of Public Safety and the Tucson Police Department.

While we initially considered Raydon Corporation Virtual Driver™ driving simulator products to appear very promising, we were unable to recommend any of their products at this time due to the following reasons: In February 2005, information on pricing, economies, warranties, safety and performance records, published studies, and references, among other liability concerns was unavailable. There was also no indication that any of the Raydon Corporation products were independently and extensively tested on older drivers and/ or at-risk drivers. Raydon Corporation declined to provide any documenttation of this information. We therefore have concerns about the safety and performance record of the Raydon Corporation driving simulator (Virtual Driver™) products at this time.

Raydon Corporation also would not disclose the networking capabilities of its products and therefore it is unclear as to whether or not their products have automation and networking capabilities. Such features are essential to automated testing and, as

demonstrated in this report, the cost-effectiveness of new driver's license testing systems and applications.

Through nearly one century of usage, driving simulators, in the automotive industry, government, law enforcement, space, military, medical, academic research fields, and driver education programs contribute to quality improvements of safety on our roads, in our military operations, and through our patient recovery processes. On the bases of these applications, as well as recent studies we highlight, the addition of a driving simulator, as a possible screening device of a comprehensive vision testing system, merits further consideration. Driving simulators appear to optimize the ability to test driver response to common road, lighting, weather, and pavement hazards without the risk of collision, fatality, or injury of driver, passenger, or driver's license bureau personnel. Ideally, a three-screen driving simulator could be used to supplement current vision testing assessments of at-risk or high-risk drivers to optimally screen the vision of those who require further medical evaluations, in particular, dementia drivers and others with neurological disorders. Since driving simulators have contributed to safety improvements on our roads and in our automobiles, they can and should be considered for use in driver's license testing practices once the safety and liability issues are adequately addressed. At a time when gas prices are on the increase, and driver's license bureau staffing and motor vehicle maintenance costs prevail, driving simulators may prove as cost-effective and "environmentally friendly" supplements to traditional driver's license vision tests once all associated safety concerns are addressed. The ESRA DVAT™, though two automated tests (to test vision condition and function) and one driving simulator (to assess eye status and strategy) constitute a system that covers the most comprehensive measures of visual acuity, condition, function, performance, and status measurements that we know of for any transportation licensing agency, including the driver's license bureau setting.

CONCLUSION

People are living longer and many older adults are licensed drivers now more than ever before. Based on these trends, a surge in the number of licensed older drivers over the next 10 years can be expected. These changes may also include a significant rise in the number of collisions, injuries, and fatalities among older drivers unless action is taken now to weed out at-risk drivers. As our population significantly increases over the next 50 years, the demand for more effective driver's license screening tools intensifies. These issues need to be addressed in each state and country now as the older driver population grows and necessitates adequate accommodations to improve safe driving. The new systems and procedures ESRA now presents may also reduce the incidence of fraudulent schemes and issuances of driver's licenses, commercial driver's licenses, and hazardous materials transportation licenses.

The core of the problem of adequately identifying visually impaired drivers not only relates to the vision testing methods, but also to the fundamental definition of vision loss, which, according to the International Council of Ophthalmology (2002), is based on visual acuity.

Quantification of visual standards that account for other ocular features, in addition to visual acuity, are direly needed to improve safety and vision, both on and off the roads. Snellen acuity measurements, the most widespread within the United States and in other countries, account for less than 0.1 percent of the visual field (Fink and Sadun, 2004). The visual standards for operating motor vehicles in the United States largely stem from 1925 (Black et. al, 1937). Increases in the number of U.S. roads, improvements in road and motor vehicle designs, and dramatic shifts in population changes are apparent from 1925. However, according to Arizona Administrative Code, Title 17, section R17-4-503, 2002, Vision standards, visual screening equipment or the Snellen Chart is used at the ADOT Motor Vehicle Division for testing purposes. New visual standards that incorporate the current visual acuity measures, will facilitate the process and procedure of comprehensively identifying all transportation licensees through application of the ESRA DVAT™.

For the sake of driver safety, an increasing number of states modify driver's license policy, renewal procedures, and vision testing frequencies. Florida, most recently, follows a newly enacted law for all drivers age 80 years and older to either complete an on-site vision screening test at a local driver's license bureau or obtain certified vision testing results from a physician. A similar law follows enactment in Virginia. In Oregon, vision screening is tested on-site for every licensed driver age 50 years and older at the time of license renewal every eight years. While these on-site driver's license bureau examinations may, in the short term, allow for limited identification of drivers with visual impairments, they completely fail, in the long term, to improve the actual vision testing process and screen the most at-risk drivers. The methodology remains unchanged so a placebo effect is effectively created. However, the State of Arizona is the first to commission such a unique study and to allow ESRA to present its designs of a new fully automated system (ESRA DAT™) for driver's licensees and applicants.

This includes a new vision testing system, the ESRA DVAT™. In the event our recommendations are accepted, our ESRA DVAT™, a comprehensive and automated vision testing system (Figure 7) will be the first of its kind in a driver's license bureau in Arizona and, possibly, the world, to implement the most sophisticated technology available to screen drivers for vision condition, function, and disease. The ESRA DAT™, including the ESRA DVAT™, may also benefit other transportation agencies, including but not limited to licensees within aviation, rail, and maritime areas.

Despite abundant research in other areas, little is known about the relationships between driver's license visual testing methods and collision risks. The current testing methods appear to be inadequate. No empirical evidence is available to support the effectiveness of these products. A lack of automation and comprehensive screening measures may account for this dearth of data. Nevertheless, it is likely that little or no relationship has been established between visual acuity and collision risk. We, therefore, support the Florida At-Risk Driver Council's (2004) recommendation, "Like visual acuity, other vision deficits must be managed more frequently and corrected whenever possible to provide a safer driving environment." Hence it is equally important for us to demonstrate the safe and effective use of the products we identify in whole and/ or in part of the ESRA DVAT System™ and ESRA DAT™ System. Networking capabilities are essential for expansion and integration of other features, such as cognition, driving skills, and written tests, among other elements, associated with transportation licensing procedures. Bilingual testing features, particularly in the United States, are also crucial for licensees whose primary language may not be English. Driving simulators, such as the STISIM models, that have been successfully tested and peer-reviewed, over long periods of time, through published studies, especially on both novice and older drivers, are particularly useful because of the needs of older drivers that not all driving simulators address.

While our objective is to identify the best product available to incorporate for an implementation phase and a pilot study for Arizona driver's license vision testing, clearly, there exists no all-in-one product, a panacea, that provides a wide range of automated tests to assess visual factors, diseases, and conditions that can impact driving performance. Nevertheless, it is necessary to design a system of products that merit implementation, review, and research in the Arizona Motor Vehicle Division in order to screen all drivers, and, in particular, older and at-risk drivers. The implementation phase, to follow, allows for immediate application of products that are independently tested and published and widely distributed. The B1Max™, for example, is now available for deployment after widespread distribution through the AAA Roadwise Review™ and demonstrated procedural reliability by its use as part of the DHI, the DRIVINGHEALTH® INVENTORY. The DHI is a tool used for driver evaluations by the Medical Advisory Board of the Maryland Motor Vehicle Administration. Additionally, the pilot study, to follow, serves to determine the effectiveness of use of the other components of the system we herein developed.

Future RAIR studies may include other variables, such as gender or race of drivers, pavement conditions, etc., in the analyses. These studies are needed in order to further

identify and assess the visual abilities of various drivers and, for example, the effectiveness of certain pavement and road designs. Outreach programs may be needed.

Interestingly, the ESRA Vision Assessment Procedure for Transportation™ (ESRA VAPT™) complements the vision testing component of the NHTSA “Model Driver Screening and Evaluation Program”(Staplin *et al.*, 2003a) for a fitness to drive determination. For example, the vision testing component of the NHTSA Model measures near and far acuity, contrast sensitivity, and visual field loss testing. The ESRA Dynamic Vision Assessment for Transportation™ (ESRA DVAT™) (Figure 7), as envisaged, provides a fully automated, comprehensive, and cost-effective approach through the testing of vision function, vision condition, and vision status. It expands and improves existing technology. The vision function element of the ESRA system includes high- and low-contrast visual acuity screening measures. The vision condition element covers the visual field and, more specifically, the detecting of eye diseases and injuries that may adversely impact driving abilities. The vision status element screens at-risk drivers and drivers age 50 years and older for dementia and other conditions that are associated with visual difficulties yet cannot be detected through contemporary vision testing techniques. It includes a driving simulator with ambient light and weather conditions.

Therefore, ADOT may provide a model for license testing improvements for all other states, countries, and agencies to follow if the ESRA Vision Assessment Procedure for Transportation™ (ESRA VAPT™) (Figure 6), the ESRA Dynamic Vision Assessment for Transportation™ (ESRA DVAT™) (Figure 7), and the ESRA Dynamic Assessment for Transportation™ (ESRA DAT™) (Figure 8) are implemented as a pilot test and, ultimately, a statewide system.

RECOMMENDATIONS

Vision Screening System

The literature, surveys, and data analyses confirm the need for a comprehensive and automated system of vision screening. According to Ball (2003), full and comprehensive computerized and automated vision testing systems at driver’s license bureaus may significantly reduce dishonorable test-taking practices (through memorization), personnel time, and transcription errors, among other limitations. Based on our review, we suggest that Arizona take the following steps:

- We recommend the following such tests, as part of the ESRA DVAT™ system:

Product Name	Useful Features
B1Max™ VACS test for vision function	<ul style="list-style-type: none"> • Fully automated and fast. • high- and low- contrast visual acuity screen. • ready for implementation. • widespread usage.
Systems Technology, Inc. Driving Simulators STISIM Drive™ Model E-01 (1-screen model with cab) STISIM Drive™ Model E-02 (1-screen desktop model) STISIM Drive™ Model E-03 (3-screen model with cab) STISIM Drive™ Model E-04 (3-screen desktop model) test for vision status	<ul style="list-style-type: none"> • pilot study test for eye status and/ or strategy through ambient light and weather conditions and to screen novice drivers, older drivers, and at-risk drivers.
Modified 3-D Amsler Grid Test test for vision condition	<ul style="list-style-type: none"> • pilot study test for possible visual diseases, injuries, and tumors that may impair driving abilities.

In addition to some refinements needed prior to emplacement for a pilot study, it is necessary to also ensure that the ESRA DVAT™ products provide instant scoring, short and effective on-site testing, and computer automation score reports linked by network to the driver’s license bureau. These changes are needed in order to ensure a smooth

transition for the driver's license bureau officials and to reduce the amount of paperwork and costs that may be associated with this unusual pilot study. Long queues account for many complaints at driver's license offices (Man, 2005). The testing should be done as effectively and as swiftly as possible, without compromising thoroughness. This will reduce the issue of simulator sickness and aftereffects that some perceive as an impediment to driving simulators.

However, the issue of aftereffects, especially of the flashback effect, is of concern. The flashback effect, when flash images or flashbacks appear, following driving simulator usage, need to be explored due to safety concerns, among others, of drivers prior to implementation in any driver's license bureau, transportation agency, or medical facility setting. These flashback effects may be delayed and occur while driving. No independent testings of the ESRA DVAT™ System and ESRA DAT™, such as the products we identify were conducted to study for safety concerns. To the best of our knowledge, no driving simulators exist in any driver's license bureaus we reviewed. These systems developed by ESRA are new and revolutionary. The potential benefits may be great if carefully instituted. We therefore highlight the following:

- A driving simulator, particularly one equipped with tests of ambient light and / or weather conditions, may also assist in identification and evaluation of possible dementia drivers and drivers with varying forms of AD who, typically, would not be detected using conventional vision testing methods. Such screening methods are imperative when the number of dementia cases is expected to increase 400% over the next twenty years (Whitmer *et al.*, 2005).
- Driving simulators may either be used as a supplementary vision screening device or an educational tool to expose novice drivers to weather conditions for which they lack experience and put themselves at risk.
- ADOT may select from the 1-screen cab, 3-screen cab, 1-screen desktop, and/ or 3-screen desktop models of simulators depending on cost, space considerations, and risk. (As discussed, the 3-screen models require additional expense and space. Although they may also account for a greater susceptibility to simulator sickness and possible aftereffects, they also provide a more realistic view of driving.)
- According to our RAIR analyses, both Arizona and Florida, drivers age 16 to 19 years, ages 80 to 89 years, and age 90 years and older are most likely at fault in angle, backing, head-on, left-turn, rear-end, and sideswipe manners of collision, in clear weather, cloudy weather, rain, fog, daylight, dawn or dusk, and darkness conditions, and due to restrictions based on visual defects. These trends tend to follow bathtub-shaped curves. On average, we find that the older age groups (ages 80 years and older) are about twice as likely as the teenage drivers to be at fault in these collisions.
- Our RAIR results support the findings of Stamatiadis and Deacon (1995): Older drivers are more unsafe than younger drivers who, in turn, are more unsafe than middle-aged drivers.

Cognition Test

We recommend the Useful Field of View (UFOV®), a cognitive test of visual attention performed and scored on a computer. As a fully automated test, it has the potential to assist licensing authorities in the recertification process of impaired drivers. It may be used as a pre-recovery assessment of patients with head injuries to predict their driving ability. The UFOV is shown to adequately predict driving performance on the low fidelity simulation task. The UFOV is widely distributed through the AAA Roadwise Review™, where it provides a rapid and effective measure of visual information processing speed in approximately five minutes. According to Staplin (2005), the UFOV also classifies performance according to the level of functional deficit, if any, and identifies examinees whose performance is associated with a significant increase in collision risk. Following thousands of test administrations, the UFOV reliably identifies mild and serious deficits in visual attention and visual information processing speed. Therefore, the UFOV may also serve as a useful method of identifying at-risk drivers that may not be easily screened through other techniques, especially in the absence of driving simulators.

- We recommend the following such test as part of the ESRA DAT™ system:

Product Name	Useful Features
Useful Field of View (UFOV®)	<ul style="list-style-type: none">• Fully automated and fast.• Measures visual information processing speed and visual attention.• Ready for implementation.• Demonstrated usage in MVD settings.• Widely distributed through AAA Roadwise Review™ as part of DRIVING HEALTH INVENTORY ®.

Knowledge Test

The knowledge test is commonly referred to as the written test. While it is now automated in many states, the knowledge test varies according to state and classifications of drivers' licenses. It often tests the examinee's understanding of accident prevention, pavement marking identification, safety rules, signal identification, traffic laws, traffic signage identification, and vehicle equipment.

Automated knowledge tests may allow for local and remote accessibility, multilingual features, adequate storage and record capabilities, biometrics, accommodation of

individuals with various impairments, and significant reductions in dishonorable test-taking practices, among other benefits.

Ideally, these types of tests and/ or their components should be developed and based on research and published studies. For example, the ReFb-06™ exists as a stand-alone and fully automated sign road sign knowledge test. It is based on research sponsored by federal and state DOTs. According to Staplin (2005), this research includes identification of the most frequent and serious collision types, the problem driving behaviors associated with these collisions, and the extent to which these driving errors could reasonably be linked to a specific knowledge deficiency. The ReFb-06™ is a significant improvement over traditional road sign knowledge tests that most states utilize to test examinees according to the literal meaning of signs. Questions on the ReFb-06™ address the driving behavior that should or must be performed to safely respond to the road or traffic conditions that would lead a highway authority to install the sign in the first place.

Driving Test

The driving test allows examinees to actually drive a motor vehicle in order to demonstrate the ability to safely operate a motor vehicle. Driving tests vary for different classifications of drivers' licenses. Since these types of tests may also differ between states, it may be necessary to eventually federalize such procedures if a federal driver's license is adopted.

Any standardization of driving tests may incorporate elements of simulation to test the different terrain, pavement conditions, weather conditions, and signage that drivers may encounter during intrastate and interstate travel.

While there are many good driving simulators in use and numerous simulation projects underway, we are now unable to identify any automated driving tests that can replace the actual driving tests. Safety, simulator sickness, and aftereffects associated with driving simulators require further research to explore this possibility as gas prices increase and driver's license bureaus are burdened with staffing matters and motor vehicle maintenance costs.

Long queues at driver's license bureaus are also an issue. Also, some driver's license bureau officials express concerns about their safety and the safety of the examinee when conducting on-road driving tests.

In the future, automated driving simulators, as illustrated in Figure 8, may therefore provide cost-effective, quick, and "environmentally friendly" methods of conducting and/ or supplementing traditional on-road driver's license tests, with little or no staff intervention, once all important safety concerns are adequately researched and addressed.

Driver's License Renewal

The existing vision testing methodology at the Arizona Motor Vehicle Division should be augmented to include driver's license renewal policy modifications and Internet-based technology to allow for testing at remote and expanded locations.

The Wearout Period of a bathtub curve, a period of increased decline, tends to initiate within the Arizona and Florida driver cohorts ages 50 to 59 years. The RAIR results, in conjunction with other preceding visual impairment studies conducted on various populations, suggest that driver's license renewal policies also need to be modified in order to screen drivers as soon as they reach the age of 50 years. Compulsory vision testing in increments of two-year renewal periods between ages 50 to 59 years and annual vision testing for drivers age 70 years and older are now needed. Since novice drivers from ages 15 to 19 years are also susceptible to at-fault automobile collisions, they, too, require frequent vision testing, perhaps in two-year intervals. A driving simulator equipped with ambient light and weather conditions to assess the vision status of drivers, as illustrated in the ESRA DVAT™, may prove beneficial to novice drivers since many collisions among younger drivers occur in poor weather when visibility decreases and driving risk increases. These drivers tend to lack the driver vision experience that older and more seasoned drivers seem to develop.

We also suggest the following provisions for the pilot test:

- The implementation phase should proceed for a period of five years to maximize cost-effectiveness of the ESRA DVAT™.
- A pilot test study should commence for a period of at least two years in order to maximize the number of licensees.
- Results should be compared to risk analyses, RAIR values, and rates of collisions, injuries, and fatalities as illustrated in this study.
- To facilitate future studies, it is necessary to suggest a national and international database where various forms of collision data can easily and readily be accessed for analysis and review for all government agencies and industries. These would encourage further studies and contribute to areas where there is now very little.
- The development of a new and comprehensive vision standard is now needed since the Snellen visual acuity standard is inadequate. This may be accomplished with the assistance of a panelist or representative of the International Council of Ophthalmology.
- We suggest the driver's license bureau decide on a maximum time allocation per test, a management and database setup for each test, and a comprehensive method of scoring and assessment to accurately screen at-risk drivers.
- A pilot test will be necessary to validate the results of our system. Driver collision, injury, and fatality data will need to be monitored. Validation of results will not only demonstrate possible effects on safety, but also gauge the effectiveness of our innovative system as an alternative to current driver's license testing methods within the State of Arizona and elsewhere.

Baggett (2003) recommended the use of on-road tests tailored to the needs of older drivers, at-risk drivers, or drivers of any age, especially at the time of driver's license renewal. However, these on-road tests may involve additional motor vehicle purchases, maintenance and fuel costs, and extra staffing issues. Nevertheless, driving simulator products, such as those available through Systems Technology, Inc., with a history of independent studies on older drivers, novice drivers, and at-risk drivers, may suit the dual purpose of vision status assessment through the driver's responses to environmental and lighting conditions, as well as, per Baggett's recommendation, motor vehicle navigation and movement. This may prove to be a cost-effective strategy that can be used as parts of the vision and driving test methodologies once all safety concerns are addressed. However, the subject of driving simulator safety issues, as these relate to tests, such as the on-road test, is beyond the scope of this study. We, nevertheless, call for research and safety testing into these areas, among others, prior to installation and implementation in any agency.

Additional Recommendations

Vision testing research, policies, practices, and systems are in dire need of improvement in the State of Arizona and elsewhere. We therefore recommend the following:

- The formation of a task force, led by both the Arizona Motor Vehicle Division and other ADOT officials to include representatives of various agencies: American Association for Retired Persons (AARP), AAMVA, American Automobile Association (AAA), Arizona Department of Economic Security Aging and Adult Administration, Alzheimer's Association (Desert Southwest Chapter), Arizona Department of Health Services, Arizona Governor's Advisory Council on Aging, Parkinson's Association, NHTSA, United States Administration on Aging, the American Medical Association, and a member of a major Ophthalmologic Organization (e.g., International Council of Ophthalmology).
- A possible partnering with the Florida At-Risk Driving Council, a group formed in response to recent modifications in Florida driver's license policy procedures, may also prove useful, especially through video-conferencing capabilities. The results and findings of our study may also support initiatives of the Florida At-Risk Driver Council, especially as these relate to possible vision pilot tests, policies, and procedures.
- A possible partnering with the Florida At-Risk Driving Council may also assist ADOT in the development of further studies to explore and implement alternative forms of transportation to accommodate at-risk and older drivers who are unable to drive.
- Due to differences in categorization of data between states, a uniform system, such as the State Data System underway at NHTSA, for comprehensively reporting collision data as well as an open database for retrieving this data, is now recommended. Ultimately, it may prove beneficial to link this data with other countries to improve collision analyses.

- We recommend new and uniform federal visual standards and vision tests in all U.S. states. This way, a completely automated system can be used to identify all drivers, irrespective of their residency. This would simplify the licensure process and ultimately reduce a lot of paperwork and bureaucracy. Federal visual standards would also eliminate the number of drivers who may not visually qualify for a driver's license in one state from obtaining a license in another state. Federal visual standards support similar recommendations as these relate to driver's licenses and other documents introduced through The 9/11 Commission Report (2004) (by The 9/11 Commission Report Implementation Act of 2004, S.2774) and The Intelligence Reform Bill. Arizona Senator John McCain and his cosponsors introduced this bill in the United States Senate on September 16, 2004. The Intelligence Reform Bill, signed into law by President Bush, December 17, 2004, requires federal agencies to implement uniform driver's license issuance standards for the U.S. States. H.R. 418 (February 8, 2005) allows for the bill "... to establish and rapidly implement regulations for State driver's license and identification document security standards..."
- The Congress should ensure privacy and protection of personal data associated with federal driver's licenses. This may be accomplished through sufficient backup copies, encryption, and automation techniques, among other methodologies.
- The ESRA DAT™, ESRA DVAT™, ESRA VAPT™, and vision testing standards may also aid in the implementation of the new national identity card scheme underway in the UK, and, ultimately, may promote compatible standards across the European Union, Australia, and New Zealand. The incorporation of biometrics, such as facial recognition, fingerprints, or iris scans as planned in the UK card scheme (United Kingdom Home Office, November 2003) may actually facilitate the use of web-based automated vision testing at private homes and in other public locations other than a driver's license bureau office or other transportation facility where licenses are issued. Other countries as well as the United States should explore these types of vision testing opportunities.
- We recommend the automation of data and information between other transportation agencies. These measures may ultimately result in significant cost-savings, especially through the avoidance of repeatability of certain vision and cognition tests. Such assessments allow for extensive transportation applications.
- The ESRA VAPT™, ESRA DVAT™, and ESRA DAT™, can be optimized to incorporate other features, such as biometrics. However, these tests need to be solicited separately rather than as part of the automated vision test process to ensure compatibility with our ESRA patents-pending systems and methodologies.
- The ESRA VAPT™, ESRA DVAT™, and ESRA DAT™, can also be optimized to incorporate multilingual capabilities.
- Networking capabilities are essential for any products incorporated in the ESRA DVAT™, ESRA VAPT™, and ESRA DAT™, to ensure automation and ease for agencies.
- Automation and networking of personal information between driver's license bureaus, as recommended, will promote the use of encryption and reduce the possibility of identity theft, such the recent robbery of private data of 8,737

people at the Department of Motor Vehicles office in Las Vegas, Nevada (MSNBC, 2005). The stolen data included Social Security numbers, signatures and pictures of residents, in addition to blank licenses and license-making equipment.

- This study also demonstrates support for more stringent federal standards for vision testing for commercial driver's licenses. The potential for disaster is particularly greatest among drivers of hazardous materials cargoes. There are more than 800,000 of these shipments on our nation's roads each day.
- The Federal Motor Carrier Safety Improvement Act now requires a new written federal test on rider management, railroad crossing safety, and emergency evacuations for school bus drivers. By Oct. 1, 2005, all school bus drivers must have a new "S" endorsement, for school children transportation, on their commercial driver's license (CDL). Yet, there are no comprehensive vision testing requirements in place. This issue needs to be addressed for safety purposes.
- We therefore also recommend a pilot program to address the screening mechanisms of dementia drivers. It is possible that the ESRA DVAT™ we identify may assist in screening many different kinds of at-risk drivers, including dementia drivers. It may also allow for screening in other areas of transportation, including but not limited to aviation, rail, maritime, agriculture, and commercial driver's license applications.
- It would also be very useful if the State of Arizona conducted a comprehensive study on estimating the number of residents affected with dementia and, in particular, Alzheimer's disease. An estimation of this population would assist the Motor Vehicle Division in gauging the need for certain driver's license screening methods, tests, and policies. Other agencies would also benefit from this information through research and support services.
- The common denominator is safety. The need for a new comprehensive and automated visual system in the State of Arizona is fundamental to reducing the high collision, injury, and fatality rates. This system should include the B1Max™ VACS and both the modified 3-D Amsler Grid Test and the driving simulator. In the unlikely event that there are technical, financial, or managerial problems hosting the simulator, then the State of Arizona should reconcile usage through the B1Max™ to quickly and easily provide automated visual acuity testing. Ultimately, the State of Arizona should also consider the modified 3DAGT product since, this not only has the potential to screen many at-risk drivers for visual impairments, but also for numerous diseases and conditions that traditional vision tests in driver's license bureau settings fail to detect.
- "Florida License On Wheels (FLOW) mobiles", mobile driver's license bureaus, are also a great concept to alleviate the long queues and heavy traffic at some driver's license bureaus. While these are generally used for administrative tasks, such as identification card issuance and license renewals (FHSMV, 2004; Man, 2005), they may prove to be especially effective in providing driver's license tests in remote areas, particularly those with limited Internet access and/ or staff shortages.

- In the event that the State of Arizona can neither fund nor support the addition of ESRA DVAT™, in whole or in part, in their driver assessment Motor Vehicle Division curricula, then these instruments, once successfully and adequately tested for safety concerns, as discussed, including the flashback effect in driving simulators, should be included in hospitals and/ or other medical settings where physicians and/ or other licensed medical professionals can adequately assess driver's license applicants. The ESRA DVAT™ and ESRA VAPT™, in whole or in part, may prove particularly useful, as this study demonstrates, in the assessment of at-risk drivers and others with vision diseases, vision injuries, and neurological disorders, including but not limited to dementia, Alzheimer's disease, and Parkinson's disease.
- Several nationwide committees exist that address simulator sickness and aftereffects. As long as ADOT incorporates the driving simulator component of the ESRA VDAT™ into its driver's license testing program, then they should follow authoritative guidelines or team up with such committees to ensure safety and comfort of examinees.
ADOT may consider participating in the Simulator Users Group (SUG) whose members include first-rate international scholars with expertise in driving simulator usage and research. The Simulator Users Group (SUG) address topics as diverse as simulator validation, simulator standards, and Simulator Adaptation Syndrome. For example, they recommend pre- and post-driving simulator session questionnaires, which may be extremely valuable during a pilot test program involving driving simulators. The SUG intends to share detection, measurement, and mitigation Simulator Adaptation Syndrome techniques (University of Iowa, 2005).
- The ESRA VAPT™ and ESRA DVAT™, can, at the discretion of the agency, incorporate other features, such as a written test, knowledge test, and/ or cognition skills test. These tests should also be automated and linked by a network. Discussions and illustrations of these ESRA designs are beyond the scope of this paper.
- Although driving simulator usage poses a safety concern, it is suggested that transportation agencies and medical facilities have examinees sign waivers, indemnification, and release of liability waivers and not drive, fly, and/ or perform roof repair, and/ or operate any machinery until at least 72 hours have elapsed following a simulator test session to reduce the possibility of potential liability for any possible aftereffects, flashbacks, and/ or simulator sicknesses that some subjects may experience.
- It is important to urge these agencies to implement driving simulators, such as the STISIM models we identify, with long histories of success, implementation, safety testing, and usage as these relate to both novice *and* older drivers. These should be documented through numerous independent and peer-reviewed publications over the last ten years in several different subject areas.
- We strongly recommend that transportation agencies and medical facilities have examinees sign waivers, indemnification, and release of liability waivers and not drive, fly, and/ or perform roof repair, and/ or operate any machinery following all other automated forms of testing. Since these may not incorporate simulation,

and the effects, if any, may be very short, a team of independent physicians and scientists should determine the appropriate amount of time to refrain from such activities.

- Transportation may need to be arranged for driving simulator and/ or other automated testing testees due to possible simulator sickness and aftereffects.
- During the pilot test, the Simulator Sickness Questionnaire (SSQ), as developed by Kennedy *et al.* should be administered to testees to gauge the incidence and impacts of possible simulator sickness and aftereffects.
- Future studies need to consider the implications of vision testing on racial groups, in particular, Asians, and Native Americans. Most scientific studies reviewed in this study focused primarily on Caucasians, African-Americans, and Hispanics. In the United States, there now exists a burgeoning population of Asians that may constitute the fastest-growing major population over the next 50 years. By 2010, this population may increase to 14 million and by 2050, this population may top 33 million (Associated Press, 2004). Many of these Asians may comprise a significant population of large U.S. cities, including Phoenix. Native Americans, per contra, may live on pueblos and reservations in rural areas where advanced vision testing facilities are scarce. In order to meet the demand of our ever-growing states and nation, driver's license bureaus now need to consider research and testing improvements in order to adequately screen a cross-section of the U.S. society.

This study shows that safety issues associated with any new driver's license testing system must be addressed prior to any implementation in any driver's license bureau, transportation agency, or medical facility setting. Driving simulator studies, in particular, must cover investigations into simulator sickness, flashbacks, and successful testing techniques of the products we identify. Space constraints in a driver's license bureau setting must also be considered due to excess heat concerns, electrical needs, lighting requirements, and crowded conditions, especially in warmer climates. Specially designed cooling systems or larger space areas may be also needed before any driving simulators are emplaced in a driver's license bureau location. Most Florida Department of Highway Safety and Motor Vehicle driver's license testing centers are, for example, located in small and leased storefront areas. New and specially designed buildings or equipped locations may therefore be needed to accommodate the use of driving simulators and the special needs of the testees.

Once adequate safety issues are addressed and technical modifications are made, as determined by an independent panel of physicians and scientists, as prescribed in this report, then driving simulators may offer the potential for more comprehensive and automated vision testing of older, and, possibly, novice drivers. Although a driving simulator study is beyond the scope of the original visual acuity report, our identification of driving simulator products necessitate a pilot study to explore these safety concerns and others prior to any implementation, especially as these relate to applications within the ESRA DAT™ and/ or ESRA DVAT™. (The original title of this report was "SPR 559: Comprehensive Automated Driver's License Testing System: The Visual Acuity Test (Phase 1: Pre-Pilot Test)". Since ESRA was unable to identify a visual acuity test

that was comprehensive for driver's license testing, we found it was advisable for ESRA to independently and entirely develop completely new and automated systems and procedures capable of thorough screening for transportation licenses and applications.) However, in the event that a driving simulator cannot be emplaced in a driver's license agency setting due to safety, management, and/ or ergonomic issues, then the ESRA DVAT™ System will be considered adequate with only the B1Max™ VACS, a high- and low- contrast visual acuity screen, and ultimately, the Modified 3DAGT according to modifications outlined by and developed with the assistance of ESRA Consulting Corporation.

Our findings underscore the significance of vision measures other than standard acuity for assessing at-risk drivers and, in particular, older drivers. Due to the high collision, injury, and fatality rates of all drivers in the State of Arizona, and the disproportionate number of at-fault older drivers in the States of Arizona and Florida, new vision screening methodologies and standards are urgently needed to promote road safety, predict visual impairment, and evaluate possible restriction or confiscation of driver's licenses. Automation techniques of other components of the driver's license test, such as the ESRA DAT™, as we identify, should also be explored. The results of our study, which spanned an 11-year period, not only apply to Arizona and Florida, two states with some of the largest populations of older individuals in the United States, but, as our global survey demonstrated, any state, country, province, territory, or commonwealth with an increasing number of older drivers.

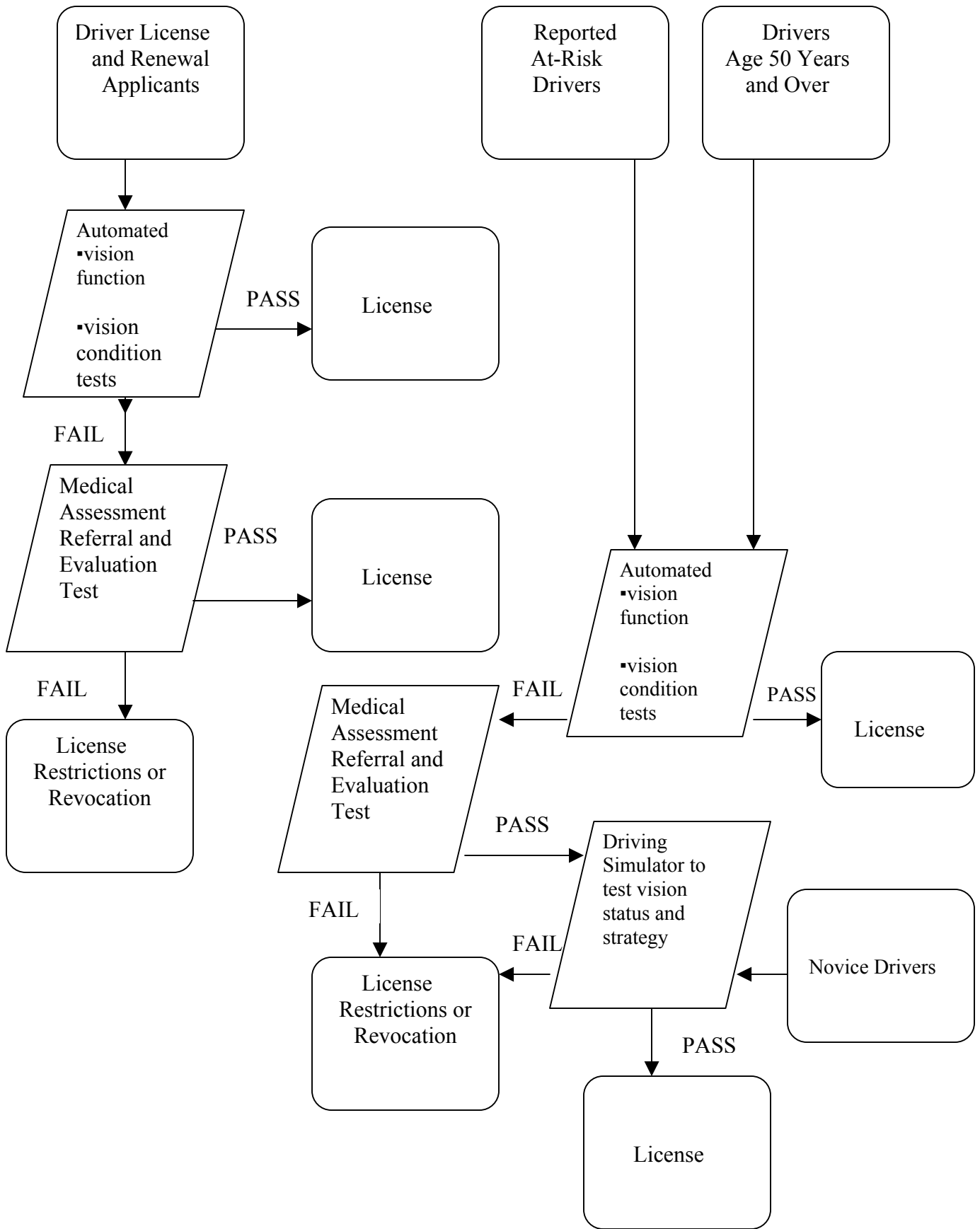


Figure 6. ESRA Vision Assessment Procedure for Transportation (ESRA VAPT™)

- At a minimum, ADOT should employ the B1Max™ VACS, a fully automated visual acuity and contrast sensitivity screening test. This test powers the Roadwise Review™ home-based assessment tool released by AAA in January 2005. The reliability of this procedure is demonstrated by its use as part of the DRIVINGHEALTH® Inventory, which is used for driver evaluations by the Medical Advisory Board of the Maryland Motor Vehicle Administration. It provides a quick and useful screening measure of visual deficiencies that can potentially put an end to mechanical failures and long queues associated with existing vision screening techniques in transportation licensing agencies and medical facilities.
- While automated vision function testing methodology is needed, so is a new comprehensive system, including an automated vision condition test and, a driving simulator, to adequately screen the vision of driver's license applicants and renewals.

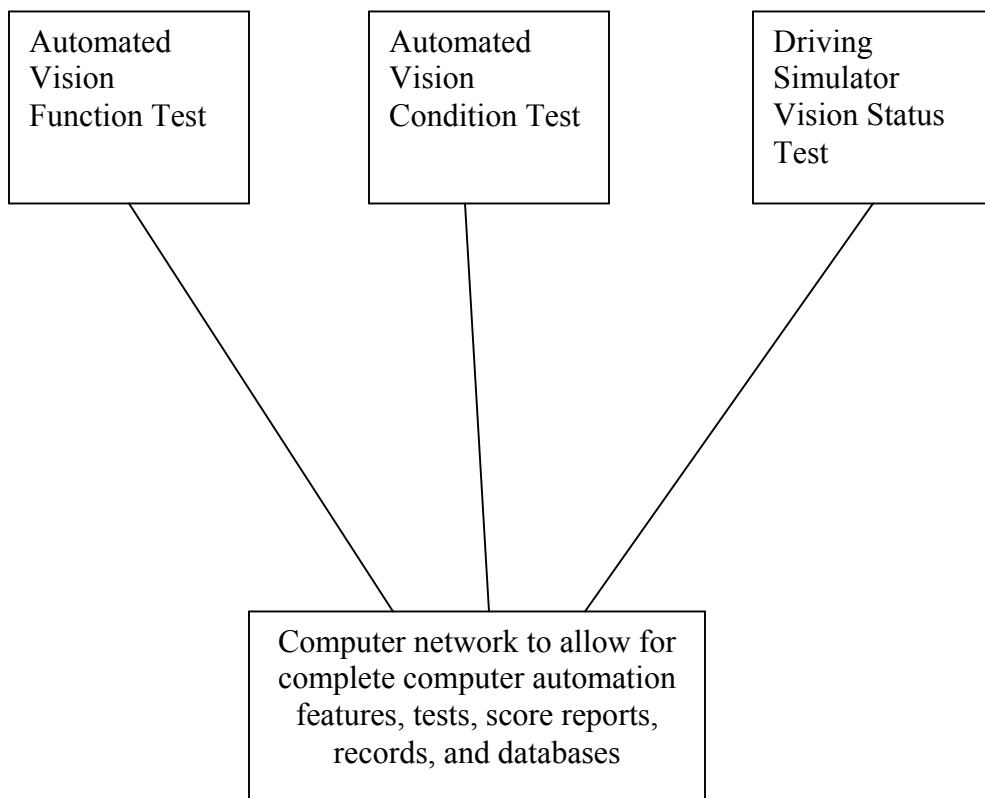


Figure 7. ESRA Dynamic Vision Assessment for Transportation (ESRA DVAT™)

- Ultimately, all other parts of the driver's license test should be considered for automation, as illustrated in Figure 8., ESRA Dynamic Assessment for Transportation (ESRA DAT™), once adequate safety concerns are addressed.

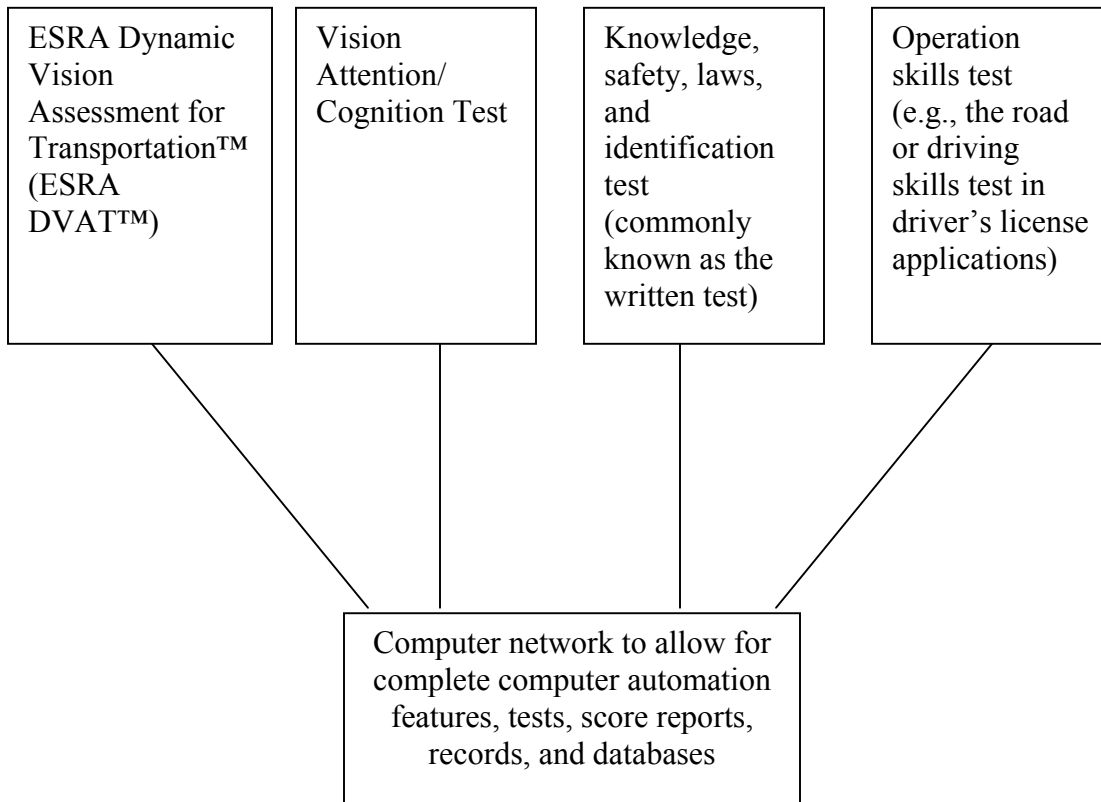


Figure 8. ESRA Dynamic Assessment for Transportation (ESRA DAT™)

Although Figure 7 illustrates the vision function test and vision condition test as two separate tests, this configuration, as part of the comprehensive and automated vision testing system developed by ESRA, may be combined into one test because the B1Max™ VACS is available as a software product. This product provides quick and reliable PC-based administration on local and networked systems and in diverse operating systems.

The ESRA Vision Assessment Procedure for Transportation™ (ESRA VAPT™) (Figure 6) and the ESRA Dynamic Vision Assessment for Transportation™ (ESRA DVAT™) System (Figure 7) allow ADOT to validate the use of new and improved vision testing technology through a full-scale study. The ESRA Dynamic Assessment for Transportation™ (ESRA DAT™) (Figure 8) also merits further consideration, especially with the availability of the cognition tests (UFOV) and ReFb-06™ Road Sign Knowledge Tests. The results of such studies, as demonstrated through our global survey, stand to not only benefit drivers and driver’s license bureau officials in Arizona and elsewhere, but to also benefit transportation personnel in many other agencies as well. Hence the automation of data and information between other transportation agencies may ultimately result in significant cost-savings, especially through the avoidance of repeatability of the ESRA Dynamic Vision Assessment for Transportation™ (ESRA DVAT™) and vision attention/ cognition tests, which provide broad transportation applications.

Implementation

As this study has shown further safety gains could be achieved by more substantial improvements to the current testing methodology. The ESRA Dynamic Vision Assessment for Drivers (DVAT™) is envisaged as a fully automated system that rigorously screens vision function, condition, and status of drivers. These include eye diseases and neuropsychologic and neuromotor disorders such as dementia. Recent studies indicate that many drivers are unaware that they have these conditions. Given the more limited option, we prescribe the ESRA DVAT™ to significantly reduce statewide motor vehicle collisions, fatalities, and injuries.

Therefore, ESRA DVAT™ justification can be accomplished through a system of evaluating the anticipated safety gains and collisions avoided. The estimated costs and benefits for a five-year period in approximately 50 Arizona Motor Vehicle Division offices can be quantified as follows:

<u>Component</u>	<u>Five Year Cost</u>	<u>Annualized Cost</u>
Visual Acuity Test	\$6,875,000	\$1,375,000
Eye Condition Test	\$2,500,000	\$500,000
Driving Simulators	\$2,750,000	\$550,000
Contingency	\$4,243,750	\$848,750
Total*	\$16,368,750	\$3,273,750

* These itemized costs were conservatively calculated on the basis of a range of estimates provided to ESRA by different manufacturers. The prices for all products are subject to change and may be considerably higher if any custom or technical modifications are required.

Benefits of ESRA DVAT™

The benefits of this improved driver testing system would be the reduction of collisions on the roadways. It is estimated that about 2 percent of drivers have serious vision or other conditions (for example, dementia) that raise their risk of collisions (National Institute of Health, 2004). Collision rates for those with diplopia are estimated to be 20 percent above average, (McCloskey *et al.* 1994) for glaucoma 50 percent above average (McCloskey *et al.* 1994) and for cataracts 150 percent above average (Owsley, *et al.* 1999). Taking the lowest of these estimates as the factor for the 2 percent of impaired drivers, these drivers are projected to account for about \$70 million of the annual \$2.8 billion in collisions costs in Arizona. If the two-step test weeds out 80 percent of these impaired drivers (Fink, 2004) and denies them driver's licenses, and keeps them off the roads, the benefit in terms of collision losses avoided would be about \$55 million per year.

The estimated potential benefit of \$45 million per year is 13 times larger than the estimated \$3.3 million annualized cost of the improved testing system. The magnitude of the benefit compared to the cost creates a strong argument for pursuing a further effort to explore possible implementation of the improved test.

Granted, the benefits will not flow directly to ADOT Motor Vehicle Division in the form of funds with which to pay for implementation. Benefits will be dispersed throughout the community in the form of fewer lives lost or damaged by collisions that might have been avoided if more impaired drivers were taken off the roads. Revenues gained and costs avoided will occur in the State's general fund. A case can be made for funding the improved driver testing procedure from these sources.

The ESRA DVAT™ model may serve as a prototype for other states, countries, and government agencies to follow.

Note: The benefit/cost estimate was calculated by John Semmens, ADOT, from data provided by ESRA.

The ESRA DAT™ System is developed by:

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APPENDIX A: HORIZONTAL SECTION OF THE HUMAN EYEBALL AND SOME COMMON CONDITIONS THAT MAY AFFECT IT

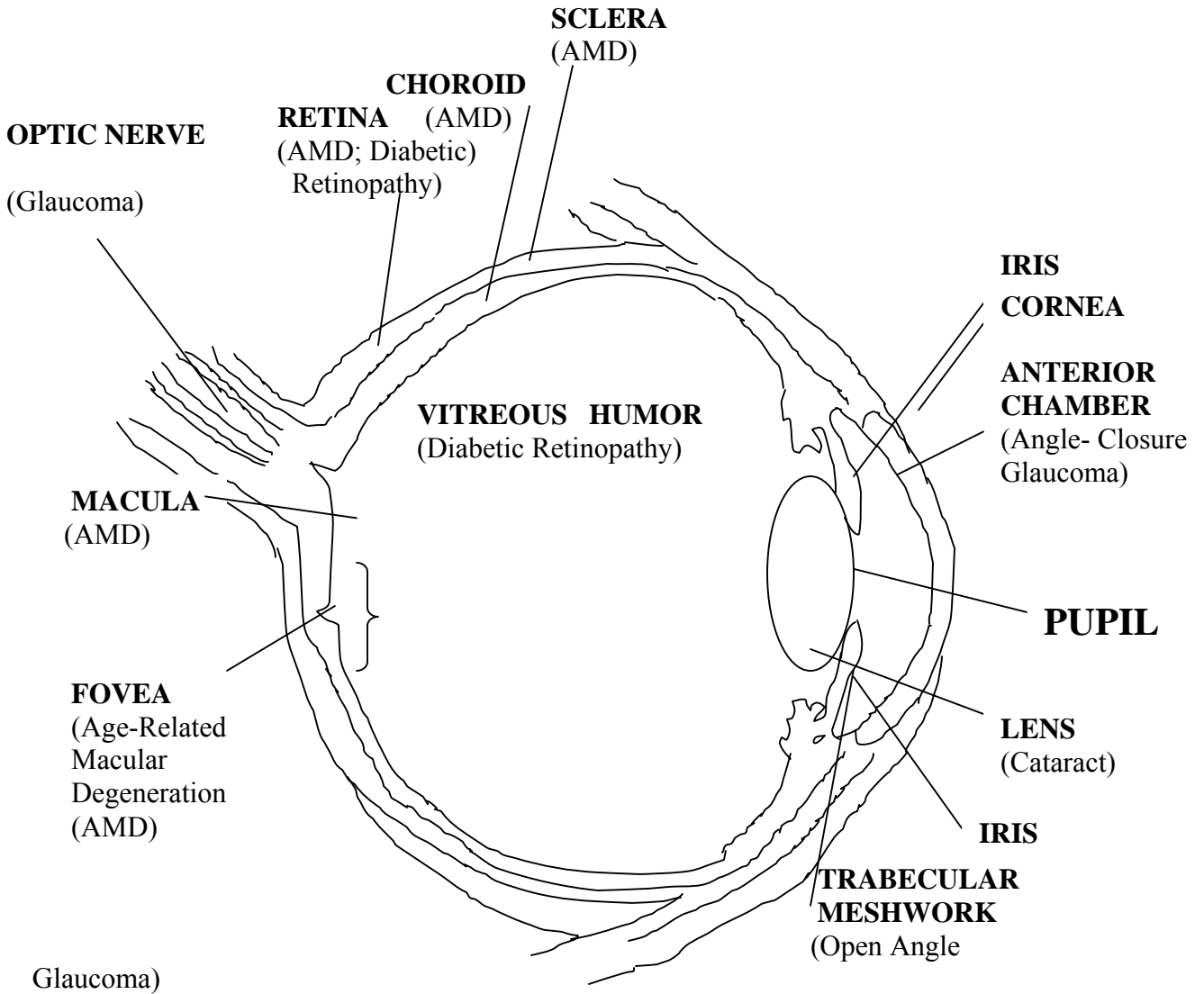


Figure 1. Horizontal section of the human eyeball and some common conditions that may affect it.

APPENDIX B: RESULTS OF GLOBAL SURVEY OF DRIVER'S LICENSE DIRECTORS OR THEIR REPRESENTATIVES, YEAR 2004

As part of our project to determine if the current vision testing practices in the State of Arizona require enhancement, a comprehensive survey on the visual acuity testing methods of drivers was developed. Questionnaires were faxed or e-mailed to the directors of all driving licensing agencies of all 51 U.S. states and the Commonwealth of Puerto Rico, Canada, New Zealand, the United Kingdom, and Australia from January 28 to April 16, 2004. Some officials were telephoned for follow-up interviews. Responses were received from 100% of all national and international driver's license bureau directors or their representatives. Our aim was to review and learn about the policies and practices of other driver's licenses bureaus within the United States and overseas in order to identify suitable driver's license testing equipment for the Arizona Department of Transportation (ADOT). When this identification was not possible, it was necessary for ESRA to develop new, comprehensive, and automated driver's license testing systems.

Our visual acuity survey covers all 51 U.S. States and the Commonwealth of Puerto Rico, all ten provinces and three territories of Canada, all of New Zealand, all of the United Kingdom, and the six states and two territories of Australia. The provinces of Canada include Newfoundland and Labrador, Nova Scotia, Prince Edward Island, New Brunswick, Québec, Ontario, Manitoba, Saskatchewan, Alberta, and British Columbia. The territories of Canada include Nunavut, Yukon, and Northwest Territories. Nunavut constitutes nearly one-fifth of Canada's land mass yet has the smallest population. Approximately 85 percent of the 28,000 residents of Nunavut are Inuit, an indigenous people formerly called Eskimos. The states of Australia include New South Wales, Queensland, South Australia, Victoria, Tasmania, and Western Australia; the territories, Australian Capital Territory and Northern Territory.

Table 1. Percentage of Driver's license Bureaus with modifications made to the visual impairment screening component of the driver's license vision screening test over the last ten years

Country	Percentage
United Kingdom	100%
New Zealand	100%
Australia	50%
United States and Commonwealth of Puerto Rico	29%
Canada	15%

Our first step is to determine if any modifications were made to the visual impairment screening component of driver's license vision screening test over the last ten years. According to our respondents, the United Kingdom and New Zealand account for the largest percentage (100%) of these changes. According to Table 1, only 29% of the

respondents in the United States and Commonwealth of Puerto Rico report such modifications.

In order for us to proceed with a design and a recommendation on a computer automated driving test, it is necessary for us to know where these tests are in operation. Interestingly, computer automated vision screening tests are currently operated in only 2% of the driver's license bureaus in the United States. An official from the State of Oklahoma reports that the Juno and Titmus Vision Screeners provide computer automated vision screening tests to their driver's license applicants. No computer automated vision screening tests exist in Australia, Canada, New Zealand, or the United Kingdom.

Table 2 shows the variety of vision screening tests at national and international driver's license bureaus. The primary models include Juno, Keystone, Optec, and Titmus. Almost all countries outside of the United States that utilize vision screening instruments employ the most current Stereo Optical Inc. equipment, the Optec 2000. As shown in Figure 2, although 57% of all driver's license bureaus in the United States exclusively use the Optec 1000 for driver's license vision testing, nearly 79% either solely or partly incorporate the Optec 1000 into their vision testing component. The Optec 1000 model, in contrast to Optec 2000, lacks many advanced features and testing mechanisms. The Optec 2000, for example, provides three times the number of vision tests as the Optec 1000. Approximately 9% of driver's license bureaus in Canada exclusively use the Optec 2000 machines. An additional 24% partly incorporate the Optec 2000 into their vision testing equipment. As illustrated in Figure 3, the Juno models are the most widely used vision testing devices in Canada. The Juno models account in part for 66% of all vision tests at driver's license bureaus in Canada. The Titmus models, currently in use, in conjunction with Snellen acuity charts, in the State of Arizona, account in whole or in part of 25% of vision tests at driver's license bureaus in the United States, 33% of the vision tests in Canada, and 100% of the vision tests in New Zealand.

Interestingly, New York is the only U.S. State that does not utilize any mechanical device to test the visual acuity of its driver's license applicants. Instead, its driver's license bureau staff administers tests through Snellen-type charts. These charts are widely used in both the United Kingdom (100%) and Australia (75%).

Table 2. Percentage of Vision Screening Tests Currently in Use at Driver's license Bureaus

Type	USA, PU*	CD	UK	NZ	AT
Keystone	2%	8%			
Keystone and Juno		8%			
Keystone, Juno, Optec, and Titmus		8%			
Keystone and Optec	10%	8%			
Keystone, Optec, and Titmus	4%				
Juno	2%	34%			
Juno, Optec, and Titmus		8%			
Juno and Titmus	2%	8%			
Off-site visual specialist	2%				12.5%
Optec 1000	57%				
Optec 2000		9%			
Optec and Titmus	8%				
Snellen-type chart only	2%		100%**		75%
Snellen-type chart and Optec 2000					12.5%***
Titmus****	11%	9%			
Titmus T2a				100%	

* Some U.S. States also listed Snellen-type charts in addition to vision screening tests.

** Car number plate readings at specified conditions and distances. Visual acuity equipment unspecified.

*** Snellen tumbling "E" and pictograph in remote areas; Optec 2000 in metro and major centers.

**** The model number(s) is/were not indicated.

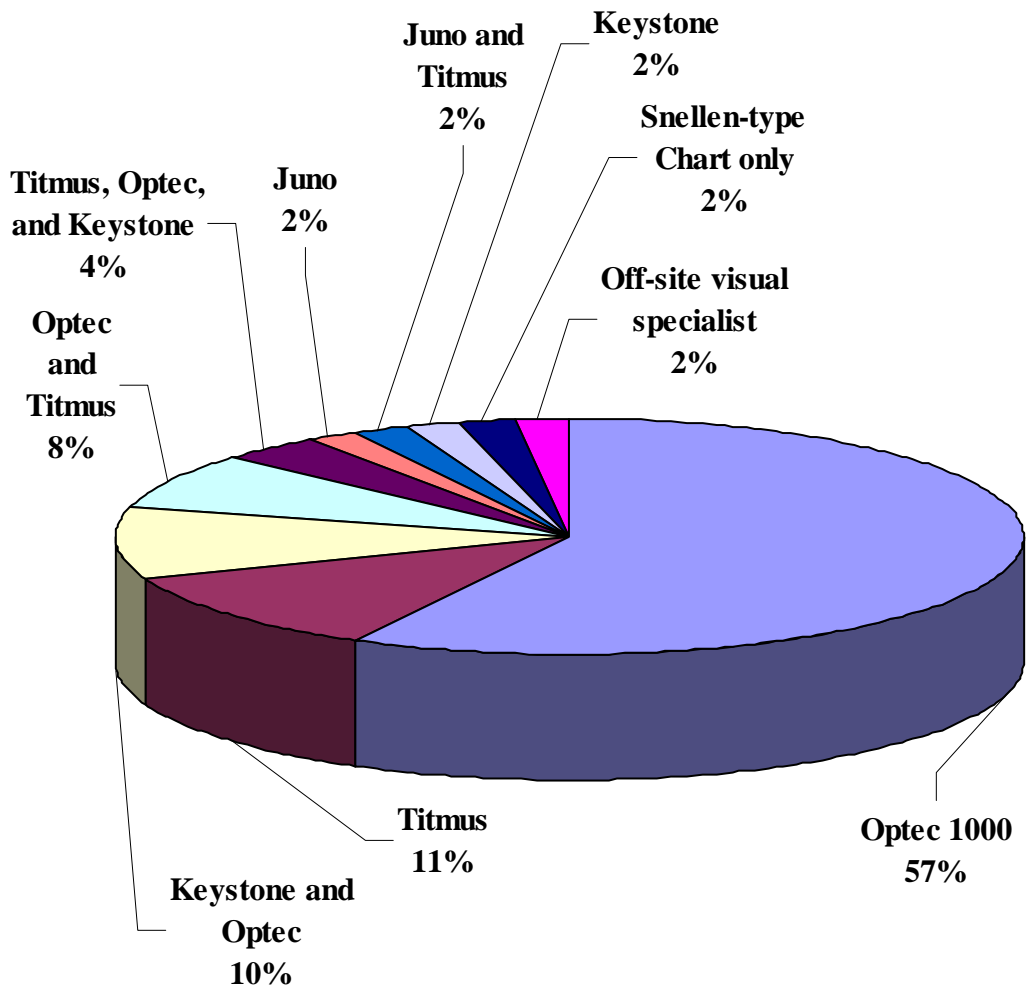


Figure 2. Vision Screening Tests at Driver's license Bureaus of the United States and Commonwealth of Puerto Rico

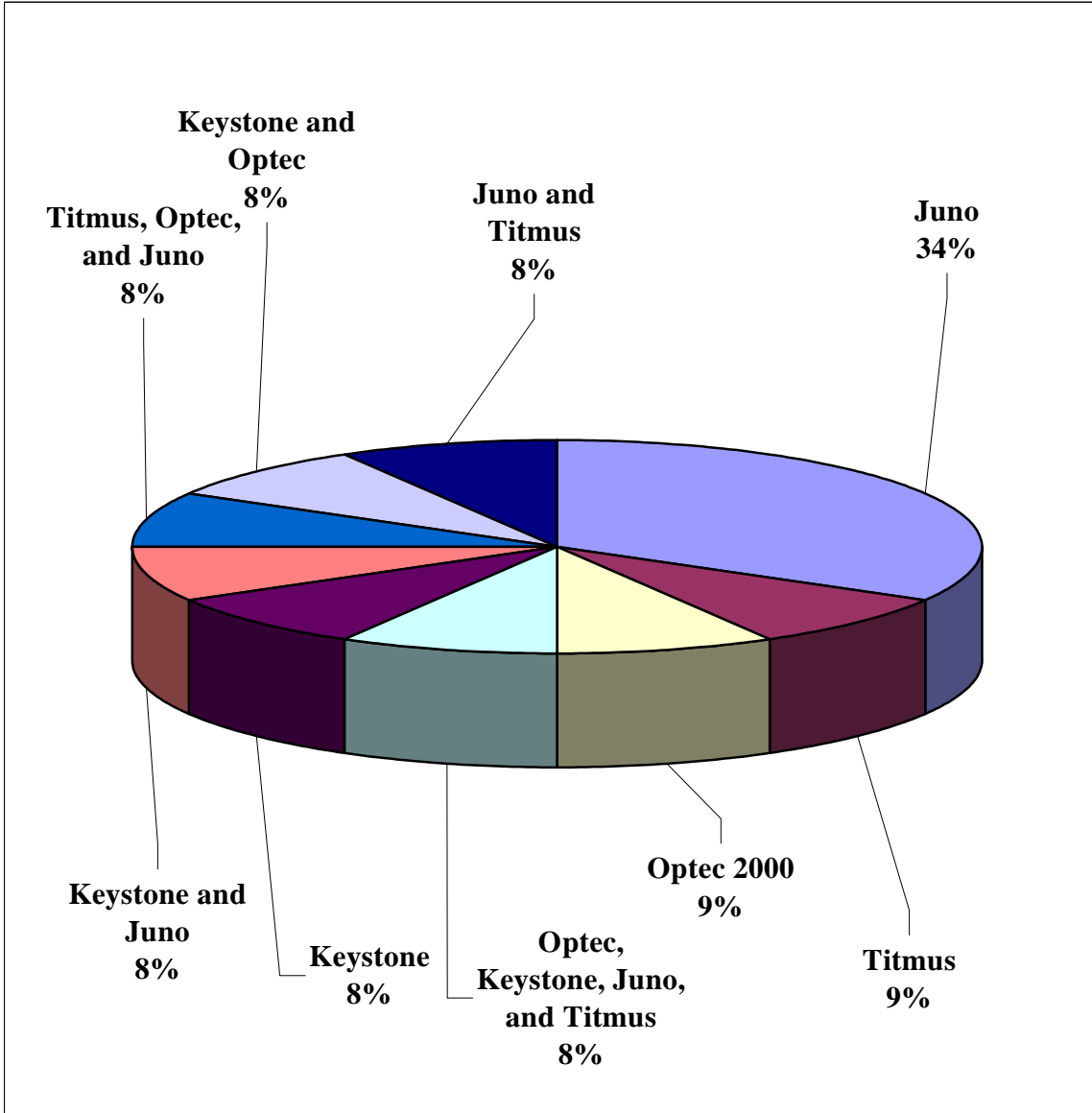


Figure 3. Vision Screening Tests at Driver's license Bureaus of the Provinces and Territories of Canada

In order to optimize a design for any driver's license vision testing system, it is necessary to know the shortcomings of the current tests in use. According to Table 3, our respondents in New Zealand (100%), the United Kingdom (50%), Australia (37.5%), and the United States (10%) express the greatest concern about inadequacy of or inaccuracy in their current screening techniques. The largest percentages of U.S. respondents also report concerns about technical difficulties (10%), visual limitations (9%), and memorization of tests or features (6%).

Understandably, this list is not an exhaustive one. Shortcomings are dependent but not limited to location, fatigue (“wear and tear”), training, and staffing of these vision screening instruments.

However, it is important to note that in the United States, Canada, New Zealand, and most of Australia, driver’s license bureau staff members, not licensed medical professionals, conduct vision testing for driver’s license applicants or holders. In both the Commonwealth of Puerto Rico and South Australia, per contra, vision testing is not conducted through its driver’s license agencies. Off-site visual specialists, such as licensed ophthalmologists and opticians, test all driver’s license applicants and licensees for visual impairments. In the United Kingdom, ophthalmic practitioners do not always conduct visual acuity testing. By law, Group 1 driver’s license applicants (cars) in the United Kingdom are required to reveal a vision condition that may impair driving.

Table 3. Shortcomings in Vision Screening Tests According to Directors of Driver’s license Bureaus

Type	USA, PU	CD	UK	NZ	AT
None Specified	55%	46%			37.5%
Technical difficulties	10%				
Inadequate and /or inaccurate screening techniques	10%	38%	50%*	100%	37.5%***
Visual Limitations	9%				
Memorization of tests or features	6%				
Inability to detect cataracts or glaucoma	2%				
Space limitations	2%				12.5%
Literary obstacles	2%				
Inadequate screening techniques, space	2%				
Mechanical breakage	2%				
Old equipment and usage		8%			
Portability obstacles		8%			
Visual acuity measurements by non-medical professionals			50%**		12.5%****

* Applies to commercial drivers (Group 2) license applicants in the United Kingdom.

** In the United Kingdom, ophthalmic practitioners do not always conduct visual acuity testing. General Practitioners usually test commercial drivers.

*** Australian respondents primarily define these inadequate screening techniques as the inability to determine low contrast acuity *and/or* peripheral field of vision of driver’s license applicants or holders. Some respondents also report a lack of varying lighting conditions and tests.

**** In Western Australia, non-medical professionals (staff) perform eyesight testing.

New Zealand is the only country where its driver’s license officials have not indicated any plans to modify its vision screening test. In the United Kingdom, there are discussions underway to determine whether or not to allow only optometrists to conduct visual acuity testing.

In Australia, there are some states with current plans underway to modify vision screening tests. In particular, Tasmania intends to switch from a 6-meters Snellen Chart to a 3- meters Snellen Chart. In Victoria, there are proposals to comprehensively review driver eyesight standards and develop a new assessment to replace the existing visual acuity test. In Western Australia, following the introduction of a new practical driving assessment for young drivers, there are also driving assessments for senior drivers under review. In Canada, revised Canadian Council of Motor Transport Administrators (CCMTA) medical standards are slated for incorporation in the Yukon Territory and some provinces. While Quebec aims for improvements, none are currently specified. In the United States, reports from the District of Columbia and Missouri indicate plans to modify driver’s license vision screening tests. Officials in the District of Columbia assess the Medical Review Policies and Procedures to decide on vision testing modifications. Although funding concerns exist in Missouri, officials continue to investigate automated vision testing methodology.

According to Table 4, officials in the United Kingdom demonstrate the greatest plans (100%) to modify their vision screening, followed by Australia (25%), Canada (15%), and the United States and Commonwealth of Puerto Rico (6%).

Table 4. Percentage of Driver’s license Bureaus with current plans to modify vision screening tests

Country	Percentage
United Kingdom	100%
Australia	25%
Canada	15%
United States and Commonwealth of Puerto Rico	6%

It is essential to learn what the directors and their representatives of national and international Driver’s license Bureaus suggest be done to improve their current visual acuity test methodologies. This information provides us with the insight necessary to proceed with computer automated testing development.

According to Table 5, officials from the United Kingdom (100%) suggest improvements to ensure acuity measurement accuracy. Respondents from Australia (25%), Canada (8%), and the United States and Commonwealth of Puerto Rico recommend improved testing methods *and/or* facilities. Respondents from the U.S. (8%) and Canada (6%) also suggest computerized testing mechanisms. There are also recommendations to incorporate dawn, dusk, and night driving vision testing from 8% of the U.S. officials. An additional 4% of these American respondents propose the simulation of weather conditions and peripheral vision testing.

Table 5. Suggested Improvements to Current Visual Acuity Test Methodologies by Driver's license Bureaus

Type	USA, PU	CD	UK	NZ	AT
None Specified	66%	76%		100%	75%
Improved testing methods and/ or facilities	8%	8%			25%
Computerized testing	6%	8%			
More visual acuity slides and instrument upgrades	4%				
Contrast sensitivity testing and/ or depth perception testing	4%				
Database-linked and web-enabled forms from visual specialists	4%				
Night driving and weather conditions vision testing	2%				
Random testing and contrast sensitivity testing	2%				
Night driving and peripheral vision testing	2%				
Web-based testing	2%				
Dawn, dusk, and night driving vision testing		8%			
Acuity measurement accuracy for Group 2 applicants*			100%		

*Group 2 includes smaller lorries up to 3.5 tonnes/ mini-buses and Heavy Goods/ Public Service Vehicles.

Table 6 shows the authority required to modify vision testing procedures at driver's license bureaus in the United States and Commonwealth of Puerto Rico, Canada, United Kingdom, New Zealand, and Australia. This authority is governed by administrative rule in both Australia (100%) and the United States and Commonwealth of Puerto Rico (23.1%) and policy in both Canada (23%) and Australia (25%). However, in the United Kingdom, this authority is evenly divided between administrative rule, policy, and legislation.

Some respondents from the United States and Canada report several instruments they would like to see adopted into their vision testing programs. Among the American respondents, these include: Fully automated testing (12%), Useful Field of View (6%), contrast sensitivity (4%), and glare recovery (2%). Among the Canadian respondents, these include: Vision screen replacement (7.7%) and computerized (fully automated) testing (7.7%).

Although only 2% of the American respondents and 8% of the Canadian respondents report the completion of any studies measuring the effectiveness of their current vision testing procedures, respondents in Australia, the United Kingdom, or New Zealand reported that no such studies were carried out.

All respondents were asked if their current vision screening test accounted for lighting changes, specifically day, dusk, and night lighting. Among the respondents from the U.S.A., lighting tests were limited to day (40%), dusk (12%), dawn (4%), and night (2%).

Among the respondents from Canada, lighting tests included day (46%), dusk (8%), and night (8%). Among the respondents from Australia, only 12.5% reported vision tests that involve day lighting tests.

Weather conditions that may impair a driver’s vision include but are not limited to clearness, cloudiness, fog, rain, sleet, and snow. Some vision tests in Australia account for clearness (25%) and cloudiness (12.5%). Respondents from the United States report vision tests that include clearness (10%). No other testing of weather-related conditions within vision testing programs is reported.

Table 6. Authority Required to Modify Vision Testing Procedures at Driver’s license Bureaus

Type	USA, PU	CD	UK	NZ	AT
Administrative Rule	23.1%	7.7%	33.3%	100%	
Administrative Rule, Executive Action, Policy, Other					12.5% ^G
Administrative Rule, Executive Action, Policy, Statute	3.8%	7.7%			
Administrative Rule, Other		7.7% ^B			
Administrative Rule, Policy	9.6%				12.5%
Administrative Rule, Policy, Other					12.5% ^H
Administrative Rule, Policy, Statute	5.8%				
Administrative Rule, Statute	17.3%				
Executive Action					12.5%
Executive Action, Policy		7.7%			
Policy	15.4%	23%	33.3%		25%
Policy, Other		7.7% ^C			
None Specified	3.8%	7.7%			12.5%
Other	2% ^A	15.4% ^D	33.3% ^F		12.5% ^J
Statute	19.2%	7.7%			
Statute, Other		7.7% ^E			

^A Health Advisory Board.

^B Canadian Council of Motor Transport Administrators (CCMTA) “Medical Standards for Drivers”

^C National Safety Code/ Medical Guidelines

^D Canadian Council of Motor Transport Administrators (CCMTA) “Medical Standards for Drivers”

^E Regulation change to vision standards, Motor Vehicle Act.

^F Legislation.

^G National Medical Assessment Guideline

^H Legislation.

^J National Standards.

It is important to know which impediments to improvement exist at national and international driver's license bureaus. Costs, in whole and in part, as shown in Table 7, account for the bulk of these impediments in the United Kingdom (50%), Canada (46%), the United States and Commonwealth of Puerto Rico (41%), and Australia (37.5%).

Policy in the United Kingdom (50%) also tends to impede driver's licensing improvements.

Clearly, it is necessary for us to design a computer automated testing system that is cost-effective.

Table 7. Percentage of Impediments to Improvements at Driver's license Bureaus

Type	USA, PU	CD	UK	NZ	AT
Costs	25%	15%	50%		
Costs, Policy, Training					12.5%
Costs, Staff/ Training	4%	8%			12.5%
Costs, Staff/ Training, Statute/ Policy/ Rule	13%	23%			12.5%
Costs, Statute/ Policy/Rule	12%				
None Specified	36%	54%		100%	62.5%
Policy			50%		
Staff/ Training	4%				
Statute/ Policy/ Rule	6%				

The design of any system is dependent on several variables. In the case of vision testing of driver's license applicants, these variables include but are not limited to the screening of certain vision impairments and possible diseases. Any visual disorder can impair an individual's ability to safely drive. Therefore, vision tests may incorporate different elements to screen for potentially harmful vision conditions. According to Table 8, the vision screening tests in the driver's license bureaus of Canada (85%) and the United States (67%) primarily account for peripheral vision (67%). Other tests in the Canada (62%) and the United States (39%) check for color blindness. Depth perception accounts for many other driver's license vision tests in Canada (62%) and the United States (27%).

These tests contrast with those in the United Kingdom, where contrast sensitivity and glare sensitivity are examined in driver's license applicants. In Australia, tests for cataracts (12.5%) and acuity/monocularity (12.5%) are principally conducted.

Table 8. Percentage of Visual Conditions Accounted for in Vision Screening Tests at Driver’s license Bureaus*

Type	USA, PU	CD	UK	AT
Cataracts	2%	----	----	12.5%
Central Scotomas	----	8%	----	----
Color Blindness	39%	62%	----	----
Contrast Sensitivity	2%	----	50%	----
Depth Perception	27%	62%	----	----
Diplopia (Double Vision)	----	46%	----	----
Eye Movement Disorder	4%	----	----	----
Glare Sensitivity	----	8%	50%	----
Glaucoma	----	----	----	----
Peripheral Vision	67%	85%	----	----
Other	8% ^A	24% ^B	----	12.5% ^C

- * Most respondents noted more than one type.
- No response.
- ^A Acuity.
- ^B Acuity, Heterophorias, and Night Blindness.
- ^C Acuity, monocularly.

Interestingly, there appears to be some consistency in the current visual acuity requirements for non-commercial drivers, as illustrated in Table 9. The **20/40** (6/12) ratio represents the most widely utilized visual acuity requirement for these drivers in New Zealand (100%), the United States and Commonwealth of Puerto Rico (92%), Australia (87.5%), and Canada (77%). In the United Kingdom, **20/32** (6/10) corresponds to the standard visual acuity requirement for car drivers. However, the American Academy of Ophthalmology (2001) reports that the 20/40 (6/12) visual acuity requirement lacks data to support its policy in many U.S. states.

In Canada, two provinces are currently considering the implementation of new standards developed by the Canadian Council of Motor Transport Administrators (CCMTA) for motorists to drive with a best eye visual acuity of **20/50** (6/15). Approximately 23% of the other provinces and territories in Canada already feature this visual acuity ratio in their driver’s license vision testing programs.

For these reasons, our results differ from those reported in the December 1999 publication, “Comparative Data: State and Provincial Licensing Systems,” the American Association of Motor Vehicle Administrators, whence 71% of U.S. states require an automobile vision screening standard of **20/40** (6/12) for both eyes without correction and 50% of all Canadian Provinces and Territories require an automobile vision screening standard of **20/40** (6/12) for both eyes without correction.

Table 9. Current Visual Acuity Requirement for Non-Commercial Drivers*

Ratio (metric)	USA, PU	CD	UK	NZ	AT
20/30 (6/9)					
20/32 (6/10)			100%		
20/40 (6/12)	92%	77%		100%	87.5%
20/50 (6/15)	4%	23%			
20/60 (6/18)	4%				
20/70 (6/21)					
None Specified					12.5%

* Ratio with both eyes opened and examined together. Some respondents indicate this ratio for “best eye”. Other respondents note this ratio as the minimum acceptable level for driving in their jurisdiction. Some respondents, particularly from the United States, also specify other visual acuity measurements on the basis of restrictions (daylight driving, e.g.). Other vision test results are often used in conjunction with visual acuity requirements (e.g., peripheral vision, visual field, etc.).

As presented in Table 10, officials at driver’s license bureaus collect a range of data in order to identify vision-impaired drivers. In New Zealand (100%), the United States and Commonwealth of Puerto Rico (21.1%), Australia (12.5%), and Canada (7.7%), vision test results are maintained in a database and used for this very purpose. Similarly, in Australia (50%), the United States and Commonwealth of Puerto Rico (26.9%), and Canada (15.4%), documented medical conditions of driver’s license applicants are filed and used to identify vision-impaired drivers. In Canada, however, medical specialists or law enforcement officials (38.5%) provide the most readily accessible information for this purpose.

Table 10. Collection of Data at Driver’s license Bureaus to Identify Vision-Impaired Drivers*

Type	USA, PU	CD	NZ	AT
Collision or conviction	11.5%			
Database of Vision Test Results	21.1%	7.7%	100%	12.5%
Documented Medical Condition	26.9%	15.4%		50%
Government Agencies	3.8%			
Medical Specialist or Law Enforcement Official		38.5%		
Periodic Assessments				12.5%
Re-test	5.8%			
Renewal Application	1.9%			
Telescopic/ Bioptic Lenses	1.9%			

* Some respondents provided multiple responses.

Additional methods of detecting at-risk drivers are illustrated in Table 11. Mandatory medical officials (98.1%), on-site vision screening (59.6%), accident reports (51.9%), anonymous tips (38.5%), and postal mail to the driver’s license bureau (38.5%), are all prime methods of at-risk driver identification in the United States and Commonwealth of Puerto Rico. In both Canada and Australia, medical officials (100%) provide the

majority of this information, followed by accident reports and postal mail to the bureaus. Furthermore, in the United Kingdom, at-risk drivers are identified by medical officials, postal mail, telephone/ hotline, age, self-disclosure of injury or illness, e-mail, and law enforcement.

Table 11. Methods of Identification of At-Risk Drivers*

Type	USA, PU	CD	AT
Accident Report	51.9%	76.9%	62.5%
Anonymous Tips	38.5%	23.1%	62.5%
Age	5.8%	15.4%	
Driver's license Application	3.8%		
Interagency Data Exchange	1.9%		
Law Enforcement	21.2%	23.1%	
Litigation	3.8%		
Mandatory On-Site Vision Screening	59.6%	30.8%	37.5%
Medical Official	98.1%	100%	100%
Online/ Website	9.6%	7.7%	12.5%
Other		7.7%**	
Postal Mail to Driver's license Bureau	38.5%	38.5%	62.5%
Relatives or Concerned Citizens	9.6%	7.7%	12.5%
Re-Test	1.9%		
Self-Disclosure of Injury or Illness			37.5%
Statute, Rule, or Policy	28.8%	23.1%	37.5%
Telephone/ Hotline	9.6%	7.7%	25%

* Some respondents replied to more than one type.

** Fax.

Driver's license renewal policies are a fundamental part of the vision screening program. These policies serve to weed out drivers who may cause harmful collision events. In light of recent studies by Owsley *et. al* 2004 at University of Alabama- Birmingham, that show, for example, how driver refresher training courses for older drivers do not reduce older driver-involved collisions, the driver's license renewal policies provide an even greater role for promoting safety on roads.

Table 12. Frequency of Visual Acuity Screening Tests for Non-Commercial Driver's License Renewal at Driver's license Bureaus*

Frequency	USA,PU	CD	UK	NZ	AT
Once every year					37.5% ^D
Once every two years				50% ^B	
Once every three years			100% ^A		
Once every four years	11.7%				
Once every five years	26.9%	7.7%			37.5% ^E
Once every six years	3.8%				
Once every eight years	9.6%				
Once every ten years	5.8%	23.1%		50% ^C	12.5% ^F
Once every twelve years	1.9%				
First Issuance	9.6%	38.4%			
Not required	3.8%	15.4%			
Other	26.9%	15.4%			12.5% ^G

* Certain rules may apply and may depend upon the age *and/or* medical condition of licensee and method and time of renewal or issuance.

^A Once every three years for age 70 years and older.

^B Once every two years for age 80 years and older.

^C Once every ten years for under age 80 years.

^D Once every year for age 70 years and older in some jurisdictions.

^E Once every year for age 75 years other jurisdictions.

^F Includes first issuance for one jurisdiction.

^F Applies if applicant wears corrective lenses.

^G Applies if renewal or replacement unless <12 months (1, 3, or 5-year license).

As shown in Table 12, a number of these national and international policies are geared toward older drivers. In the United States and Commonwealth of Puerto Rico, an average of 26.9% of renewals require vision testing once every five years. In Canada, first issuance (38.4%) represents the sole method of vision testing, followed by vision tests once every ten years (23.1%). In New Zealand, the renewal policies dictate vision testing once every ten years for drivers age 80 years and under and once every two years for age 80 years and older. In Australia, an average of 37.5% of renewals require drivers to undergo vision testing once every year for age 70 years and older in some jurisdictions and age 75 years and older in other jurisdictions. The United Kingdom, per contra, allows drivers 70 years and older, every three years, to self-declare their ability to meet the number plate requirement.

Table 13. Current Age-Based Driver’s license Renewal Policies for Vision Testing of Non-Commercial Drivers*

Policy Exists	USA, PU	CD	UK	NZ	AT
Yes	48%	23%	100%**	100%	75%***
No	50%	23%			12.5%
None Specified	2%	54%			12.5%

* When information from a state’s licensing agency in the United States is not available, the information above is obtained from *Physician’s Guide to Assessing and Counseling Older Drivers* (American Medical Association in cooperation with the National Highway Traffic Safety Administration, 2003).

** Self-declaration of ability to satisfy number plate vision testing requirement for drivers 70 years and older is compulsory.

*** Includes Queensland.

According to Table 13, age-based driver’s license renewal policies for vision testing of non-commercial drivers exist, with some stipulations, in 100% of the United Kingdom, 100% of New Zealand, 75% of Australia, 48% of the United States, and 23% of Canada. In Australia, there exists a mandatory vision testing requirement at driver’s license renewal in Queensland only if a condition is medically disclosed. In Victoria, there are no vision test requirements for driver’s license renewal.

Table 14 shows the variation in minimum age requirements for vision testing of older drivers for national and international driver’s license renewals. The most common vision testing requirement applies to drivers age 70 years and older in policies of New Zealand (100%), the United Kingdom (100%), and the United States (18%). These vision testing requirements affect drivers age 75 years and older in policies in Australia (37.5%) and drivers age 80 years and older in policies in Canada (15%). Many conditions apply to these policies. For example, although driver’s licensees age 65 years and older are required to renew their licenses every two years in Pennsylvania, vision testing is not required at the time of renewal. However, driver’s licensees age 45 years and older are subject to random requests to produce current vision testing results and physical exam results to the Motor Vehicle Bureau or Pennsylvania Department of Transportation (PENNDOT).

Table 14. Current Minimum Age Requirement for Vision Testing of Older Drivers for Driver's license Renewals*

Age	USA, PU	CD	UK	NZ	AT
45+	2%**				
50+	2%				
60+	2%				
65+	12%				
70+	18%		100%***		
75+	8%	8%			37.5%
80+	2%	15%		100%	
Multiple ages	2%				
No Age Specified					37.5%*****
No Requirement	50%	23%			12.5%
No Testing Specified	2%	54%			12.5%

* When information from a state's licensing agency in the United States is not available, the information above is obtained from *Physician's Guide to Assessing and Counseling Older Drivers* (American Medical Association in cooperation with the National Highway Traffic Safety Administration, 2003). This information applies to non-commercial drivers only.

** Includes Pennsylvania where driver's licensees are randomly selected at age 45 years and older to produce current vision testing results and physical exam results to the Motor Vehicle Bureau or PENNDOT.

*** Self-declaration of ability to satisfy number plate vision testing requirement for drivers 70 years and older is compulsory.

**** Includes Queensland.

Vision testing requirements for driver's license renewals in the United States and Commonwealth of Puerto Rico for years 1989 and 2004 are presented in Table 15. These show that in 1989, only 41 states had vision testing requirements. In 2004, vision testing requirements at driver's license renewals are implemented in 45 U.S. states and the Commonwealth of Puerto Rico.

Table 15. Driver's License Renewal Policies for Vision Testing in the United States and Commonwealth of Puerto Rico, 1989 and 2004*

State	Test required at renewal 1989	Test required at renewal 2004
Alabama	None	None
Alaska	Vision	Vision
Arizona	Vision	Vision
Arkansas	Vision	Vision
California	Vision	Vision
Colorado	Vision	Vision
Connecticut	Vision	None
Delaware	Vision	Vision
District of Columbia		Vision
Florida	Vision	Vision
Georgia	Vision	Vision
Hawaii	Vision	Vision
Idaho	Vision	Vision
Illinois	Vision	Vision
Indiana	Vision	Vision
Iowa	Vision	Vision
Kansas	Vision	Vision
Kentucky	None	None
Louisiana	Vision	Vision
Maine	Vision	Vision
Maryland	Vision	Vision
Massachusetts		Vision
Michigan	Vision	Vision
Minnesota	Vision	Vision
Mississippi	None	Vision
Missouri	Vision	Vision
Montana	Vision	Vision
Nebraska	Vision	Vision
Nevada	Vision	Vision
New Hampshire	Vision	Vision
New Jersey	None	Vision**
New Mexico	Vision	Vision
New York	Vision	Vision
North Carolina	Vision	Vision
North Dakota	Vision	Vision
Ohio	Vision	Vision
Oklahoma	None	None
Oregon	Vision	Vision
Pennsylvania	Vision	Vision

State	Test required at renewal 1989	Test required at renewal 2004
Puerto Rico		Vision
Rhode Island	Vision	Vision
South Carolina	Vision	Vision
South Dakota	Vision	Vision
Tennessee	None	None
Texas	Vision	Vision
Utah	Vision	Vision
Vermont	None	None
Virginia	Vision	Vision
Washington	Vision	Vision
West Virginia	None	None
Wisconsin	Vision	Vision
Wyoming	Vision	Vision

* When information from a state's licensing agency in the United States is not available, the information above is obtained from the following sources:
2004 data: U.S. Department of Transportation, Federal Highway Administration; AARP; American Automobile Association; American Association of Motor Vehicle Administrators; Insurance Institute for Highway Safety as cited on Insurance Information Institute website < <http://www.iii.org/media/hottopics/insurance/olderdrivers/>>, accessed March 27, 2004. and *Physician's Guide to Assessing and Counseling Older Drivers* (American Medical Association in cooperation with the National Highway Traffic Safety Administration, 2003).
1989 data: Levy *et al.*, JAMA, October 4, 1995, Vol. 274, no. 13.
This information applies to non-commercial drivers only.
Blank boxes represent unknown renewal procedure.

Finally, this study examines the driver's license screening tests for commercial drivers at national and international driver's license bureaus. Most countries require additional testing, enforce federal regulations, and implement stricter visual acuity standards for commercial drivers. The visual standards for commercial drivers are often more stringent due to the long hours required for transporting goods and the severe consequences likely to result from a collision.

According to our survey, respondents report that commercial drivers are primarily subject to the same vision tests as non-commercial drivers in New Zealand (100%) and the United States and Commonwealth of Puerto Rico (63.3%), plus more stringent standards in Canada (100%). While these may be the cases in both the United Kingdom and Australia, both countries chiefly offer different visual acuity tests for commercial driver applicants.

In the United Kingdom, the standard visual acuity requirements for commercial drivers are at a minimum of **20/30** (6/9) in the "best eye" and no worse than **20/40** (6/12). In New Zealand, commercial drivers are also required to demonstrate a minimum visual acuity ratio of **20/30** (6/9).

In the December 1999 publication, "Comparative Data: State and Provincial Licensing Systems," the American Association of Motor Vehicle Administrators reports that 73%

of U.S. states require a commercial vision screening standard of **20/40** (6/12) for both eyes without correction, 8% of all Canadian Provinces and Territories require a commercial vision screening standard of **20/40** (6/12) for both eyes without correction, and 50% of all Canadian Provinces and Territories require a commercial vision screening standard of **20/30** (6/9) for both eyes without correction. On the basis of a survey of US driver's license bureaus, Peli (2003) notes that a visual field of 70 degrees horizontally in each eye, the federal requirement for commercial drivers, is significantly less than non-commercial driver's license requirements in most US states. These findings underscore the need for promoting commercial driver safety through improvements to the state and federal commercial driver vision testing process and requirements. Craft (2004) reports that more than 800,000 trucks transport hazardous materials across the United States each day. Although collisions, fatalities, and injuries are low relative to the quantity of hazardous materials shipments, the potential for a catastrophe is much greater among these trucks than any other trucks on our roads.

Our objective is to review and learn about the policies and practices of national and international driver's licenses bureaus within the United States and overseas through the development of a survey. Driver's license Bureau Directors and their representatives in all jurisdictions of the United States and Commonwealth of Puerto Rico, Canada, the United Kingdom, New Zealand, and Australia completed the survey.

These findings, in conjunction with the results of our statistical study and risk analyses, will enable us to complement a sound recommendation on a suitable comprehensive and automated driver's license vision testing system for evaluation by the Arizona Department of Transportation (ADOT).

Table 16. Commercial Driver Vision Screening Tests at Driver's License Bureaus

Type	USA, PU	CD	UK	NZ	AT
Federal Guidelines	3.4%				
None specified	7.7%				
Ophthalmologist, optometrist, or other medical official	3.4%		50%		12.5%
Other visual acuity test	3.4%		50%*		87.5%*
Same as non-commercial drivers	63.3%			100%	
Same as non-commercial drivers plus additional vision tests	15.4%				
Same as non-commercial drivers plus federal guidelines	3.4%				
Same as non-commercial drivers plus more stringent standards		100%			

* More stringent standards tend to exist for this visual acuity test.

APPENDIX C: COLLISIONS IN ARIZONA, YEARS 1991 TO 2001

Following the results of our global survey of directors or their representatives of the driver's license bureaus of all U.S. States, Commonwealth of Puerto Rico, it is necessary to analyze the collisions of Arizona over an eleven-year period, 1991 to 2001.

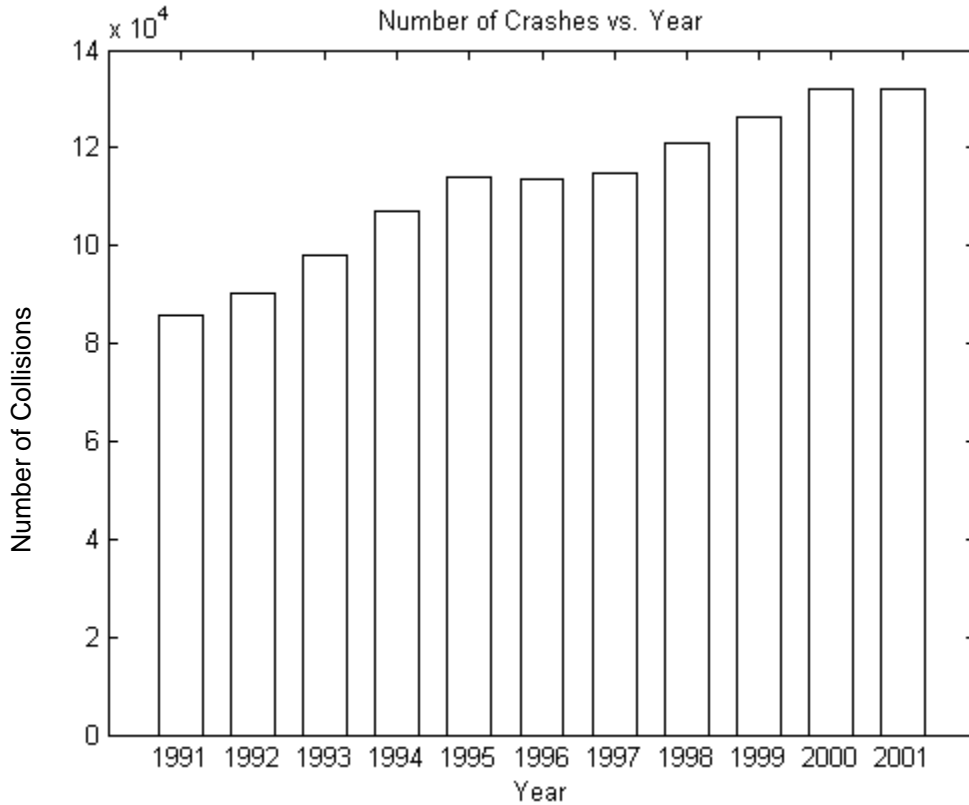


Figure 4. Number of Arizona Collisions in Years 1991 to 2001

From Figure 4 and Table 17, we can infer that the number of collisions in Arizona increases by 54% from years 1991 to 2001. Over this eleven-year period, we see that the greatest number of collisions, 132,001, occurred in 2001 and that the median is 113,922 collisions.

Table 17. Total Arizona Motor Vehicle Collisions and Descriptive Statistics, Years 1991 to 2001

Year	Total Number of Collisions	Year	Total Number of Collisions
1991	85,809	1997	114,947
1992	90,097	1998	121,027
1993	97,916	1999	126,472
1994	106,913	2000	131,890
1995	113,922	2001	132,001
1996	113,486		
		5 PCTL	87,953
Median	113,922	95 PCTL	131,946
SD	15,781	MIN	85,809
95%CI	9,326	MAX	132,001

Table 18. Percentages of All Age Cohorts in Arizona Collisions for Years 1991 to 2001

Age	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Teens	12	12	12	12	11	12	12	12	13	13	13
20s	30	29	29	27	27	26	26	27	27	27	27
30s	23	23	23	22	22	21	21	22	22	21	21
40s	15	15	16	15	15	16	16	16	17	17	17
50s	8	8	8	8	8	9	9	10	11	11	11
60s	6	6	6	6	5	5	5	6	6	5	6
70s	4	4	4	4	4	4	4	4	4	4	4
80s	1	1	1	6	7	1	7	4	1	1	1
90s	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1

From Table 18, the age 20s cohorts consistently represent the largest percentage of drivers in Arizona automobile collisions over the eleven-year period from 1991 to 2001. They average approximately 27% of all collisions. However, if the sum of drivers in age cohorts 50s, 60s, 70s, 80s, and 90s, are considered, then this group, over this period, typically constitutes the second highest percentage of drivers in Arizona automobile collisions.

APPENDIX D: DESCRIPTIVE STATISTICS OF COLLISIONS, FATALITIES, AND INJURIES OF ARIZONA AND FLORIDA DRIVERS, YEARS 1991 TO 2001

Between 1995 and 1996, Arizona and Florida were among the twenty-five states that raised the maximum controlled-access highway speed limit for automobiles and light trucks. The mean collision rate for these 25 states increased from 2.70 to 3.69 (Saricks and Tompkins, 2000). This may account for some spikes in rates of collisions, injuries, and fatalities of both Arizona and Florida drivers.

Table 19. Arizona Driver Collisions for Years 1991 to 2001

Age	Mean	Median	MIN	MAX	5% PCTL	95% PCTL	STD
16-19	23,935	24,347	17,629	29,227	17,672	29,194	3,930.3
20-24	29,423	29,220	22,929	34,620	22,999	34,612	3,781.5
25-34	48,555	50,442	39,177	54,385	39,253	54,289	5,036.6
35-44	38,802	39,873	27,865	45,877	27,974	45,831	6,133.1
45-54	25,119	25,682	15,198	32,257	15,309	32,224	5,793.3
55-64	14,034	13,804	10,206	17,491	10,234	17,479	2,539.9
65-74	9,788	9,952	8,172	10,394	8,204	10,391	709.8
75&Over	9115	7,523	4,795	19,052	4,824	18,823	4,429.4

Tables 19 and 20 show collisions for Arizona and Florida drivers from years 1991 to 2001. The largest mean in the eleven-year period for Arizona collisions, represented in Table 19, is the age group 25 to 34 years (\bar{x} = 48,555). The second highest mean is the years age group 35 to 44 years (\bar{x} = 38,802). In Table 20, the highest mean for any years age group of Florida drivers involved in collisions occurs in the 25 to 34 years age group (\bar{x} = 84,764). The second highest mean for age group collisions is the 35 to 44 years age group (\bar{x} = 70,634).

Table 20. Florida Driver Collisions for Years 1991 to 2001

Age	Mean	Median	MIN	MAX	5% PCTL	95% PCTL	STD
16-19	37,723	40,165	31,577	42,123	31,597	42,110	4,461
20-24	46,863	47,878	42,916	50,592	42,963	50,527	2,547
25-34	84,764	82,210	79,061	92,944	79,099	92,897	5,339
35-44	70,634	77,325	54,147	81,163	54,299	81,044	10,134
45-54	44,813	48,322	31,351	54,655	31,476	54,535	8,488
55-64	26,968	28,555	22,156	31,341	22,171	31,307	3,629
65-74	20,030	19,319	17,804	22,519	17,826	22,494	1,683
75&Over	14,531	15,195	11,025	17,140	11,062	17,133	2,196

Table 21. Arizona Driver Injuries for Years 1991 to 2001

Age	Mean	Median	MIN	MAX	5% PCTL	95% PCTL	STD
16-19	9,520	9,771	7,449	11,173	7,467	11,155	1,202
20-24	11,628	11,936	9,889	13,283	9,903	13,265	1,146
25-34	19,255	19,580	16,466	20,844	16,500	20,834	1,425
35-44	15,218	15,830	11,405	17,490	11,456	17,468	1,934
45-54	9,772	10,029	6,299	12,217	6,341	12,197	1,939
55-64	5,501	5,478	4,253	6,720	4,264	6,701	800
65-74	3,841	3,914	3,393	4,000	3,406	4,000	192
75&Over	3,759	2,991	1,941	5,956	1,957	5,954	1,532

Tables 21 and 22 show the number of drivers who were injured in collisions in Arizona and Florida. In Table 21, the highest number of injuries occurs among the ages 25 to 34 years group ($\bar{x} = 19,255$) among the Arizona drivers. The second highest number of injuries occurs among the ages 35 to 44 years group ($\bar{x} = 15,218$). The number of injuries decreases as the ages decrease and increase away from the ages 25 to 34 years group. Table 22 shows that the highest mean for the number of drivers who were injured in collisions in Florida occurs in the ages 25 to 34 years group ($\bar{x} = 34,676$). The second highest number of injuries occurs among the ages 35 to 44 years group ($\bar{x} = 28,872$). Overall, the number of injuries decreases as the age range diverged from the 25 to 34 years age group.

Table 22. Florida Driver Injuries for Years 1991 to 2001

Age	Mean	Median	MIN	MAX	5% PCTL	95% PCTL	STD
16-19	15,486	16,049	13,162	16,976	13,163	16,969	1,521
20-24	19,526	19,687	17,721	20,632	17,767	20,619	839
25-34	34,676	34,455	32,293	37,699	32,310	37,658	1,883
35-44	28,872	31,217	21,745	32,384	21,846	32,353	3,742
45-54	18,369	19,857	12,524	22,192	12,592	22,158	3,441
55-64	10,971	11,612	8,603	12,795	8,628	12,774	1,503
65-74	8,254	8,318	7,081	9,129	7,101	9,121	652
75&Over	6,192	6,633	4,486	7,169	4,508	7,167	957

Table 23. Arizona Driver Fatalities for Years 1991- 2001

Age	Mean	Median	MIN	MAX	5% PCTL	95% PCTL	STD
16-19	124	121	109	150	109	149	12
20-24	172	161	148	214	148	214	23
25-34	287	287	244	339	245	338	28
35-44	227	235	174	269	174	269	34
45-54	147	161	95	189	95	188	33
55-64	91	95	71	115	71	115	16
65-74	75	74	55	91	56	91	11
75&Over	97	92	42	161	43	161	43

Tables 23 and 24 show fatalities for Arizona and Florida drivers from years 1991 to 2001. According to Table 23, the highest number of fatalities among Arizona drivers occurs among ages 25 to 34 years ($\bar{x} = 287$), ages 35 to 44 years cohorts ($\bar{x} = 227$), and age 20 to 24 years cohorts ($\bar{x} = 172$). Table 24 shows that the highest mean for Florida Fatalities from years 1991 to 2001 exists within in the ages 25 to 34 years group ($\bar{x} = 311$), the ages 35 to 44 years group ($\bar{x} = 274$), and the age 75 years and older group ($\bar{x} = 195$). Overall, the means of fatalities decreases as the age range increases from the age 25 to 34 years groups for both states. However, the 75+ years age group of Florida drivers experiences a sharp increase in fatalities ($\bar{x} = 195$), compared to Arizona drivers of the same age cohorts, ($\bar{x} = 97$).

Table 24. Florida Driver Fatalities for Years 1991 to 2001

Age	Mean	Median	MIN	MAX	5% PCTL	95% PCTL	STD
16-19	135	132	101	169	102	168	19
20-24	186	187	149	221	150	220	22
25-34	311	319	276	332	276	332	19
35-44	274	269	218	326	218	325	35
45-54	188	179	125	275	126	274	46
55-64	132	121	100	173	100	172	24
65-74	135	133	104	159	104	159	17
75&Over	195	201	129	243	129	242	35

Table 25. Arizona driver data for 1991

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	191,987	17,629	116	7,449
20-24	199,116	22,929	159	9,889
25-34	415,256	39,177	296	16,466
35-44	445,062	27,865	187	11,405
45-54	300,916	15,198	95	6,299
55-64	169,699	10,206	75	4,253
65-74	216,086	8,172	74	3,393
75&Over	65,377	4,795	42	1,941

Table 25 shows that the ages 35 to 44 years group has the greatest number of driver's licenses in Arizona, in the year 1991. The 35 to 44 years age group ($l=445,602$) and the years age group 25 to 34 years ($l=415,256$), has 415,256 licensees. Contrastingly, the age group 25 to 34 years demonstrates a larger amount of collisions than the other. The 25 to 34 years age cohorts also have a higher fatality and injury rate than the age group of 35 to 44 years. Florida driver's licensees for the year 1991 appear in Table 26. Similarly, the age group 25 to 34 years shows a larger amount of collisions than the other. The greatest number of driver's licenses is held by the years age group 25 to 34 years, ($l=2,945,070$) and the second highest resides within age 35 to 44 years, ($l=2,518,197$). More licensees are within the age group 65 to 74 years ($l=1,311,530$) than from age 55 to 64 years ($l=1,311,046$).

Table 26. Florida driver data for 1991

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	499,573	32,010	132	13,162
20-24	1,048,611	42,916	209	17,721
25-34	2,945,070	79,061	319	32,293
35-44	2,518,197	54,147	218	21,745
45-54	1,631,847	31,351	125	12,524
55-64	1,311,046	22,156	119	8,603
65-74	1,311,530	17,804	104	7,081
75&Over	869,187	11,025	129	4,486

Table 27. Arizona driver data for 1992

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	202,967	18,494	116	7,801
20-24	216,625	24,319	153	10,386
25-34	444,015	40,692	275	17,153
35-44	481,157	30,036	181	12,428
45-54	339,260	17,413	104	7,144
55-64	197,992	10,774	79	4,478
65-74	226,310	8,823	69	3,691
75&Over	84,191	5,374	57	2,266

Table 27 shows Arizona Driver data for year 1992. The age group that holds the largest number of driver's licenses is the age 35 to 44 years cohorts, ($l = 481,157$). The second largest number of driver's licensees is within ages 25 to 34 years, ($l = 444,015$). The number of collisions is highest for ages 25 to 34 years in 1992 Arizona. The age group 65 to 74 years holds more licenses ($l = 226,310$) than from 45 to 54 years ($l = 339,260$). Florida driver's licensees show similar trends. Table 28 reveals that the greatest number of driver's licenses is held by the age group 25 to 34 years, ($l = 2,633,002$) and the second highest resides within age 35 to 44 years, ($l = 2,300,693$). The number of collisions is highest for ages 25 to 34 years among Florida drivers in 1992. The age cohorts 65 to 74 years hold more licenses ($l = 1,319,575$) than the 55 to 64 years cohorts ($l = 1,271,029$).

Table 28. Florida driver data for 1992

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	488,237	31,577	101	13,181
20-24	1,039,861	43,858	149	18,647
25-34	2,633,002	80,099	322	33,436
35-44	2,300,693	57,187	223	23,761
45-54	1,613,133	33,848	154	13,877
55-64	1,271,029	22,458	100	9,094
65-74	1,319,575	18,430	132	7,484
75&Over	847,252	11,761	134	4,935

Table 29. Arizona driver data for 1993

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	213,946	20,215	109	8,388
20-24	234,134	26,200	148	11,075
25-34	472,773	44,355	267	18,259
35-44	517,252	33,207	174	13,649
45-54	377,603	19,938	105	8,114
55-64	226,286	11,787	71	4,791
65-74	236,534	9,458	55	3,833
75&Over	103,006	5,665	56	2,281

Table 29, Arizona Driver Data for year 1993, shows a similar trend to the one illustrated in table 27. Arizona's drivers have a greater number of licensees ages 35-44 years ($l = 517,252$) than 25 to 34 years ($l = 472,773$), the group with the largest number of collisions, $c = 44,355$. The number of fatalities is highest among ages 25 to 34 years ($f = 267$). Table 30 shows that in the year 1993, Florida drivers age 75 and older had a significant increase in the amount of fatalities ($f = 201$) compared to the previous year. However, the greatest number of collisions ($c = 2,626,808$) occurs among the Florida driver's licensees, ages 25 to 34 years. Fatalities ($f = 332$) and injuries ($i = 34,455$) are also highest among this group.

Table 30. Florida driver data for 1993

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	497,592	31,980	116	13,762
20-24	1,033,808	44,071	205	19,284
25-34	2,626,808	79,830	332	34,455
35-44	2,370,645	59,290	261	25,361
45-54	1,699,753	35,558	154	14,896
55-64	1,288,578	22,565	121	9,440
65-74	1,335,676	18,250	112	7,674
75&Over	876,189	12,139	201	5,209

Table 31. Arizona driver data for 1994

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	224,926	22,480	117	9,349
20-24	251,643	28,921	161	12,188
25-34	501,532	47,764	287	19,921
35-44	553,347	36,865	230	14,993
45-54	415,947	22,707	139	9,186
55-64	254,579	12,800	71	5,093
65-74	246,758	9,848	66	3,995
75&Over	121,820	14,467	118	4,596

Table 31, Arizona Driver Data for 1994, depicts the highest number of driver's licenses in the age group of 35 to 44 years ($l=553,347$). As the age range diverges from the age 35 to 44 years group, the number of driver's licenses decreases. The number of collisions, fatalities, and injuries are highest among the ages 25 to 34 years cohorts. However, when compared to 1993, the age 75 years and older group has a significantly higher than normal number of fatalities ($f=118$), collisions ($c=14,467$), and injuries ($i=4,596$). Table 32 depicts the highest number of Florida driver's licenses in the age group of 25 to 34 years ($l=2,616,916$). As the age range diverges from the age 25 to 34 years group, the number of driver's licenses, collisions, fatalities, and injuries decreases. However, the 65 years and older age group has a significantly high number of fatalities: Age 65 to 74 years ($f=131$) and 75 years ($f=192$).

Table 32. Florida driver data for 1994

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	507	33,784	137	14,789
20-24	1,020	44,674	187	19,712
25-34	2,616,916	81,508	309	35,159
35-44	2,442,937	62,956	249	27,227
45-54	1,786,467	38,340	152	16,171
55-64	1,312,984	23,415	107	9,747
65-74	1,353,305	19,176	131	8,192
75&Over	911,846	12,976	192	5,638

Table 33. Arizona driver data for 1995

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	235,905	24,016	136	9,825
20-24	269,152	30,562	213	12,620
25-34	530,290	51,287	339	20,637
35-44	589,441	39,689	243	15,830
45-54	454,291	24,993	167	10,057
55-64	282,872	13,478	81	5,458
65-74	256,983	10,266	81	4,000
75&Over	140,634	19,052	145	5,913

Table 33 depicts the highest number of driver's licensees in the age group of 35 to 44 years (589,441). As the age range diverges from the ages 35 to 44 years group, the number of driver's licensees decreases. The number of collisions, fatalities, and injuries are in a similar pattern to the number of license holders in the age group. However, the 75 years and older age group has a significantly higher than normal to the trend number of fatalities ($f= 145$), collisions ($c= 19,052$), and injuries ($i= 5,913$). Also, the age group 25 to 34 years has more collisions ($c= 51,287$) than the 35 to 44 years age group.

Table 34. Florida driver data for 1995

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	516,825	37,773	129	15,428
20-24	984,784	48,683	197	20,284
25-34	2,602,050	89,944	327	36,724
35-44	2,499,326	72,220	289	29,499
45-54	1,845,945	44,758	162	18,152
55-64	1,296,726	26,711	108	10,761
65-74	1,282,111	21,390	148	8,652
75&Over	850,262	15,264	196	6,333

Table 34 depicts the highest number of driver's licensees in the age group of 25 to 34 years ($l= 2,602,050$). As the age range diverges from the 25 to 34 years age group, the number of driver's licensees decreases. The number of collisions, fatalities, and injuries are in a similar pattern to the number of license holders in the age group. However, the 65 years and older age group has a significantly high number of fatalities: Ages 65 to 74 years ($f= 148$) and 75 years and older ($f= 196$).

Table 35. Arizona driver data for 1996

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	248,954	24,347	121	9,771
20-24	285,723	29,130	168	12,090
25-34	575,906	50,442	294	20,455
35-44	635,643	39,873	237	16,119
45-54	498,319	25,682	141	10,029
55-64	320,298	13,804	95	5,577
65-74	270,496	10,216	91	3,985
75&Over	164,526	7,740	160	5,956

Table 35 depicts the highest number of driver's licensees in the age group of 35 to 44 years ($l= 635643$). As the age range diverges from the 35 to 44 years age group, the number of driver's licensees decreases. The number of collisions, fatalities, and injuries are in a similar pattern to the number of license holders in the age group. However, the 75 years and older age group has a significantly high number of fatalities ($f= 160$) and injuries ($i= 5956$).

Table 36. Arizona driver data for 1997

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	256,474	25,007	116	9,678
20-24	313,474	29,220	177	11,349
25-34	579,684	49,420	260	19,067
35-44	656,149	40,832	216	15,729
45-54	527,828	26,515	161	9,951
55-64	328,381	14,348	100	5,478
65-74	274,690	9,952	80	3,832
75&Over	173,739	8,000	161	5,554

Table 36 depicts the highest number of driver's licensees in the age group of 35 to 44 years ($l= 656,149$). As the age range diverges from the 35 to 44 years age group, the number of driver's licensees decreases. The number of collisions, fatalities, and injuries are in a similar pattern to the number of license holders in the age group, except ages 25 to 34 years is the peak.

Table37. Florida driver data for 1997

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	574,091	40,538	132	16,049
20-24	985,419	48,149	170	19,687
25-34	2,615,502	92,011	276	36,876
35-44	2,678,829	78,649	269	31,755
45-54	2,034,482	50,634	197	20,673
55-64	1,422,624	29,442	153	11,831
65-74	1,332,779	22,024	159	8,916
75&Over	993,142	16,677	223	6,949

Table 37 shows the number of Florida drivers ages 35 to 44 years with licenses has exceeded that of the age group 25 to 34 years. However, the most number of collisions, fatalities and injuries remain within the age group 25 to 34 years ($c=92,011$, $f= 276$, and $i= 36,876$).

Table 38. Arizona driver data for 1998

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	265,415	25,313	132	9,853
20-24	305,886	31,167	160	11,936
25-34	582,238	51,919	244	19,580
35-44	678,371	43,352	265	16,233
45-54	558,566	28,961	170	10,980
55-64	362,514	15,786	111	6,021
65-74	283,268	10,394	89	3,914
75&Over	190,890	12,733	93	4,125

Table 38 depicts the highest number of driver's licensees in the age group of 35 to 44 years ($l= 678,371$). As the age range diverges from the 35 to 44 years age group, the number of driver's licensees, collisions, fatalities, and injuries decrease.

Table 39. Florida driver data for 1998

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	602,730	42,123	149	16,782
20-24	1,013,843	48,180	183	19,361
25-34	2,606,815	90,118	283	35,776
35-44	2,754,353	81,163	300	32,384
45-54	2,113,984	52,159	198	21,379
55-64	1,494,954	30,663	140	12,374
65-74	1,330,530	21,956	147	8,961
75&Over	1,039,407	17,140	243	7,133

Table 39 shows similar behavior to that of Table 37. However, more Florida drivers in the age group 35 to 44 years die from collisions ($f= 300$) than from the age group 25 to 34 years ($f= 283$).

Table 40. Arizona driver data for 1999

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	282,572	28,004	150	10,813
20-24	346,616	32,130	184	10,162
25-34	670,916	52,463	276	20,063
35-44	748,552	44,956	259	17,045
45-54	615,885	31,057	189	11,822
55-64	403,232	16,647	103	6,310
65-74	301,717	10,330	83	3,957
75&Over	221,523	7,491	88	2,939

Table 40 shows the age group 35 to 44 years has the most Arizona licensees ($l= 748552$). Yet, the highest number of collisions, injuries, and fatalities occur within the age 25 to 34 years group.

Table 41. Florida driver data for 1999

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	628,672	41,834	155	16,827
20-24	1,056,064	47,189	163	19,122
25-34	2,624,609	83,490	309	33,221
35-44	2,835,287	77,736	301	31,217
45-54	2,218,653	51,063	225	20,816
55-64	1,562,681	29,924	151	12,065
65-74	1,332,472	20,228	133	8,374
75&Over	1,082,842	15,773	224	6,827

In Table 41, Florida drivers ages 35 to 44 years have the most licensees ($l=2,835,287$). However, the highest number of collisions ($c=83,490$), fatalities ($f=309$), and injuries ($i=33,221$) exist within the age group 25 to 34 years.

Table 42. Arizona driver data for 2000

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	152,936	29,227	121	11,173
20-24	277,772	34,456	214	13,283
25-34	660,222	54,385	293	20,844
35-44	750,804	45,877	235	17,490
45-54	643,977	32,257	179	12,217
55-64	423,899	17,491	115	6,720
65-74	300,824	10,308	74	3,994
75&Over	223,958	7,523	92	2,991

Table 42 exhibits similar trends as shown in Table 40. The highest number of collisions ($c=54,385$), fatalities ($f=293$), and injuries ($i=20,844$) occur among the Arizona drivers 25 to 34 years.

Table 43. Florida driver data for 2000

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	659,999	41,305	169	16,976
20-24	1,128,242	47,878	200	19,964
25-34	2,681,209	81,193	323	33,168
35-44	2,927,153	77,513	326	31,681
45-54	2,374,937	52,252	275	21,521
55-64	1,658,581	29,416	159	12,358
65-74	1,365,502	19,239	133	8,318
75&Over	1,174,858	14,893	192	6,800

Table 43 shows that the fatality count among Florida drivers age 35 to 44 years ($f=326$) and 35 to 44 years ($f=323$) appears nearly equal.

Table 44. Arizona driver data for 2001

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	145,814	28,557	128	10,619
20-24	286,726	34,620	159	12,928
25-34	683,478	52,199	326	19,362
35-44	769,820	44,275	269	16,475
45-54	686,821	31,592	171	11,699
55-64	449,429	17,251	103	6,338
65-74	303,063	9,903	67	3,663
75&Over	225,615	7,426	58	2,783

Table 44 illustrates that the numbers of collisions, fatalities, and injuries have relatively decreases among Arizona drivers from 2000 to 2001.

Table 45. Florida driver data for 2001

Driver Age	Number of Driver Licensees	Number of Driver Collisions	Number of Driver Fatalities	Number of Driver Injuries
16-19	667,249	41,862	148	16,803
20-24	1,169,440	50,592	221	20,632
25-34	2,698,008	82,210	330	32,628
35-44	2,949,814	78,787	314	31,373
45-54	2,436,219	54,655	248	22,192
55-64	1,755,654	31,341	173	12,795
65-74	1,377,683	19,319	130	8,015
75&Over	1,219,074	15,195	209	6,633

Table 45 shows that Florida drivers age 25 to 34 years clearly have the most collisions ($c=82,210$), fatalities ($f=330$), and injuries ($i=32,628$). However, drivers age 35 to 44 years ($l=2,949,814$) constitute the largest population of licensees.

APPENDIX E: OVERVIEW OF ARIZONA AND FLORIDA DRIVER'S LICENSEES, YEARS 1991 TO 2001

Table 46. Percentage Increase in Driver's Licensees in the States of Arizona and Florida, 1991 to 2001

Age	1991		2001		Percentage Increase	
	Arizona*	Florida	Arizona	Florida	Arizona	Florida
All ages	2,003,499 (100%)	12,170,841 (100%)	3,550,766 (100%)	14,346,373 (100%)	1.77	1.18
16- 19	191,987 (9.58%)	499,573 (4.10%)	145,814 (4.11%)	667,249 (4.65%)	-0.76	1.33
20- 24	199,116 (9.94%)	1,048,611 (8.62%)	286,726 (8.08%)	1,169,440 (8.15%)	1.44	1.12
25- 34	415,256 (20.73%)	2,945,070 (24.20%)	683,478 (19.25%)	2,698,008 (18.81%)	1.65	-0.92
35- 44	445,062 (22.21%)	2,518,197 (20.69%)	769,820 (21.68%)	2,949,814 (20.56%)	1.73	1.17
45- 54	300,916 (15.02%)	1,631,847 (13.41%)	686,821 (19.34%)	2,436,219 (16.98%)	2.28	1.49
55- 64	169,699 (8.47%)	1,311,046 (10.77%)	449,429 (12.66%)	1,755,654 (12.24%)	2.65	1.34
65- 74	216,086 (10.79%)	1,311,530 (10.78%)	303,063 (8.54%)	1,377,683 (9.60%)	1.40	1.05
75&over	65,377 (3.26%)	869,187 (7.43%)	225,615 (6.35%)	1,219,074 (8.5%)	3.45	1.40

SOURCE: For Arizona, year 1991, these conservative values for licensed drivers were obtained by linear regression techniques based on years 1996- 2001 data. This data may or may not include cancelled, suspended, expired, marked for deletion, disqualification and deceased driver's licenses.

According to Table 46, over an eleven-year period, from 1991 to 2001, the greatest percentage increase in Arizona licensed drivers is among the 75 years and older age group (3.45%). The group with the least increase in Arizona licensed drivers is the ages 16 to 19 years group (-0.76%). The greatest percentage increase in Florida licensed drivers occurs among the ages 45 to 54 years group (1.49%). The group with the least increase in Florida licensed drivers is the 25 to 34 years group (-0.92%).

Table 47. Percentage Increase in Driver's Licensees in the States of Arizona and Florida, 1991 to 2001

Age	1991		2001		Percentage Increase	
	Arizona*	Florida	Arizona	Florida	Arizona	Florida
All ages	2,003,499 (100%)	12,170,841 (100%)	3,550,766 (100%)	14,346,373 (100%)	1.77	1.18
Under65	1,722,036 (85.95%)	9,990,124 (82.08%)	3,022,088 (85.11%)	11,749,616 (81.90%)	1.75	1.18
65&over	281,463 (14.05%)	2,180,717 (17.92%)	528,678 (14.89%)	2,596,757 (18.10%)	1.88	1.19
75&over	65,377 (3.26%)	869,187 (7.43%)	225,615 (6.35%)	1,219,074 (8.5%)	3.45	1.40

As shown in Table 47, over an eleven-year period, from 1991 to 2001, the greatest percentage increase in licensed drivers occurs in Arizona for all three groups: 75 years and older (3.45%), 65 years and older (1.88%), all ages (1.77%), and under 65 years (1.75%). Similar trends, though slightly lower percentage increases, appear among licensed Florida drivers: 75 years and older (1.40%), 65 years and older (1.19%), and an equal increase among drivers of all ages (1.18%) and under 65 years (1.18%).

APPENDIX F: COMPARATIVE RATES OF COLLISIONS, FATALITIES, AND INJURIES OF ARIZONA AND FLORIDA DRIVERS, YEARS 1991 TO 2001

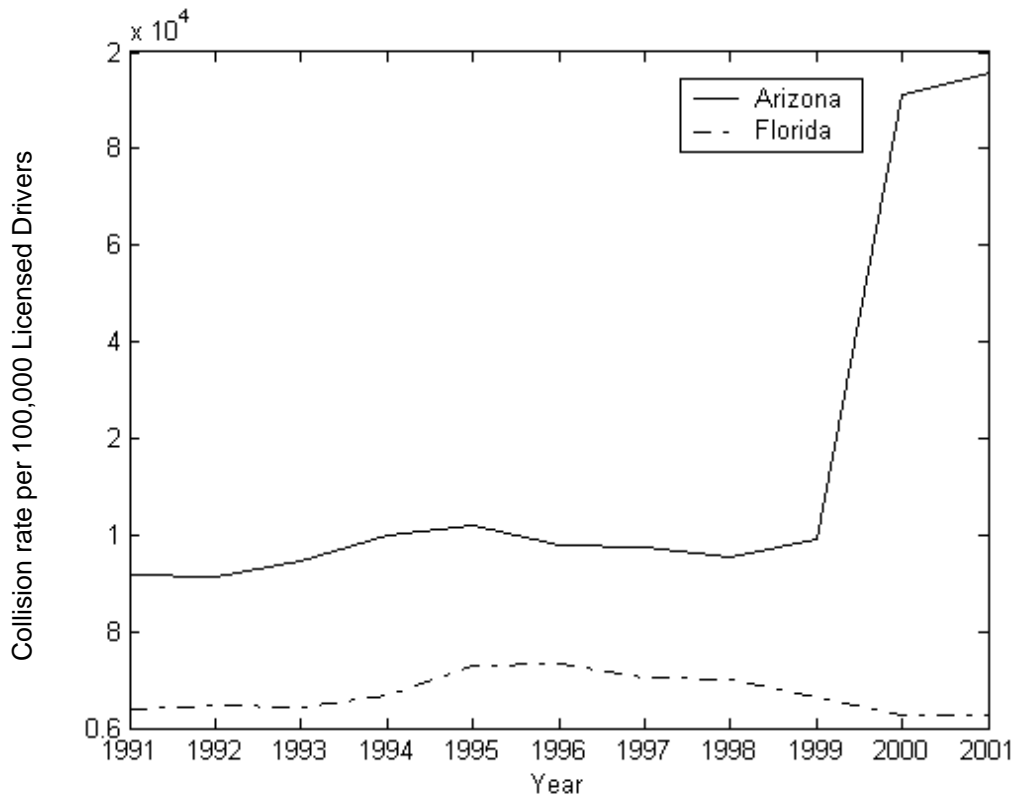


Figure 5. Collision Rates per 100,000 Licensed Drivers at Ages 16 to 19 Years in Arizona and Florida for Years 1991 to 2001

Figure 5 shows that Arizona has a much higher collision rate than Florida among licensed drivers at ages 16 to 19 years. Between 1999 and 2001, there is a significant rise in the collision rate of the Arizona drivers from around $c= 0.95 \times 10^4$ to about 1.95×10^4 . Florida remains fairly constant between 2000 and 2001. Florida has a minimum of $c= 0.64 \times 10^4$ collisions per 10,000 licensed drivers ages 16 to 19 years and a maximum of about $c=0.75 \times 10^4$.

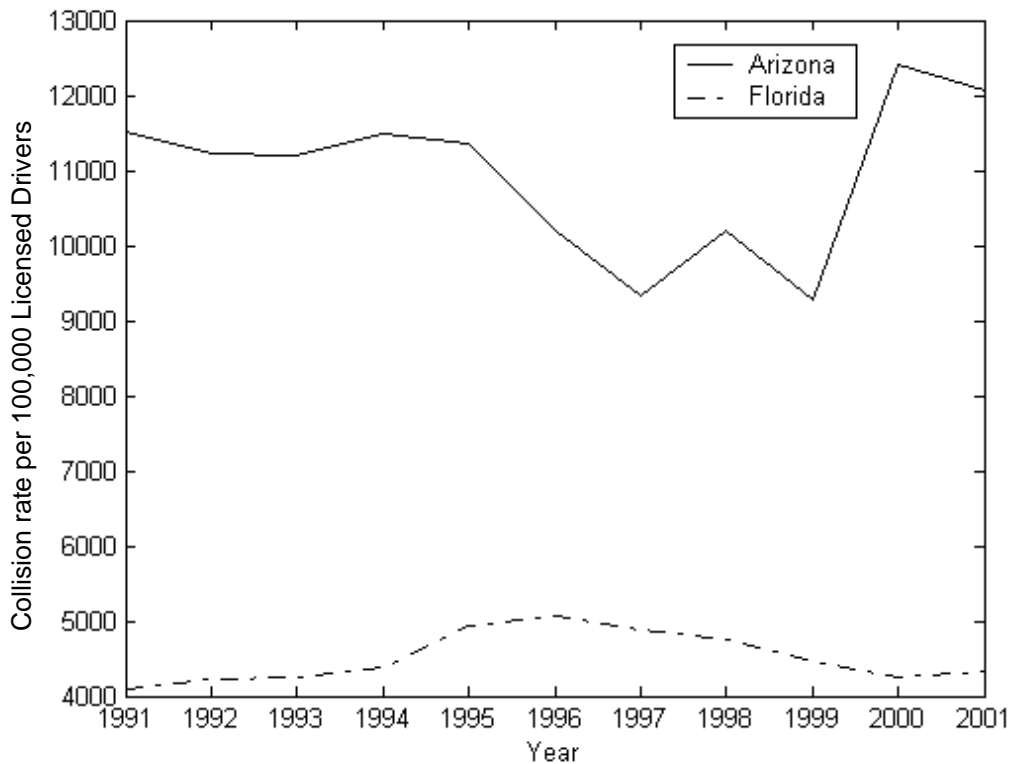


Figure 6. Collision Rates per 100,000 Licensed Drivers at Ages 20 to 24 Years in Arizona and Florida for Years 1991 to 2001

Figure 6 demonstrates that Arizona, again, has a much higher collision rate than Florida, especially among licensed drivers at ages 20 to 24 years. Between 1999 and 2001, there is some fluctuation in the collision rate of the Arizona drivers, per 100,000 licensed drivers, from around $c = 11,500$ in 1991 to about $c = 9,800$ in the years 1997 and 1999 to $c = 12,000$ in the year 2001. Contrastingly, the Florida rate of collisions per 100,000 drivers remains fairly constant between years 1991 to 1994 and years 2000 to 2001. Florida has a minimum of $c = 4,000$ and a maximum of about $c = 5,100$ collisions per 100,000 drivers.

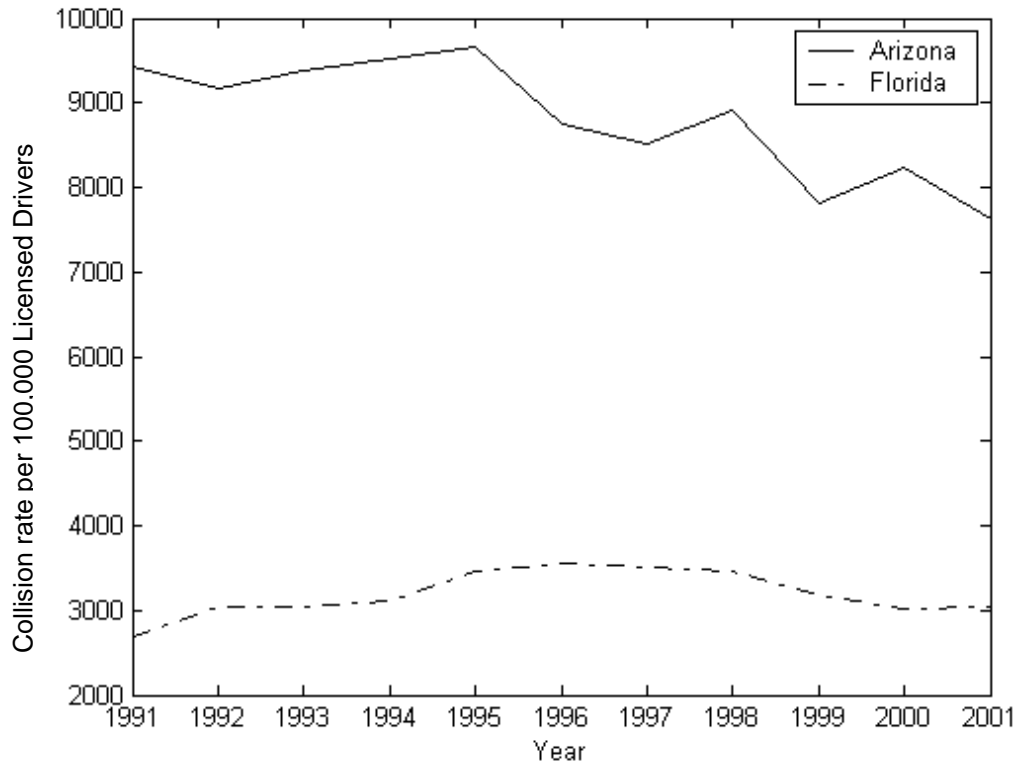


Figure 7. Collision Rates per 100,000 Licensed Drivers at Ages 25 to 34 Years in Arizona and Florida for Years 1991 to 2001

Figure 7 highlights the relative decrease in number of collisions per 100,000 licensed drivers. Arizona has a higher collision rate. Arizona starts with about $c=9,500$ collisions and falls to about $c=7,500$ collisions. Florida starts from $c=2,800$ and rises to $c=3,500$, before falling back to 3,000.

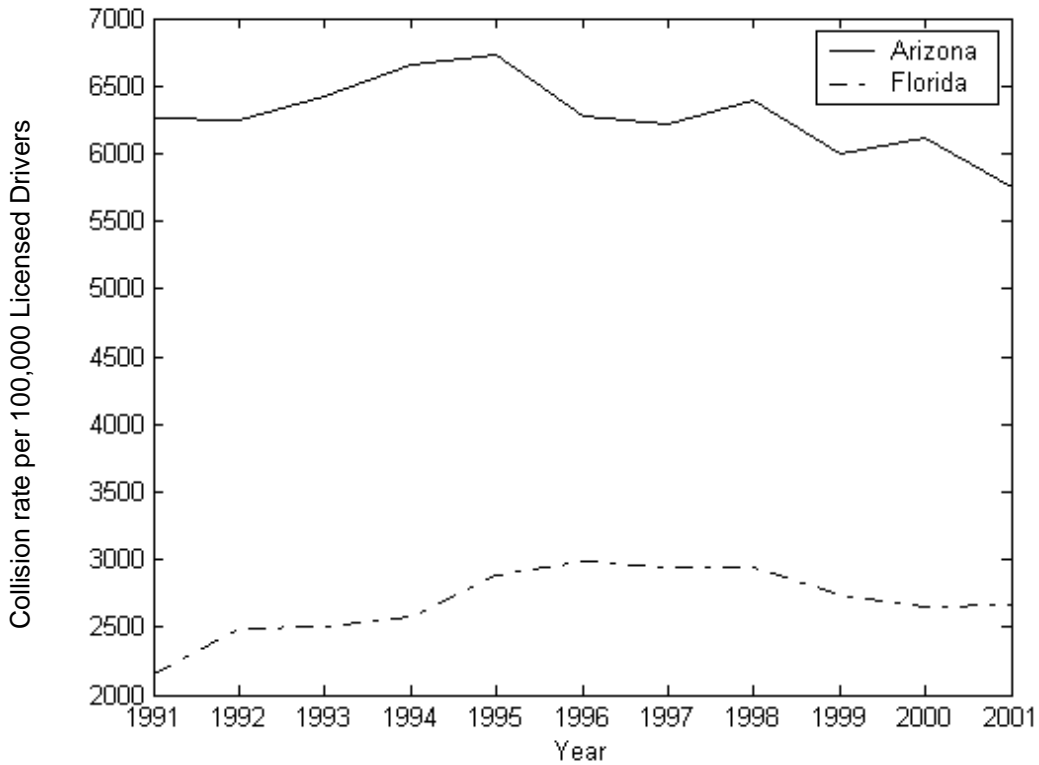


Figure 8. Collision Rates per 100,000 Licensed Drivers at Ages 35 to 44 Years in Arizona and Florida for Years 1991 to 2001

Figure 8 shows the collision rate in Arizona remains higher, yet Florida increases its collision rate from 1991 to 2001. Arizona had a maximum of $c=6,575$ in 1995 and continues decreasing. In 2001, the collision rate is $c=5,575$. Florida starts from a low collision rate of $c=2,200$ and increases until 1996, where it decreases until a rate of $c=2,700$.

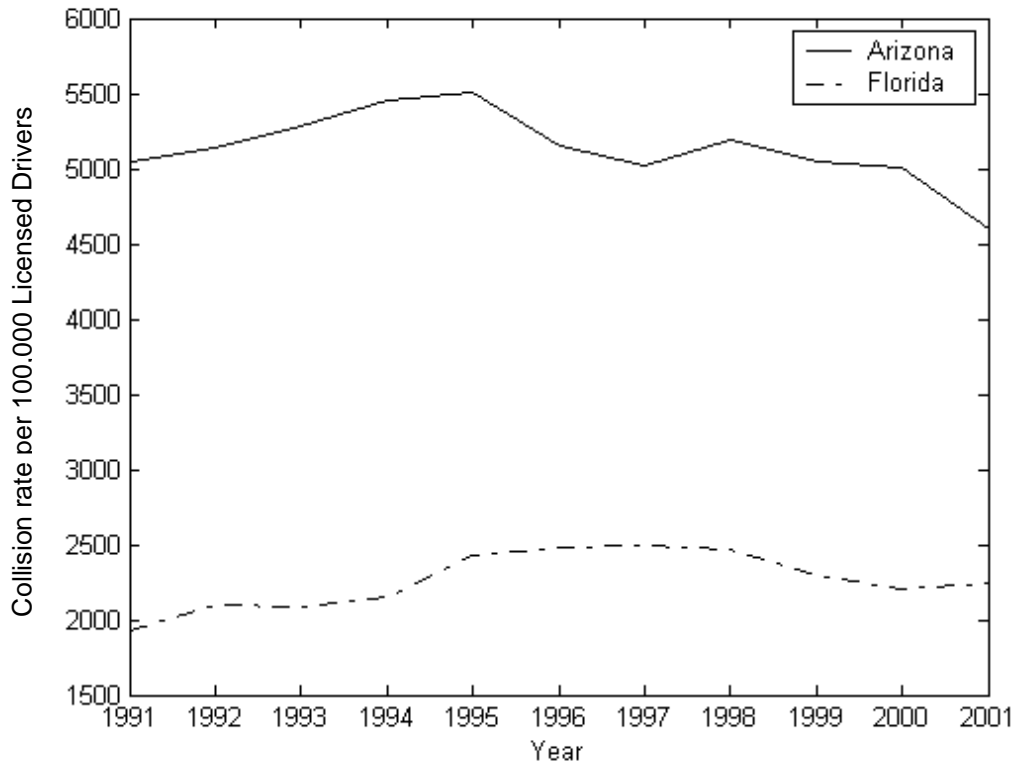


Figure 9. Collision Rates per 100,000 Licensed Drivers at Ages 45 to 54 Years in Arizona and Florida for Years 1991 to 2001

Figure 9 shows similar behavior to Figure 7. Arizona had a high of $c=5,500$ in 1995 and decreases to $c=4,600$. Florida starts from about $c=1,950$ and increases in 1997 to $c=2,500$, where it then decreases to about $c=2,250$.

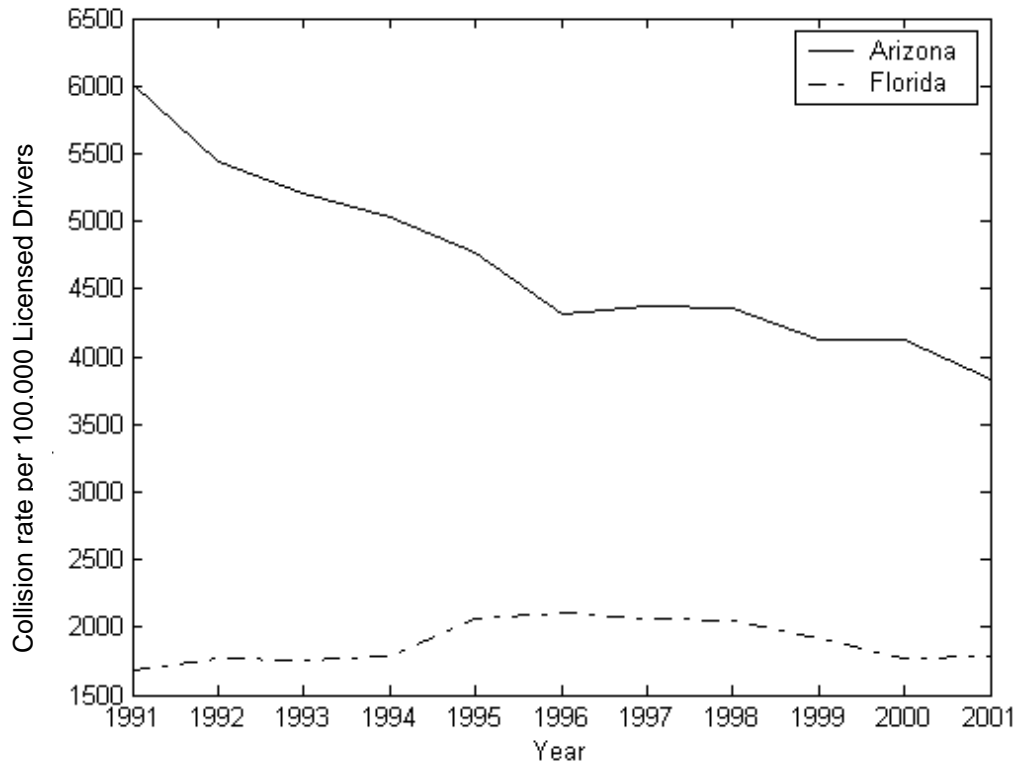


Figure 10. Collision Rates per 100,000 Licensed Drivers at Ages 65 to 64 Years in Arizona and Florida for Years 1991 to 2001

Figure 10 shows a significant decrease in the collision rate for Arizona, but still it is higher than that of Florida. Arizona starts at $c=6,000$ and then decreases rapidly to $c=3,580$. Florida starts with $c=1,700$ and then reaches a flat of about $c=2,100$ around 1996, where it proceeds to decrease to $c=1,750$.

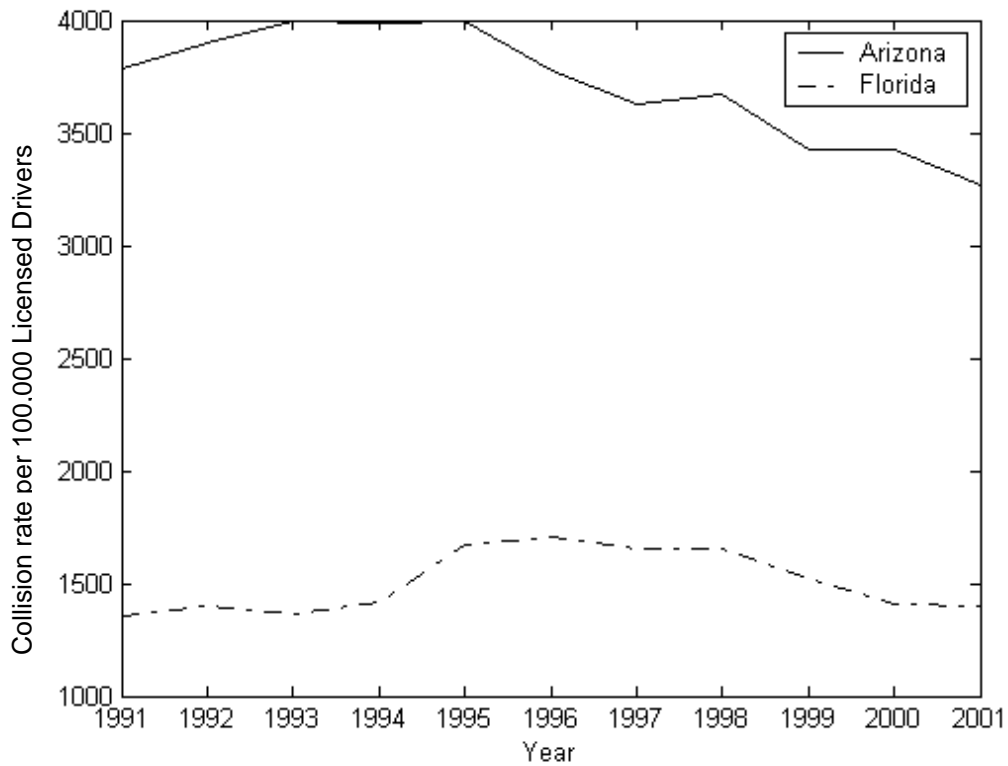


Figure 11. Collision Rates per 100,000 Licensed Drivers at Ages 65 to 74 Years in Arizona and Florida for Years 1991 to 2001

Figure 11 shows the same behavior as Figure 10, except there is a visible increase in the year 1995 for both figures. Arizona has a larger collision rate than Florida. Arizona had a maximum collision rate of about $c=4,000$ that is from 1993 to 1995. Arizona then decreasing and reaches about $c=3,300$. Florida starts at $c=1,400$ and then steadily increases to about $c=1,700$ around 1996 and then decreases back to $c=1,400$.

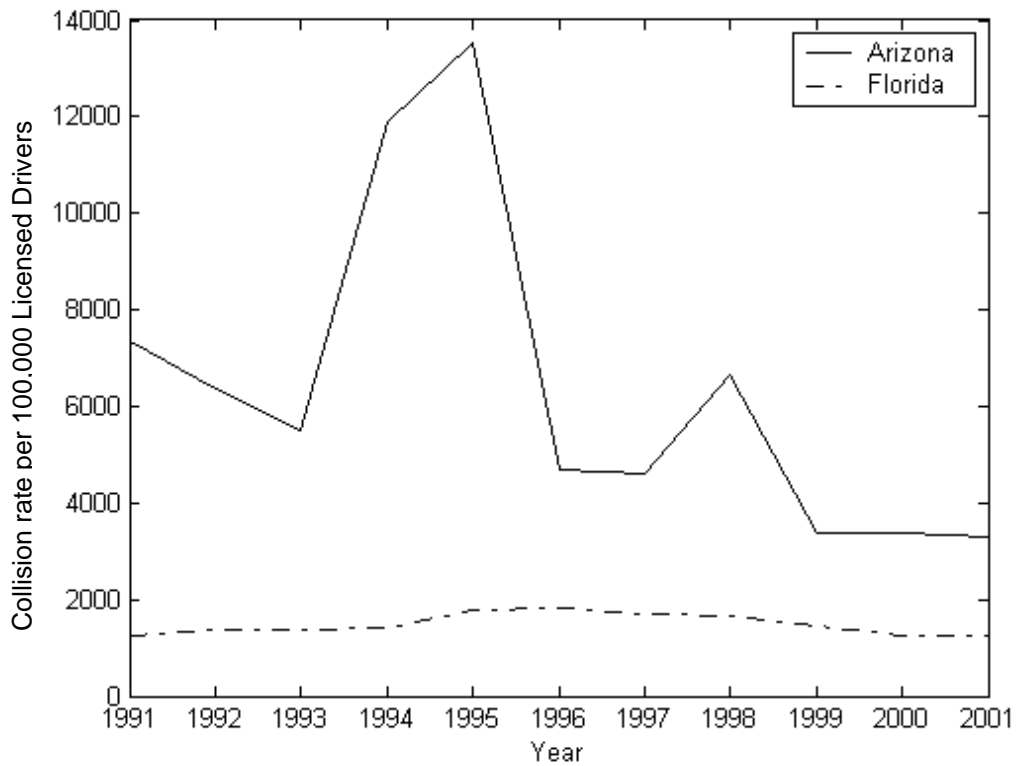


Figure 12. Collision Rates per 100,000 Licensed Drivers at Ages 75 Years and Older in Arizona and Florida for Years 1991 to 2001

In Figure 12, although the collision rate for Arizona remains much higher than that of Florida, it shows a downward trend but without consistency. Florida remains constant at a value of about $c=1,400$ while Arizona showed a peak at around 1994-1995 of about $c=13,000$ and another smaller one at 1998 before finally decreasing to $c=4,000$.

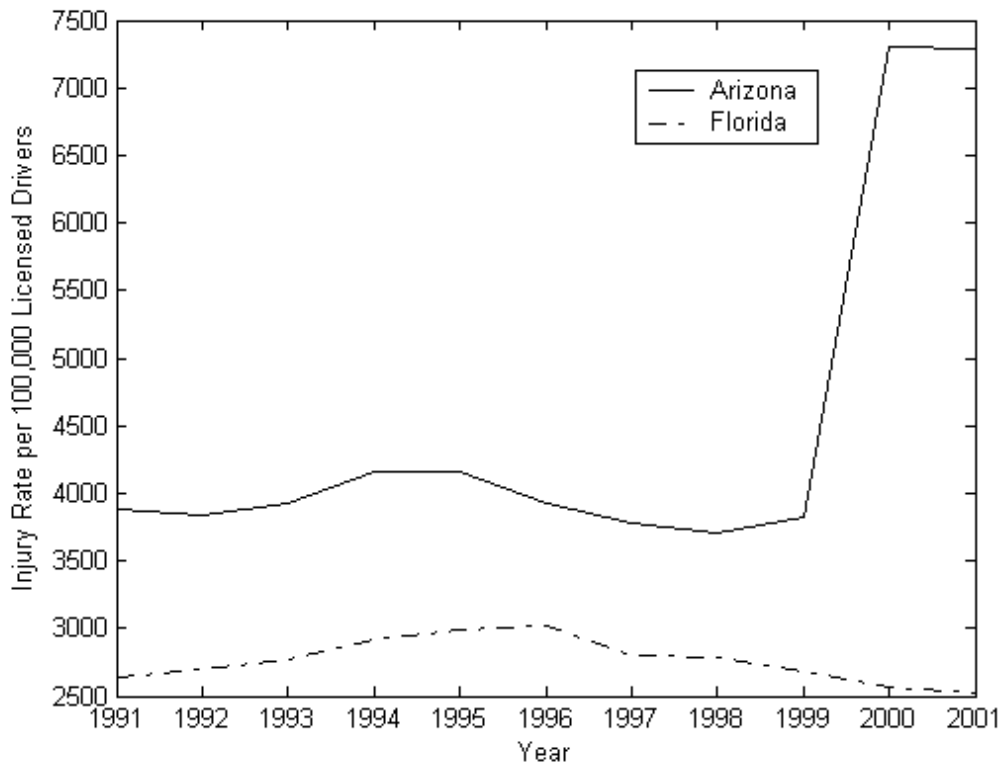


Figure 13. Injury Rates per 100,000 Licensed Drivers at Ages 16 to 19 Years in Arizona and Florida for Years 1991 to 2001

In Figure 13, Arizona has a higher injury rate (i), and shows the spike near the year 2000. Florida shows a peak around 1996 with a value of $c=3,000$ and then goes back to $c=2,500$. Arizona starts around $i=4,000$ then spikes up to $i=7300$ around 2000.

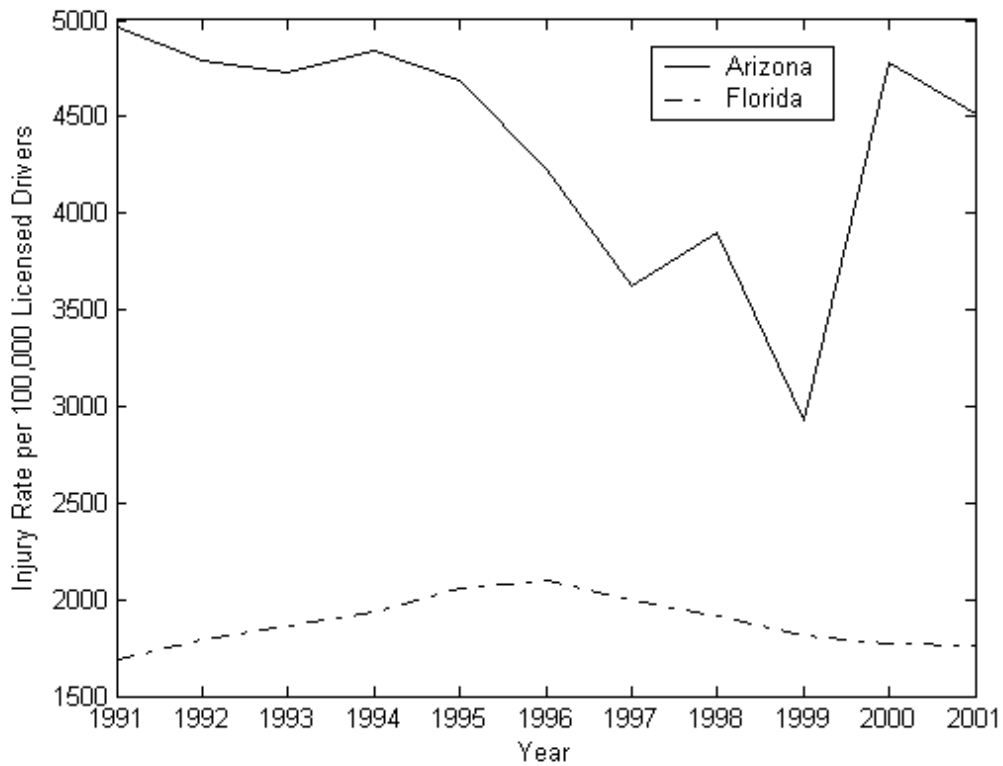


Figure 14. Injury Rates per 100,000 Licensed Drivers at Ages 20 to 24 Years in Arizona and Florida for Years 1991 to 2001

In Figure 14, Arizona dips near year 1999 and then rebounds. Florida maintains its regular trend starting and ending at an injury rate of about $i=1,700$ with a peak of $i=2,100$ in 1996. Arizona starts at $i=5,000$ and then decreases rapidly with a low of $i=3,000$ at 1999, where it spikes up again back to $i=4,500$.

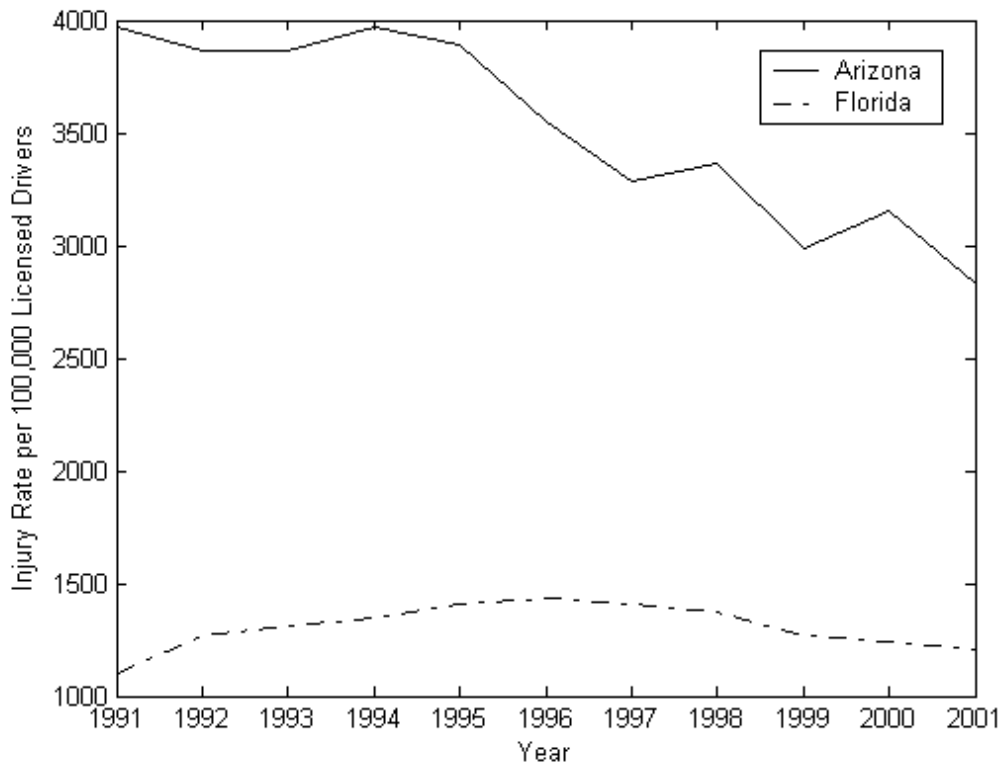


Figure 15. Injury Rates per 100,000 Licensed Drivers at Ages 25 to 34 Years in Arizona and Florida for Years 1991 to 2001

In Figure 15, Arizona shows a steady decrease in the collision rate for ages 25 to 34 years. Florida continues its trend, as defined earlier, starting and ending about $i=1,150$ until it reaches a value of $i=1,500$. Arizona starts at $i=4,000$ and then starts decreasing at 1995 and reaches $i=3,000$ in 2001.

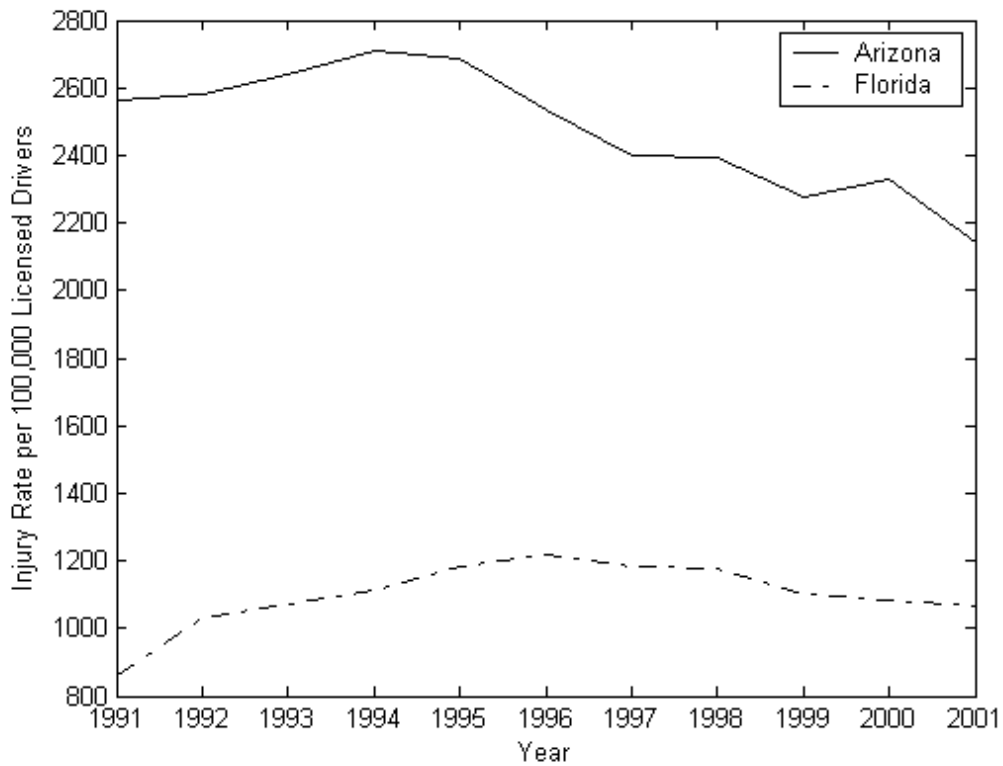


Figure 16. Injury Rates per 100,000 Licensed Drivers at Ages 35 to 44 Years in Arizona and Florida for Years 1991 to 2001

In Figure 16, Arizona has the same decline, but Florida shows a slight incline. Arizona starts at $i=2,550$ and then increases to about $i=2,700$ in 1994, where it follows to proceed to fall to $i=2,200$. Florida starts at $i=870$ and then increases to the peak of 1996 at about $i=1,200$, where it then decreases until $i=1,070$.

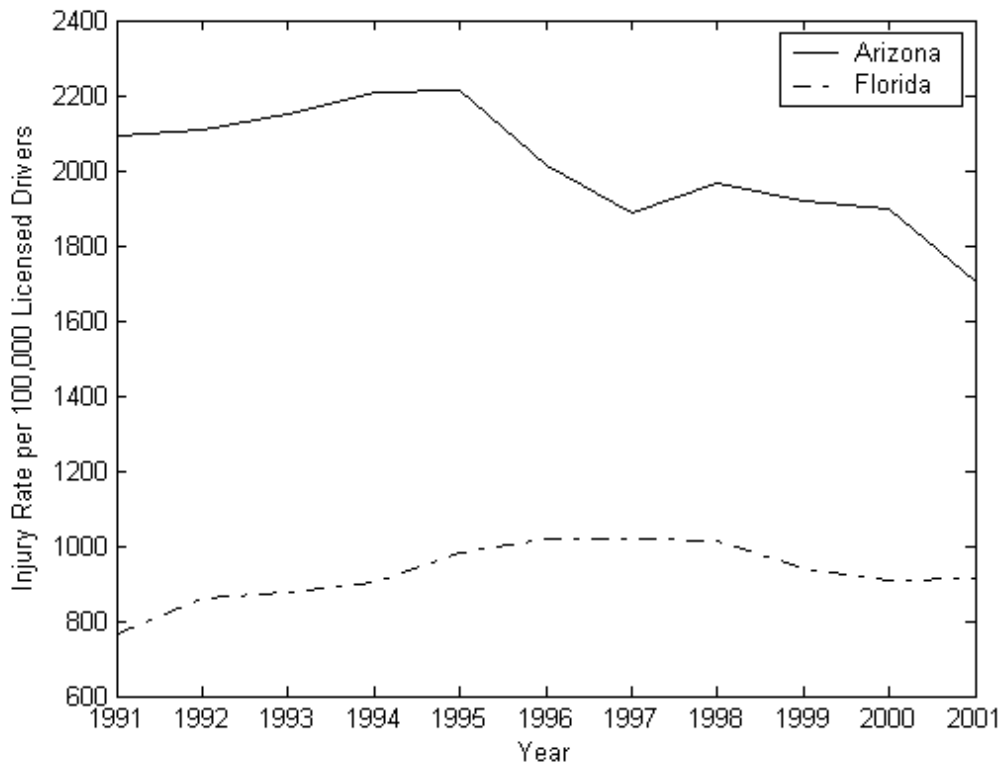


Figure 17. Injury Rates per 100,000 Licensed Drivers at Ages 45 to 54 Years in Arizona and Florida for Years 1991 to 2001

Figure 17 shows the same behavior as Figure 16. Arizona starts at an injury rate of $i=2,100$ and then increases to a high of $i=2,200$ at 1995, where it then proceeds to decrease to a low of $i=1,700$ in 2001.

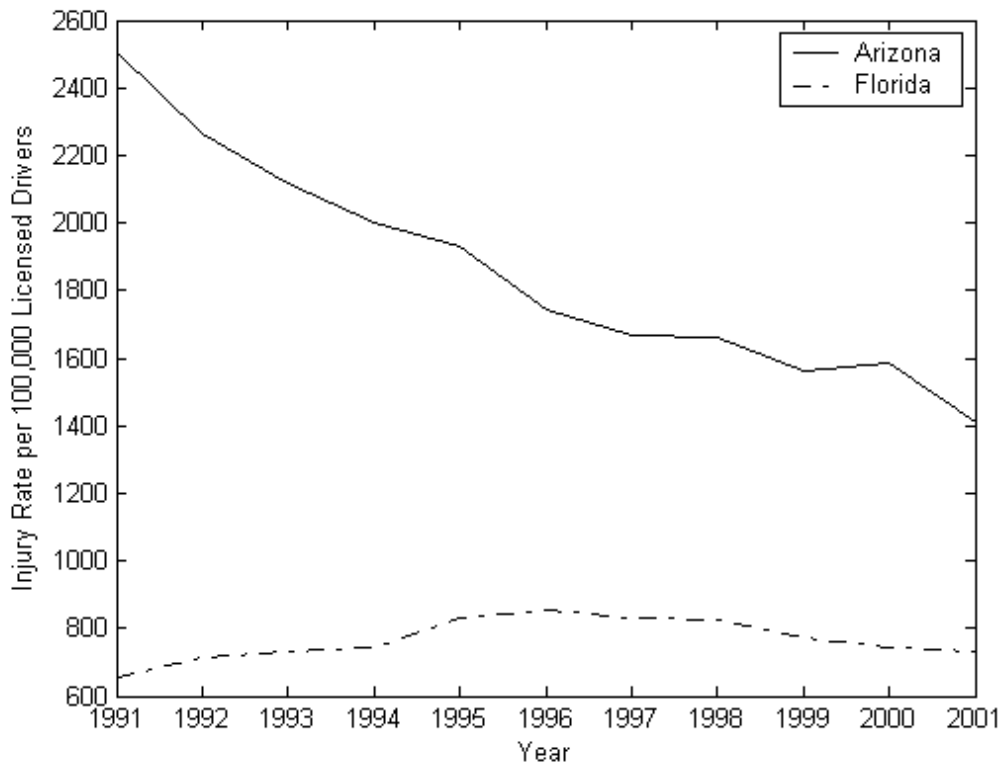


Figure 18. Injury Rates per 100,000 Licensed Drivers at Ages 55 to 64 Years in Arizona and Florida for Years 1991 to 2001

In Figure 18, Arizona has a major decrease in the injury rate, while Florida shows a slight insignificant increase. Arizona starts at $i=2,500$ and then decreases steadily to $i=1,400$ in 2001. Florida starts with $i=650$ in 1991 and then reaches $i=820$ in the peak of 1996, when it decreases back to $i=725$.

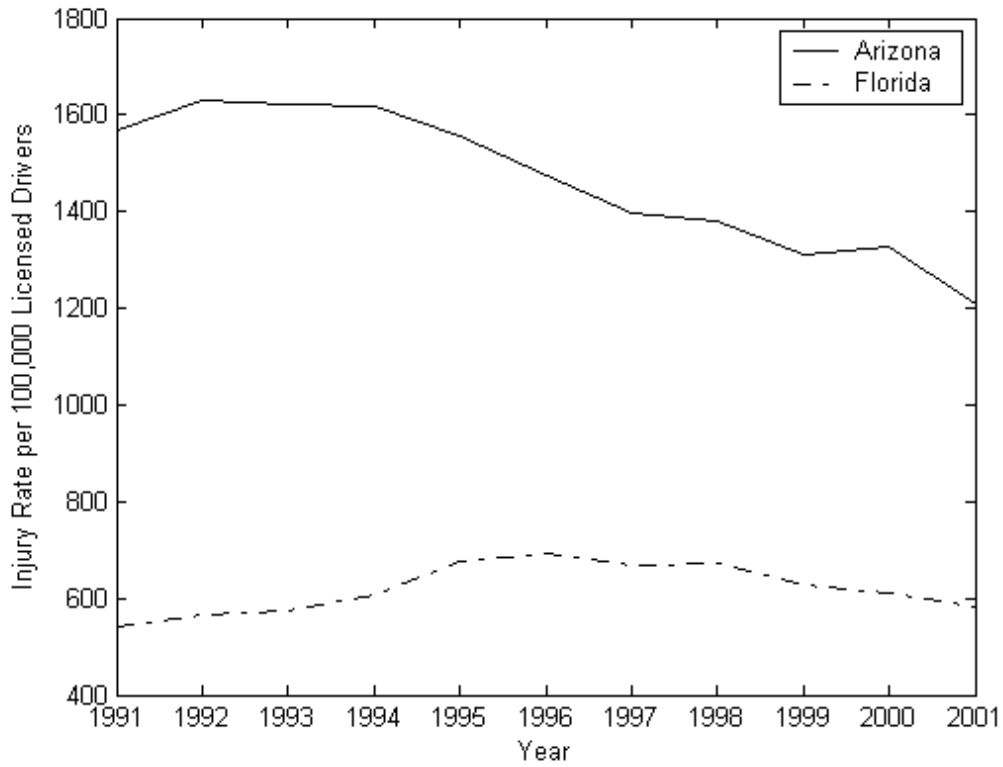


Figure 19. Injury Rates per 100,000 Licensed Drivers at Ages 65 to 74 Years in Arizona and Florida for Years 1991 to 2001

In Figure 19, Arizona has a significantly higher injury rate than Florida, but shows a mild decrease, while Florida shows an increase. Arizona starts around $i=1,600$ and then decreases until it reaches a value of about $i=1,200$ in 2001.

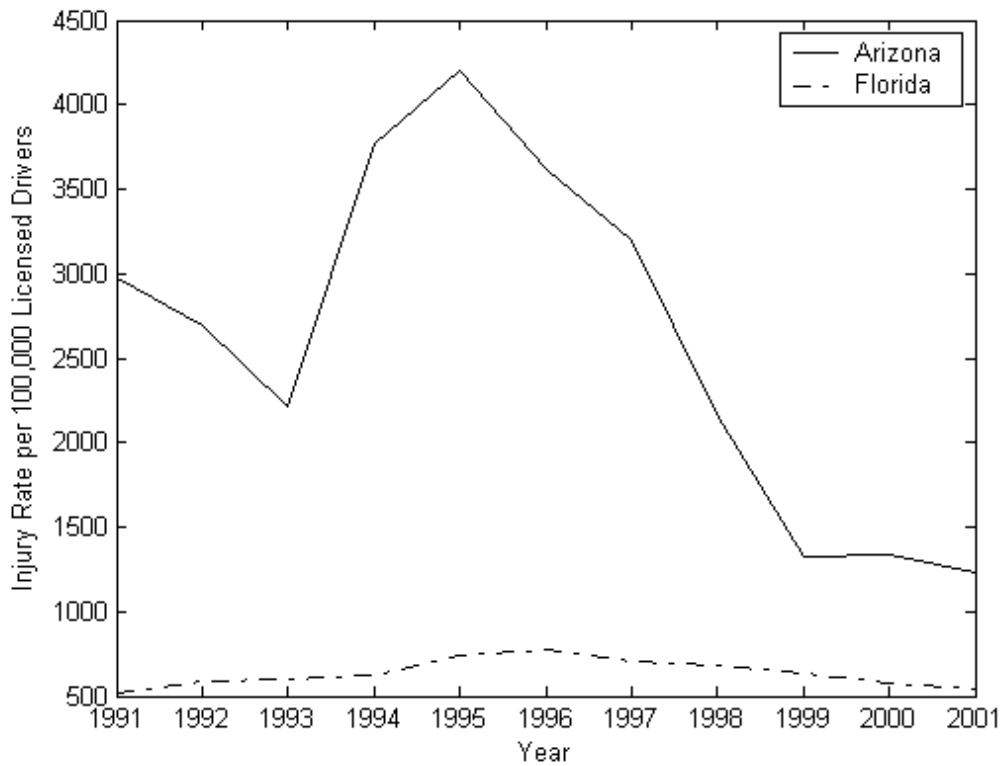


Figure 20. Injury Rates per 100,000 Licensed Drivers at Age 75 Years and Older in Arizona and Florida for Years 1991 to 2001

In Figure 20, although Arizona has a significantly higher injury rate than Florida, it decreases over the years, but shows inconsistency from 1993 to 1999. Florida starts and ends at an injury rate of $i=500$ over the 11-year period but has a peak that is $i=750$ in 1996. Arizona has a sharp peak around 1995 with a max of $i=4,250$ injuries that flattens out near 1999 with a low injury rate of $i=1250$.

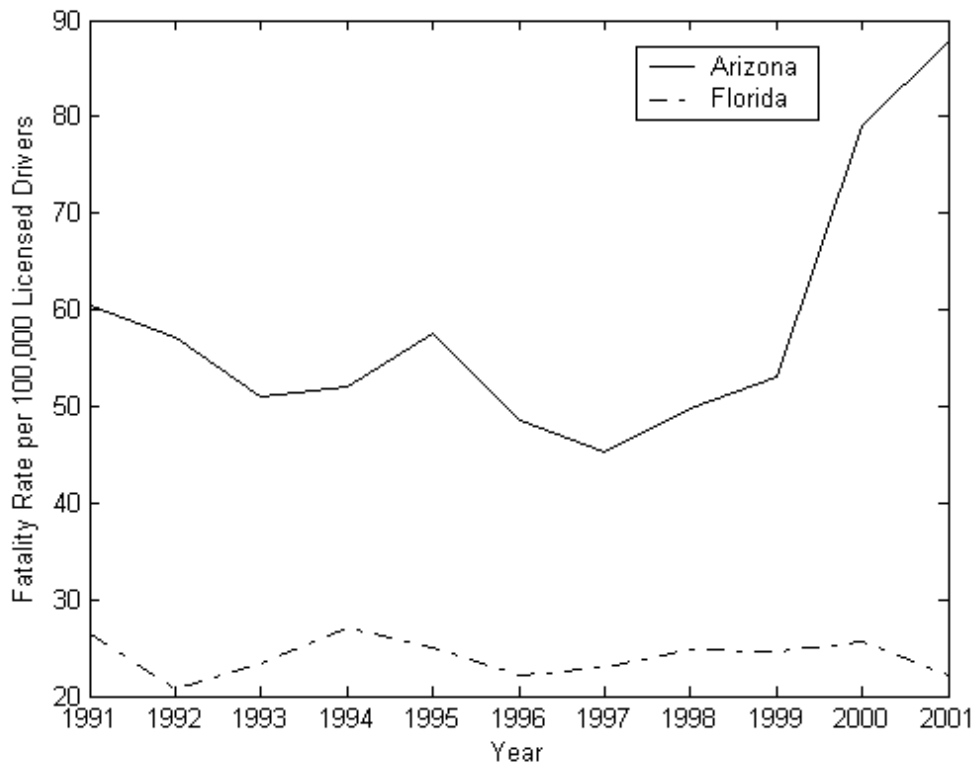


Figure 21. Fatality Rates per 100,000 Licensed Drivers, Age 16 to 19 Years, in Arizona and Florida for Years 1991 to 2001

In Figure 21, Arizona shows a spike in its fatality rate near the year 2000 while Florida remains constant. Florida starts out at a rate of $f=26$ in 1991 and keeps steady to end at around $f=22$ in 2001. Arizona starts at $f=60$ and then keeps at a constant decrease except for a small spike in 1995 before reaching a low fatality rate of $f=45$, where it then increases rapidly and spikes at 2000 to 2001 at about $f=87$.

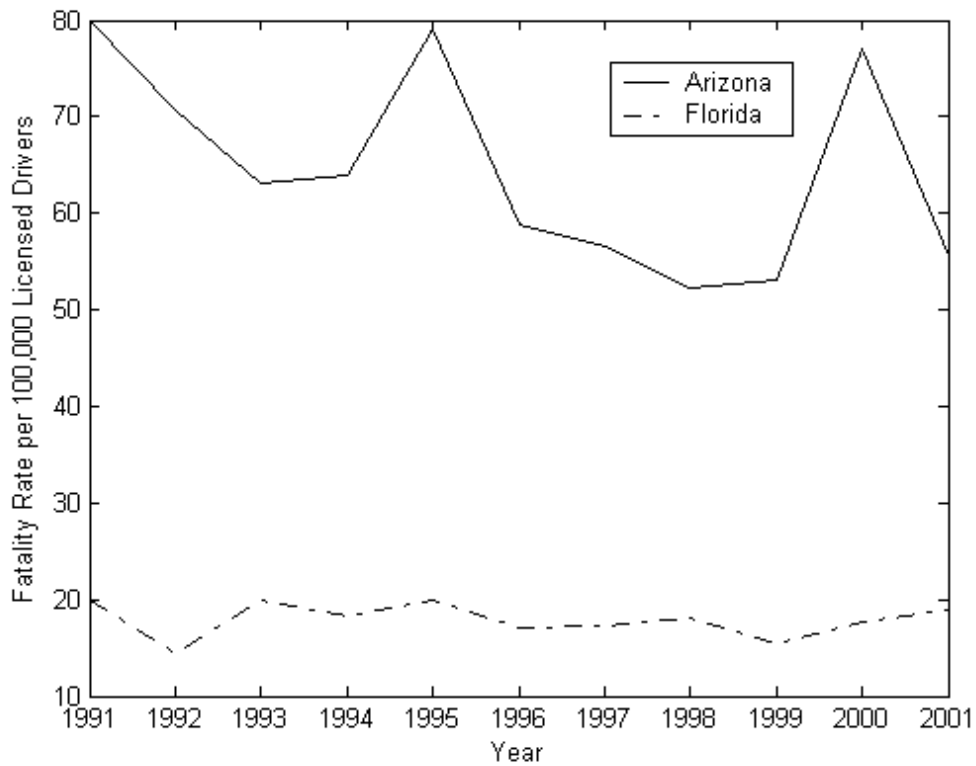


Figure 22. Fatality Rates per 100,000 Licensed Drivers at Ages 20 to 24 Years in Arizona and Florida for Year 1991 to 2001

In Figure 22, Arizona shows a relative decrease while Florida again remains constant. Florida remains constant, at a fatality rate of about $f=17$ over the eleven-year period. Arizona starts at $f=80$ fatalities and then starts to decrease, but has two peaks that reach almost to $f=80$, at 1995 and 2000.

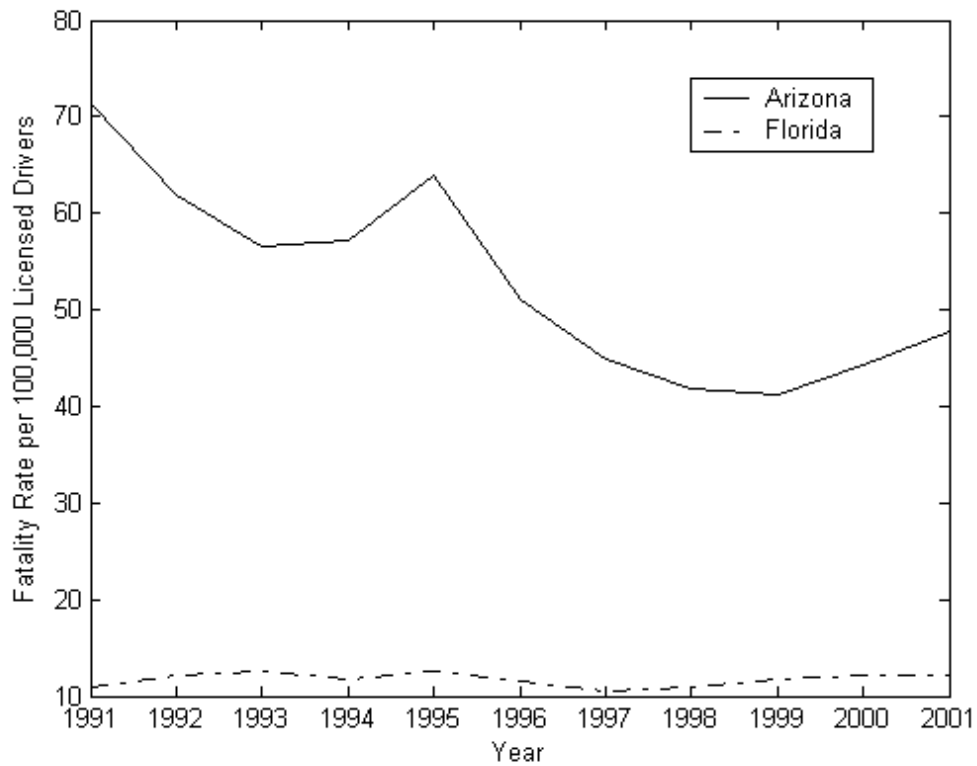


Figure 23. Fatality Rates per 100,000 Licensed Drivers at Ages 25 to 34 Years in Arizona and Florida for Year 1991 to 2001

Figure 23 shows about the same behavior as Figure 22. Florida remains constant and is dwarfed by Arizona because it remains at a low fatality rate of $f=11$. Arizona starts at $f=71$ fatalities and decreases until two spikes appear in 1995, where it went to fatality rate of $f=65$ fatalities, and, in the year 2000, where it starts increasing again.

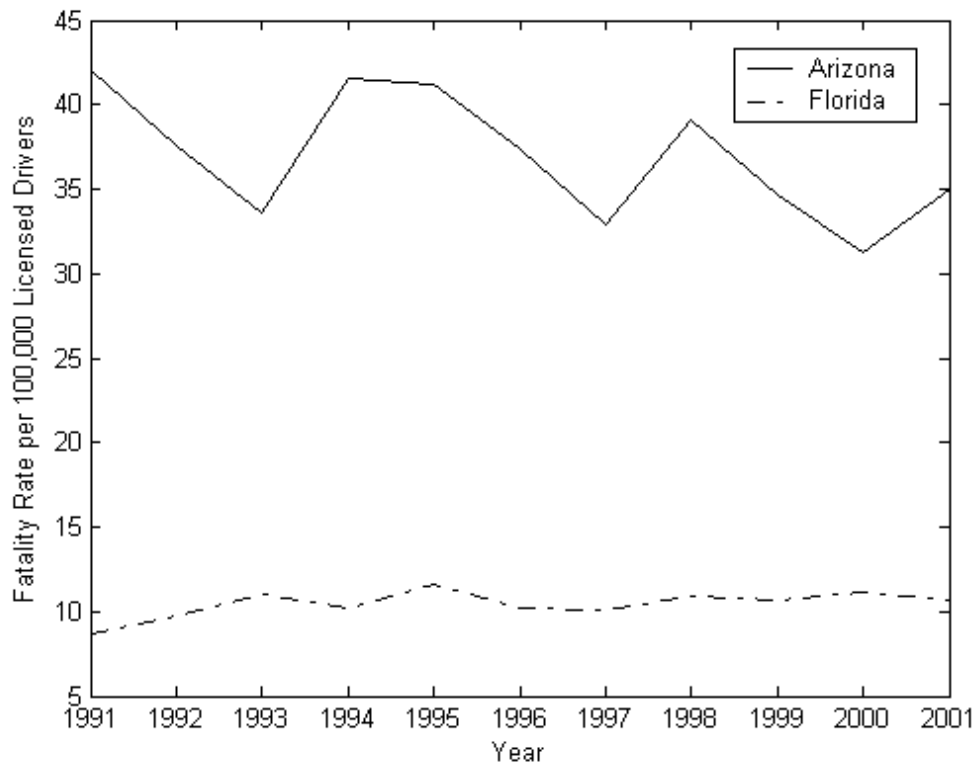


Figure 24. Fatality Rates per 100,000 Licensed Drivers at Ages 35 to 44 Years in Arizona and Florida for Year 1991 to 2001

In Figure 24, Florida remains relatively constant throughout the years, although Arizona shows some fluctuation. The fatality rate of Florida remains about constant at $f=10$ while Arizona has a high of $f=42$ and a low of $f=34$.

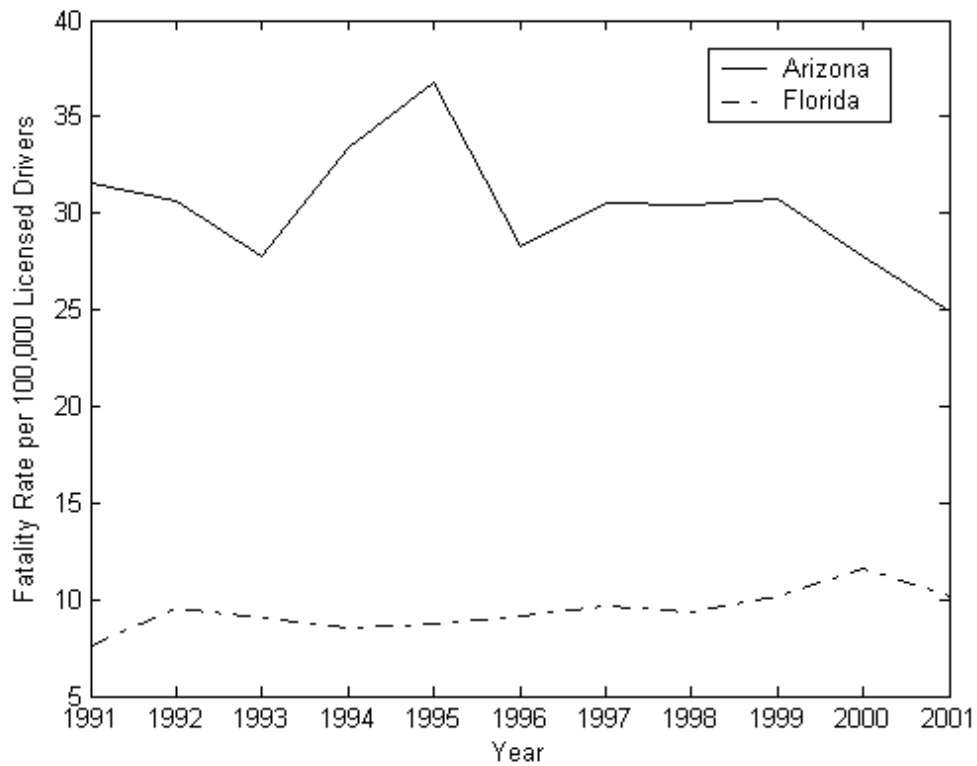


Figure 25. Fatality Rates per 100,000 Licensed Drivers at Ages 45 to 54 Years in Arizona and Florida for Year 1991 to 2001

In Figure 25, Arizona shows a relative decrease in its fatality rate while Florida shows a slight increase. Florida starts at $f=8$ and then increases to $f=10$, but starts decreasing after the year 2000. Arizona decreases until 1993, where it is $f=28$ and then spikes in 1995 at $f=36$ and decreases again until $f=25$ in 2001.

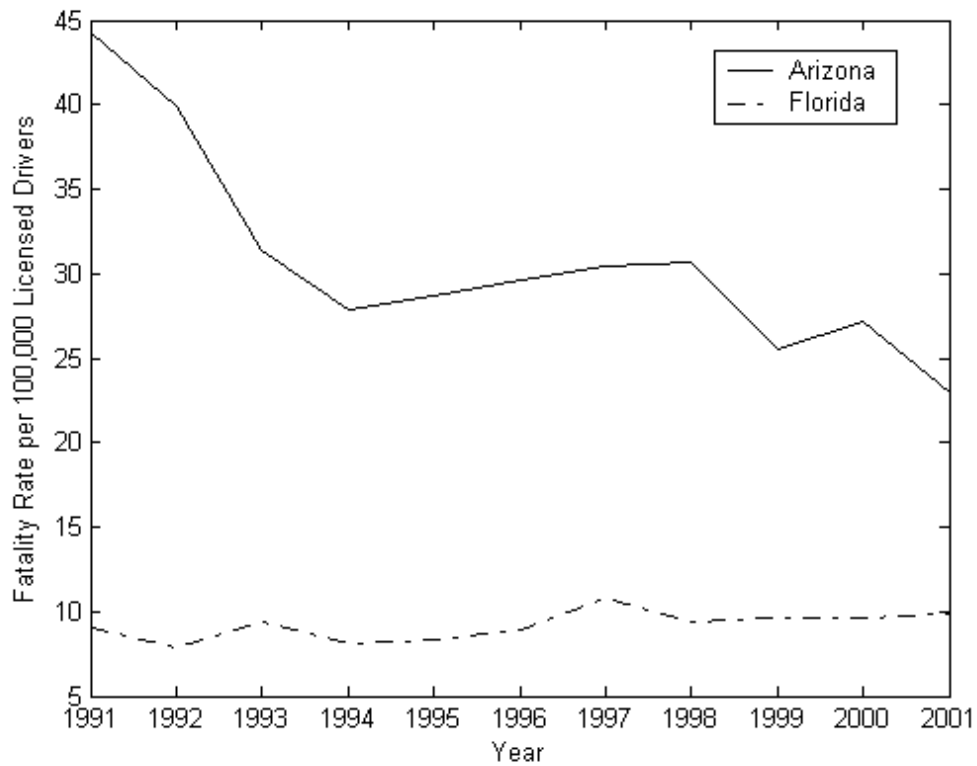


Figure 26. Fatality Rates per 100,000 Licensed Drivers at Ages 55 to 64 Years in Arizona and Florida for Year 1991 to 2001

In Figure 26, Arizona shows a significant decrease in the fatality rate while Florida shows a steady rate. Fatalities for Florida remains at about $f=10$ while Arizona starts at a high of $f=44$ and drops until 1994, where it steadies out at around $f=28$, and then drops in 1998 to reach $f=23$ fatalities in 2001.

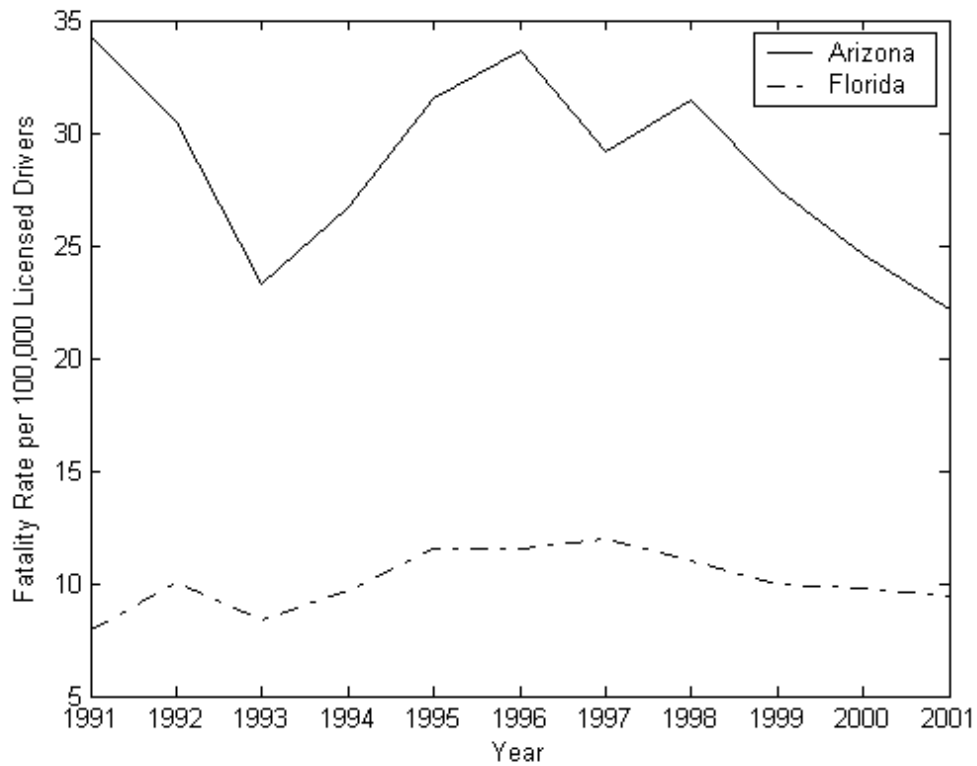


Figure 27. Fatality Rates per 100,000 Licensed Drivers at Ages 65 to 74 Years in Arizona and Florida for Year 1991 to 2001

In Figure 27, Florida remains steady while Arizona fluctuates and shows a steady decrease in the fatality rate, f . Florida starts with $f=7$ and slowly increases in 1997 where it reaches a high of $f=12$, and then decreases to $f=9$ in 2001. Arizona starts at $f=34$ and then reaches a low in 1993 of $f=23$, where it decreases back to $f=34$ in 1996 and then decreases back to $f=23$ steadily by 2001.

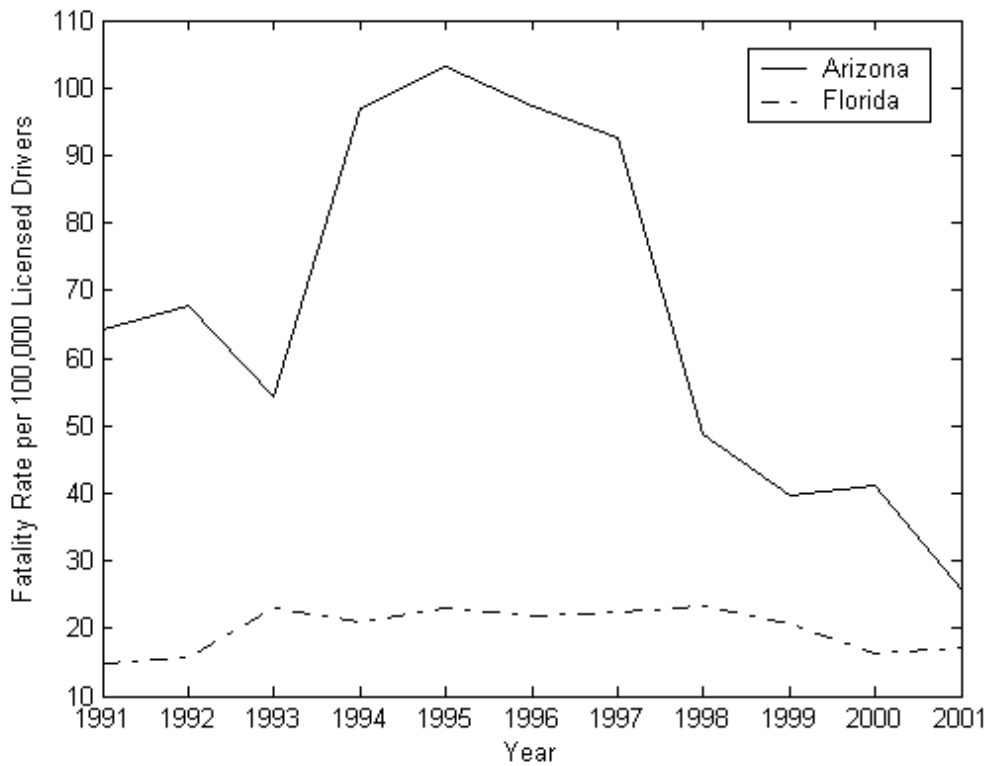


Figure 28. Fatality Rates per 100,000 Licensed Drivers at Age 75 Years and Older in Arizona and Florida for Year 1991 to 2001

In Figure 28, Arizona shows an increase until 1995. By 2001, it decreases to a fatality rate, $f=25$ close to the fatality rate of Florida, $f=18$. Florida starts at $f=15$ and then reaches a stable region between 1993 and 1998 at $f=22$, where it then decreases back to $f=17$ in 2000. Arizona starts in 1991 with $f=65$ and then reaches a low of $f=55$ in 1993, where it spikes to reach a maximum fatality rate of $f=102$ in 1995.

APPENDIX G: COMPARISON OF RELATIVE ACCIDENT INVOLVEMENT RATIO (RAIR) OF COLLISIONS OF ARIZONA AND FLORIDA DRIVERS, YEARS 1991 TO 2001

As shown by Chandraratna *et al.* (2002), we define RAIR as follows:

$$RAIR_{i,j} = \frac{\frac{D1_{i,j}}{\sum \sum D1_{i,j}}}{\frac{D2_{i,j}}{\sum \sum D2_{i,j}}}$$

Where:

i = type of drivers

j = type of conditions

D1_{*i,j*} = number of at-fault drivers of driver type *i* for type *j* conditions.

D2_{*i,j*} = number of not-at-fault drivers of driver type *i* for type *j* conditions.

RAIR values greater than 1.0 denote a driver group more likely to be at-fault in motor vehicle collisions. RAIR values less than 1.0 designate a driver group that is less likely to be at-fault (Robertson and Aultman-Hall, 2001).

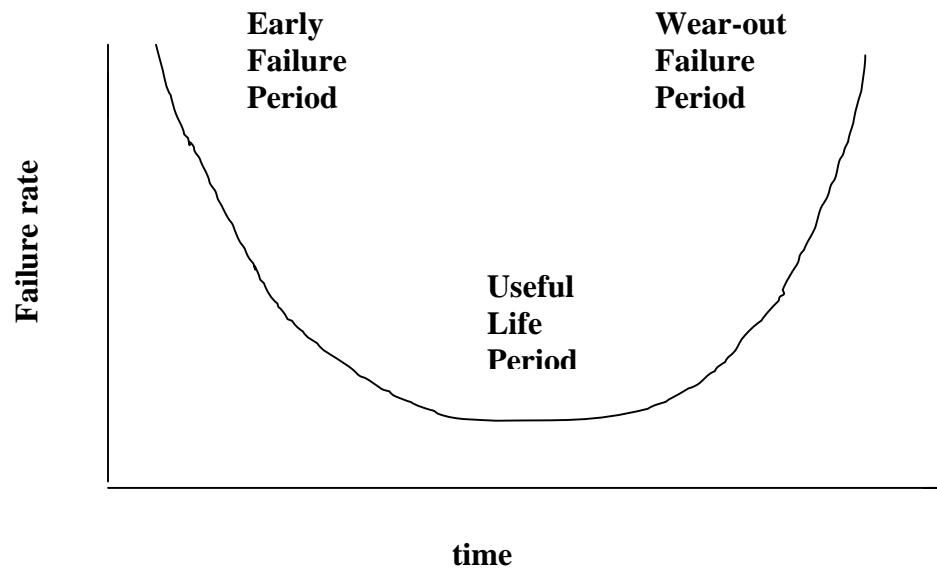


Figure 29. The Bathtub Curve.

The failure probability density function illustrates the type of behavior shown in a bathtub curve:

$$f(t) = b\theta(\theta t)^{b-1} \exp [-(e^{\theta t} - \theta t - 1)] \text{ for } b > 0, \theta > 0, t \geq 0$$

where:

b = shape parameter,

t = time,

and θ = scale parameter

$R(t)$, the component reliability function, as an approximate fit, is defined as:

$$R(t) = \exp [-(e^{\theta t} - \theta t - 1)]$$

$h(t)$, Hazard rate, which explains probability of failure changes over the lifetime of the component (Modarres, *et al.* 1999), is represented by:

$$h(t) = \frac{f(t)}{R(t)} = b\theta(\theta t)^{b-1} e^{\theta t}$$

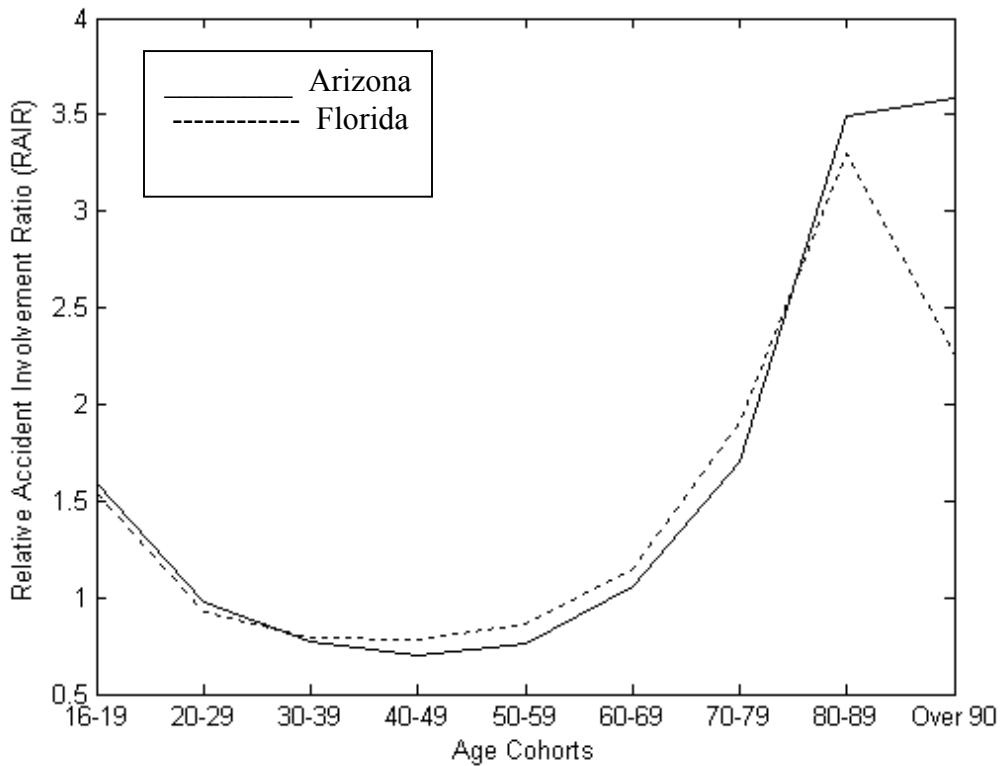


Figure 30. Comparison of Angle Manner of Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 30, although the ages 16 to 19 years cohorts demonstrate a RAIR value of approximately 1.5, we notice a gradual decline, followed by a period of relative stability until ages 40–49 cohorts in both the States of Arizona and Florida with respect to angle manner of collision. The Wearout Period appears to initiate among the ages 40 to 49 years cohorts (Arizona RAIR ~ 0.75; Florida RAIR ~ 0.85) until it reaches a peak among the ages 80 to 89 years cohorts (Arizona RAIR ~ 3.25; Florida RAIR ~ 3.5). Since the highest RAIR value occurs among Arizona drivers age 90 years and older (RAIR ~ 3.6), a data error may account for the anomalies of this age group. However, it is interesting to note that the ages 30 to 59 years cohorts are most likely to not be at-fault in angle manner of collisions due to RAIR values <1.

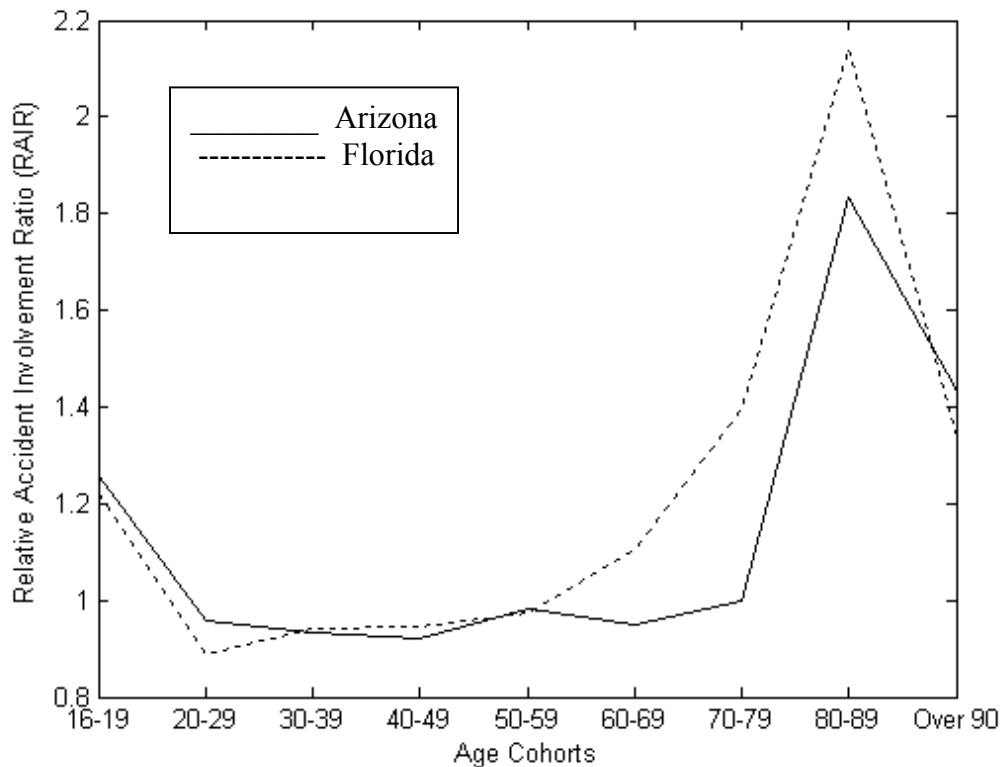


Figure 31. Comparison of Backing Manner of Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 31, both Arizona and Florida drivers seem to follow a bathtub curve for the backing manner of collision. The Wearout Period appears to initiate among the Florida drivers age 50 to 59 years (RAIR~ 1) until it reaches a peak among the ages 80 to 89 year cohorts (RAIR ~ 2.15). The Wearout Period appears to initiate among the Arizona drivers ages 60 to 69 years (RAIR~ 0.9) until it reaches a peak among the ages 80 to 89 year cohorts (RAIR ~ 1.85). However, it is interesting to note that the Florida drivers ages 20 to 29 cohorts are most likely to not be at-fault in backing manner of collisions due to RAIR values <1. Significant dips between drivers ages 80 to 89 years to drivers ages 90 and older in both Arizona and Florida are noticed.

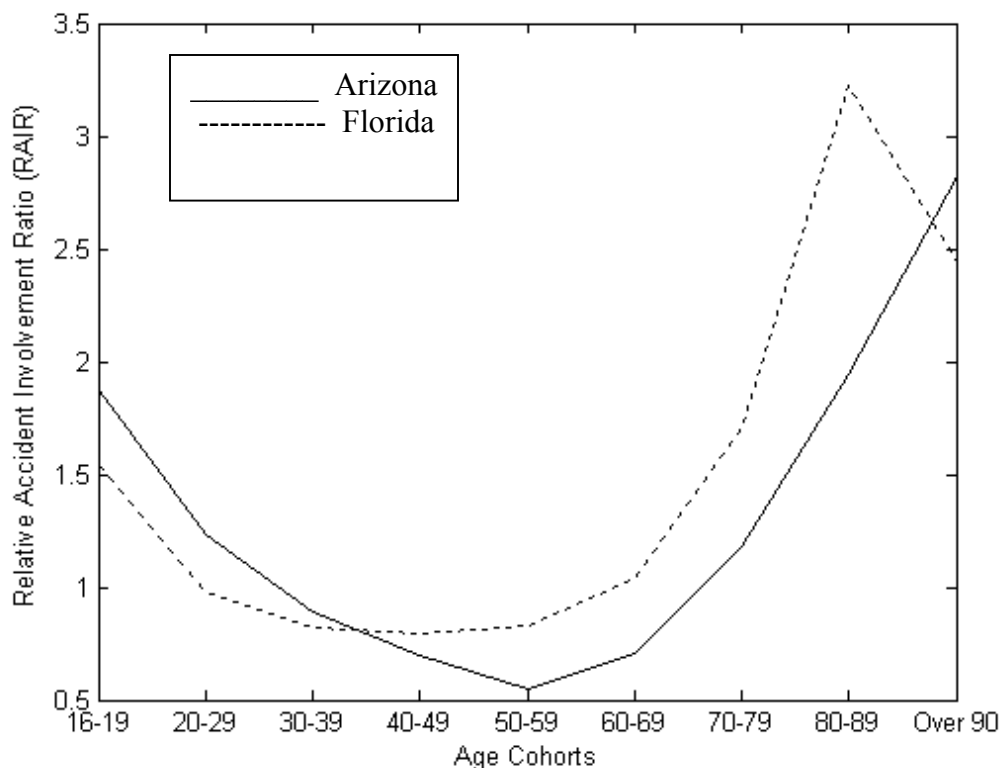


Figure 32. Comparison of Head-on Manner of Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 32, both Arizona and Florida drivers, again, seem to follow a bathtub curve for the head-on manner of collision. The Wearout Period appears to initiate among the Arizona drivers ages 50 to 59 years (RAIR~ 0.55) until it reaches a peak among the ages 90- and older cohorts (RAIR ~ 2.85). There does not appear to be a Useful Life Period. The Wearout Period appears to initiate among the Florida drivers ages 50 to 59 years (RAIR~ 0.9) until it reaches a peak among the ages 80 to 89 years cohorts (RAIR ~ 3.25). However, it is interesting to note that the Arizona drivers ages 50 to 59 years cohorts are most likely to not be at-fault in head-on manner of collisions due to RAI values <1. Significant dips between drivers ages 80 to 89 years to drivers age 90 years only in Florida are observed.

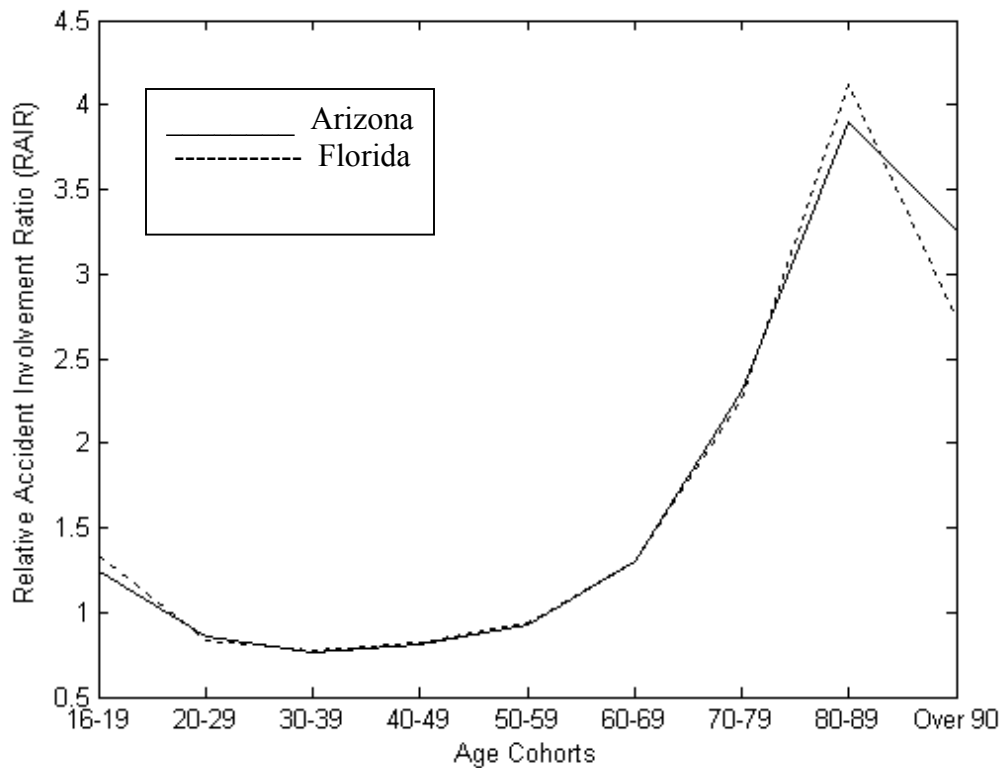


Figure 33. Comparison of Left Turn Manner of Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 33, an unusual phenomenon among left turn manner of collisions is witnessed. The Early Failure Period is very short. While both Arizona and Florida drivers feature the onset of the Wearout Period at about the cohorts age 50 to 59 years (RAIR~ 1), it reaches a peak among the cohorts ages 80 to 89 years (Arizona RAIR ~ 3.9; Florida RAIR~ 4.25) and retires. Drivers ages 16 to 19 years are three times less likely to be involved in collisions due to left turns than drivers ages 80 to 89 years.

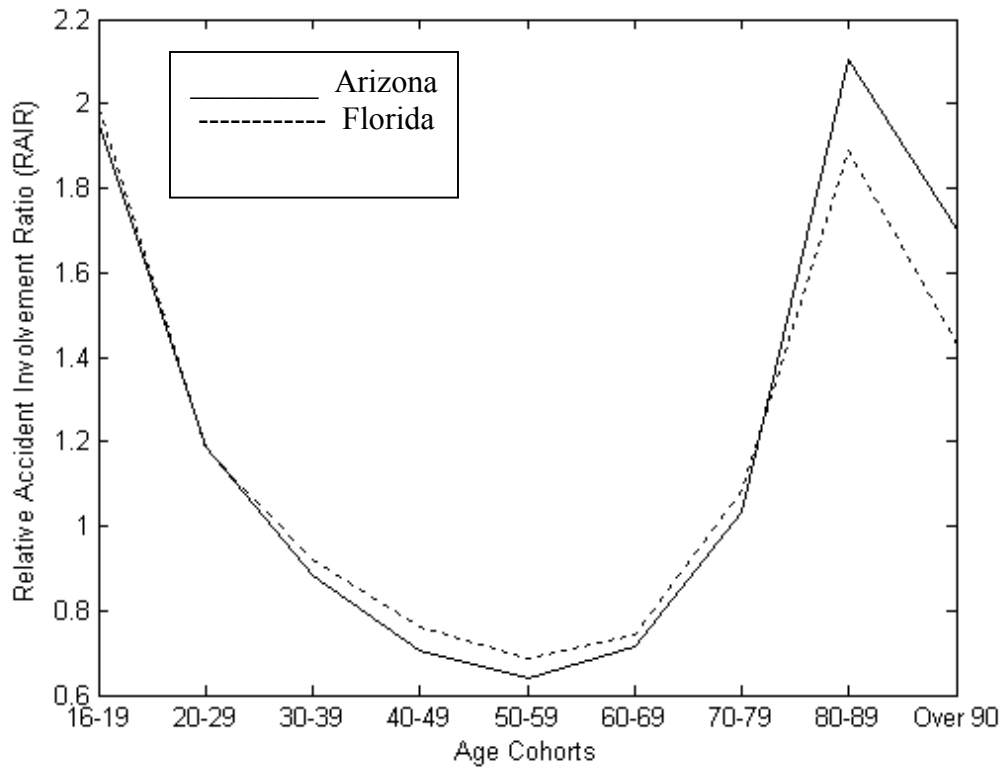


Figure 34. Comparison of Rear End Manner of Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 34, both Arizona and Florida drivers, again, seem to follow a bathtub curve for the rear end manner of collision. The Early Failure Period is seemingly long. The Wearout Period appears to initiate among the Arizona drivers ages 50 to 59 years (RAIR~ 0.65) until it reaches a peak among cohorts ages 80 to 89 years (Arizona RAIR ~ 2.1; Florida RAIR~1.9) and then retires. Yet, Florida drivers ages 16 to 19 years (RAIR~ 2) are more likely to be at-fault in a rear end collision due to higher RAIR values than the cohorts ages 80 to 89 years (RAIR~ 1.9). Contrastingly, Arizona drivers ages 80 –89 (RAIR ~ 2.19) are more likely to be at-fault in a rear end collision due to higher RAIR values than the cohorts ages 16 to 19 years (RAIR~ 1.95).

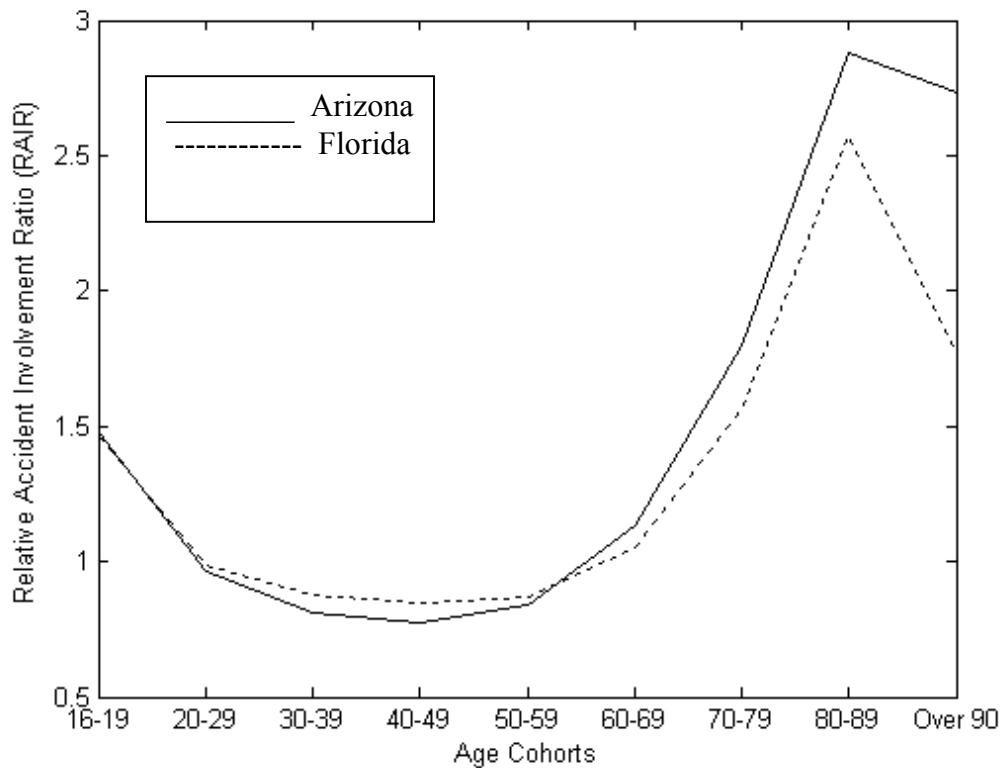


Figure 35. Comparison of Sideswipe Manner of Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 35, both Arizona and Florida drivers seem to follow the same pattern curve for the sideswipe manner of collision as they do for left turns. The Early Failure Period is rather short. The Wearout Period appears to initiate among the Florida drivers ages 50 to 59 years (RAIR~ 0.95) until it reaches a peak among cohorts ages 80 to 89 years (Arizona RAIR ~ 2.9; Florida RAIR~2.6) and then retires. Arizona and Florida drivers ages 80 –89 years are about twice as likely to be at-fault in a sideswipe manner of collision due to higher RAIR values than the cohorts ages 16 to 19 years (RAIR~ 1.5).

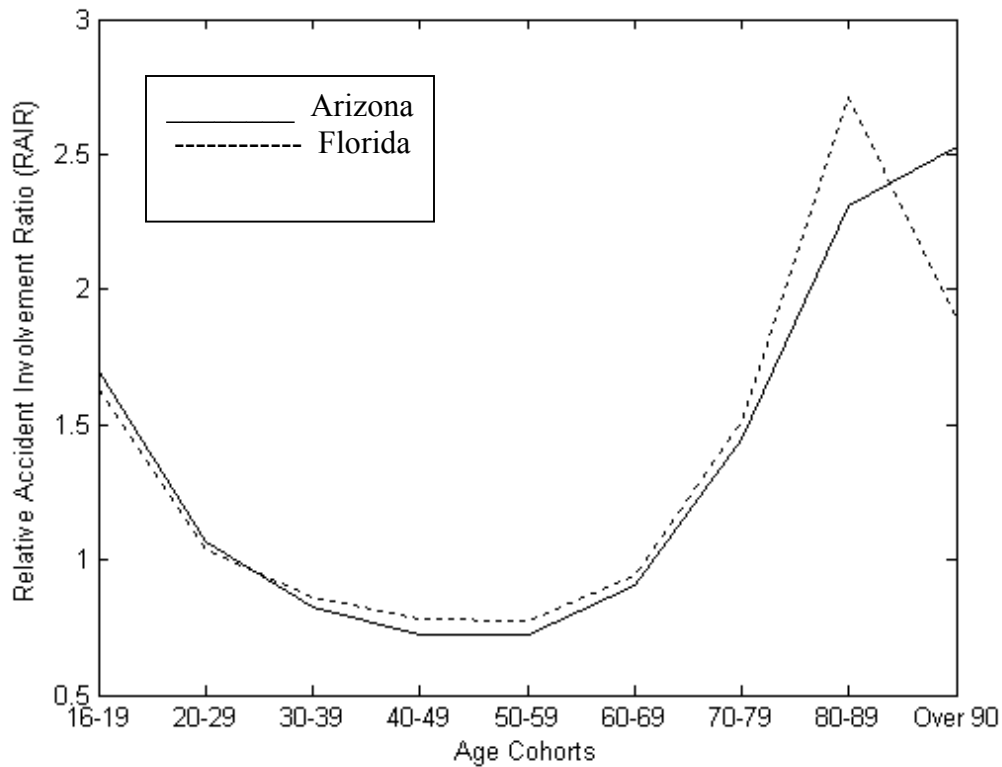


Figure 36. Comparison of Clear Weather-Related Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 36, we evaluate the relative involvement of clear weather-related collisions among both Arizona and Florida drivers. Arizona (RAIR~ 2.45) and Florida (RAIR~ 2.75) drivers ages 80 –89 years are about twice as likely to be at-fault in a clear weather-related collision than the cohorts ages 16 to 19 years. However, the Florida RAIR values retire by age 90 years and over; the Arizona RAIR values increase to about 2.5.

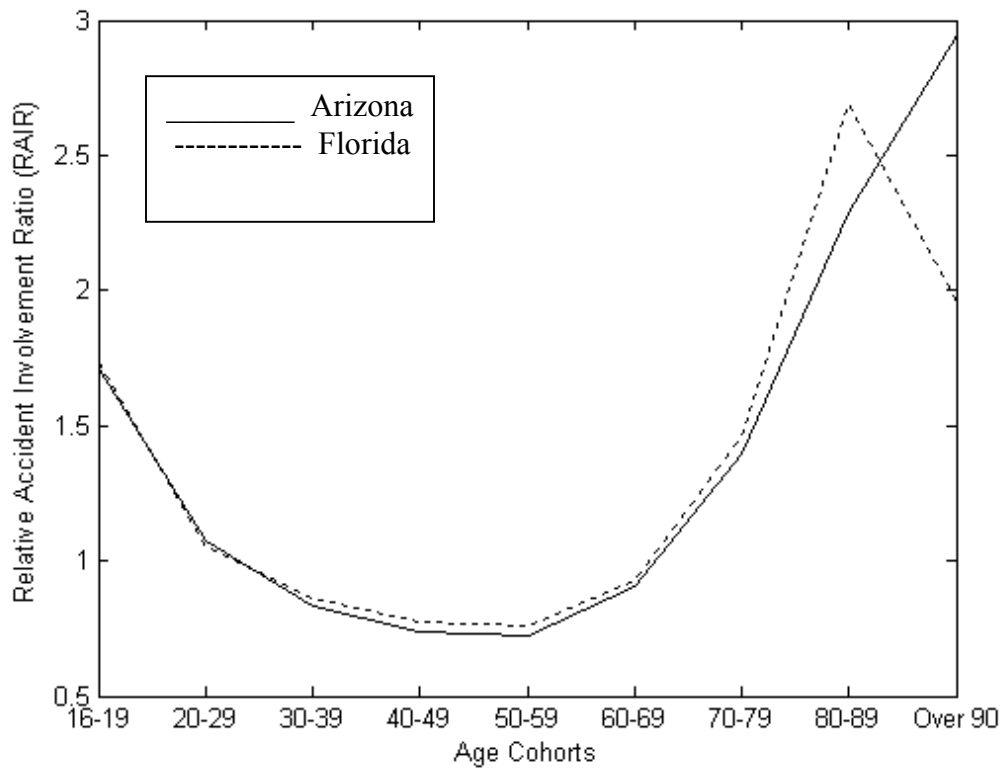


Figure 37. Comparison of Cloudy Weather-Related Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 37, this study allows an evaluation of the relative involvement of cloudy weather-related collisions among both Arizona and Florida drivers. Florida (RAIR~ 2.75) drivers ages 80 –89 years are about twice as likely to be at-fault in a cloudy weather-related collision than the cohorts ages 16 to 19 years (RAIR~ 1.75). Arizona (RAIR~ 2.95) drivers age 90 years and older are about twice as likely to be at-fault in a cloudy weather-related collision than the cohorts ages 16 to 19 years (RAIR~ 1.75). However, the Florida RAIR values retire by age 90 years and older; the Arizona RAIR values increase.

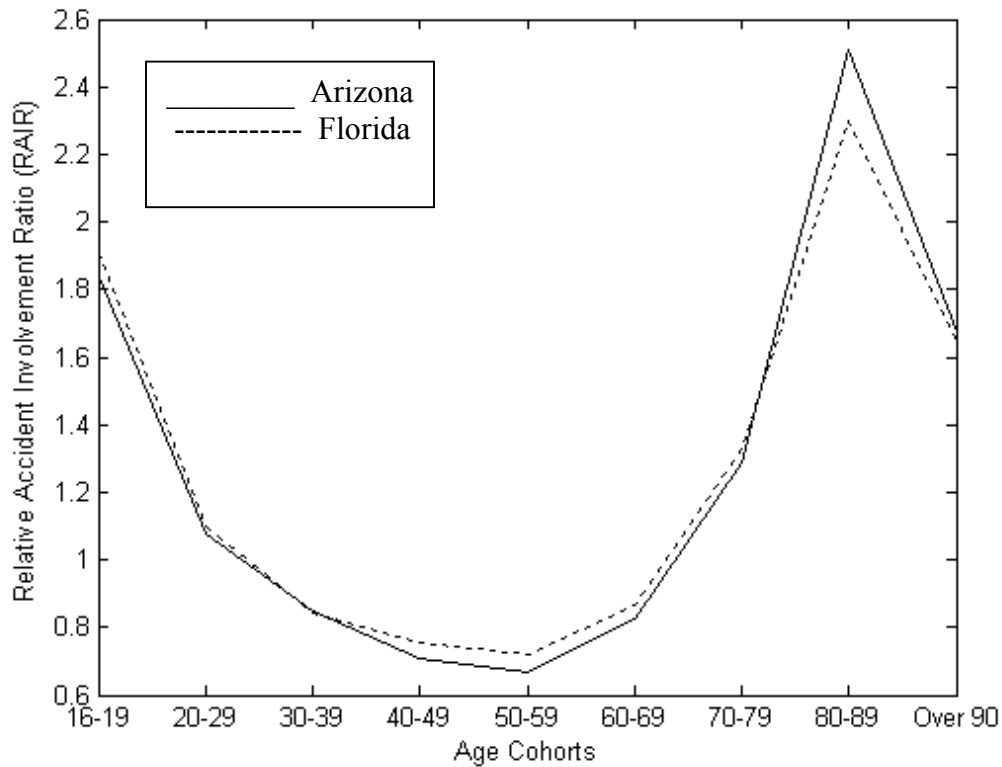


Figure 38. Comparison of Rain-Related Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 38, the study provides an observation of the relative involvement of rain weather-related collisions among both Arizona and Florida drivers. Florida (RAIR~ 2.55) and Arizona (RAIR~ 2.35) drivers ages 80 –89 years are about twice as likely to be at-fault in a rain-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.8; Florida RAIR~ 1.9). Retirement occurs by age 90 years and older for both Arizona and Florida drivers.

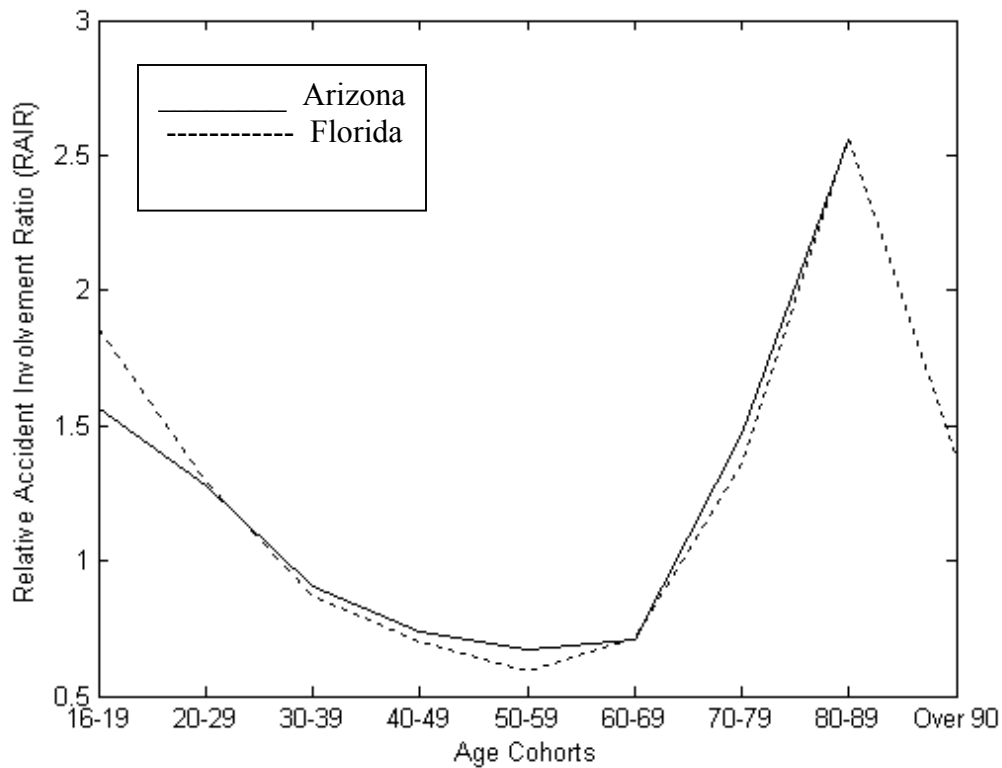


Figure 39. Comparison of Fog -Related Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 39, the relative involvement of fog-related collisions among both Arizona and Florida drivers is evaluated. Florida (RAIR~ 2.6) and Arizona (RAIR~ 2.6) drivers ages 80 –89 are about twice as likely to be at-fault in a fog-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.55; Florida RAIR~ 1.85). Retirement occurs by age 90 years and over for only Florida drivers. It appears that either missing data or no data accounts for the absence of data beyond Arizona drivers ages 80 –89. The onset of the Wearout Period begins at ages 50 to 59 years for Florida drivers and ages 60 to 69 years for Arizona drivers.

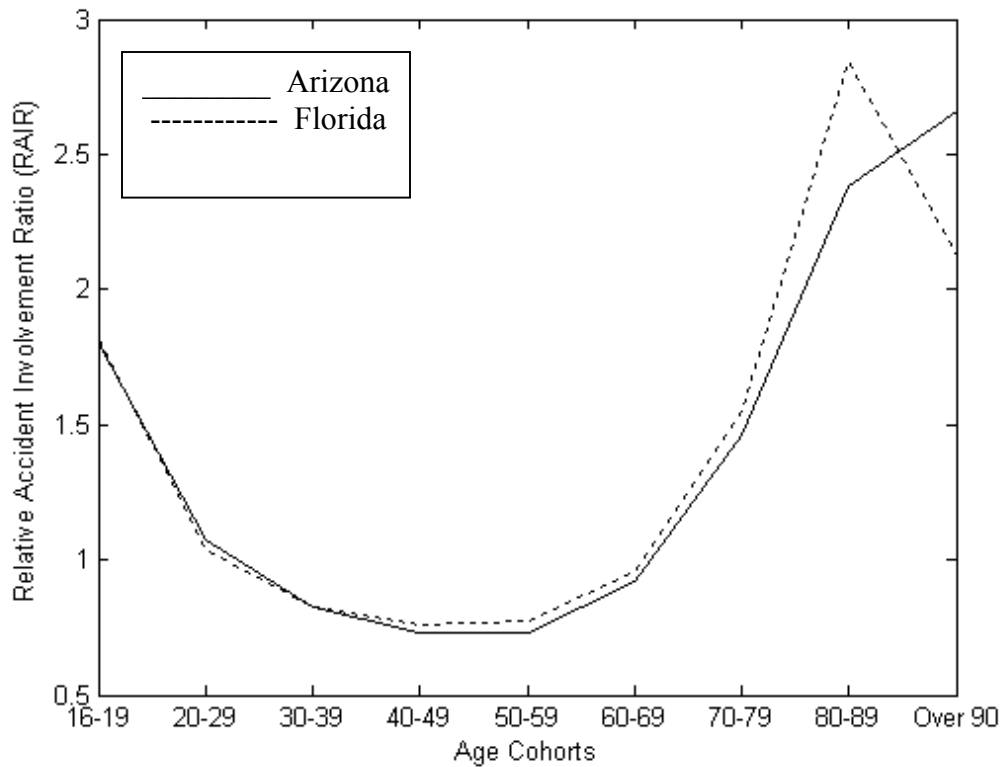


Figure 40. Comparison of Day Light-Related Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 40, the relative involvement of daylight-related collisions among both Arizona and Florida drivers is viewable. Florida (RAIR~ 2.8) drivers ages 80 to 89 years and Arizona (RAIR~ 2.65) drivers age 90 years and over are about twice as likely to be at-fault in a daylight-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.75; Florida RAIR~ 1.75). A random period occurs between ages 40 to 49 years and ages 50 to 59 years. Retirement occurs by age 90 years and older for only Florida drivers. The onset of the Wearout Period begins at ages 50 to 59 years for both Arizona and Florida drivers.

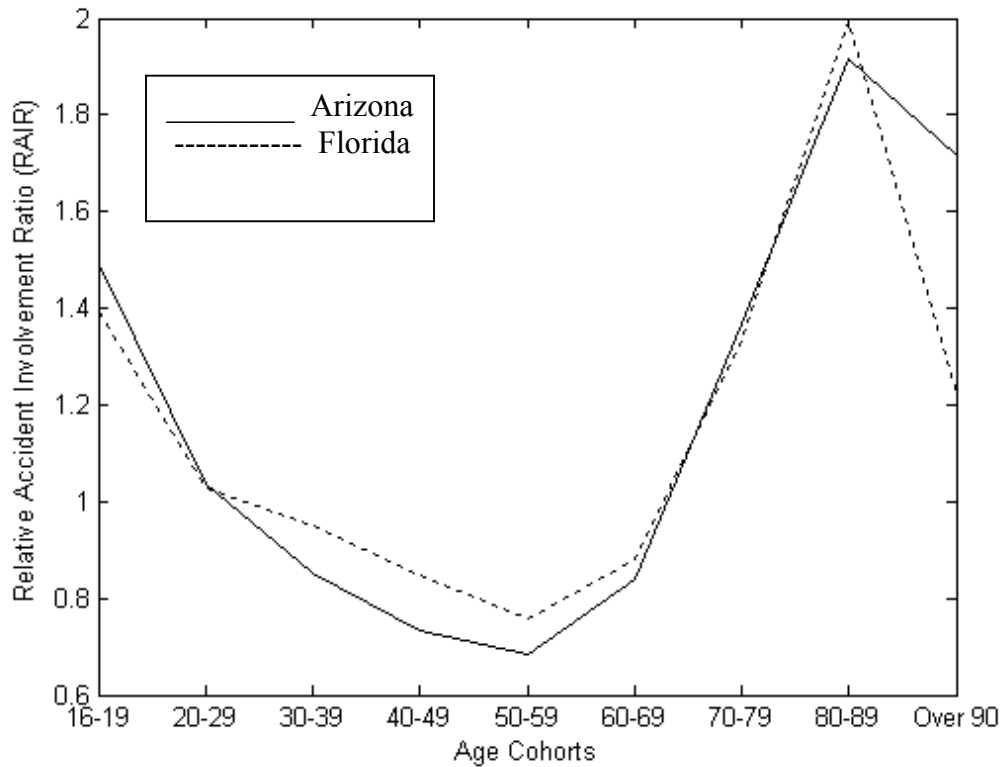


Figure 41. Comparison of Darkness-Related Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 41, we evaluate the relative involvement of darkness-related collisions among both Arizona and Florida drivers. Florida (RAIR~ 2) drivers and Arizona drivers (RAIR~1.9) age 80 –89 years are about one times as likely to be at-fault in a darkness-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.5; Florida RAIR~ 1.4). Retirement occurs by age 90 years and over for both Arizona and Florida drivers. The onset of the Wearout Period begins at ages 50 to 59 years for both Arizona and Florida drivers.

Staplin *et al.* (1997b) cite several studies that demonstrate that older drivers are most affected by lower illumination levels, in particular, night driving and associated weakening of vision. Lower illumination levels cause weakening of most spatial vision. Reduced contrast sensitivity and acuity, for all age groups, typify night vision.

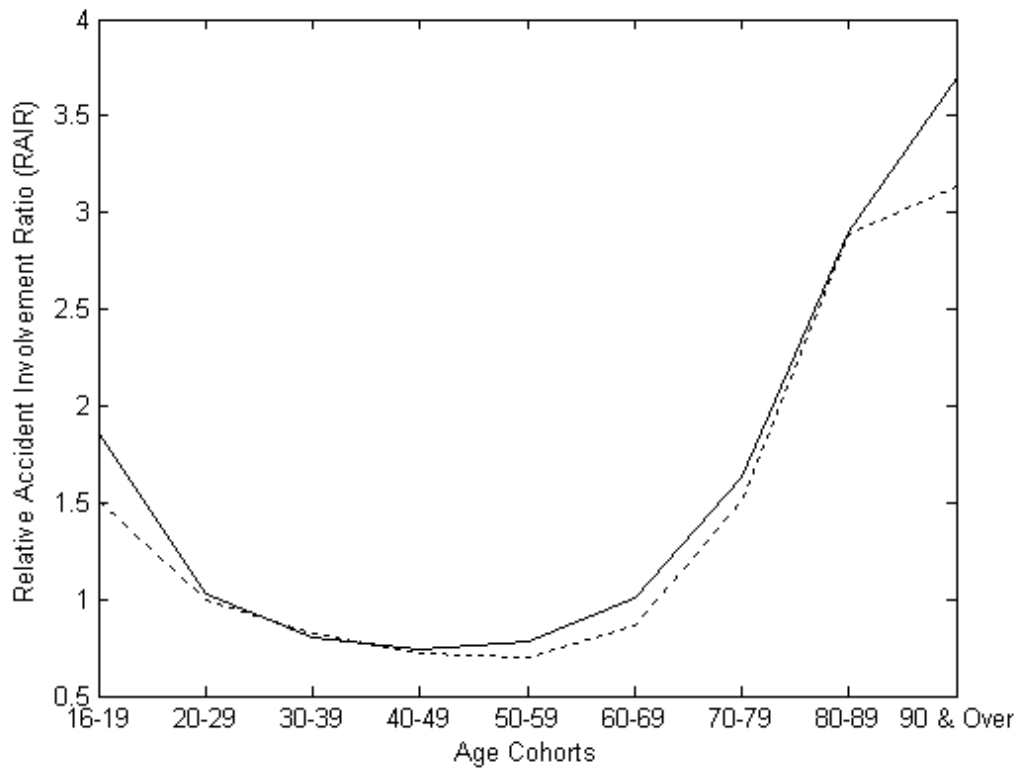


Figure 42. Comparison of Dawn or Dusk Related Collisions Among Drivers in Arizona and Florida for years 1991 to 2001

In Figure 42, the study shows the relative involvement of dawn or dusk-related collisions among both Arizona and Florida drivers. Arizona drivers (RAIR~3.6) and Florida (RAIR~ 3.1) drivers age 90 years and older are about twice as likely to be at-fault in a dawn or dusk-related collision than the cohorts ages 16 to 19 years (Arizona RAI~ 1.8; Florida RAI~ 1.5). The onset of the Wearout Period begins at ages 50 to 59 years for both Arizona and Florida drivers.

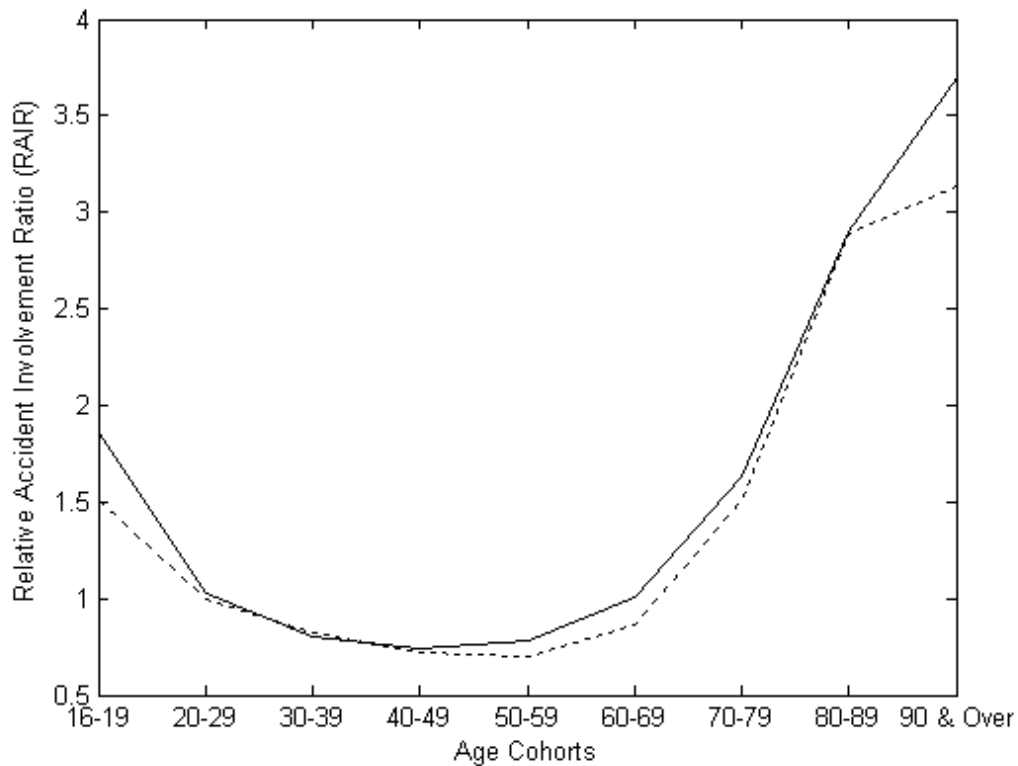


Figure 43. Comparison of Collisions Among Drivers with Visual Defects in Arizona and Florida for years 1991 to 2001

In Figure 43, the study evaluates the relative involvement of corrective lenses-related collisions among both Arizona and Florida drivers. Arizona drivers (RAIR~3.6) and Florida (RAIR~ 3.1) drivers age 90 years and older with visual defects are about twice as likely to be at-fault in a corrective lenses-related collision than the cohorts ages 16 to 19 years (Arizona RAIR~ 1.8; Florida RAIR~ 1.5). The onset of the Wearout Period begins at ages 50 to 59 years for both Arizona and Florida drivers.

APPENDIX H: RELATIVE ACCIDENT INVOLVEMENT RATIO OF ARIZONA DRIVERS WITH CORRECTIVE LENSES, INVOLVED COLLISIONS, YEARS 1991 TO 2001

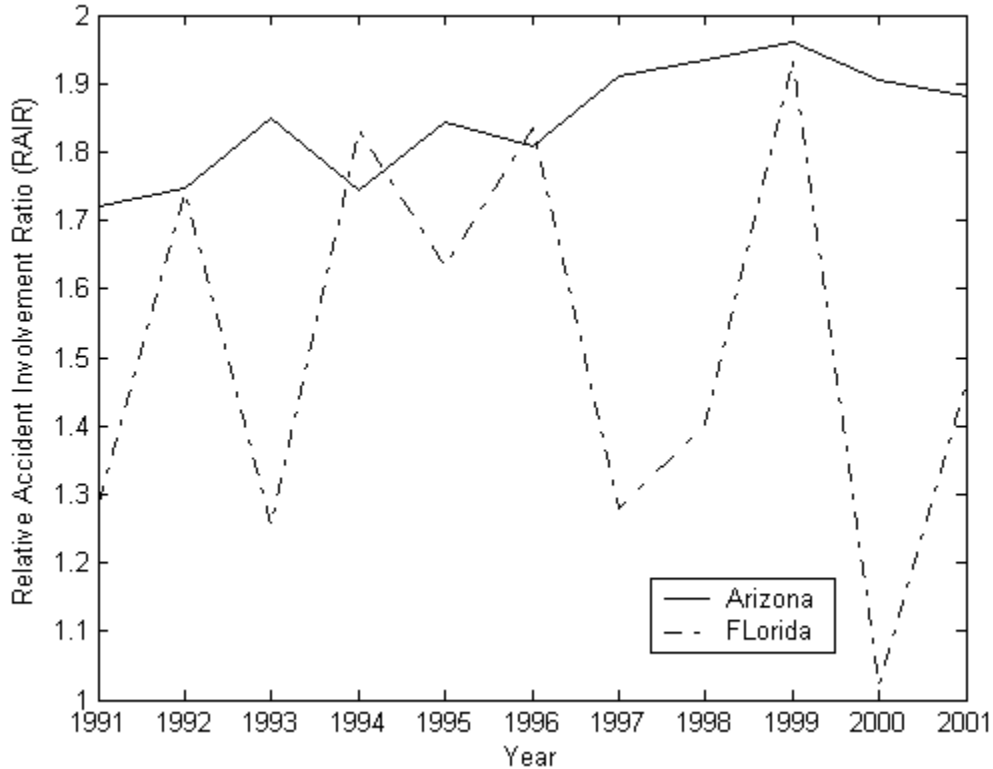


Figure 44. Relative Accident Involvement Ratio of Ages 16 to 19 Years by Restriction of Corrective Lens for Arizona and Florida Drivers, Years 1991 to 2001

Figure 44 shows an overall decrease in likelihood of collision involvement of Arizona drivers ages 16 to 19 years with Restriction of Corrective Lenses with a high in 1999 (RAIR ~ 1.98) and a low in 1991 (RAIR ~1.71). The level of RAIR for these Florida cohorts fluctuates with the highest RAIR in 1999 (RAIR ~1.95) and the lowest in 2000 (RAIR ~ 1). Both groups tend to be most likely at-fault in collisions of this kind because RAIR>1.

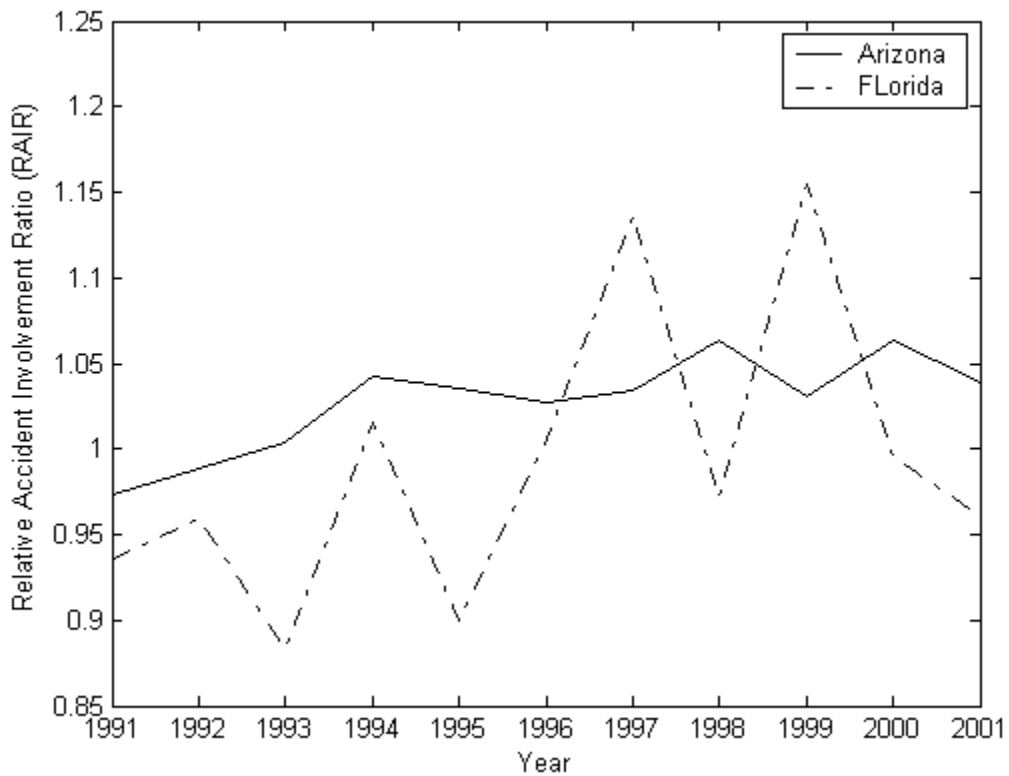


Figure 45. Relative Accident Involvement Ratio of Ages 20 to 29 Years by Restriction of Corrective Lens for Arizona and Florida Drivers, Years 1991 to 2001

Figure 45 shows a slight increase in likelihood of collision involvement of Arizona drivers ages 20 to 29 years with Restriction of Corrective Lenses with a high in 1999 (RAIR ~ 1.07) and a low in 1991 (RAIR ~0.975). The level of RAIR for these Florida cohorts fluctuates, at an overall increase, with the highest RAIR in 1999 (RAIR ~1.16) and the lowest in 1993 (RAIR ~ 0.88). Both groups tend to be most likely at-fault in collisions because RAIR>1.

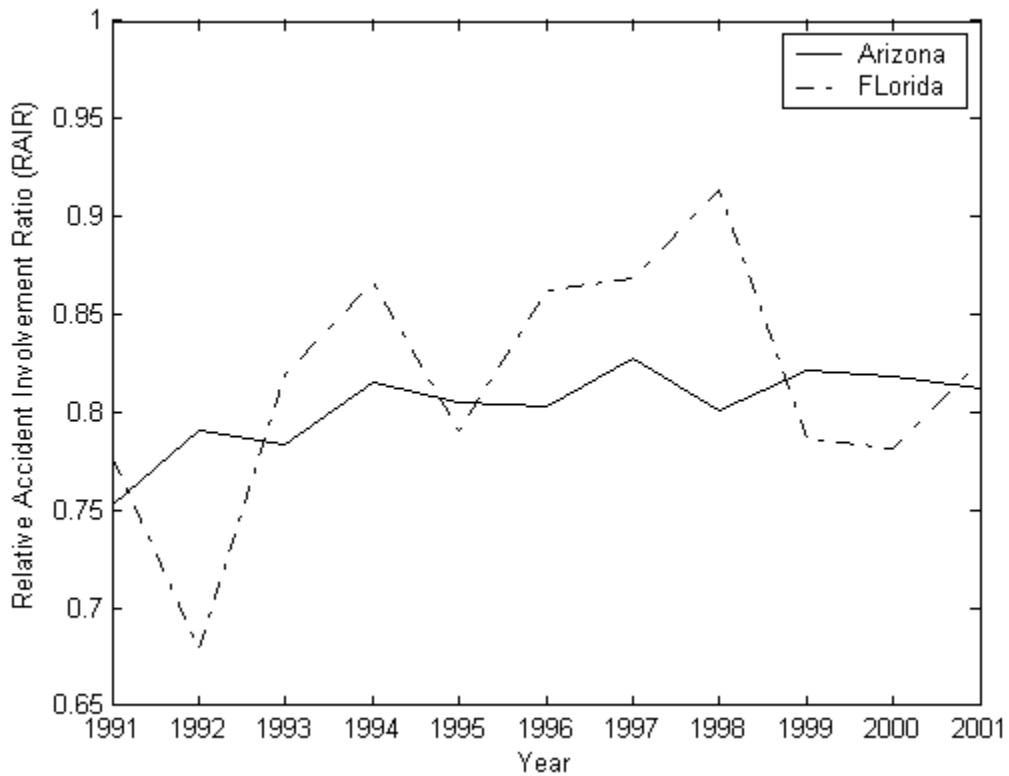


Figure 46. Relative Accident Involvement Ratio of Ages 30 to 39 Years by Restriction of Corrective Lens for Arizona and Florida Drivers, Years 1991 to 2001

Figure 46 shows Arizona drivers ages 30 to 39 years with Restriction of Corrective Lenses increase their likelihood of collision involvement from 1991 (RAIR ~ 0.75) to 2001 (RAIR ~ 0.81). The level of RAIR for these Floridian cohorts fluctuates very unsteadily from the highest in 1998 (RAIR ~ 0.91) and the lowest in 1992 (RAIR ~ 0.68). The level of the RAIR remains averagely below 1. Both groups tend to be most likely not at-fault in collisions of this kind because RAIR < 1.

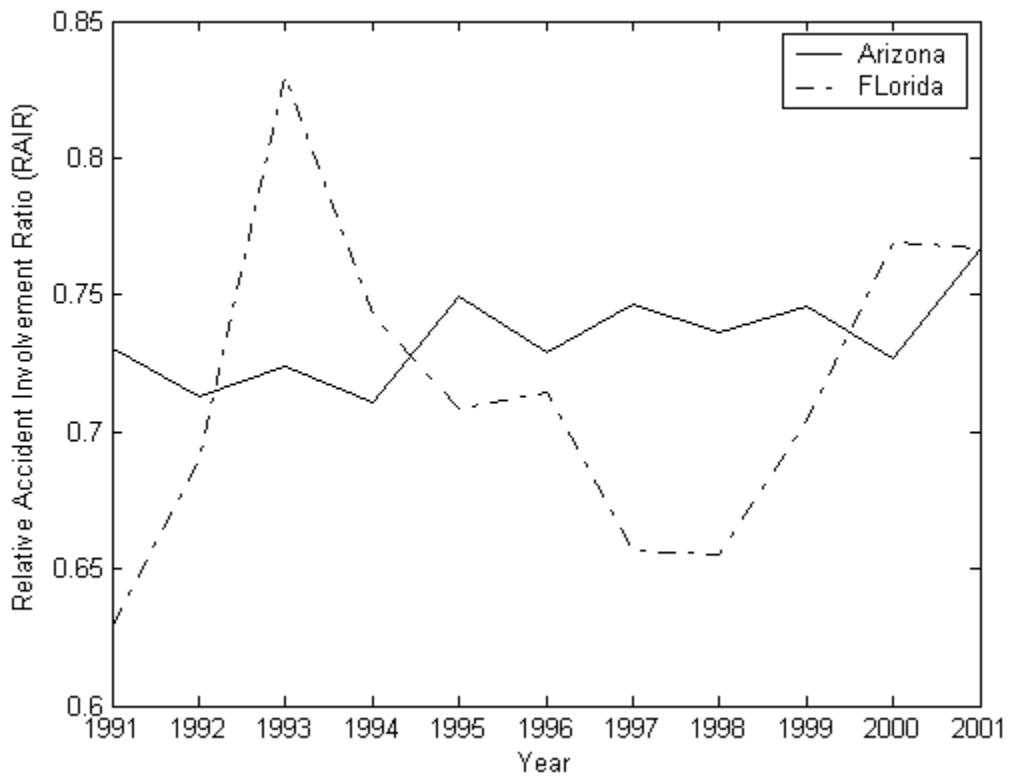


Figure 47. Relative Accident Involvement Ratio of Ages 40 to 49 Years by Restriction of Corrective Lens for Arizona and Florida Drivers, Years 1991 to 2001

Figure 47 shows Arizona drivers ages 40 to 49 Years with Restriction of Corrective Lenses increase their likelihood of collision involvement from 1991 (RAIR ~ 0.73) to 2001 (RAIR ~ 0.77). The level of RAIR for these Floridian cohorts fluctuates very unsteadily from the highest in 1998 (RAIR ~ 0.83) and the lowest in 1991 (RAIR ~ 0.63). Both groups tend to be most likely not at-fault in collisions because RAIR < 1.

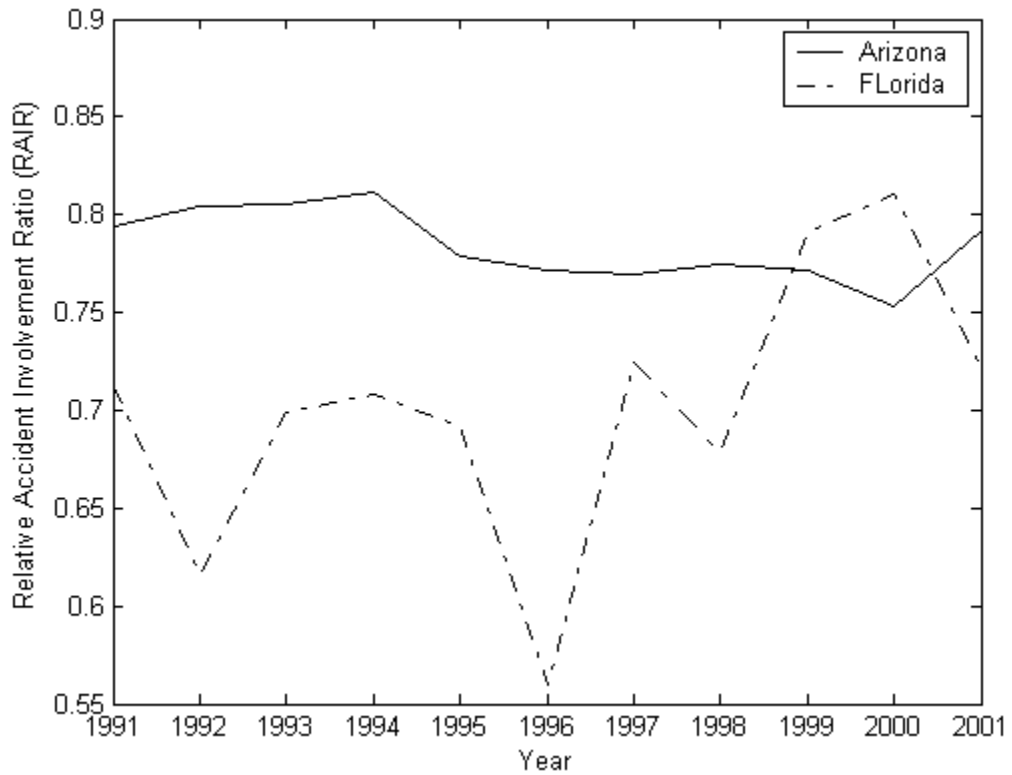


Figure 48. Relative Accident Involvement Ratio of Ages 50 to 59 Years by Restriction of Corrective Lens for Arizona and Florida Drivers, Years 1991 to 2001

Figure 48 shows the likelihood of collision involvement Arizona drivers ages 50 to 59 years with Restriction of Corrective Lenses from 1991 (RAIR ~ 0.79) to 2001 (RAIR ~ 0.75). The level of RAIR for these Floridian cohorts fluctuates very unsteadily from the highest in 2000 (RAIR ~ 0.81) and the lowest in 1996 (RAIR ~ 0.55). Both groups tend to be most likely not at-fault in collisions of this kind because RAIR < 1.

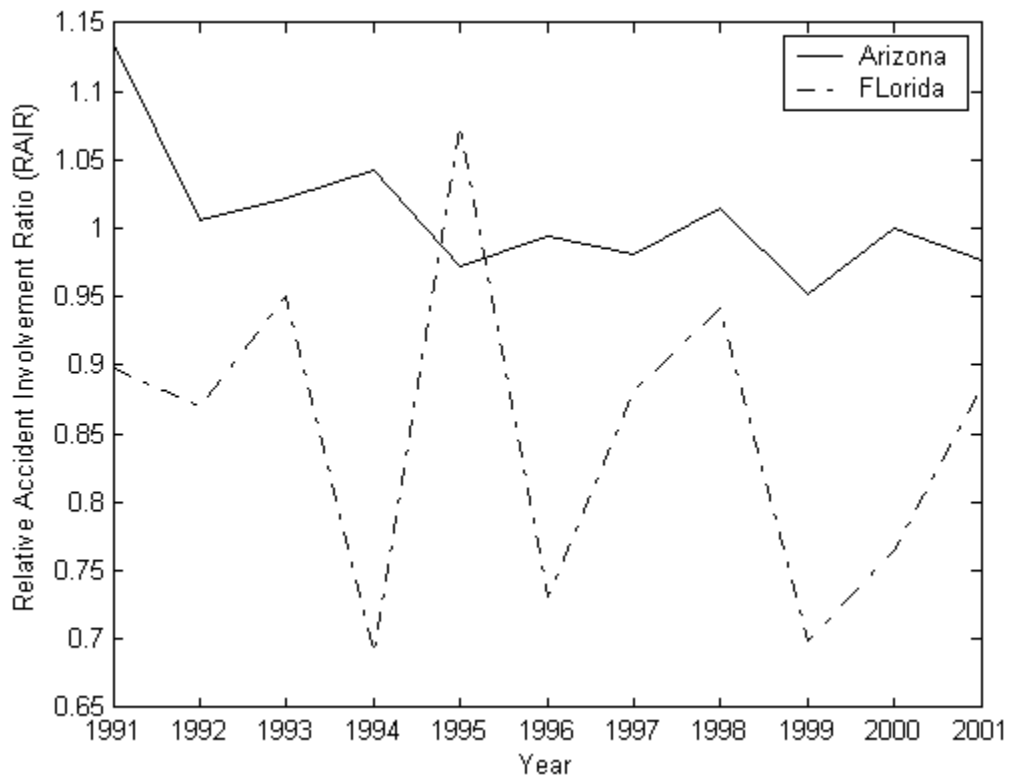


Figure 49. Relative Accident Involvement Ratio of Ages 60 to 69 Years by Restriction of Corrective Lens for Arizona and Florida Drivers, Years 1991 to 2001

Figure 49 shows the likelihood of collision involvement of Arizona drivers ages 60 to 69 years with Restriction of Corrective Lenses with a high in 1991(RAIR ~ 1.13) and a low in 1999 (RAIR ~0.96). The level of RAIR for these Florida cohorts fluctuates very unsteadily from the highest in 1995 (RAIR ~ 1.09) and the lowest in 1994 (RAIR ~ 0.69). Arizona drivers age 60s tend to be most likely at-fault in collisions of this kind because RAIR >1.

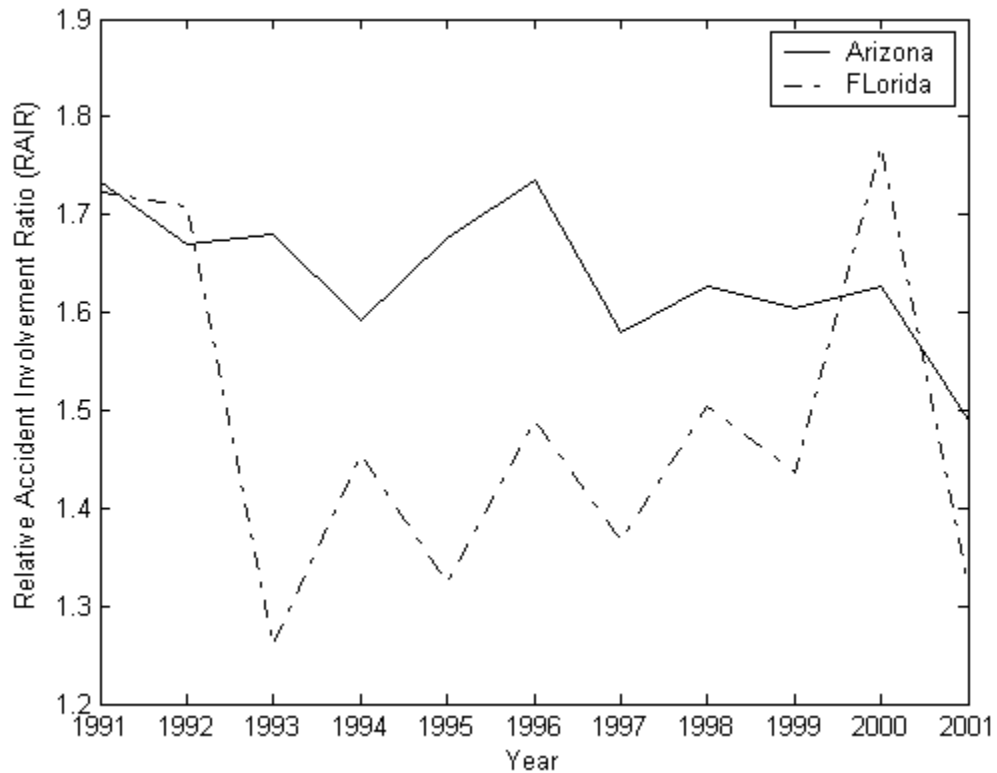


Figure 50. Relative Accident Involvement Ratio of Ages 70 to 79 Years by Restriction of Corrective Lens for Arizona and Florida Drivers, Years 1991 to 2001

Figure 50 shows the likelihood of collision involvement of Arizona drivers ages 70 to 79 years with Restriction of Corrective Lenses with a high in 1996 (RAIR ~ 1.73) and a low in 2001 (RAIR ~1.49). The level of RAIR for these Florida cohorts fluctuates very unsteadily from 1993 to 2000. The highest RAIR for Florida occur in 2000(RAIR ~1.77) and the lowest 1993 (RAIR ~ 1.26). Drivers age 70s in both states tend to be most likely at-fault in collisions because RAIR >1.

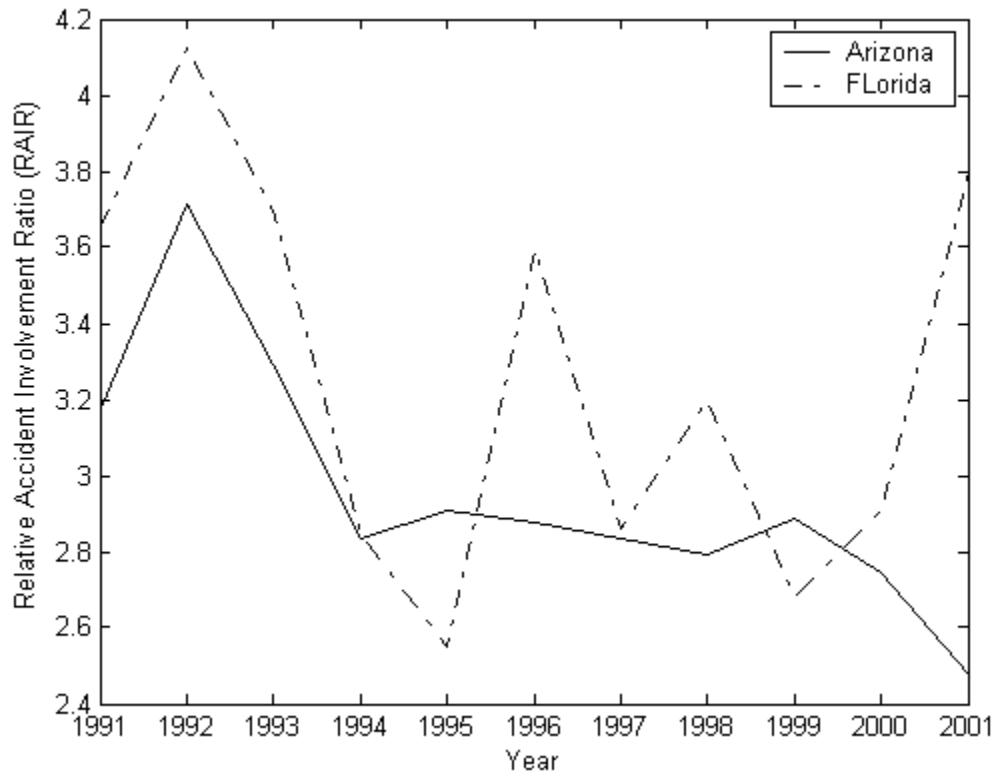


Figure 51. Relative Accident Involvement Ratio of Ages 80 to 89 Years by Restriction of Corrective Lens for Arizona and Florida Drivers, Years 1991 to 2001

Figure 51 shows the likelihood of collision involvement of Arizona drivers ages 80 to 89 years with Restriction of Corrective Lenses with a high in 1992 (RAIR ~ 3.7) and a low in 1995 (RAIR ~2.55). The level of RAIR for these Florida cohorts fluctuates very unsteadily with the highest RAIR in 1992 (RAIR ~4.18) and the lowest in 1995 (RAIR ~ 2.55). Drivers ages 80 to 89 years in both states tend to be most likely at-fault in collisions because RAIR >1.

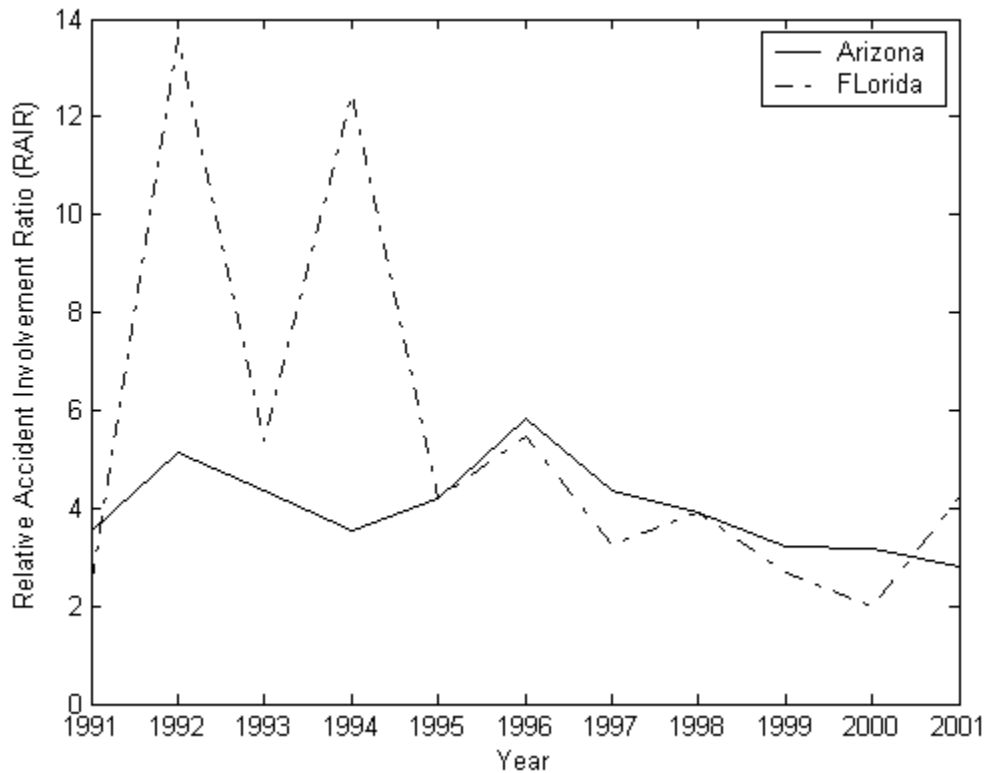


Figure 52. Relative Accident Involvement Ratio of Ages 90 Years and Older by Restriction of Corrective Lens for Arizona and Florida Drivers, Years 1991 to 2001

Figure 52 shows the likelihood of collision involvement of Arizona drivers ages 90 years and older with Restriction of Corrective Lenses with a high in 1996 (RAIR ~ 5.8) and a low in 2001 (RAIR ~3.5). The level of RAIR for these Florida cohorts fluctuates and relatively decreases with the highest RAIR in 1992 (RAIR ~14) and the lowest in 2000 (RAIR ~ 3). Drivers age 90 years and older in both states tend to be most likely at-fault in collisions because $RAIR \gg 1$. These represent the highest RAIR values among all other age cohorts.

APPENDIX I: RELATIVE ACCIDENT INVOLVEMENT RATIO OF FLORIDA DRIVERS ASSOCIATED WITH INJURIES, YEARS 1991 TO 2001



Figure 53. RAIR for Injuries of Florida drivers of Ages 15 to 19 years

In Figure 53, Florida drivers ages 15 to 19 years show a steady increase in likelihood of at-fault accident involvement associated with injuries over the eleven-year period, 1991-2001.

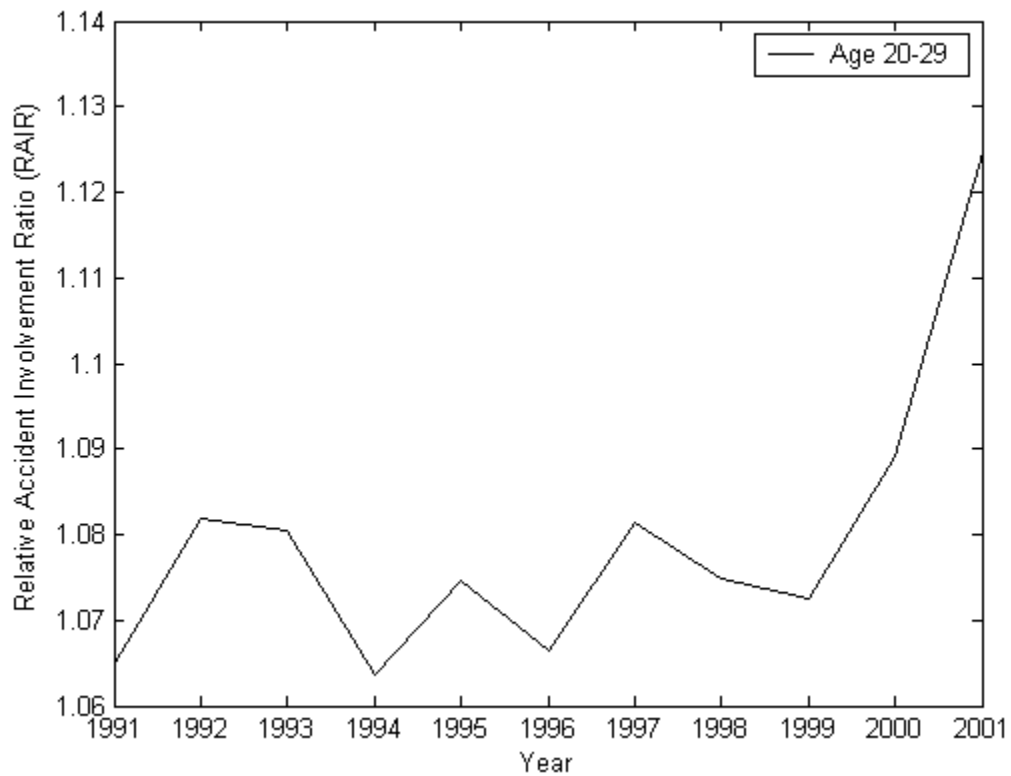


Figure 54. RAIR for Injuries of Florida drivers of Ages 20 to 29 years

In Figure 54, Florida drivers ages 20 to 29 years show a fluctuation and relative increase in likelihood of at-fault accident involvement associated with injuries over the eleven-year period, 1991 to 2001.



Figure 55. RAIR for Injuries of Florida drivers of Ages 30 to 39 years

In Figure 55, Florida drivers age 30 to 39 years show a slight increase followed by a constant decrease in likelihood of at-fault accident involvement associated with injuries over the eleven-year period, 1991 to 2001.

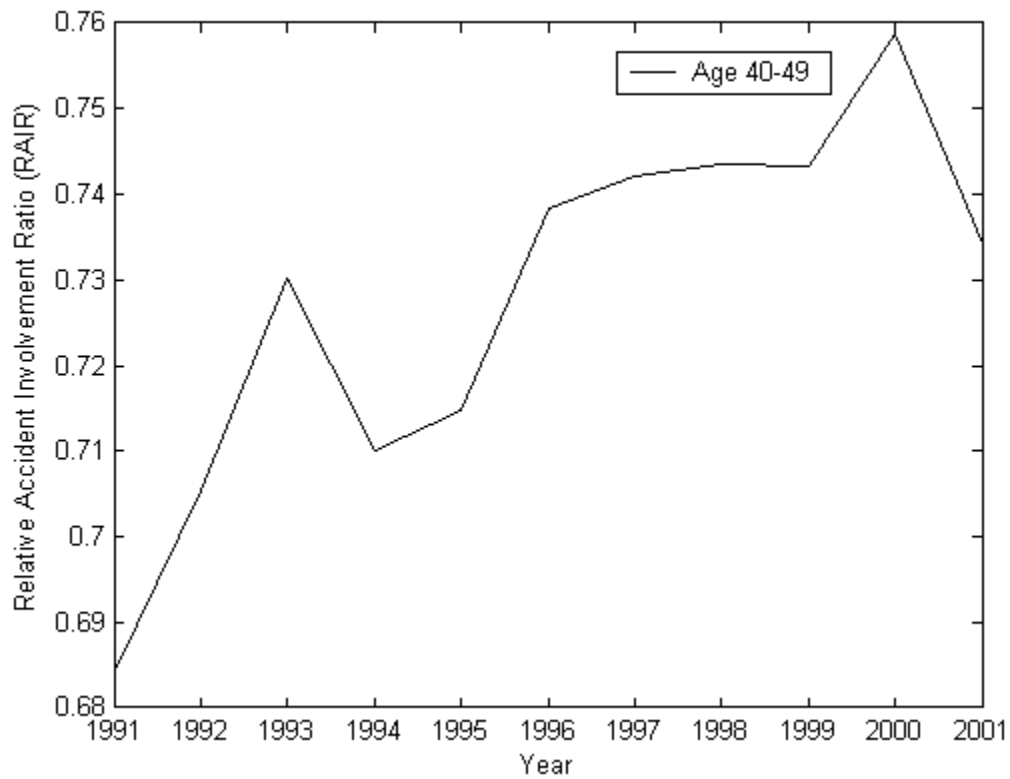


Figure 56. RAIR for Injuries of Florida drivers of Ages 40 to 49 years

In Figure 56, Florida drivers ages 40 to 49 years show a fluctuation and relative increase in likelihood of at-fault accident involvement associated with injuries over the eleven-year period, 1991 to 2001.



Figure 57. RAIR for Injuries of Florida drivers of Ages 50 to 59 years

In Figure 57, Florida drivers ages 50 to 59 years show a fluctuation and relative increase in likelihood of at-fault accident involvement associated with injuries over the eleven-year period, 1991 to 2001.

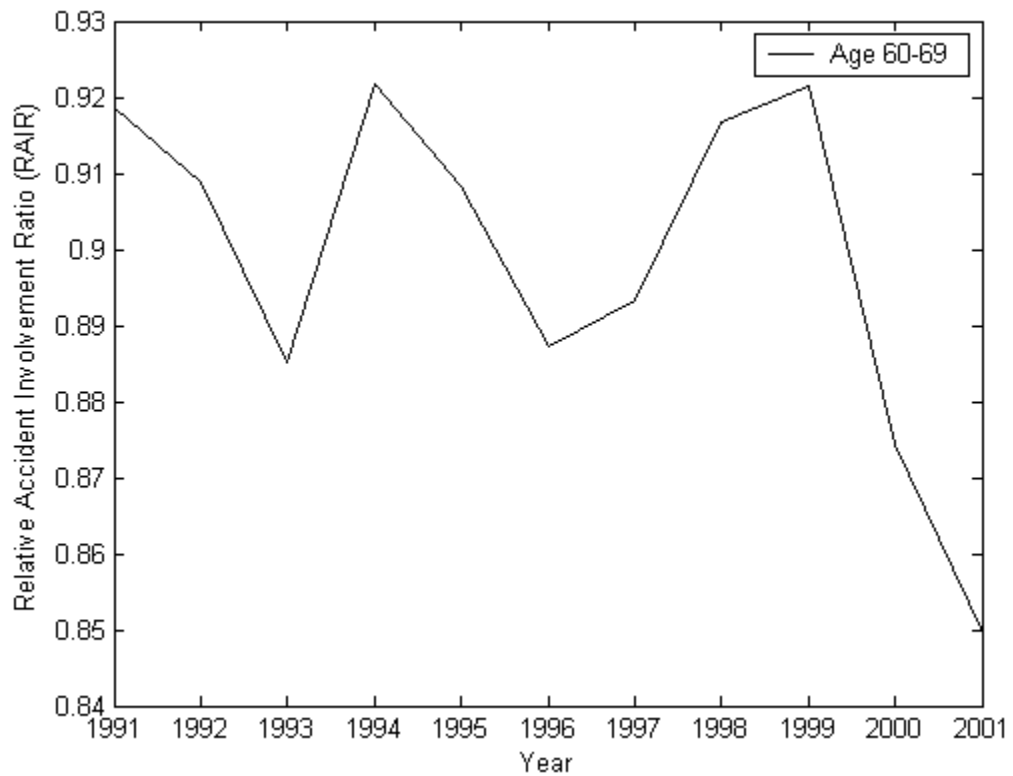


Figure 58. RAIR for Injuries of Florida drivers of Ages 60 to 69 years

In Figure 58, Florida drivers age 60 to 69 years show a fluctuation and relative decrease in likelihood of at-fault accident involvement associated with injuries over the eleven-year period, 1991 to 2001.



Figure 59. RAIR for Injuries of Florida drivers of Ages 70 to 79 years

In Figure 59, Florida drivers ages 70 to 79 years show a fluctuation and relative decrease in likelihood of at-fault accident involvement associated with injuries over the eleven-year period, 1991 to 2001. Notice the significantly high RAIR values, when compared to the previous age cohorts, with the exception of the cohorts ages 15 to 19 years.



Figure 60. RAIR for Injuries of Florida drivers of Ages 80 to 89 years

In Figure 60, Florida drivers ages 80 to 89 years show a fluctuation and overall decrease in likelihood of at-fault accident involvement associated with injuries over the eleven-year period, 1991 to 2001. Notice the significantly high RAIR values, when compared to the previous age cohorts.

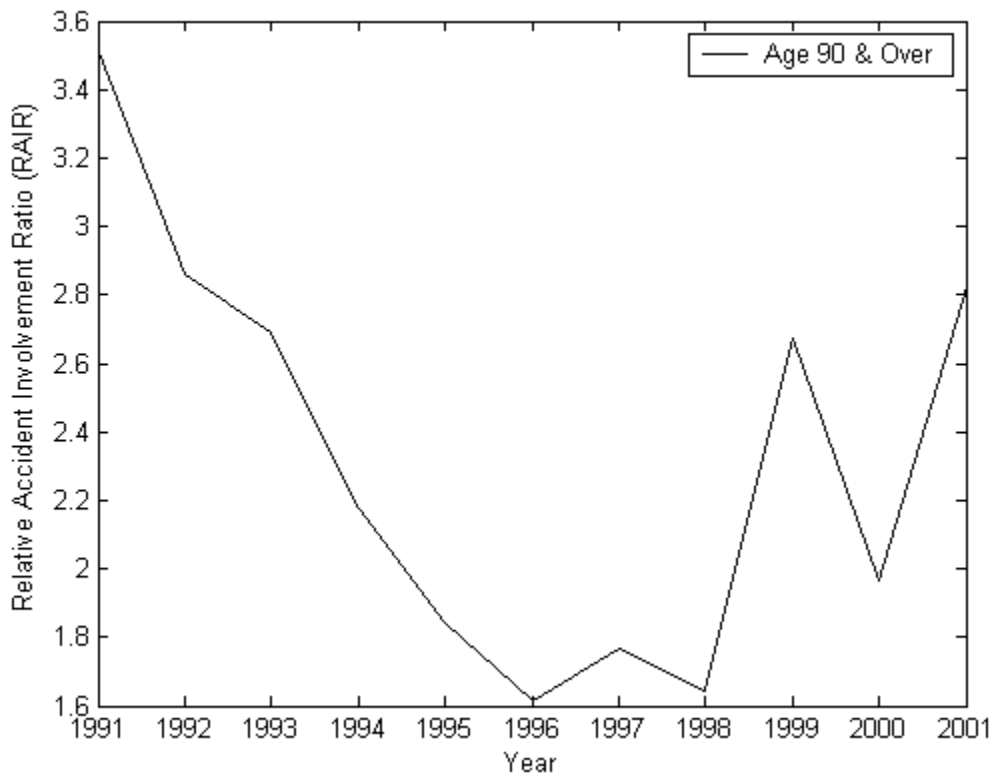


Figure 61. RAIR for Injuries of Florida drivers of Age 90 Years and Older

In Figure 61, Florida drivers age 90 years and show a fluctuation and relative decrease followed by an increase in likelihood of at-fault accident involvement associated with injuries over the eleven-year period, 1991 to 2001. Notice the significantly high RAIR values, when compared to the previous age cohorts.

APPENDIX J: RELATIVE ACCIDENT INVOLVEMENT RATIO OF FLORIDA DRIVERS ASSOCIATED WITH FATALITIES YEARS 1991 TO 2001



Figure 62. RAIR for Fatalities of Florida drivers of Ages 15 to 19 years

In Figure 62, Florida drivers ages 15 to 19 years show fluctuations and a slight decrease from 1991 (RAIR = 1.75) to 2001 (RAIR = 1.65) in likelihood of at-fault accident involvement associated with fatalities. However, this age group is more likely to be at-fault, as the RAIR values stayed above 1 for most of the 11-year period.

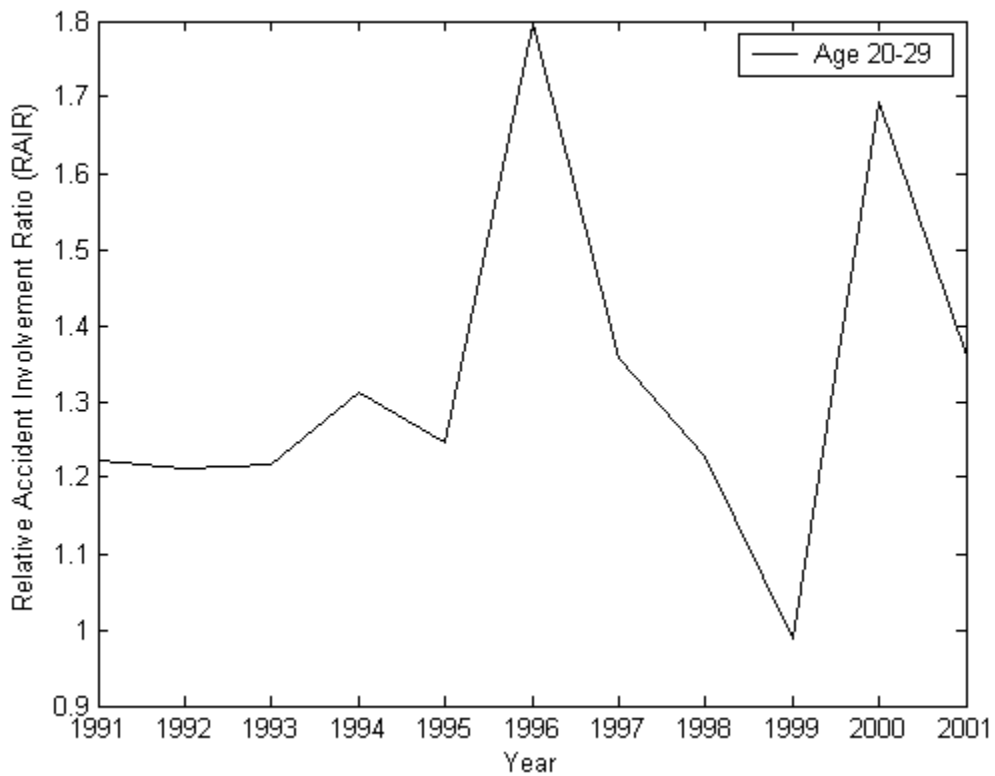


Figure 63. RAIR for Fatalities of Florida drivers of Ages 20 to 29 years

In Figure 63, Florida drivers ages 20 to 29 years show fluctuations and a slight increase from 1991 (RAIR ~1.22) to 2001 (RAIR ~1.38) in likelihood of accident involvement associated with fatalities. However, this age group is more likely to be at-fault, as the RAIR values are above 1 for most of the 11-year period.



Figure 64. RAIR for Fatalities of Florida drivers of Ages 30 to 39 years

In Figure 64, Florida drivers ages 30 to 39 years show fluctuations and a slight yet steady increase from 1991 (RAIR ~1.08) to 2001 (RAIR ~1.1) in likelihood of accident involvement associated with fatalities. However, this age group is more likely to be at-fault, as the RAIR values stayed above 1 for most of the 11-year period.



Figure 65. RAIR for Fatalities of Florida drivers of Ages 40 to 49 years

In Figure 65, Florida drivers ages 40 to 49 years show fluctuations and a steady increase from 1991 (RAIR ~0.81) to 2001 (RAIR ~0.95) in likelihood of accident involvement associated with fatalities.



Figure 66. RAIR for Fatalities of Florida drivers of Ages 50 to 59 years

In Figure 66, Florida drivers ages 50 to 59 years show fluctuations and a slight yet steady increase from 1991 (RAIR ~0.46) to 2001 (RAIR ~0.64) in likelihood of accident involvement associated with fatalities. However, this age group is more likely to be at-fault, as the RAIR values are above 1 for most of the 11-year period.



Figure 67. RAIR for Fatalities of Florida drivers of Ages 60 to 69 years

In Figure 67, Florida drivers ages 60 to 69 years relatively decrease from 1991 (RAIR ~0.65) to 2001 (RAIR ~0.52) in likelihood of accident involvement associated with fatalities.



Figure 68. RAIR for Fatalities of Florida drivers of Ages 70 to 79 years

In Figure 68, Florida drivers ages 70 to 79 years show fluctuations and a slight yet steady decrease from 1991 (RAIR ~1.02) to 2001 (RAIR ~0.83) in the likelihood of at-fault accident involvement associated with fatalities. However, this age group is more likely to be at-fault, as the RAIR values are above 1 for most of the 11-year period.



Figure 69. RAIR for Fatalities of Florida drivers of Ages 80 to 89 years

In Figure 69, Florida drivers ages 80 to 89 years show fluctuations and a slight yet steady decrease from 1991 (RAIR ~2.1) to 2001 (RAIR ~1.7) in the likelihood of at-fault accident involvement associated with fatalities. However, this age group is more likely to be at-fault, as the RAIR values stayed above 2 for most of the 11-year period.

APPENDIX K: RELATIVE ACCIDENT INVOLVEMENT RATIO OF FLORIDA DRIVERS ASSOCIATED WITH COLLISIONS, YEARS 1991 TO 2001



Figure 70. RAIR for Collisions of Florida drivers of Ages 15 to 19 years

According to Figure 70, the RAIR value for this age group relatively increases from 1991 (RAIR ~ 1.602) to 2001 (RAIR ~ 1.718) in the likelihood of at-fault accident involvement associated with collisions. This age group is very likely to be at-fault for collision, as the RAIR values are above 1 for the entirety of the 11-year period.

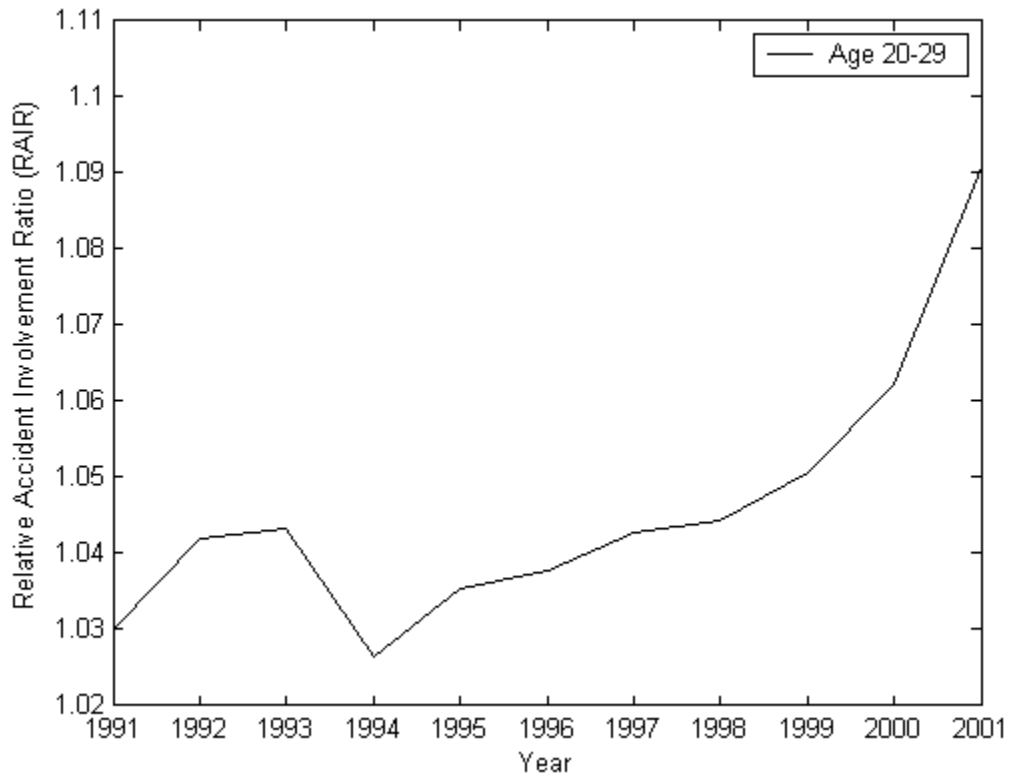


Figure 71. RAIR for Collisions of Florida drivers of Ages 20 to 29 years

According to Figure 71, the RAIR values for this age group relatively increase from 1991 (RAIR ~ 1.03) to 2001 (RAIR ~ 1.09) in the likelihood of at-fault accident involvement associated with collisions. This age group is very likely to be involved in an at-fault collision, as the RAIR values stayed above 1 for the entirety of the 11-year period.



Figure 72. RAIR for Collisions of Florida drivers of Ages 30 to 39 years

According to Figure 72, the RAIR values for this age group relatively increase from 1991 (RAIR ~ 0.869) to 2001 (RAIR ~ 0.848) in the likelihood of accident involvement associated with collisions.

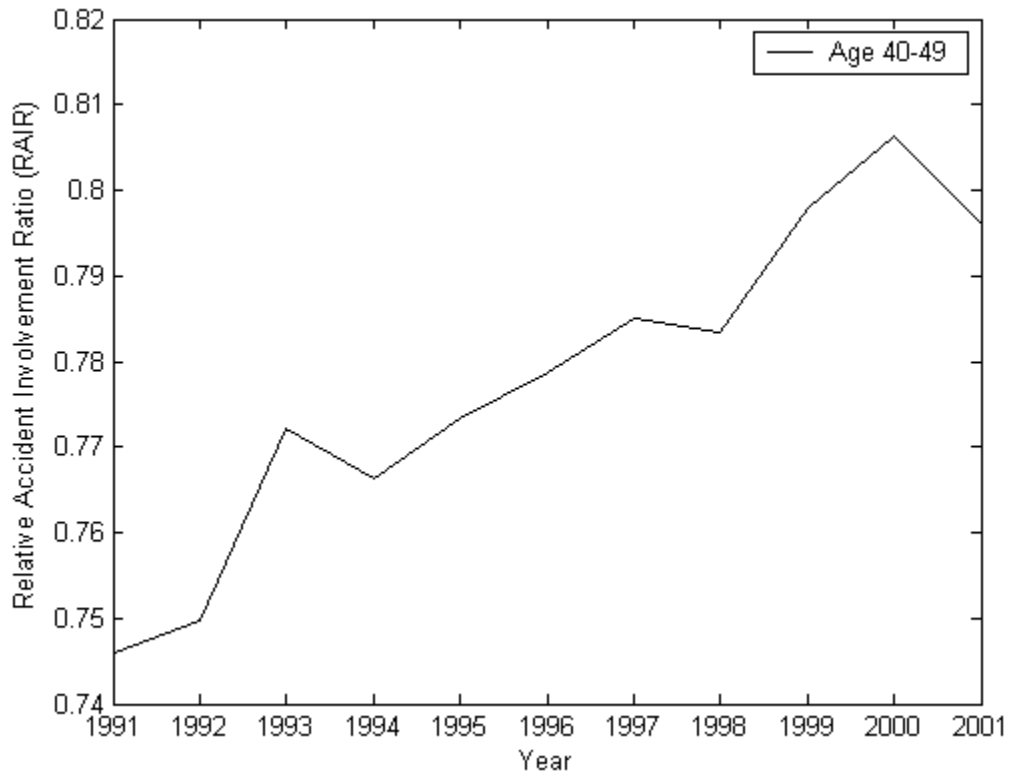


Figure 73. RAIR for Collisions of Florida drivers of Ages 40 to 49 years

According to Figure 73, the RAIR values for this age group relatively increase from 1991 (RAIR ~ 0.746) to 2001 (RAIR ~ 7.96) in the likelihood of accident involvement associated with collisions.



Figure 74. RAIR for Collisions of Florida drivers of Ages 50 to 59 years

According to Figure 74, the RAIR values for this age group fluctuate and remain at nearly RAIR ~0.77 from 1991 to 2001 in the likelihood of accident involvement associated with collisions.



Figure 75. RAIR for Collisions of Florida drivers of Ages 60 to 69 years

According to Figure 75, the RAIR values for this age group relatively decrease from 1991 (RAIR ~ 0.965) to 2001 (RAIR ~ 0.865) in the likelihood of at-fault accident involvement associated with collisions.



Figure 76. RAIR for Collisions of Florida drivers of Ages 70 to 79 years

According to Figure 76, the RAIR value for the age group relatively decreases from 1991(RAIR ~ 1.55) to 2001(RAIR ~ 1.4) in the likelihood of at-fault accident involvement associated with collisions. This age group is very likely to be involved in at-fault collisions, as the RAIR values are over 1 for the entirety of the 11-year period. Notice how significantly high these RAIR values are compared to all other age groups, except for the cohorts ages 15 to 19 years.



Figure 77. RAIR for Collisions of Florida drivers of Ages 80 to 89 years

According to Figure 77, the RAIR value for the age group relatively decreases from 1991 (RAIR ~ 3.04) to 2001 (RAIR ~ 2.5) in the likelihood of at-fault accident involvement associated with collisions. This age group is very likely to be involved in at-fault collisions, as the RAIR values are above 2.4 for the entirety of the 11-year period. Notice how significantly high these RAIR values are compared to all other age groups.

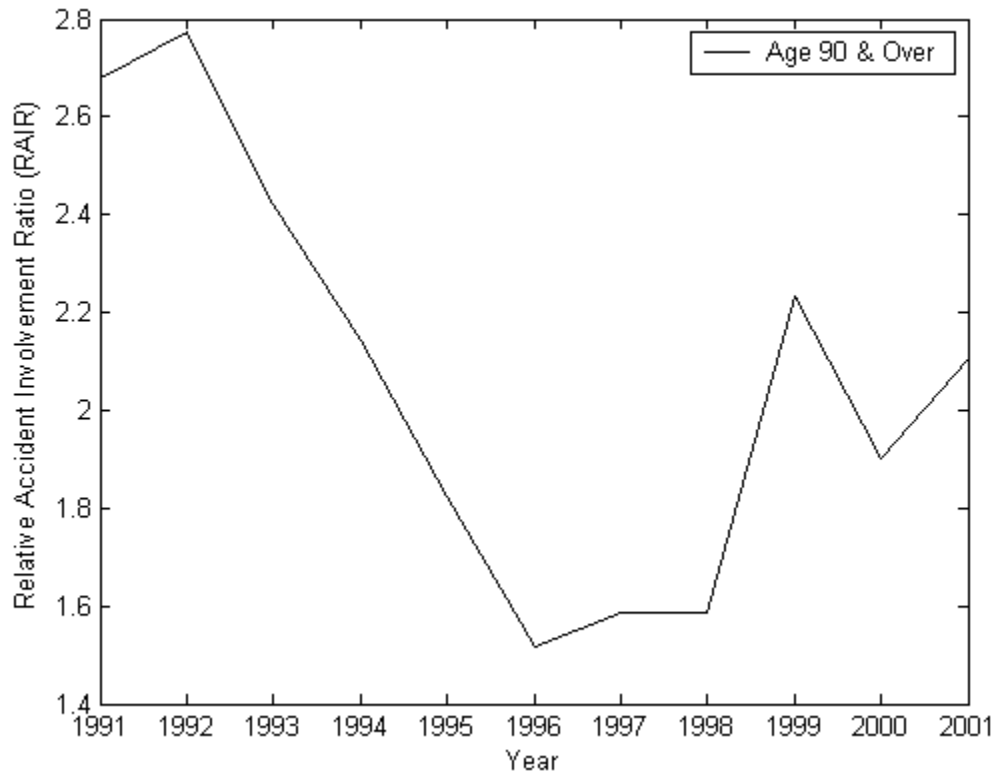


Figure 78. RAIR for Collisions of Florida drivers of Age 90 years and older

According to Figure 78, the RAIR values for this age group fluctuate and relatively decrease from 1991 (RAIR ~ 2.7) to 2001 (RAIR ~ 2.1) in the likelihood of at-fault accident involvement associated with collisions. This age group is very likely to be involved in an at-fault collision, as the RAIR values are above 1 for the entirety of the 11-year period.

APPENDIX L: DESCRIPTIVE STATISTICS OF WEATHER-RELATED COLLISIONS IN THE STATE OF ARIZONA, YEARS 1991 TO 2001

Table 48. Descriptive Statistics for Snow-Related Collisions in the State of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	121	360	296	240	126	64	29	36	0
Median	116	403	326	240	127	64	31	12	0
STD	35	79	74	61	40	18	14	38	1
95%CI	24	53	50	41	27	12	9	26	0
5 PCTL	54	197	176	143	78	38	8	2	0
95 PCTL	172	464	384	336	188	94	55	102	2
MIN	52	192	174	141	78	38	8	2	0
MAX	172	466	385	338	189	94	56	102	2

Table 48 shows that the cohorts ages 20 – 29 years (\bar{x} =360) are most susceptible to snow-related collisions over an eleven-year period. The second highest group include the cohorts ages 30 –39 years (\bar{x} =296). Values relatively decrease as age increases.

Table 49. Descriptive Statistics for Blowing Sand, Soil, Dirt, and Snow Weather-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	10	31	26	22	15	8	6	3	0
Median	8	30	24	20	12	7	5	2	0
STD	5	15	12	11	12	4	3	3	0
95%CI	3	10	8	8	8	3	2	2	0
5 PCTL	3	13	6	7	1	2	1	0	0
95 PCTL	18	57	42	42	34	16	11	8	0
MIN	3	13	6	7	1	2	1	0	0
MAX	18	57	42	42	34	16	11	8	0

This Figure shows that the people most affected by Blowing Sand, Soil, Dirt, and Snow Weather-Related collisions are in their cohorts ages 20 – 29 years. As age values diverge from the cohorts age 20 – 29 years, the average values decrease.

Table 50. Descriptive Statistics for Clear Weather-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	20,447	45,986	36,978	26,849	15,759	9,549	6,756	6,337	194
Median	20,965	48,287	39,400	27,572	15,887	9,807	6,994	2,998	196
STD	3,885	6,877	5,565	5,801	4,278	1,210	848	4,919	79
95%CI	2,610	4,620	3,739	3,897	2,874	813	570	3,304	53
5 PCTL	14,475	34,843	27,185	17,154	9,464	7,426	5,104	1,696	86
95 PCTL	25,564	54,838	43,198	34,000	21,419	10,963	7,803	13,256	306
MIN	14,471	34,828	27,157	17,093	9,437	7,412	5,081	1,689	85
MAX	25,589	54,916	43,210	34,022	21,438	10,967	7,816	13,261	306

This figure shows that Clear Weather-Related Collisions for Arizona drivers appear the most in the cohorts age 20 – 29 years. As age values diverge from the cohorts ages 20 – 29 years, the average values of these collisions decrease.

Table 51. Descriptive Statistics for Cloudy Weather-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	2,393	5,355	4,393	3,215	1,900	1,175	827	689	21
Median	2,361	5,403	4,504	3,199	1,781	1,213	808	350	19
STD	313	610	487	474	391	120	94	495	7
95%CI	210	410	327	319	263	80	63	333	5
5 PCTL	2,037	4,276	3,476	2,471	1,395	897	632	235	11
95 PCTL	2,992	6,349	4,958	3,936	2,561	1,298	979	1,472	36
MIN	2,037	4,248	3,449	2,458	1,394	888	625	235	11
MAX	3,001	6,369	4,960	3,943	2,576	1,299	981	1,480	36

This figure shows that Cloudy Weather-Related Collisions for Arizona drivers appear the most in the cohorts age 20 – 29 years. As age values diverge from the cohorts ages 20 – 29 years, the average values of these collisions decrease.

Table 52. Descriptive Statistics for Fog, Smog, and Smoke Weather-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	13	38	33	25	15	6	3	4	0
Median	8	26	20	18	10	5	2	1	0
STD	14	36	28	19	11	5	3	6	0
95%CI	10	24	19	12	8	4	2	4	0
5 PCTL	2	6	5	3	4	0	0	0	0
95 PCTL	44	116	88	61	39	16	9	19	0
MIN	2	6	5	3	4	0	0	0	0
MAX	44	118	88	61	39	16	9	19	0

The highest average for fog, smog, and smoke weather-related collisions of Arizona drivers occurs in the Cohorts, ages 20 to 29 years. As age values diverge from the cohorts ages 20 to 29 years, the average values of these collisions decrease. However, the cohorts ages 80 to 89 years represent a greater average than the cohorts ages 70 to 79 years.

Table 53. Descriptive Statistics for Rain-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	1,294	2,848	2,201	1,576	878	510	329	306	8
Median	1,352	2,815	2,039	1,531	924	516	340	113	7
STD	273	697	522	352	193	143	79	262	4
95%CI	183	468	350	237	130	96	53	176	2
5 PCTL	839	1,866	1,544	1,058	542	302	216	76	4
95 PCTL	1,739	4,099	3,126	2,090	1,214	754	457	774	15
MIN	829	1,861	1,544	1,050	533	300	215	76	4
MAX	1,748	4,126	3,148	2,093	1,221	759	459	784	15

The highest average for rain-related collisions of Arizona drivers occurs in the Cohorts, ages 20 – 29 years. As age values diverge from the cohorts ages 20 – 29 years, the average values of these collisions decrease.

Table 54. Descriptive Statistics for Severe Crosswinds-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	74	171	148	119	75	47	33	26	0
Median	78	183	146	122	72	47	32	23	0
STD	35	61	56	48	37	18	14	21	1
95%CI	23	41	38	32	25	12	10	14	1
5 PCTL	13	39	40	32	15	11	7	2	0
95 PCTL	134	272	263	216	137	81	61	72	3
MIN	12	34	37	30	14	10	6	2	0
MAX	135	274	267	219	138	82	61	74	3

The highest average for severe crosswinds-related collisions of Arizona drivers occurs in the Cohorts, ages 20 to 29 years. As age values diverge from the cohorts ages 20 to 29 years, the average values of these collisions decrease.

Table 55. Descriptive Statistics for Sleet/ Hail Weather-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	25	45	36	34	22	12	9	3	0
Median	0	0	0	0	0	0	0	0	0
STD	71	126	104	99	64	35	27	8	1
95%CI	48	85	70	66	43	24	18	6	1
5 PCTL	0	0	0	0	0	0	0	0	0
95 PCTL	228	403	334	316	203	112	85	27	3
MIN	0	0	0	0	0	0	0	0	0
MAX	238	421	349	330	212	117	89	28	3

The highest average for sleet/ hail weather-related collisions of Arizona drivers occurs in the cohorts, ages 20 – 29 years. As age values diverge from the cohorts ages 20 – 29 years, the average values of these collisions decrease.

APPENDIX M: DESCRIPTIVE STATISTICS OF LIGHT-RELATED COLLISIONS IN THE STATE OF ARIZONA, YEARS 1991 TO 2001

Table 56. At-Fault Rates for Lighting Condition-Related Collisions of Arizona Drivers for Years 1991 to 2001.

Age	Darkness	Dawn or Dusk	Daylight
Teens	0.017407682	0.003014594	0.048497814
20s	0.011489398	0.002203620	0.033037744
30s	0.006137956	0.001391435	0.022046765
40s	0.003936197	0.000971581	0.016341342
50s	0.002771762	0.000800070	0.013987090
60s	0.002109798	0.000630531	0.014287885
70s	0.002040677	0.000700042	0.018970499
80s	0.013672474	0.002291729	0.037747646
90s	0.003170426	0.001082121	0.028856571

The Arizona drivers with the highest rate of at-fault collision rates during darkness, daylight, dusk or dawn are the cohorts ages 16 to 19 years and ages 80 to 89 years.

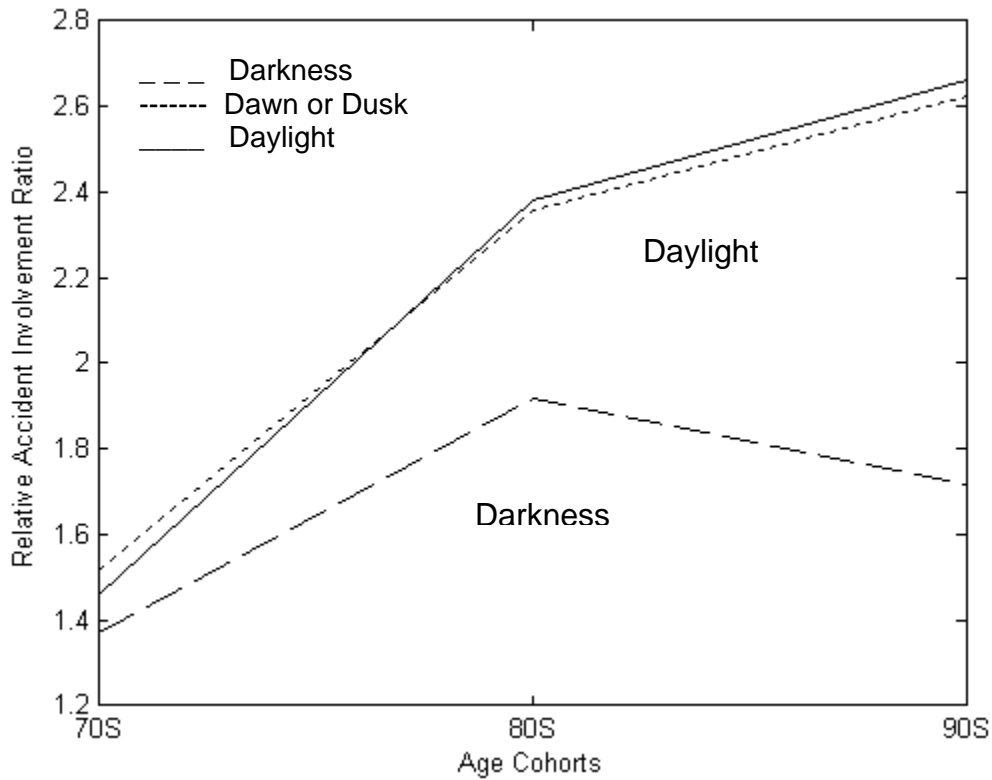


Figure 80. Relative Accident Involvement Ratio (RAIR) for Arizona Driver Cohorts Age 70 Years and Older

Arizona drivers age 90 years and older are most susceptible to at-fault collisions during daylight (RAIR ~2.65) and dawn or dusk (RAIR ~2.62). This may be due to the greater number of drivers during the day than the night hours. However, the cohorts ages 80 to 89 years are most likely at-fault in darkness (night), RAIR ~1.9.

Table 57. Descriptive Statistics for Darkness-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	6,273	13,047	8,533	5,567	2,878	1,386	734	1,944	24
Median	6,318	13,267	8,778	5,803	2,869	1,351	747	248	21
STD	845	1,246	749	934	664	158	89	2,169	14
95%CI	568	837	503	627	446	106	60	1,457	9
5 PCTL	5,118	11,376	7,261	3,941	1,894	1,130	562	125	4
95 PCTL	7,570	14,928	9,368	6,867	3,836	1,644	857	5,106	48
MIN	5,116	11,376	7,250	3,921	1,887	1,124	559	124	4
MAX	7,578	14,939	9,371	6,882	3,839	1,647	858	5,119	48

The highest average for darkness-related collisions of Arizona drivers occurs in the cohorts, ages 20 – 29 years. As age values diverge from the cohorts ages 20 – 29 years, the average values of these collisions decrease until an increase appears among the drivers ages 80 to 89 years.

Table 58. Descriptive Statistics for Dawn- or Dusk-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	1,049	2,538	2,071	1,483	844	422	251	314	7
Median	1,055	2,583	2,151	1,567	811	416	259	106	7
STD	231	479	379	386	265	67	41	286	3
95%CI	155	322	254	259	178	45	27	192	2
5 PCTL	677	1,773	1,380	847	471	312	169	47	3
95 PCTL	1,423	3,314	2,601	2,029	1,247	531	299	740	12
MIN	673	1,765	1,372	839	468	310	167	46	3
MAX	1,431	3,333	2,614	2,038	1,254	532	300	742	12

The highest average for dawn or dusk-related collisions of Arizona drivers occurs in the cohorts, ages 20 to 29 years. As age values diverge from the cohorts ages 20 – 29 years, the average values of these collisions decrease until an increase appears among the drivers ages 80 to 89 years.

Table 59. Descriptive Statistics for Daylight-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	17,124	39,382	33,617	25,103	15,111	9,587	7,027	5,220	195
Median	17,415	40,184	35,008	25,962	14,718	9,743	7,331	2,997	191
STD	2,935	4,928	4,233	4,744	3,728	904	665	3,329	73
95%CI	1,972	3,311	2,843	3,187	2,504	607	447	2,236	49
5 PCTL	12,241	30,492	25,378	16,730	9,521	7,872	5,637	1,890	97
95 PCTL	20,893	45,642	37,925	30,584	20,007	10,588	7,688	9,896	302
MIN	12,200	30,399	25,291	16,634	9,475	7,852	5,608	1,881	96
MAX	20,921	45,733	37,953	30,621	20,033	10,596	7,693	9,908	303

The highest average for daylight-related collisions of Arizona drivers occurs in the cohorts, ages 20 – 29 years. As age values diverge from the cohorts ages 20 – 29 years, the average values of these collisions decrease.

APPENDIX N: DESCRIPTIVE STATISTICS OF MANNER OF COLLISIONS IN THE STATE OF ARIZONA, YEARS 1991 TO 2001

Table 60. Descriptive Statistics for Angle-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	4,999	10,420	8,195	5,965	3,688	2,678	2,217	1,528	72
Median	5,306	11,083	8,597	6,483	3,752	2,745	2,222	1,097	77
STD	743	1,084	815	927	727	136	157	768	25
95%CI	499	728	548	623	488	92	106	516	17
5 PCTL	3,654	8,425	6,621	4,263	2,523	2,401	1,962	731	37
95 PCTL	5,719	11,360	8,913	6,927	4,507	2,807	2,405	2,583	106
MIN	3,635	8,400	6,599	4,238	2,511	2,396	1,958	729	37
MAX	5,719	11,369	8,918	6,940	4,507	2,807	2,405	2,584	106

Table 60 shows that the highest average for angle-related collisions occurs in Arizona drivers ages 20 to 29 years (\bar{x} =10420). As age ranges diverge from the cohorts ages 20 to 29 years, the averages decrease.

Table 61. Descriptive Statistics for Backing-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	334	833	803	628	377	216	133	137	3
Median	313	811	776	587	320	207	131	56	2
STD	61	100	103	121	102	40	15	122	3
95%CI	41	67	69	81	69	27	10	82	2
5 PCTL	274	696	657	443	268	164	101	22	0
95 PCTL	439	1,022	933	822	528	284	153	320	9
MIN	274	694	657	439	268	163	100	21	0
MAX	439	1,026	933	823	528	286	153	320	9

Table 61 shows that the highest average for backing-related collisions during the 11-year period occurs in the Arizona drivers ages 20 to 29 years (\bar{x} =833). As the ages diverge from the cohorts ages 20 to 29 years, the averages decrease until an increase among the cohorts ages 80 to 89 years (\bar{x} =137).

Table 62. Descriptive Statistics for Head On-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	151	378	309	218	125	76	47	40	2
Median	158	371	312	204	113	70	44	27	2
STD	29	65	47	44	37	16	10	31	1
95%CI	20	44	32	29	25	11	7	21	1
5 PCTL	95	268	236	165	75	47	36	5	0
95 PCTL	193	475	370	311	193	96	68	88	4
MIN	94	265	235	164	74	46	36	5	0
MAX	194	476	370	313	194	96	69	88	4

Table 62 shows that the highest average for head-on collisions in the 11-year period occurs in the Arizona drivers ages 20 to 29 years (\bar{x} =378). As age ranges diverge from the cohorts ages 20 to 29 years, the averages decrease.

Table 63. Descriptive Statistics for Left Turn-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	3,084	6,405	4,678	3,335	2,034	1,421	1,248	811	40
Median	3,169	6,537	4,910	3,463	2,077	1,439	1,280	663	35
STD	500	696	477	530	414	110	112	351	16
95%CI	336	467	320	356	278	74	75	236	11
5 PCTL	2,290	5,181	3,803	2,391	1,374	1,211	1,057	435	14
95 PCTL	3,789	7,231	5,130	3,994	2,570	1,546	1,374	1,333	64
MIN	2,289	5,177	3,802	2,385	1,372	1,208	1,056	434	14
MAX	3,795	7,234	5,132	4,001	2,572	1,547	1,375	1,336	64

Table 63 shows that the highest average for left turn-related collisions in the 11-year period occurs in the Arizona drivers ages 20 to 29 years (\bar{x} =6405). As age ranges diverge from the cohorts ages 20 to 29 years, the averages decrease.

Table 64. Descriptive Statistics for Non-Contact-Related Collisions (not MC) of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	16	54	54	42	25	12	5	6	0
Median	16	43	43	36	19	11	4	4	0
STD	10	35	34	26	15	8	5	5	1
95%CI	7	24	23	17	10	5	3	3	0
5 PCTL	5	22	23	20	7	5	0	1	0
95 PCTL	34	123	131	95	47	31	17	16	2
MIN	5	22	23	20	7	5	0	1	0
MAX	34	123	133	95	47	32	17	16	2

Table 64 shows that the highest average for non-contact-related collisions occur in the Arizona drivers ages 20 to 29 years ($\bar{x}=54$). As age ranges diverge from the cohorts ages 20 to 29 years, the averages decrease until an increase among the cohorts ages 80 to 89 years.

Table 65. Descriptive Statistics for Other-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	571	1,385	1,227	897	549	325	224	316	7
Median	544	1,336	1,153	855	538	314	210	88	7
STD	92	175	186	143	96	42	39	316	4
95%CI	62	118	125	96	64	28	26	212	3
5 PCTL	490	1,212	1,049	702	419	275	178	52	3
95 PCTL	793	1,817	1,673	1,165	689	417	304	797	14
MIN	490	1,210	1,047	700	419	274	177	52	3
MAX	801	1,831	1,689	1,171	690	419	306	798	14

Table 65 shows that the highest average for other-related collisions occur in Arizona drivers ages 20 to 29 years ($\bar{x}=1385$). As age ranges diverge from the cohorts ages 20 to 29 years, the averages decrease until an increase among the cohorts ages 80 to 89 years.

Table 66. Descriptive Statistics for Rear End-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	9,086	22,454	18,791	13,647	7,721	4,080	2,382	2,094	56
Median	9,066	22,722	19,501	14,175	7,412	4,174	2,442	829	51
STD	1,863	3,538	2,975	3,089	2,268	623	371	1,789	25
95%CI	1,251	2,377	1,998	2,075	1,523	418	249	1,202	17
5 PCTL	6,184	16,426	13,200	8,279	4,377	2,971	1,624	409	26
95 PCTL	11,752	27,161	22,029	17,407	10,734	4,850	2,795	4,576	107
MIN	6,157	16,362	13,140	8,213	4,348	2,955	1,609	406	26
MAX	11,758	27,186	22,052	17,420	10,735	4,857	2,798	4,576	108

Table 66 shows that the highest average for rear end-related collisions occur in Arizona drivers ages 20 to 29 years (\bar{x} =22,454). As age ranges diverge from the cohorts ages 20 to 29 years, the averages decrease.

Table 67. Descriptive Statistics for Opposite Direction Side Swipe-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	223	522	476	353	184	113	68	93	2
Median	207	489	449	368	182	113	67	22	2
STD	46	112	95	50	38	19	15	95	2
95%CI	31	75	64	33	26	13	10	63	1
5 PCTL	178	418	378	258	117	87	51	9	0
95 PCTL	317	744	670	418	239	147	100	261	5
MIN	178	418	377	256	116	87	51	9	0
MAX	318	746	672	419	239	147	101	265	5

Table 67 shows that the highest average for opposite direction side swipe-related collisions is the 20s age group of Arizona drivers (\bar{x} =522). As age ranges diverge from the cohorts ages 20 to 29 years, the averages decrease, until an increase among the cohorts ages 80 to 89 years.

Table 68. Descriptive Statistics for Same Direction Side Swipe-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	2,105	5,275	4,584	3,446	2,112	1,277	888	822	23
Median	2,175	5,428	4,734	3,373	1,971	1,259	913	396	20
STD	489	1,006	865	858	655	209	152	643	11
95%CI	329	676	581	576	440	140	102	432	7
5 PCTL	1,279	3,491	2,988	2,032	1,160	906	589	171	8
95 PCTL	2,812	6,646	5,613	4,622	3,003	1,583	1,066	1,759	40
MIN	1,268	3,459	2,961	2,014	1,151	896	583	168	8
MAX	2,821	6,660	5,618	4,634	3,009	1,586	1,067	1,762	40

Table 68 shows that the highest average for same direction side swipe-related collisions among Arizona drivers ages 20 to 29 years (\bar{x} =5,275). As age ranges diverge from the cohorts ages 20 to 29 years, the averages decrease.

Table 69. Descriptive Statistics for Single Vehicle-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	3,524	6,627	4,633	3,291	1,825	1,067	682	1,551	19
Median	3,434	6,504	4,637	3,350	1,781	1,059	679	270	19
STD	330	340	185	414	357	61	61	1,629	8
95%CI	221	228	124	278	240	41	41	1,094	5
5 PCTL	3,058	6,304	4,328	2,625	1,328	988	590	183	6
95 PCTL	4,101	7,322	4,992	3,821	2,402	1,169	768	3,788	32
MIN	3,050	6,304	4,326	2,622	1,323	988	589	183	6
MAX	4,107	7,330	5,004	3,825	2,409	1,169	769	3,788	32

Table 69 shows that the highest average for single vehicle-related collisions occurs among Arizona drivers ages 20 to 29 years (\bar{x} =6,627). As age ranges diverge from the cohorts ages 20 to 29 years, the averages decrease until an increase among the cohorts ages 80 to 89 years (\bar{x} =1,551).

Table 70. Descriptive Statistics for U-turn-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	366	638	491	349	203	135	124	81	3
Median	363	625	482	347	189	134	124	54	3
STD	74	103	80	85	55	19	14	48	1
95%CI	50	69	54	57	37	13	10	32	1
5 PCTL	249	475	364	212	125	106	103	27	2
95 PCTL	495	784	619	456	302	168	145	152	5
MIN	248	473	362	211	124	105	103	27	2
MAX	498	785	622	457	304	169	145	152	5

Table 70 shows that the highest average for U-turn- related collisions occurs among Arizona drivers ages 20 to 29 years (\bar{x} =638). As age ranges diverge from the cohorts ages 20 to 29 years, the averages decrease.

APPENDIX O: DESCRIPTIVE STATISTICS OF RESTRICTIONS-RELATED COLLISIONS IN THE STATE OF ARIZONA, YEARS 1991 TO 2001

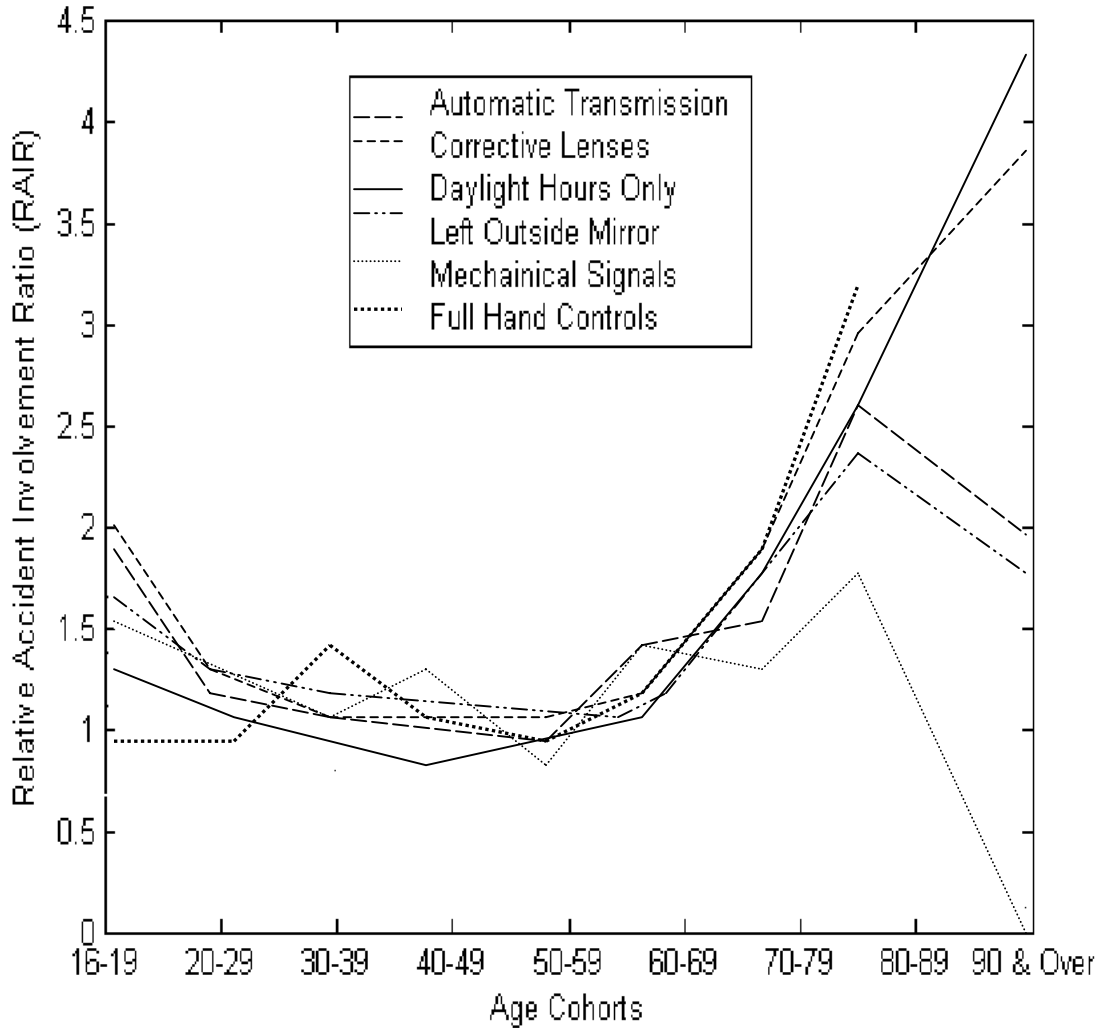


Figure 81. Relative Accident Involvement Ratio for Age Restriction Among Arizona Drivers, Years 1991 to 2001

The Wearout Period begins among ages 50 to 59 years cohorts for mechanical signals and automatic transmission age restrictions. At ages 80 to 89 years, there are peak RAIR values between 1.5 and 3 for automatic transmission, full hand controls, left outside mirror, and mechanical signals. The age 90 years and older cohorts demonstrated the highest RAIR values for corrective lenses (~3.7) and restriction daylight hours (~4.3).

Table 71. Descriptive Statistics for Automatic Transmission Restriction-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	20	58	57	54	45	43	42	16	1
Median	17	56	59	54	42	41	49	17	1
STD	13	32	28	28	27	25	24	8	1
95%CI	9	22	19	19	18	17	16	6	1
5 PCTL	3	9	14	8	10	11	2	1	0
95 PCTL	40	109	97	93	89	78	84	26	3
MIN	3	9	14	8	10	11	2	1	0
MAX	40	109	97	93	89	78	85	26	3

Table 71 shows that the highest average for automatic transmission restriction-related accidents occurs in the cohorts ages 20 to 29 years age group ($\bar{x}=58$). As age ranges diverge from the cohorts ages 20 to 29 years, the averages decrease.

Table 72. Descriptive Statistics for Corrective Lenses Restriction-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	2,964	8,247	8,592	8,245	6,241	4,701	3,955	1,644	114
Median	2,946	8,311	8,800	8,836	6,133	4,817	4,182	1,785	111
STD	609	1,323	936	1,691	1,787	692	545	282	46
95%CI	409	889	629	1,136	1,200	465	366	189	31
5 PCTL	2,031	5,891	6,705	5,114	3,545	3,461	2,917	1,125	53
95 PCTL	3,910	9,903	9,592	10,047	8,612	5,627	4,556	1,923	175
MIN	2,018	5,856	6,677	5,071	3,526	3,443	2,903	1,117	53
MAX	3,916	9,909	9,597	10,057	8,631	5,639	4,559	1,925	175

Table 72 shows that the highest average for corrective lenses restriction-related accidents occurs in the cohorts ages 30 to 39 years ($\bar{x}=8,592$). As age ranges diverge from the cohorts ages 30 to 39 years, the averages decrease.

Table 73. Descriptive Statistics for Daylight Hours Only Restriction-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	14	37	25	21	21	20	34	34	4
Median	14	42	27	21	23	20	33	33	3
STD	8	15	12	11	11	7	9	13	2
95%CI	5	10	8	7	8	5	6	9	1
5 PCTL	2	10	6	3	2	7	20	17	2
95 PCTL	26	54	46	37	37	30	49	60	7
MIN	2	10	6	3	2	7	20	17	2
MAX	26	54	47	37	37	30	49	61	7

The highest average for daylight hours only restriction-related accidents occurs in the cohorts ages 20 to 29 years age group ($\bar{x}=37$). Generally, averages lower as the age range diverge from the cohorts ages 20 to 29 years.

Table 74. Descriptive Statistics for Full Hand Control Restriction-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	2	9	10	12	6	6	8	3	0
Median	2	9	10	13	6	7	7	4	0
STD	1	4	5	5	3	3	6	2	0
95%CI	1	3	3	3	2	2	4	2	0
5 PCTL	0	1	2	4	1	1	0	0	0
95 PCTL	4	15	16	19	11	12	23	7	1
MIN	0	1	2	4	1	1	0	0	0
MAX	4	15	16	19	11	12	23	7	1

The highest average for full hand controls restriction-related accidents occurs in the cohorts ages 40 to 49 years age group ($\bar{x}=12$). Generally, averages lower as the age range diverge from these cohorts until it reaches the cohorts, ages 70 –79 years.

Table 75. Descriptive Statistics for Left Outside Mirror Restriction-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	31	129	100	102	104	122	107	33	2
Median	34	151	110	109	115	122	119	40	2
STD	17	61	27	29	29	32	44	16	2
95%CI	11	41	18	20	20	21	29	11	1
5 PCTL	6	29	37	46	56	68	25	5	0
95 PCTL	58	198	126	139	140	164	159	48	6
MIN	6	29	36	45	55	68	24	5	0
MAX	58	199	126	139	140	164	159	48	6

Table 75 shows that the highest average for left outside mirror restriction-related accidents occurs in the cohorts ages 20 to 29 years age group ($\bar{x}=129$).

Table 76. Descriptive Statistics for Mechanical Signals Restriction-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	4	5	6	5	4	3	2	1	0
Median	2	4	5	4	3	3	2	1	0
STD	8	4	5	3	2	3	2	1	0
95%CI	5	3	3	2	1	2	1	0	0
5 PCTL	0	2	1	1	1	0	0	1	0
95 PCTL	26	13	16	11	7	9	6	3	1
MIN	0	2	1	1	1	0	0	1	0
MAX	27	13	16	11	7	9	6	3	1

Table 76 shows that the highest average for mechanical signals restriction-related accidents occurs among the group ages 30 to 39 years ($\bar{x}=6$).

Table 77. Descriptive Statistics for Right, Left, and Inside Mirrors Restriction-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	9	3	3	2	2	1	1	1	0
Median	10	4	2	2	1	1	0	0	0
STD	7	2	2	3	2	1	1	1	0
95%CI	4	2	1	2	1	1	1	1	0
5 PCTL	0	0	0	0	0	0	0	0	0
95 PCTL	20	6	6	9	6	4	4	3	0
MIN	0	0	0	0	0	0	0	0	0
MAX	20	6	6	9	6	4	4	3	0

Table 77 shows that the highest average for right, left, and inside mirrors restriction-related accidents occurs in the 15 to 19 years age group ($\bar{x}=8.7273$). As age increases, averages decrease.

APPENDIX P: DESCRIPTIVE STATISTICS AND CALCULATED RISKS OF VIOLATIONS / BEHAVIOR-RELATED COLLISIONS IN THE STATE OF ARIZONA, YEARS 1991 TO 2001

Interestingly, from 1991 to 2001, we can calculate and analyze the Relative Accident Involvement Ratios of Arizona drivers of all age cohorts on the bases of select violations and behavior-related collisions.

Table 78. Relative Accident Involvement Ratios (RAIR) of Select Violations and Behaviors of Arizona Drivers for Years 1991 to 2001.

Violation/ Behavior	Low RAIR (Age Cohort)	Average RAIR	High RAIR (Age Cohort)
Disregarded traffic signal	0.6491 (40s)	1.7318	4.8074 (80s)
Drove in Opposing Traffic Lane	0.6054 (50s)	1.7638	6.3658 (80s)
Exceeded Lawful Speed	0.2752 (60s)	1.1692	3.0524 (Teenage)
Failed to Yield Right-of-Way	0.6811 (40s)	2.1116	5.253 (90s)
Followed Too Closely	0.6637 (50s)	1.359	3.0964 (80s)
Inattention	0.7263 (50s)	1.5005	3.2127 (80s)
Knowingly Operated With Faulty or Missing Equipment	0.3824 (70s)	0.9636	2.2456 (Teenage)
Made Improper Turn	0.737 (40s)	2.182	6.1776 (80s)
Other Unsafe Passing	0.7284 (40s)	1.545	5.7622 (80s)
Pass in No-Passing Zone	0.5796 (50s)	3.2319	21.4255 (80s)
Ran Stop Sign	0.5746 (40s)	2.1366	7.5814 (80s)
Speed Too Fast For Conditions	0.606 (50s)	1.2435	1.9136 (Teenage)
Unsafe Lane Change	0.755 (40s)	1.8720	5.7187 (80s)

The top three RAIR values for teenage drivers are: Exceeded lawful speed (3.0524), knowingly operated with faulty or missing equipment (2.2456), and ran stop sign (2.0425).

The top three RAIR for the age cohorts ages 20 to 29 years driver cohorts are: Exceeded lawful speed (1.3956), knowingly operated with faulty or missing equipment (1.2147), and followed too closely (1.1247). The top three RAIR for the age 30s driver cohorts are: Knowingly operated with faulty or missing equipment (0.9451), followed too closely (0.8772), and drove in the opposing traffic lane (0.8749). The top three RAIR for the age 40s driver cohorts are: Made improper turn (0.737), inattention (0.7314), other unsafe passing (0.7284). The top three RAIR for the age 50s driver cohorts are: Unsafe lane change (0.8751), made improper turn (0.8529), and failed to yield right-of-way (0.7755). The top three RAIR for the age 60s driver cohorts are: Failed to yield right-of-way (1.2552), made improper turn (1.2443), and unsafe lane change (1.1576). The top three RAIR for the age 70s driver cohorts are: Failed to yield right-of-way (2.5224), made improper turn (2.3805), and unsafe lane change (1.937). The top three RAIR for the age 80s driver cohorts are: Pass in No-Passing Zone (21.4255), ran stop sign (7.5814), and drove in opposing traffic lane (6.3658). The top three RAIR for the age 90s driver cohorts are: Failed to yield right-of-way (5.253), made improper turn (5.1705), and ran stop sign (4.2084). Of these RAIR values, the age 80s driver cohorts are 36.97 times more likely than the age 50s driver cohorts to be involved in a collision due to passing in No-Passing Zone, are 13.19 times more likely than the age 40s driver cohorts to be involved in a collision due to running a stop sign, and are 10.52 times more likely than the age 50s driver cohorts to be involved in a collision due to driving in an opposing traffic lane.

As shown in Table 78, the age 80s driver cohorts, followed by teenage driver cohorts, represent a disproportionate number of RAIR violations and at-risk behaviors in the State of Arizona, over an eleven-year period.

Table 79. Descriptive Statistics for Disregarded Traffic Signal-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	749	1,535	989	638	402	317	297	302	10
Median	798	1,561	1,016	628	406	315	300	134	10
STD	102	122	97	84	47	24	29	220	3
95%CI	68	82	65	56	31	16	20	148	2
5 PCTL	569	1,297	797	468	317	273	222	113	6
95 PCTL	843	1,681	1,114	744	455	354	331	620	16
MIN	569	1,293	794	465	316	271	219	113	6
MAX	843	1,682	1,115	746	455	354	332	621	16

This table shows that the highest average for disregarded traffic signal-related collisions in Arizona belong to the age group of the cohorts ages 20 to 29 years ($\bar{x}=1,535.3$). As the age ranges diverge from the cohorts ages 20 to 29 years group range, the average values decrease except for a slight increase for the age 80s cohorts. There is also a significant decrease for drivers in the age 90s cohorts. This may be attributable to a smaller driving population in that age group.

Table 80. Descriptive Statistics for Driving in an Opposing Traffic Lane-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	234	448	337	210	106	69	61	121	3
Median	243	445	341	220	109	70	61	38	3
STD	27	29	30	32	27	12	8	116	2
95%CI	18	19	20	22	18	8	5	78	1
5 PCTL	180	387	280	160	53	54	43	13	0
95 PCTL	269	482	387	261	145	89	71	291	5
MIN	179	385	278	159	52	54	42	13	0
MAX	270	482	388	262	146	89	71	292	5

Table 80 shows that the highest average for opposing traffic lane-related collisions in Arizona belong to the drivers ages 20 to 29 years age group ($\bar{x}=448$).

Table 81. Descriptive Statistics for Exceeded Lawful Speed-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	442	606	288	140	56	27	17	54	1
Median	424	592	286	145	55	27	14	9	1
STD	57	53	19	27	13	5	5	62	1
95%CI	38	36	13	18	9	3	4	42	1
5 PCTL	369	535	266	94	40	18	10	2	0
95 PCTL	546	682	320	178	87	35	24	155	3
MIN	368	535	266	93	40	18	10	2	0
MAX	546	682	320	179	88	35	24	156	3

Table 81 shows that the highest number of collisions for exceed lawful speed-related collisions occurs in the drivers ages 20 to 29 years group for Arizona ($\bar{x}=606.27$).

Table 82. Descriptive Statistics for Failed to Yield Right-of-Way -Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	3,580	5,733	4,105	3,033	2,024	1,781	1,936	1,480	74
Median	3,678	5,955	4,229	3,223	2,057	1,833	1,923	1,117	82
STD	561	643	384	416	357	87	142	637	24
95%CI	377	432	258	280	240	58	96	428	16
5 PCTL	2,544	4,579	3,368	2,240	1,398	1,639	1,723	795	38
95 PCTL	4,226	6,490	4,483	3,497	2,509	1,864	2,159	2,369	100
MIN	2,530	4,571	3,363	2,231	1,389	1,638	1,723	791	38
MAX	4,229	6,499	4,486	3,501	2,514	1,864	2,164	2,371	100

Table 82 shows that the highest average for failed to yield right-of-way collisions in Arizona's 11-year period belong to the drivers 20 to 29 years age group ($\bar{x}=5732.5$).

Table 83. Descriptive Statistics for Followed Too Closely-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	738	1,309	930	596	319	181	129	162	6
Median	730	1,400	976	610	311	188	143	71	6
STD	209	310	221	180	107	42	34	141	3
95%CI	141	208	149	121	72	28	23	95	2
5 PCTL	425	796	563	292	156	120	67	20	1
95 PCTL	1,034	1,718	1,179	843	465	250	166	365	11
MIN	422	793	562	289	154	120	67	19	1
MAX	1,035	1,719	1,182	847	466	251	166	366	11

Table 83 shows that the highest average for followed too closely-related collisions in Arizona's 11-year period belong to the drivers 20 to 29 years age group (\bar{x} =1309).

Table 84. Descriptive Statistics for Inattention-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	4,660	8,213	5,910	4,013	2,336	1,584	1,368	1,126	49
Median	4,621	8,034	5,994	4,036	2,232	1,541	1,392	764	45
STD	1,037	1,366	912	946	660	223	201	627	21
95%CI	697	918	612	636	443	150	135	421	14
5 PCTL	3,262	6,480	4,535	2,645	1,486	1,297	1,090	437	26
95 PCTL	6,271	10,287	7,211	5,301	3,256	1,902	1,661	1,973	94
MIN	3,253	6,467	4,523	2,633	1,481	1,294	1,087	435	26
MAX	6,293	10,313	7,231	5,318	3,261	1,904	1,663	1,975	96

Table 84 shows that the highest average for inattention-related collisions in Arizona's 11-year period belong to the drivers age 20 to 29 years (\bar{x} =8,213). As the age range becomes older, the average decreases, except for the 15 to 19 years age range (\bar{x} =4,660).

Table 85. Descriptive Statistics for ‘Knowingly Operated with Faulty or Missing Equipment’ -Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	110	179	127	72	35	14	7	9	0
Median	114	184	125	72	36	13	7	4	0
STD	15	29	17	15	8	5	3	8	1
95%CI	10	19	11	10	5	3	2	6	0
5 PCTL	82	133	107	51	18	7	3	1	0
95 PCTL	124	221	159	98	45	22	11	23	2
MIN	82	133	107	51	18	7	3	1	0
MAX	124	222	159	99	45	22	11	23	2

Table 85 shows that the highest average for ‘Knowingly Operated with Faulty or Missing Equipment’-related collisions in Arizona’s 11-year period belong to the drivers ages 20 to 29 years (\bar{x} =178.55).

Table 86. Descriptive Statistics for ‘Made Improper Turn’-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	563	972	776	592	401	318	329	317	13
Median	592	996	800	616	389	315	339	197	13
STD	119	143	85	112	95	22	29	193	6
95%CI	80	96	57	75	64	15	20	130	4
5 PCTL	388	758	647	414	263	285	279	118	5
95 PCTL	721	1,164	884	738	530	354	362	595	26
MIN	387	756	646	412	263	284	278	118	5
MAX	721	1,166	885	740	531	354	362	596	26

Table 86 shows that the highest average for ‘Made Improper Turn’-related collisions in Arizona’s 11-year period belong to the drivers ages 20 to 29 years (\bar{x} =972).

Table 87. Descriptive Statistics for ‘No Improper Driving’-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	8,539	25,623	23,343	18,039	10,572	5,748	3,108	1,153	57
Median	8,689	26,115	24,414	18,814	10,332	5,855	3,172	931	52
STD	1,390	3,153	2,909	3,428	2,760	711	393	566	31
95%CI	934	2,118	1,954	2,303	1,854	478	264	380	21
5 PCTL	6,376	20,052	17,809	11,906	6,556	4,413	2,353	475	21
95 PCTL	10,371	29,680	26,320	22,089	14,328	6,564	3,562	1,915	109
MIN	6,364	20,003	17,753	11,823	6,530	4,390	2,341	474	21
MAX	10,376	29,740	26,333	22,113	14,345	6,567	3,567	1,916	109

Table 87 shows that the highest average for ‘No Improper Driving’-related collisions in Arizona’s 11-year period belong to the drivers 20 to 29 years age group (\bar{x} =25623).

Table 88. Descriptive Statistics for Other Violations/ Behavior-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	943	2,029	1,590	1,129	624	370	255	474	8
Median	956	2,079	1,641	1,165	603	381	264	104	8
STD	160	299	229	221	160	57	41	534	3
95%CI	107	201	154	148	107	38	28	359	2
5 PCTL	552	1,255	1,030	734	406	238	153	65	4
95 PCTL	1,150	2,306	1,851	1,441	870	434	302	1,296	14
MIN	536	1,221	1,008	728	404	233	150	64	4
MAX	1,153	2,309	1,856	1,444	872	434	303	1,303	14

Table 88 shows that the highest average for Other Violations/ Behavior -related collisions in Arizona’s 11-year period belong to the drivers ages 20 to 29 years (\bar{x} =2028.9).

Table 89. Descriptive Statistics for Other Unsafe Passing-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	152	294	212	143	79	52	40	72	1
Median	157	303	220	137	79	50	38	23	1
STD	25	35	32	30	21	10	8	72	1
95%CI	17	23	22	20	14	7	5	49	1
5 PCTL	116	235	160	99	52	37	30	7	0
95 PCTL	181	336	252	192	105	69	54	189	3
MIN	116	235	160	98	52	37	30	7	0
MAX	181	336	252	193	105	69	54	190	3

Table 89 shows that the highest average for other unsafe passing-related collisions for Arizona drivers occurs in the drivers ages 20 to 29 years (\bar{x} =294).

Table 90. Descriptive Statistics for ‘Pass in No Passing Zone’-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	63	137	103	74	40	28	24	162	1
Median	32	62	41	27	11	9	8	5	0
STD	107	252	216	157	96	64	56	499	2
95%CI	72	169	145	106	64	43	38	335	1
5 PCTL	24	49	27	17	7	4	4	0	0
95 PCTL	367	854	720	522	313	210	185	1,585	6
MIN	24	49	27	17	7	4	4	0	0
MAX	384	895	755	547	329	220	194	1,667	6

Table 90 shows that the highest average number of collisions for ‘Pass in No Passing Zone’-related collisions in Arizona belong to the cohorts ages 80 –89 years range group (\bar{x} =162).

Table 91. Descriptive Statistics for Ran Stop Sign-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	289	447	267	172	103	87	82	145	4
Median	290	463	270	183	106	86	82	47	4
STD	34	49	25	32	25	13	11	136	3
95%CI	23	33	17	21	17	9	8	91	2
5 PCTL	230	368	226	123	71	70	64	29	0
95 PCTL	341	487	310	210	141	105	100	368	10
MIN	229	368	225	123	71	70	64	29	0
MAX	342	487	311	210	141	105	100	370	10

Table 91 shows that the highest average for ran stop sign-related collisions belong to the drivers ages 20 to 29 years (\bar{x} =447).

Table 92. Descriptive Statistics for ‘Speed Too Fast for Conditions’-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	6,501	12,271	8,101	4,988	2,549	1,401	955	1,467	30
Median	6,596	12,273	8,473	5,096	2,505	1,416	981	412	29
STD	1,045	1,385	954	1,011	618	137	117	1,417	12
95%CI	702	930	641	679	415	92	79	952	8
5 PCTL	4,911	10,048	6,251	3,353	1,571	1,165	711	234	10
95 PCTL	7,929	14,040	9,106	6,080	3,316	1,612	1,120	3,501	52
MIN	4,903	10,023	6,228	3,340	1,558	1,161	703	233	10
MAX	7,939	14,041	9,109	6,081	3,317	1,616	1,123	3,507	53

Table 92 shows that the highest average for ‘speed too fast for conditions’-related collisions belong to the drivers ages 20 to 29 years (\bar{x} =12,271).

Table 93. Descriptive Statistics for Unsafe Lane Change-Related Collisions of Arizona, Years 1991 to 2001.

Age	15-19	20s	30s	40s	50s	60s	70s	80s	90s
Average	658	1,309	988	747	508	365	330	362	10
Median	693	1,377	1,039	756	471	371	361	161	7
STD	164	272	167	183	146	40	53	285	7
95%CI	110	182	112	123	98	27	35	192	4
5 PCTL	411	903	665	473	300	294	236	79	4
95 PCTL	863	1,652	1,166	1,000	699	415	393	759	24
MIN	410	902	658	472	298	293	235	77	4
MAX	863	1,653	1,166	1,001	700	415	394	760	24

Table 93 shows that the highest average for unsafe lane change-related collisions belong to the age group 20 to 29 years (\bar{x} =1,309).

APPENDIX Q: COMPARISON OF AVERAGE INDIVIDUAL RISKS OF COLLISIONS, INJURIES, AND FATALITIES OF ARIZONA AND FLORIDA DRIVERS, YEARS 1991 TO 2001

Risk calculations are often used to quantify radioactive releases and predict nuclear power reactor accident sequence frequencies (McCormick, 1981). However, in our study, we can illustrate Average Individual Risks associated with collisions, fatalities, or injuries. Risk methodologies are also useful as a method of ranking risks and prioritizing measures to prevent collisions.

Table 94. Thresholds of Annual Fatality Risk Levels According to Otway and Erdmann

Annual fatality Risk level, yr⁻¹	Conclusion
10 ⁻³	This level is unacceptable to everyone. Accidents providing hazard at this level are difficult to find. When risk approaches this level, immediate action is taken to reduce the hazard.
10 ⁻⁴	People are willing to spend public money to control a hazard (traffic signs/ control and fire departments). Safety slogans popularized for accidents in this category show an element of fear, i.e., “the life you save may be your own”
10 ⁻⁵	People still recognize. People warn children about these hazards (drowning, firearms, poisoning). People accept inconveniences to avoid, such as avoiding air travel. Safety slogans have precautionary ring: “never swim alone, “ “never point a gun,” “never leave medicine within a child’s reach.”
10 ⁻⁶	Not of great concern to average person. People aware of these accidents but feel that they can’t happen to them. Phrases associated with these hazards have element of resignation: “lightning never strikes twice,” “an act of God”
10 ⁻⁷	Acceptable risk of death to an individual from nuclear power plant accidents.

H. J. Otway and R. C. Erdmann, 1970, *Nuclear Engineering Design*, **13**, 365, as cited in McCormick, p.370.

Table 95. Average Individual Risk of Collisions

Age	Arizona	Florida
16-19	1.14E-01	6.71E-02
20- 24	1.09E-01	4.51E-02
25- 34	8.82E-02	3.19E-02
35- 44	6.28E-02	2.68E-02
45- 54	5.13E-02	2.26E-02
55- 64	4.69E-02	1.89E-02
65- 74	3.71E-02	1.50E-02
75 & over	6.42E-02	1.49E-02

According to Table 95, the Average Individual Risk of Collisions is greatest for the Arizona drivers: ages 16 to 19 years cohorts (1.14 E-01), ages 20 to 24 years cohorts (1.09E-01), and ages 25 to 34 years cohorts (8.82E-02). The lowest Average Individual Risk of Collisions among Arizona drivers is the ages 65 to 74 years cohorts (3.71E-02). However, the Average Individual Risk of Collisions Florida drivers is highest among age 16 to 19 years cohorts (6.71E-02), ages 20 to 24 years cohorts (4.51E-02), and ages 25 to 34 years cohorts (3.19E-02). The age 75 years and older cohorts (1.49E-02) have the lowest Average Individual Risk of Collisions among Florida drivers. It is interesting to also note that Arizona drivers in all age cohorts have higher Average Individual Risks of Collisions than Florida drivers. Arizona drivers age 75 years and older are more than four more times as likely to be at risk of collision than Florida drivers of the same age group.

Table 96. Average Individual Risk of Injuries

Age	Arizona	Florida
16-19	4.53E-02	2.76E-02
20- 24	4.36E-02	1.88E-02
25- 34	3.52E-02	1.31E-02
35- 44	2.48E-02	1.10E-02
45- 54	2.01E-02	9.27E-03
55- 64	1.86E-02	7.67E-03
65- 74	1.46E-02	6.20E-03
75 & over	2.61E-02	6.33E-03

According to Table 96, the Average Individual Risk of Injuries, similar to the Average Risks of Collisions of Figure 96, is highest among Arizona drivers. The Arizona driver age groups with the greatest Average Individual Risk of Injuries include: ages 16 to 19 years cohorts (4.53E-02), ages 20 to 24 years cohorts (4.36E-02), and ages 25 to 34 years cohorts (3.52E-02). The lowest Average Individual Risk of Injuries among Arizona drivers is the age 65 years and older cohorts (1.46E-02). However, the Average Individual Risk of Injuries among Florida drivers is highest among ages 16 to 19 years cohorts (2.76E-02), ages 20 to 24 years cohorts (1.88E-02), and ages 25 to 34 years cohorts (1.31E-02). The ages 65 to 74 years cohorts (6.20E-03) have the lowest

Average Individual Risk of Injuries among Arizona drivers. Arizona drivers age 75 years and older, on average, are more than four times as likely to be at an individual risk of injury than Florida drivers of the same age group.

Table 97. Average Individual Risk of Fatalities

Age	Arizona	Florida
16-19	5.83E-04	2.41E-04
20- 24	6.45E-04	1.79E-04
25- 34	5.29E-04	1.17E-04
35- 44	3.69E-04	1.04E-04
45- 54	3.03E-04	9.43E-05
55- 64	3.08E-04	9.18E-05
65- 74	2.86E-04	1.01E-04
75 & over	6.65E-04	2.00E-04

According to Table 97, the Average Individual Risk of Fatalities, similar to the Average Risks of Collisions of Figure 96, is highest among Arizona drivers. The Arizona driver age groups with the greatest Average Individual Risk of Injuries include: ages 16 to 19 years cohorts (4.53E-02), ages 20 to 24 years cohorts (4.36E-02), and ages 25 to 34 years cohorts (3.52E-02). The lowest Average Individual Risk of Injuries among Arizona drivers age 65 years and older is 1.46E-02. However, the Average Individual Risk of Injuries among Florida drivers is highest among ages 16 to 19 years cohorts (2.76E-02), ages 20 to 24 years cohorts (1.88E-02), and ages 25 to 34 years cohorts (1.31E-02). The ages 65 to 74 years cohorts (6.20E-03) have the lowest Average Individual Risk of Injuries among Arizona drivers. Arizona drivers age 75 years and older, on average, are more than four times as likely to be at an individual risk of injury than Florida drivers of the same age group.

According to the Thresholds of Annual Fatality Risk Levels (Table 94), these Average Individual Risk of Fatalities may encourage people to control these safety hazards.

Table 98. Yearly Individual Risk of Age 80s Arizona Drivers

Year	Driver Licensees by Age 80s	'Pass in No- Passing Zone'	'Ran Stop Sign'	'Drove in Opposing Traffic Lane'
1991	54,001	5.56E-05	5.74E-04	2.41E-04
1992	59,252	0.00E+00	4.89E-04	3.71E-04
1993	65,507	7.63E-05	4.89E-04	3.05E-04
1994	116,301	1.38E-04	1.79E-03	1.87E-03
1995	131,819	2.58E-04	2.81E-03	2.22E-03
1996	137,415	1.96E-04	2.41E-03	1.95E-03
1997	77,230	3.24E-04	3.95E-03	3.48E-03
1998	96,876	1.72E-02	1.59E-03	1.27E-03
1999	97,930	2.04E-05	4.29E-04	3.78E-04
2000	100,419	3.98E-05	4.58E-04	3.78E-04
2001	103,077	1.94E-05	4.56E-04	3.20E-04
Average	94,530	1.67E-03	1.40E-03	1.16E-03

According to Table 98, the greatest individual risks are computed for “Pass in No-Passing Zone,” “Ran Stop Sign”, and “Drove in Opposing Traffic Lane. The greatest yearly individual risk, among these calculated risks is “Pass in No Passing Zone.

APPENDIX R: ARIZONA COLLISION RATES BY RESTRICTIONS, VIOLATIONS, AND BEHAVIORS, YEARS 1991 TO 2001

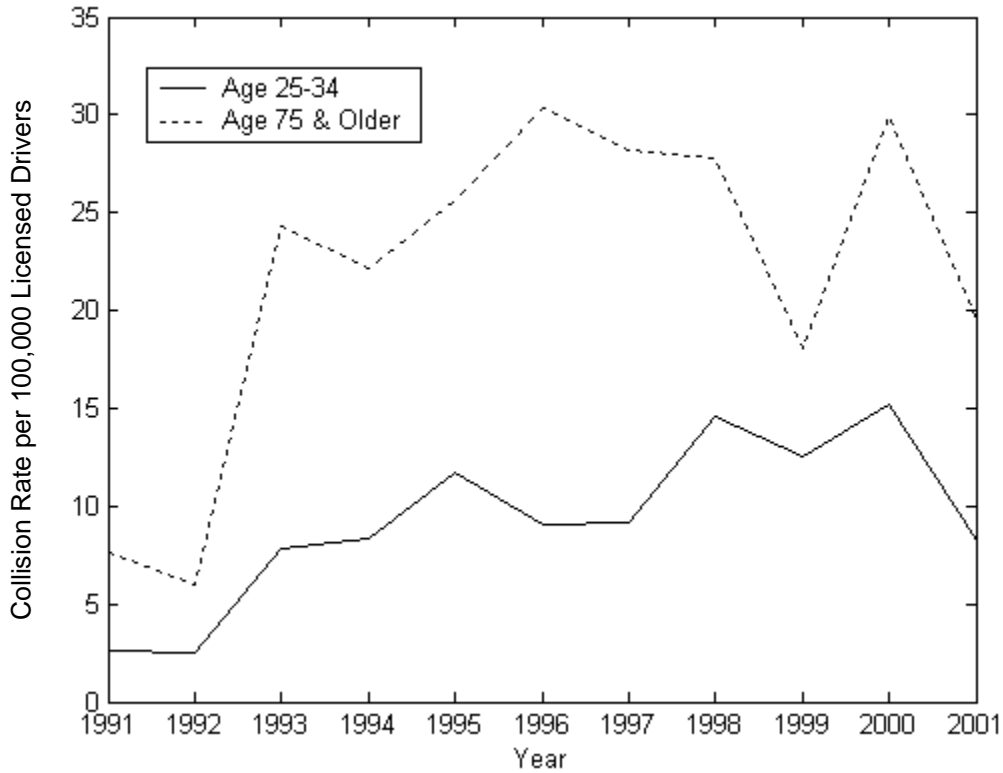


Figure 82. Collision Rate By Restriction “Automatic Transmission” for Arizona Drivers

Over an eleven year period, from 1991 to 2001, the collision rate, per 100,000 licensed drivers, by restriction “automatic transmission”, among drivers age 75 years and older, may be as high as three times the rate for drivers ages 25 to 34 years. Overall, there is an increase in these collision rates for both cohorts.

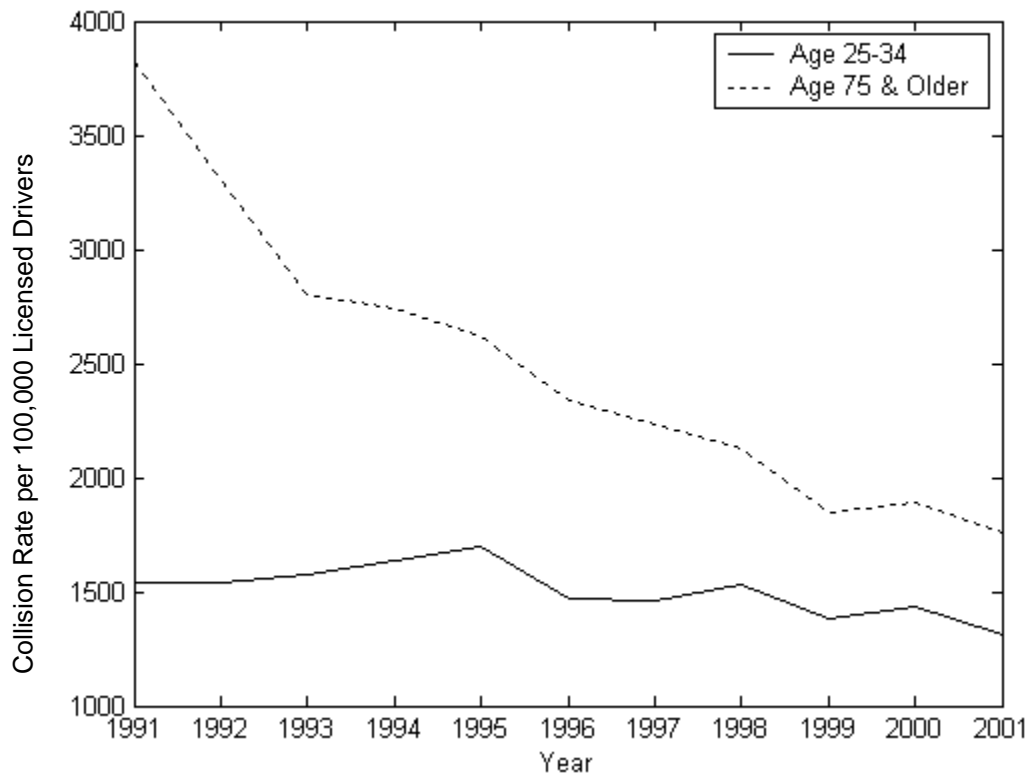


Figure 83. Collision Rate By Restriction “Corrective Lenses” for Arizona Drivers

Over an eleven year period, from 1991 to 2001, the collision rate, per 100,000 licensed drivers, by restriction “automatic transmission”, among drivers age 75 years and older, may be twice as high as the rate for drivers ages 25 to 34 years. Overall, there is a decrease in these collision rates for both cohorts.

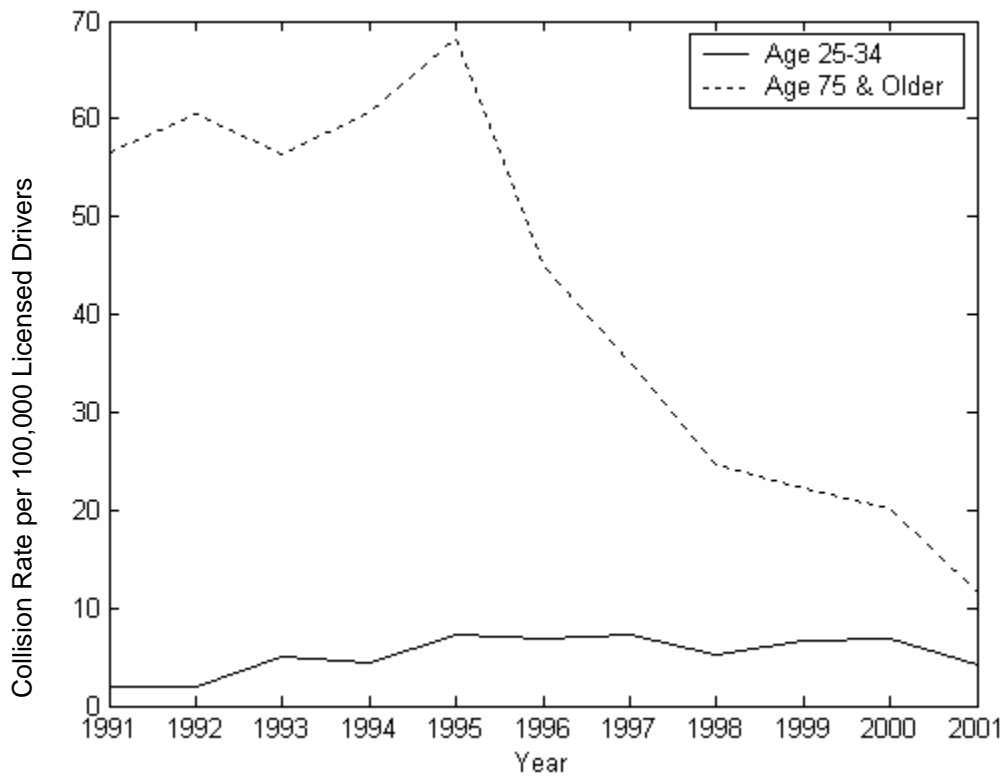


Figure 84. Collision Rate By Restriction “Daylight Hours” for Arizona Drivers

Over an eleven year period, from 1991 to 2001, the collision rate, per 100,000 licensed drivers, by restriction “daylight hours”, among drivers age 75 years and older, may be as high as seven times the rate for drivers ages 25 to 34 years. Overall, there is a decrease in the collision rates for the age 75 years and older cohorts and a very small increase in these collision rates for the drivers ages 25 to 34 years.

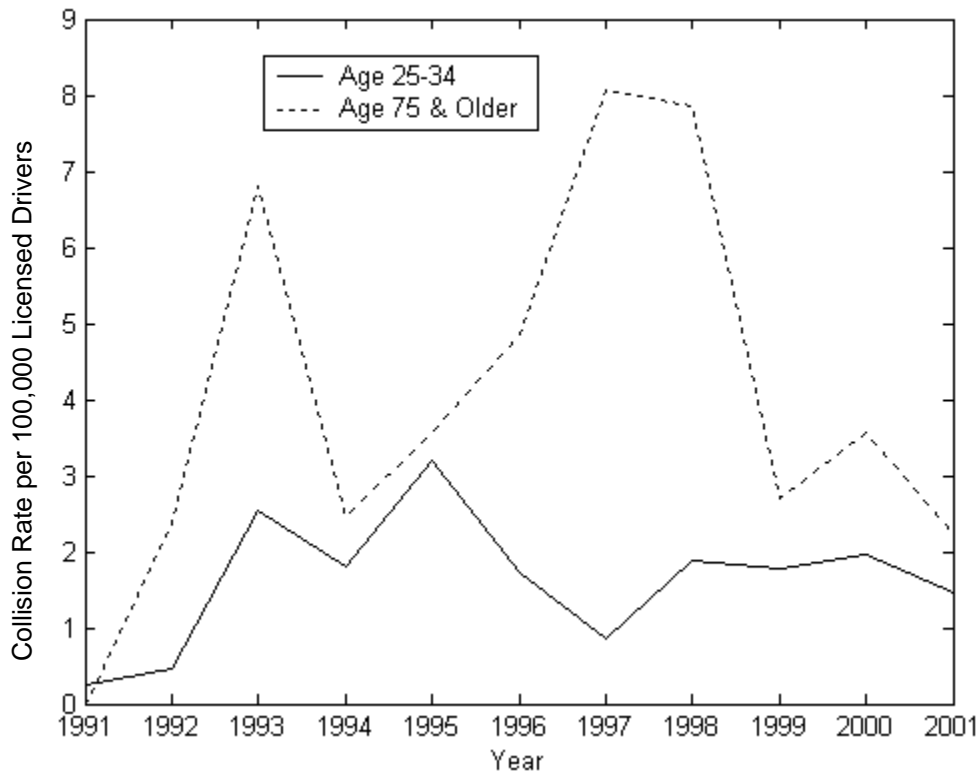


Figure 85. Collision Rate By Restriction “Full Hand Controls” for Arizona Drivers

Over an eleven year period, from 1991 to 2001, the collision rate, per 100,000 licensed drivers, by restriction “full hand controls”, among drivers age 75 years and older, may be eight times as high as three times the rate for drivers ages 25 to 34 years. Overall, there is an increase in these collision rates for both cohorts.

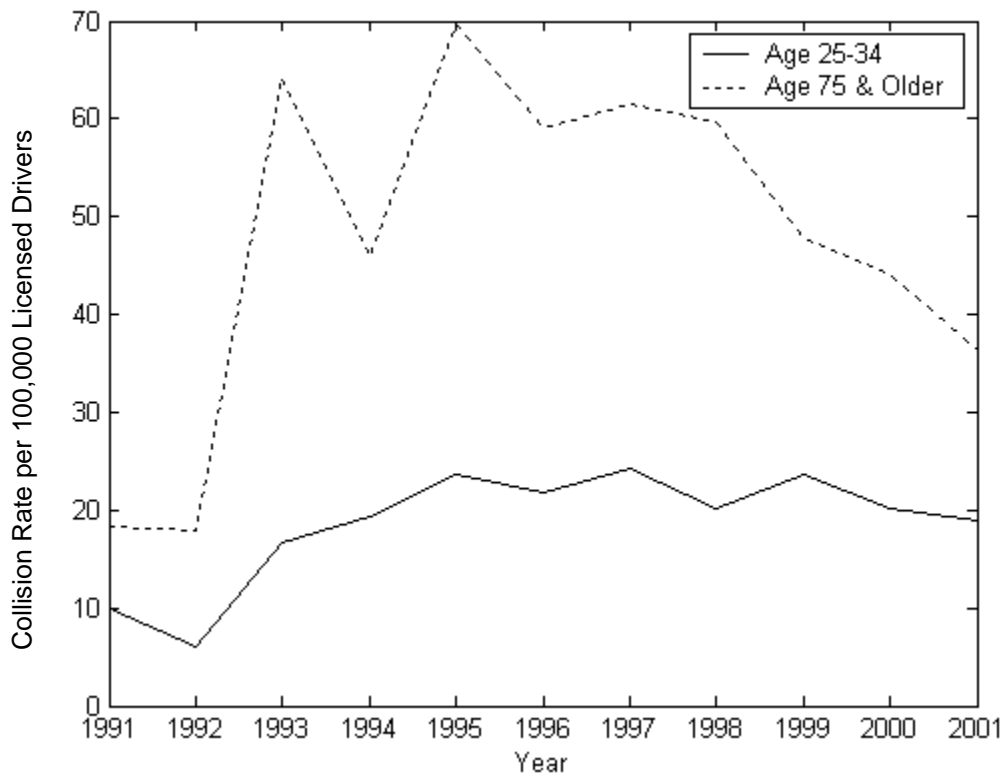


Figure 86. Collision Rate By Restriction “Left Outside Mirror” for Arizona Drivers

Over an eleven year period, from 1991 to 2001, the collision rate, per 100,000 licensed drivers, by restriction “left outside mirror”, among drivers age 75 years and older, may be as high as three times the rate for drivers ages 25 to 34 years. Overall, there is an increase in these collision rates for both cohorts.

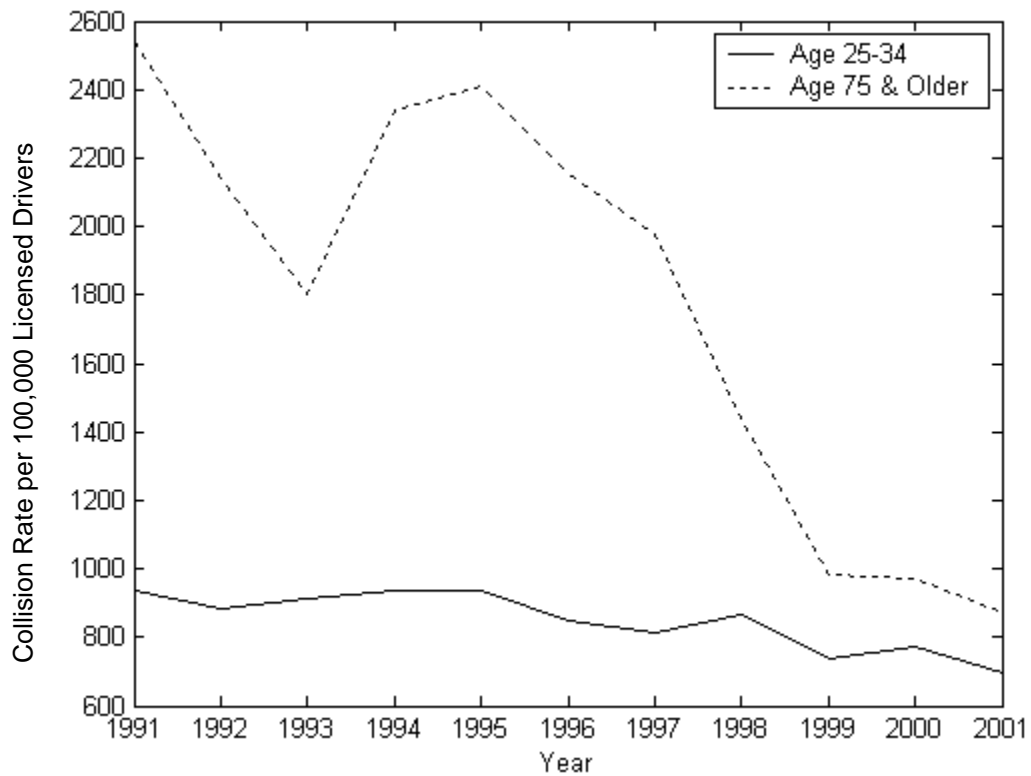


Figure 87. Collision Rate By “Failed to Yield Right of Way” for Arizona Drivers

Over an eleven year period, from 1991 to 2001, the collision rate, per 100,000 licensed drivers, by restriction “failed to yield right of way”, among drivers age 75 years and older, may be twice as high as the rate for drivers ages 25 to 34 years. Overall, there is a decrease in these collision rates for both cohorts.

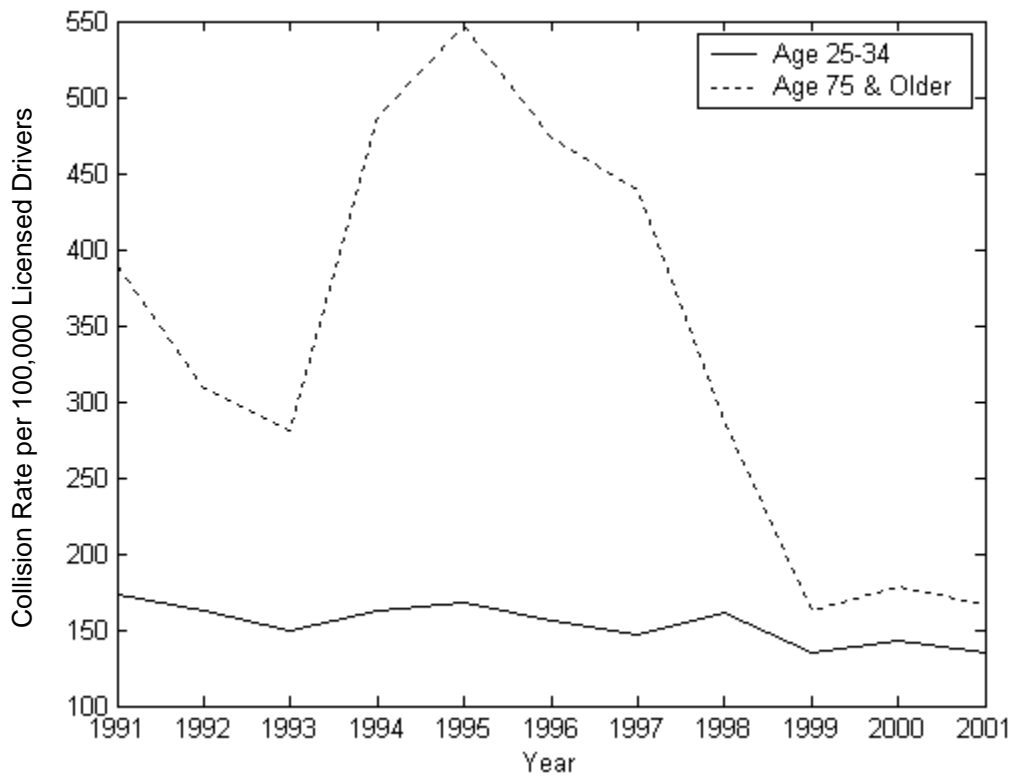



Figure 88. Collision Rate By Restriction “Made Improper Turn” for Arizona Drivers

Over an eleven year period, from 1991 to 2001, the collision rate, per 100,000 licensed drivers, by restriction “made improper turn”, among drivers age 75 years and older, may be twice as high as the rates for drivers ages 25 to 34 years. Overall, there is a decrease in these collision rates for both cohorts.

APPENDIX S: VISION SCREENING DEVICES


The following vision screening devices were identified through extensive research, interviews, and/or live presentations. It is important to note that each of these products fill a niche for vision testing improvements. So all deserve a more thorough review to meet the demands of different settings. Nevertheless, our review is not an exhaustive one. We merely highlight vision screening devices of interest:

Table 99. Special Features and Manufacturers of Vision Testing Equipment

Vision Testing Equipment & Manufacturer	Special Features
<p>TransAnalytics LLC B1Max™ VACS Visual Acuity and Contrast Sensitivity Test Marketed through Mr. Robert Morgan ESRA DAT™ Sales Division ESRA Consulting Corporation 1650 South Dixie Highway, Third Floor Boca Raton, Florida 33432 USA Telephone: (561) 361-0004 Arizona Fax: (520) 844-8555 e-mail: dat@esracorp.com web: http://www.esracorp.com</p> 	<ul style="list-style-type: none"> • may be highly recommended based on the performance of the DRIVINGHEALTH® INVENTORY (DHI) during multiple years of scientific study as a tool used for driver evaluations by the Medical Advisory Board of the Maryland Motor Vehicle Administration. • Widely distributed as a component of the AAA Roadwise Review™. • Computer-automated tests • Automatic scoring. • Rapidly tests high and low contrast visual acuity in approximately 5 minutes or less. • Prevents cheating. • Saves and formats results per clients' database requirements. • Immediate printable feedback that relates measured acuity to collision risk. • Presents screening instructions in English and Spanish. • Optional verbal/ spoken narration.

Vision Testing Equipment & Manufacturer	Special Features
3-D Computer-Automated Threshold Amsler Grid Test Wolfgang Fink, Ph. D. Visiting Associate in Physics at Caltech 305 W. K. Kellogg Radiation Laboratory California Institute of Technology Mail Code 106-38, Pasadena, California 9125 Phone: (626) 395-4587 FAX: (626)-564-8708 wfink@krl.caltech.edu http://www.wfbabcom5.com/wf335.htm	<ul style="list-style-type: none"> • Potentially screens any visual disease or injury that affects the central visual field, including glaucoma and AMD.
Juno RVP123P Tulsa, Oklahoma http://www.junosystemsinc.com/prod02.htm	<ul style="list-style-type: none"> • visual acuity • color vision • depth perception • phoria • some peripheral vision
Juno RV123PN Tulsa, Oklahoma http://www.junosystemsinc.com/prod02.htm	<ul style="list-style-type: none"> • visual acuity • color vision • depth perception • phoria • some peripheral vision
Keystone DVS-GT Drivers Vision Screener with glare testing - 110 volt (also available in 220 volt) Keystone View Reno, Nevada http://www.keystoneview.com	<ul style="list-style-type: none"> • Normal viewing with illumination by reflected lights • Glare recovery testing (night driving with oncoming headlights) • Eight stereoscopic vision tests • Hand Control, Visual acuity • Color perception • Phoria, eye balance • Stereopsis, Depth perception • Contrast sensitivity
Keystone DVS-III Drivers Vision Screener - 110 Volt (also available in 220 volt) Keystone View Reno, Nevada http://www.keystoneview.com	<ul style="list-style-type: none"> • Same as above without contrast sensitivity and glare recovery features

Vision Testing Equipment & Manufacturer	Special Features
Optec 1000 Stereo Optical (Chicago, Illinois) http://www.stereooptical.com/	Acuity Color Muscle Balance Optional contrast sensitivity
Optec 2000 Stereo Optical (Chicago, Illinois) http://www.stereooptical.com/	<ul style="list-style-type: none"> • Standardized glare source test • 12 different slide tests • Distance/ Near Testing • Peripheral Test
Optec 5000 Stereo Optical (Chicago, Illinois) http://www.stereooptical.com/	<ul style="list-style-type: none"> • Manual • Optional peripheral test
Optec 5500 Stereo Optical (Chicago, Illinois) http://www.stereooptical.com/	<ul style="list-style-type: none"> • Remote control • Optional peripheral test
Optec 6500 Stereo Optical (Chicago, Illinois) http://www.stereooptical.com/	<ul style="list-style-type: none"> • Day/ night • Day/ night/ glare • Peripheral Test • Distance/ Near Testing • Remote Control • Radial Glare Source
Roadwise Review American Automobile Association (AAA) AAA Arizona Club Office 3144 North 7th Ave Phoenix, AZ 85013 (602)274-1116 \$15 retail or free usage at many libraries and senior centers nationwide	<ul style="list-style-type: none"> • Self-assessment of eight functional areas including high contrast visual acuity, low visual acuity, Useful Field of View, visualization of missing information, visual search.
Titmus	<ul style="list-style-type: none"> • Acuity • Depth perception • Muscle Balance (Lateral and Vertical Balance) • Horizontal Visual Fields

Vision Testing Equipment & Manufacturer	Special Features
Titmus 2a	<ul style="list-style-type: none"> • 8 test slides • remote control
Titmus 2s	<ul style="list-style-type: none"> • • 8 test slides • manual
<p>Useful Field of View Test (UFOV® test) Visual Awareness, Inc. TransAnalytics, LLC Marketed through Mr. Robert Morgan ESRA DAT™ Sales Division ESRA Consulting Corporation 1650 South Dixie Highway, Third Floor Boca Raton, Florida 33432 USA Telephone: (561) 361-0004 Arizona Fax: (520) 844-8555 e-mail: dat@esracorp.com web: http://www.esracorp.com</p> 	<ul style="list-style-type: none"> • Computerized visual attention and visual information processing speed test. • Optional touch screen technology • Fast and effective measure of visual information processing speed and visual attention. • Network capable. • Most updated version. • Demonstrated usage in MVD settings. • Widely distributed through AAA Roadwise Review™ as part of DRIVING HEALTH INVENTORY®.
<p>Vision Rx Professional Vision Test Software VisionRx LLC 16 Heronvue Greenwich, CT 06831 Tel. 203-863-2050 Fax. 203-869-5775 www.visionrx.com jls@visionrx.com http://www.visionrx.com/dmv.asp EyeTester™ module, computer and touch screen monitor</p>	<ul style="list-style-type: none"> • Computer-automated tests • randomized • Color vision • Contrast sensitivity • Visual Acuity • Visual Field

Please refer to page 99- 101 for information on the recommended vision screening system.

APPENDIX T: DRIVING SIMULATORS

The following simulators are identified and evaluated through an on-line search. There appear to be numerous driving simulators under development and in use for research purposes at both national and international universities. Some research driving simulators are prototypes constructed and designed exclusively for study at university facilities. Others are developed solely for analyses of various road conditions and possible hazards (e.g., cell phone usage). Several commercial driving simulators are already in place at driving schools, medical facilities, and military installations. Many are based on or serve as a basis for driving simulator games that are popular in the toy and CD/ DVD/ video markets. It is important to note that each of these research driving simulators and commercial driving simulator products fill a niche for road safety and improvements. So all deserve a more thorough review to meet the demands of different settings. Please refer to pages 96- 97 for additional information. No driving simulators currently exist in transportation licensing agencies or medical facilities for the system and/ or methodologies we envisage as part of the ESRA DVAT™, ESRA DAT™, and/ or ESRA VAPT™. We caution on the use of any driving simulator. A review of references, peer-reviewed publications, and independent safety and performance records are recommended. Please refer to the ESRA Consulting Corporation disclaimer at the beginning of this report. This report is for informational purposes only. Readers are encouraged to confirm the information contained herein with other sources. The information is not intended to replace medical advice offered by physicians. Reliance on any information in this report is solely at your own risk. ESRA Consulting Corporation is not responsible or liable for any direct, indirect, consequential, special, exemplary, or other damages arising from any use of any product, information, idea, or instruction contained in this report and all publications and presentations therefrom. Nevertheless, our review is not an exhaustive one. We merely highlight products of interest:

Table 100. Motor Vehicle Driving Simulators and Special features.


Motor Vehicle Driving Simulator & Website URL Address*	Special Features**
AutoSim AS 100 Car Research Simulator (Norway) http://www.autosim.no/	-Actual automobile -Different motion systems -Three screens
Cardiff University School of Psychology Human Interfaces and Virtual Environments Laboratory Driving Simulator (United Kingdom) http://www.cf.ac.uk/psych/ruddle/C-HIVE/Drive/	-Fog densities -realistic graphics
Center for Advanced Transportation Systems at University of Central Florida (CATSS) Simulator (USA) http://www.catss.ucf.edu/	-ambient traffic -random movements -limited visibility -weather controls -numerous scenarios

Motor Vehicle Driving Simulator & Website URL Address*	Special Features**
Center for Intelligent Systems Research Driving simulator at George Washington University (USA) http://www.cisr.gwu.edu/lab_simulator.html	-eye-tracking data -curved screen -135-degree wide-angle field of view
Centre de développement des transports, Transports Canada, and University of Calgary (Canada) Driving Simulator http://www.tc.gc.ca/cdt/publication/actualites/v12n1.htm	-dynamic setting -critical events -street and highway configurations -actual automobile -150 degree field of view -eye movement system
Chalmers University of Technology Driving Simulator (Sweden) http://www.me.chalmers.se/5/1.shtml	-small hexapod -motion
Computer Graphics Systems Development Corporation Virtual Reality Driving Simulator DS-230 (USA) http://www.cgsd.com/DrivingSimulator/index.html	-collision detection
Cranfield University Driving Research Unit Driving Simulator (United Kingdom) http://www.drive.cranfield.ac.uk/cfml/ldorn.cfm	-driver behavior studies -driver performance measurements
DaimlerChrysler Driving Simulator (Germany) http://www.daimlerchrysler.com/	-hexapod -lateral motion system
Doron Precision Systems, Inc. Driver Analyzer (USA) http://www.doronprecision.com/	-three operational modes driving simulator
DriveSafety™ Simulator, (via GlobalSim), (USA) DriveSafety, Inc. 1125 West Center Street Orem, Utah 84057 Telephone: (888)314-0082 http://www.drivesafety.com	-tile-based scene authoring. -event and behavior triggers. -data collection features. -self-customization features. -many research and testing applications.

Motor Vehicle Driving Simulator & Website URL Address*	Special Features**
Drive Square Portable Road Simulator Drive Square LLC. 831 Beacon Street, Ste. 283 Newton Centre, MA 02459 Phone: (617) 762-4013 http://www.drivesquare.com	- models road conditions - uses actual vehicle - Head Mounted Display (HMD) - Simulator sensors and actuators quickly and non-invasively attached to the vehicle. - Interactive driving conditions including ambient road and weather scenarios.
Dynamic Research, Inc. Driving Simulator (USA) http://www.dynres.com/simulator.html	-actual automobile -numerous configurations -repeatable conditions
Dr. Ing. Reiner Foerst GmbH Fahrmaschinen (Germany) http://www.drfoerst.de/simulator.htm	-weather conditions -actual automobile
FAAC Incorporated (USA) http://www.faac.com/Driving_Simulators.htm	-variable lighting and weather conditions
Fachhochschule Esslingen Hochschule für Technik Projekt EVA (Esslinger Virtuelles Auto) Fahrmaschinen (Germany) http://www2.fht-esslingen.de/fachbereiche/fz/proj/eva/index.html	-real motor vehicle
Federal Highway Administration (FHWA), Human Factors Laboratory, Highway Driving Simulator (HYSIM) (USA) http://www.tfhr.gov/pubrds/winter94/p94wi19.htm	-modified car cab in use since 1983
Ford Motor Company Virtual Test Track Experiment (VIRTEX) Driving Simulator (USA) http://www.ford.com/en/innovation/safety/driver-DistractionLab.htm	-180 degrees field of view -dome-like structure
Fraunhofer Institut Verkehrs- und Infrastruktursysteme (IVI) (Germany) Fahrmaschinen, Die Fraunhofer-Gesellschaft http://www.ivi.fhg.de/frames/german/projects/produktbl/fahrmaschinen_strasse.pdf	-actual car with large and realistic roadway screen projections
General Electric (GE) Driver Development Driving Simulator (USA) http://www.cefcorp.com/driverdev/	-actual automobile -large dome-like structure
Grupo Simulación Conducción (Spain) Driving Simulator http://www.gscautosim.com/	-aerodynamic design
Honda Driving Simulators http://world.honda.com/safety/	-6 axis motion base

Motor Vehicle Driving Simulator & Website URL Address*	Special Features**
Institut für Kraftfahrwesen und Kolbenmaschinen Universität der Bundeswehr Hamburg Fahrsimulator (Germany) http://www.unibw-hamburg.de/MWEB/ikk/fkw/simulator/simulatoren.html#allgemeines	-brake behavior -control forces
Institut für Psychologie der Universität Würzburg Lehrstuhl III, Interdisziplinäres Zentrum für Verkehrswissenschaften, der simulator (Germany) http://www.psychologie.uni-wuerzburg.de/methoden/methff.html	-part of an actual car fitted with devices in a projection screened Stewart Platform
Institut National de Recherche Sur Les Transports et Leur Securite SIM ² Driving simulator and simulation CIR-MSIS (France) http://www.inrets.fr/ur/simus/sim2e.htm	-realistic graphics
Instructional Technologies (formerly Illusion Technologies International, Inc. (ITI) of (Ishington)) Driving Simulators http://www.tread1.com	- computer based trainers (CBTs)
Japanese Civil Engineering Research Institute (Japan) http://www2.ceri.go.jp/eng/e3b.html	-winter conditions -diversified drivers
KookMin University Driving Simulators (Korea) http://vc.kookmin.ac.kr/ds/index.htm	-motion-based -wide Field-of-View visual system -Stewart Platform
Lehrstuhl für Fahrzeugtechnik der TU München (Germany) (München Technical University FTM Driving Simulator) http://www.ftm.mw.tum.de/english/institute/projects/drivingsimulator.htm	-projection dome design -"fixed screen" concept with a Stewart platform.
Monash University Accident Research Centre Advanced Driving Simulator (Australia) http://www.general.monash.edu.au/MUARC/simsite/simhome.html	-Mid-Range Driving Simulator
National Advanced Driving Simulator (NADS) at The University of Iowa (USA) http://www.nads-sc.uiowa.edu/	-dubbed world's most advanced ground vehicle simulator - 360-degree field of view
Northeastern University Virtual Environments Laboratory Driving Simulator (USA) http://www1.coe.neu.edu/~mourant/velab.html	-glare -weather conditions -lighting changes
Oak Ridge National Laboratory (USA) In-Vehicle Information System Driving Platform (IVIS) http://www.csm.ornl.gov/ivisdc.html	-actual automobile - eye-gaze research apparatus

Motor Vehicle Driving Simulator & Website URL Address*	Special Features**
Raydon (USA) Virtual Driver™ Model NDX Simulation System (1-screen display); Raydon (USA) Virtual Driver Model NDX ³ Simulation System (3-screen display), James F. Wopart, (800) 360-3956 Interactive Testing and Training Systems, Inc. http://www.virtualdriver.net/	<ul style="list-style-type: none"> -fully interactive -3 screens -ambient light and weather conditions -80 different assessment criteria -immediate feedback -geared toward driver education programs in secondary schools
Renault Dynamic Driving Simulator (France) http://www.experts.renault.com/kemeny/projects/dynamic_driving_simulator/index.html	<ul style="list-style-type: none"> -fully instrumented automobile -6 degrees of freedom mobile platform
Simulator des Instituts für Straßen- und Schienenverkehrs der Technischen Universität Berlin (Germany) http://www.tu-berlin.de/fb10/ISS/FG8/forschun/menschma.htm	<ul style="list-style-type: none"> -road and weather condition studies -visual information investigations
Simulator Systems International (Oklahoma, USA) and Faros Group (France) 1130 East 56 th Street Tulsa, Oklahoma 74146 Telephone: (918)250-4500 Fax: (918)250-4502 http://www.simulatorsystems.com/	<ul style="list-style-type: none"> -wide screen views -simulators in research, medical, and driver education applications
State University of New York at Buffalo, Department of Mechanical and Aerospace Engineering, Automation Robotics and Mechatronics (ARM) Driving Simulator (USA) http://mechatronics.eng.buffalo.edu/research/hapticdrivingsimulator/	<ul style="list-style-type: none"> -haptic feedback (e.g., sense of touch)
Texas A & M University (USA) Texas Transportation Institute Driving Environment Simulator http://tti.tamu.edu/cts/cts/facilities/driving_simulator.stm	<ul style="list-style-type: none"> -fully interactive vehicle components -three high-reflectance screens -realistic environments (traffic, light, climate, etc.) -static, dynamic entities

Motor Vehicle Driving Simulator & Website URL Address*	Special Features**
<p>Systems Technology, Inc.</p> <ul style="list-style-type: none"> -STISIM Drive™ Model E-01 Driving Simulator (1-screen with cab) -STISIM Drive™ Model E-02 Driving Simulator (1-screen desktop) -STISIM Drive™ Model E-03 Driving Simulator (3-screen with cab) -STISIM Drive™ Model E-04 Driving Simulator (3-screen desktop) <p>Marketed through Mr. Robert Morgan ESRA DAT™ Sales Division ESRA Consulting Corporation 1650 South Dixie Highway, Third Floor Boca Raton, Florida 33432 USA Telephone: (561) 361-0004 Arizona Fax: (520) 844-8555 e-mail: dat@esracorp.com web: http://www.esracorp.com</p> 	<ul style="list-style-type: none"> -numerous self-customization driving scenarios. -1 or 3-screen display models. -driver behavior test. -Networking capabilities. -PC Windows capabilities. -Ambient and simulated light and weather conditions. -simulation similar to visibility and contrast reduction due to fog, rain, and snow. -based on very strong record of publication (more than 50 peer-review studies). -Widespread national and international applications at more than 100 locations. -clients include the DOT/ FHA, Arizona Department of Public Safety and the Tucson Police Department.
<p>ThoroughTec Driving Simulators (South Africa) http://www.thoroughtec.com/simulate.asp</p>	<ul style="list-style-type: none"> -"virtual car" design -wide screen
<p>TNO, ANWB Driving Simulator (Netherlands) http://www.tm.tno.nl/product/res_to_20.html</p>	<ul style="list-style-type: none"> -actual car -screen projection
<p>Tokyo University Department of Mechano-Informatics, Faculty of Engineering, Graduate School of Information Science and Technology Driving Simulator (Japan) http://www.ynl.t.u-tokyo.ac.jp/projects/vehicle/index.html</p>	<ul style="list-style-type: none"> -steering and speed control -Stewart platform
<p>TRL (United Kingdom) Driving Simulator http://www.trl.co.uk/</p>	<ul style="list-style-type: none"> -full-size automobile -projection system -motion system

Motor Vehicle Driving Simulator & Website URL Address*	Special Features**
Université de Technologie de Belfort-Montbéliard (UTBM), Simulateur Automobile (France) http://set.utbm.fr/ercos/plateforme/s/index.php?lang=fr	-actual automobile -one screen -forty-five degrees field of vision
Université de Valenciennes et du Hainaut-Cambrésis, (UVHT/C3T) Simulateur Automobile (France) http://www.univ-valenciennes.fr/actualites/presse/2002/fevrier/c3t.html	-actual automobile -three screens
Universiteit van Groningen (RuG) Phileas project – Driving Simulator (Netherlands) http://www.rug.nl/rc/hpcv/projects/phileas	-unexpected road traffic scenarios
University of Iowa Simulator for Interdisciplinary Research in Ergonomics and Neuroscience (SIREN) (USA) http://www.uiowa.edu/%7Eneuroerg/SIRENLab.html	- high-fidelity simulated collision avoidance scenarios
University of Leeds Advanced Driving Simulator (United Kingdom) http://www.its.leeds.ac.uk/facilities/lads/	-actual car -large wrap-around screen projection of traffic
University of Massachusetts, Human Performance Laboratory, Project MIDAS (Massachusetts Interactive Driving and Acoustic Simulator) (USA) http://www.ecs.umass.edu/hpl/equipment.htm	-actual car -three-screen display
University of Michigan Transportation Research Institute (UMTRI) Driving Simulator (USA) http://www.umich.edu/~driving/sim.html	- full size vehicle cab -touch screen console -three screens -numerous scenes
University of Minnesota, Department of Mechanical Engineering, Human Factors Interdisciplinary Research in Simulation and Transportation (HumanFIRST Program), Virtual Environment for Surface Transportation Research (VESTR) Driving Simulator (USA) http://www.humanfirst.umn.edu/Facilities/index.html	- high-resolution five-channel 210-degree forward field of view with rear and side mirror views - generates any type of road environment
University of Minnesota, Human Factors Research Laboratory, School of Kinesiology, College of Education and Human Development HFRL Wrap-Around Simulator (USA) http://education.umn.edu/kls/research/hftrl/facilities/is.html	-full-size car in 360-degree dome with 152-degree forward viewing area
University of Rochester Driving Simulator (USA) http://www.cs.rochester.edu/u/bayliss/UofRSim.html	-fog condition -four-lane highway

Motor Vehicle Driving Simulator & Website URL Address*	Special Features**
University of Sydney Research Driving Simulator (STISIM) (Australia) http://www.psych.usyd.edu.au/HumanFactors/DrivingSimulator.html	-135 degree visual field-of-view -three screens -actual automobile
Universidad de Valencia, Instituto de Robótica (Spain) del grupo ARTEC, Simulador de Conducción http://glup.irobot.uv.es/grupos/artec/Spanish/home.html	-Stewart platform -sensorized car cabin
University of Ishington Human Interface Technology Laboratory Driving Simulator (HITLAB) (USA) http://www.hitl.ishington.edu/projects/drive_sim/index.html	-investigates simple to complex maneuvers -many road elements, geometries, and control devices
Väg- och transport- forskningsinstitutet Simulator III (Sweden) Swedish National Road and Transport Research Institute Simulator III http://www.vti.se/avd/simulator/edetalj.asp?RecID=3137	-sophisticated motion system. -three main screens -three rearview mirrors. -chassis interchange system -fast acceleration.
Verkeers Veiligheids Centrum Rozendum (VVCR) Simulator voor de Rijopleiding (Netherlands) http://www.vvcr.nl/trainingen/Simulator/NL/SimulatorMainNL.html	-actual automobile -120 degrees screen projection
Waikato University (New Zealand) , Department of Psychology, Faculty of Arts and Sciences, Transportation and Road Safety Research Group, TARS Driving Simulator http://psychology.waikato.ac.nz/research/driverSim/diverSim.html	-eye tracker -low-level simulator -one screen

Based on our extensive research and review, we highlight the following:

- The GSC Simulator is completely geared toward the driving school student in Europe.
- Universiteit van Groningen (RuG) Phileas project – Driving Simulator (Netherlands) provides simulation of a road vehicle with properties of a bus, tram or metro system. The Cranfield University Driving Research Unit Driving Simulator (United Kingdom) also appears to focus on bus and fleet research.
- Other driving simulators, while very interesting, appears to be in experimental stages such as Tokyo University and Fachhochschule Esslingen Hochschule für Technik Projekt EVA (Esslinger Virtuelles Auto) Fahrsimulator,
- Lehrstuhl für Fahrzeugtechnik der TU München (München Technical University FTM Driving Simulator) is under construction yet offer studies on-site features relating to steering, braking systems, and other driver controls and behavioral responses.

- Institut für Kraftfahrwesen und Kolbenmaschinen
Universität der Bundeswehr Hamburg Fahrsimulator (Germany) provides on-site physiological and vehicular measurements and has applied this technology to truck driver education programs.
- No photos are available for Simulator des Instituts für Straßen- und Schienenverkehrs der Technischen Universität Berlin (Germany), though an on-line proposal included various plans of study.
- University of Leeds Advanced Driving Simulator provides flexible design modifications of road definition (hills, elevations, etc.) and junctions. An actual vehicle is used for studies. However, it appears as if this simulator is primarily a research tool.
- University of Iowa Simulator for Interdisciplinary Research in Ergonomics and Neuroscience (SIREN) is utilized for at-risk drivers for research in a medical environment. However, the special features allow for quantification of various driver performance and behavior characteristics.
- Chalmers University of Technology Driving Simulator (Sweden) is a research simulator in the works. It is a hexapod with one small screen and various forms of motion.
- The National Advanced Driving Simulator at the University of Iowa is the “mother of all simulators” in the world. It is the largest simulator in exclusive use for research purposes. It is also known as an operator-in-the-loop high fidelity driving simulator. An actual vehicle and a visual system are contained within a dome-like structure, mounted onto the base of a six-degree-of-freedom hexapod. The NADS motion system, however, has nine degrees of freedom. This allows for ample movement and orientation. Current studies include collision prevention, older driver performance research, validation of vision testing for simulated driving performance tests, alcohol and driver performance studies, and driver distraction and wireless phone research. These studies are possible due to the enormity of the facility, divided into medical and simulation operations control rooms, and the driving simulator features designed for advanced testing.
- Computer Graphics Systems Development Corporation
Virtual Reality Driving Simulator DS-230 does not incorporate an actual chassis.
- FAAC Incorporated (Ann Arbor, Michigan, United States) provides different driving simulators equipped with a variety of features suitable for police, truck, and motor vehicle driver. One is currently undergoing modifications for use in low vision research investigations at Harvard University Medical School (Peli, 2004). However, the simulators appear to be relatively expensive (in comparison to other models we evaluated) and there exists difficulty in modifying the simulators to accommodate features of interest.
- Although the University of Minnesota, Human Factors Research Laboratory, School of Kinesiology, College of Education and Human Development HFRL Wrap-Around Simulator and the University of Minnesota, Department of Mechanical Engineering, Human Factors Interdisciplinary Research in Simulation and Transportation (HumanFIRST Program), Virtual Environment for Surface

- Transportation Research (VESTR) Driving Simulator appear to be limited to research purposes and usage, both offer some very practical applications. The VESTR not only produces any kind of road setting, but also simulates intersection scenarios, among other features, including hazard mitigation and road design studies.
- Institut National de Recherche Sur Les Transports et Leur Securite (France) SIM2 Driving Simulator and Simulation CIR-MSIS is currently in use to study driving task analysis, perception studies in reduced visibility situations, and ageing effects on driver's behavior. This appears to be a research simulator.
 - Instructional Technologies (formerly Illusion Technologies International, Inc. (ITI) of (Ishington)) focuses primarily on truck driver education. However, high-fidelity automobile simulators appear to be produced on a client-by-client basis. They also offer e-Tread®, a hybrid CD-ROM/Internet approach to driving lessons, available to anyone of their registered students anywhere and anytime. This approach, while not suitable for driver's license vision or driver testing purposes today, may hold merit for future Motor Vehicle Driver's License Bureaus, especially in areas where significant population growth is expected over the next decade and beyond.
 - Texas A & M University Texas Transportation Institute (TTI) Driving Environment Simulator provides many outstanding road design and hazard mitigation features. However, it appears to be designed for research study only because its well-equipped motor vehicle faces large screen projections of various road environments and conditions (lighting, weather, etc.). This large setup is not ergonomic or practical for the interior of a Driver's License Motor Vehicle Bureau.
 - While the University of Michigan Transportation Research Institute (UMTRI) Driving Simulator offers 120 degree field of view and numerous scenes and weather configurations, it has only the daylight driving feature.
 - Väg- och transport- forskningsinstitutet Simulator III (Sweden) Swedish National Road and Transport Research Institute Simulator III uses a real automobile chassis. A vibration table, beneath the chassis, simulates contact with the road surface, providing a more realistic driving experience.
 - Fraunhofer Institut Verkehrs- und Infrastruktursysteme (IVI) (Germany) Fahrsimulator, Die Fraunhofer-Gesellschaft, Institut für Psychologie der Universität Würzburg Lehrstuhl III, Interdisziplinäres Zentrum für Verkehrswissenschaften, der simulator (Germany), KookMin University Driving Simulators (Korea), University of Massachusetts, Human Performance Laboratory, Project MIDAS (Massachusetts Interactive Driving and Acoustic Simulators all appear to be impressive research simulators.
 - Raydon Corporation- a driving simulator company offering Virtual Driver™ products including fully interactive 1 or 3 screen display models, immediate feedback and different assessment criteria. These products, developed primarily for driver education applications in secondary schools, also include day, night, rain, and fog driving conditions.
 - Systems Technology, Inc.- a 45-year old driving simulator company that has more than 50 peer-reviewed publications available on their driving simulator

products. These driving simulators are in widespread national and international use at more than 100 locations. The STISIM Model E Series, available in 1 or 3 screens, offer ambient and simulated light and weather conditions and simulation similar to visibility and contrast reduction due to fog, rain, and snow. There are numerous self-customization features ideal for transportation license applications and purposes.



For further investigation of many of these driving simulators, the reader is advised to visit the official website of Institut National de Recherche Sur Les Transports et Leur Securite of France: <http://www.inrets.fr/>



A wealth of information is also available from:
<http://www.inrets.fr/ur/cir/ressources/index.html>



For further information on the Simulator Sickness Questionnaire (SSQ), developed by Kennedy *et al.*, and used in numerous military and government applications, please contact:

Dr. Robert S. Kennedy
RSK Assessments, Inc.
1040 Woodcock Road, Suite 227
Orlando, Florida 32803
USA
Telephone: (407) 894-5090
Fax: (407)896-0638



For product information on the ReFb-06™ Road Sign Knowledge Test, please contact:

ReFb-06 Road Sign Knowledge Test
Marketed through Mr. Robert Morgan
ESRA DAT™ Sales Division
ESRA Consulting Corporation
1650 South Dixie Highway, Third Floor
Boca Raton, Florida 33432
USA
Telephone: (561) 361-0004
Arizona Fax: (520) 844-8555
e-mail: dat@esracorp.com
web: <http://www.esracorp.com>



ESRA

APPENDIX U: COMPLETED GLOBAL SURVEYS

United States of America and Commonwealth of Puerto Rico

Alabama

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Titmus 2N Vision Screener, Optec 1000, Keystone, and Snellen Eye Chart.
- **Shortcomings:**
"If the applicant has instrument myopia, they have difficulty."
- **Suggested improvements for current visual acuity test methodologies:**
"Less functions and more efficiency. Computerized testing."
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule. "Federal DOT for commercial driver license."
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Dawn, Day, Dusk, Night.
- **Weather conditions that current vision screening test accounts for:**
Clear.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, depth perception, peripheral vision.

- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"First issuance. Never unless cited for re-test or revoked or expired over three years."
- **Data collected to identify potential vision impaired drivers:**
"If driver is cited for re-test or if medical problem documentation on form and eye report from vision specialist is required."
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers and "same procedures as above which meet CFR 383 and CFR 391."
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, mandatory on-site testing, accident report. "Initial application, cited for re-test."
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined. "Individually."

"Class D= 20/60 or better in at least one eye with or without correction.

CDL= 20/40 or better in both eyes with or without correction."

Alaska

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 1000 DMV
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
"Night driving and weather conditions."
- **Current plans underway to modify these tests:**
No.

- **Impediments to improvements:**
Costs.
- **Instruments used in current vision screening test(s):**
Distance, peripheral, color, and lighting.
- **Suggested instruments for adoption:**
Field of view.
- **Authority required to modify vision testing procedures:**
Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color Blindness, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every ten years.
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial driver.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, accident report, law enforcement.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Arizona

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.

- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Titmus Vision Screener and Snellen Acuity Chart.
- **Shortcomings:**
“Test difficult to administer peripheral testing for corrective lens wearing applicants.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Statute/ Policy/ Rule, Staff/Training.
- **Instruments used in current vision screening test(s):**
“Currently test for visual acuity and peripheral vision.”
- **Suggested instruments for adoption:**
“Glare recovery.”
- **Authority required to modify vision testing procedures:**
Statute, administrative rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**

Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Every twelve years.”

- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, accident report.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together. “Also 20/50 with a daytime driving restriction.”

Arkansas

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 1000, test for acuity and field vision.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Policy.

- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every four years.
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial driver.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, mandatory on-site vision testing.
- **Current visual acuity requirements:**
20/40 unrestricted.... 20/50 restricted to corrective lenses. Field of 140 degrees.

California

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
"No modification to measurement tools- Snellen acuity chart, Optec 1000."
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Snellen acuity chart, Optec 1000.
- **Shortcomings:**
None specified.

- **Suggested improvements for current visual acuity test methodologies:**
“Possible recommendations on contrast sensitivity test for safe driving.”
- **Current plans underway to modify these tests:**
Yes.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Snellen acuity chart, Optec 1000.
- **Suggested instruments for adoption:**
“Chart based contrast sensitivity testing.”
- **Authority required to modify vision testing procedures:**
Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
“Visual acuity.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Field office allows renewal up to two times in five year intervals. At age 70, there is no longer renewal by mail.”
- **Data collected to identify potential vision impaired drivers:**
“California Report of Vision Examination. This includes visual acuity among other possible visual impairments and prognoses. When a person fails a screen on-site, the person is referred to a visual specialist for completion of vision exam.”
- **Vision screening test used for commercial drivers:**
Same as non-commercial driver.

- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, Mandatory on-site vision testing. Also, according to the American Medical Association, “Courts, police, other DMVs, family members, and virtually any other source.... Name of reporter will not be divulged (unless a court order mandates disclosure).”
- **Current visual acuity requirements:**
According to the American Medical Association:

20/40 (both eyes with correction)
20/40 if one eye blind and other with/without correction.

Colorado

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
Yes.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Acuity and phoria.
- **Shortcomings:**
“Customer and doctor confusion with phoria exam.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs.
- **Instruments used in current vision screening test(s):**
Keystone and Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule, Policy. “Promulgated rules.”

- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day, Dusk. “Available- not used.”
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Depth perception, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
Once every ten years. “Unless customer renews by mail then it’s every 20 years.”
- **Data collected to identify potential vision impaired drivers:**
Police reports, medical reports.
- **Vision screening test used for commercial drivers:**
DOT medical- doctor tests.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, mandatory on-site vision testing, police official.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Connecticut

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“Activity-Line-Color, Roads, Depth Recognition, and Peripheral Vision.”
- **Shortcomings:**
None specified.

- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, statute/rule/ policy.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute.
- **Conducted studies measuring effectiveness of current procedures:**
Yes. "Documentation no longer available."
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
None specified.
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Optec 1000.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, statute/ rule/ policy.
- **Current visual acuity requirements:**
"20/40 (Snellen) in each eye.

Delaware

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
None specified.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
None specified.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.

- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
Once every five years.
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, statute/ rule/ policy, mandatory on-site vision testing.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.
“20/50 daylight driving only.”

District of Columbia

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
Yes.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 1000 DMV Vision Tester. “Individuals who are unable to pass the vision test are given an eye report to have completed by ophthalmologist or optometrist.”
- **Shortcomings:**
“Individuals who may have a specific eye disorder such as glaucoma and cataracts are not detected if applicant fails to self disclose.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
Yes.
- **Impediments to improvements:**
Statute/ policy/ rule. “Most of the Department’s Policy and Procedural changes require City Council approval.

- **Instruments used in current vision screening test(s):**
Optec 1000 DMV Vision Tester.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule, Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Dawn, Day, Dusk.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, peripheral vision. “The vision screening is also designed to test the applicant’s ability to read and understand official traffic devices.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
Once every five years.
- **Data collected to identify potential vision impaired drivers:**
Eye reports.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, statute/ rule/ policy, age, mandatory on-site vision testing, accident report.
- **Current visual acuity requirements:**
“Regulations state that each applicant must demonstrate visual acuity of at least 20/40 in one eye and no less than 20/70 in the other eye with or without corrective lenses.”

Florida

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.

- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Visual acuity.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"Florida requires a vision screening for all "in-person" renewals. Customers over 79 years of age must submit a vision report when renewing via phone, mail, or intranet. Additional information on mature driver vision requirements is available through <http://www.hsmv.state.fl.us/html/dlnew.html>."

- **Data collected to identify potential vision impaired drivers:**
“Information from physicians, concerned citizens, and law enforcement.”
- **Vision screening test used for commercial drivers:**
Visual acuity.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, postal mail to our bureau, accident reports.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Georgia

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“We test visual acuity which requires vision of at least 20/60 in one eye and peripheral vision of at least 140 degrees for Regular Drivers. Commercial Drivers are required to see a minimum of 20/40 in both eyes and 140 degrees on the peripheral. These tests are done on a Juno Vision Screener.”
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
“Would like to modernize to a computer-based system.”
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, statute/ policy/ rule, staff/ training.
- **Instruments used in current vision screening test(s):**
Juno Vision Screeners.
- **Suggested instruments for adoption:**
“We have not seen a computerized system that is completely reliable, but as the technology progresses we would like to see a system that could be used in kiosks

and remote locations that would not require an examiner to administer the test. We would also like to see a system that could store vision records or update our mainframe when the test is passed or failed”

- **Authority required to modify vision testing procedures:**
Statute. “It would have to be approved by the General Assembly.”
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, contrast sensitivity, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“We recently implemented an Automated License Renewal System that allows good drivers to renew once by Mail, Phone, and Internet every other renewal cycle. The statute was changed for these renewals from every four years to eight years.”
- **Data collected to identify potential vision impaired drivers:**
“If they fail to pass the screening they are required to have a licensed eye doctor to check and verify that the applicant can/can’t meet the requirements. If these requirements are not meet their license will not be renewed. If the applicant passes the test with the doctor then the documentation that is produced by the doctor is recorded on the applicants file and the license is issued.”
- **Vision screening test used for commercial drivers:**
“They are required to meet the Federal Mandate listed under Commercial Drivers Act. 20/40 or better in both eyes and Peripheral vision of 140 Degrees.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, mandatory on-site vision testing.
- **Current visual acuity requirements:**
20/60 with both eyes opened and examined together.

Hawaii

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
Yes. "Use of Titmus 2N Vision Screeners (DMV Version)."
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Acuity and peripheral.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
"Use of Titmus 2N Vision Screeners (DMV Version)."
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
None specified.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.

- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“2 years: 72 years of age and older; 4 years: 16- 17 years of age;
6 years: 18- 71 years of age.”
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Pursuant to Subpart E, 391-41(b)(10) FCR.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
“Mandatory on-site vision testing.”
- **Current visual acuity requirements:**
HAWAII ADMINISTRATIVE RULES
TITLE 19
DEPARTMENT OF TRANSPORTATION
CHAPTER 122
EXAMINATION OF APPLICANTS FOR ISSUANCE AND RENEWAL OF MOTOR
VEHICLE **DRIVER’S** LICENSES AND INSTRUCTION PERMITS
SUBCHAPTER 1
GENERAL PROVISIONS

§19-122-8 **Vision test; standards.** Each applicant shall meet the minimum standards of the vision test to qualify for a permit or license. Where the tests indicate a restriction is appropriate, the permit or license shall be subject to the appropriate restrictions established under section 19-122-9. All restrictions shall be noted on the **driver’s** license. The minimum standards for applicants of a category 1, 2 or 3 **driver’s** license shall be:

(1)
Visual acuity. The applicant shall have 20/40 or better vision in one eye, corrected or uncorrected;

§19-122-9 **Vision test; restrictions for categories 1, 2 and 3.** (a) When the applicant has monocular visual acuity or when the applicant is able to see with only one eye:

(1)
If without corrective lenses the applicant has at least 20/40 vision, the applicant shall be restricted to operating vehicles with an outside rear view mirror installed on the side corresponding to the eye with no vision which provides a clear view to the side and rear of the vehicle.

(2)
If with corrective lenses the applicant has at least 20/40 vision, the applicant shall be restricted to operating vehicles with an outside rear view mirror installed on the side corresponding to the eye with no vision, which provides a clear view to the side and rear of the vehicle, and a corrective lens shall be worn while driving.

(b) When the applicant has coordinate use of both eyes in binocular vision (applicant able to see with both eyes):

(1)

If without corrective lenses the applicant has at least 20/40 vision in each eye, there shall be no restriction.

(2)

If with corrective lenses the applicant has at least 20/40 vision in each eye, corrective lenses shall be worn while driving.

(3)

If without corrective lenses the applicant has at least 20/40 vision in one eye but less than 20/40 vision in the other eye, the applicant shall be restricted to operating a vehicle with an outside rear view mirror installed on the side corresponding to the applicant's weaker vision, which provides a clear view to the side and rear of the vehicle.

(4)

If with corrective lenses the applicant has at least 20/40 vision in one eye, but less than 20/40 vision in the other eye, the applicant shall be restricted to operating a vehicle only when corrective lenses are worn. The applicant shall also be restricted to operating a vehicle with an outside mirror installed on the side corresponding to the applicant's weaker vision, which provides a clear view to the side and rear of the vehicle

Idaho

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Snellen.
- **Shortcomings:**
"Just sometimes hard to distinguish between the O and C."
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Statute/ policy/ rule.
- **Instruments used in current vision screening test(s):**
Optec 1000.

- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute.
- **Conducted studies measuring effectiveness of current procedures:**
None specified.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
“At renewal time which can be 1, 2, 3, 4, or 8 years.”
- **Data collected to identify potential vision impaired drivers:**
Vision screening test data that can result in referrals to ophthalmologists.
- **Vision screening test used for commercial drivers:**
Same as non-commercial driver.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, mandatory on-site vision testing.
- **Current visual acuity requirements:**
20/40 in at least one eye, testing eyes individually.

Illinois

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Acuity and peripheral.

- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs. “Not yet statewide.”
- **Instruments used in current vision screening test(s):**
Titmus, Keystone, and Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule, Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
Clear.
- **Optical conditions that current vision screening test accounts for:**
Eye movement disorder, peripheral vision. “ Nasal reading for peripheral and temporal reading.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Once every four years for age 21- 80; 81- 86 every 2 years; 87 and over every year.”
- **Data collected to identify potential vision impaired drivers:**
None.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.

- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, statute/ rule/ policy, mandatory on-site vision testing, police official. “Cited in court, physician, or law enforcement.”
- **Current visual acuity requirements:**
“20/40 with both eyes opened and examined together for full time driving; 20/41 for daylight only; 20/71 or below, no license.”

Indiana

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 1000.
- **Shortcomings:**
“They have only one slide and the customers usually memorize the line they need to read.”
- **Suggested improvements for current visual acuity test methodologies:**
“Need more slides for visual acuity with this machine.”
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.

- **Lighting changes that current vision screening test accounts for:**
Day, Dusk.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, depth perception, peripheral vision. “Muscle balance.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Three years for seniors. Four years renewal on everyone else.”
- **Data collected to identify potential vision impaired drivers:**
“Certificate of vision form completed by their low-vision specialist.” (These include Certificate of Vision (Eye Referral).)
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, website, postal mail to our bureau, mandatory on-site vision testing, accident report.
- **Current visual acuity requirements:**
20/70 with both eyes opened and examined together.

Iowa

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Visual acuity and peripheral.
- **Shortcomings:**
“There are aspects of vision and perception that are not screened or checked when only testing for acuity and peripheral field.”
- **Suggested improvements for current visual acuity test methodologies:**
“Web enabled reporting from vision specialists.”

- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, statute/ policy/ rule. “We need updated Best Practice recommendations and supporting information.”
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
UFOV. Contrast sensitivity.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
None specified.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
Once every five years. “Every two years for people under 18 and over 70.”
- **Data collected to identify potential vision impaired drivers:**
Crash and conviction.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, postal mail to our bureau, statute/ rule/ policy, mandatory on-site vision testing, accident report.
- **Current visual acuity requirements:**
“20/40 with both eyes opened and examined together for no restriction.”

Kansas

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Distance.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 1000 and Titmus.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute.
- **Conducted studies measuring effectiveness of current procedures:**
None specified.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.

- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Every four or six years unless on an annual vision.”
- **Data collected to identify potential vision impaired drivers:**
Vision test.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official.
- **Current visual acuity requirements:**
“20/40 with both eyes opened and examined together for no restriction.”

Kentucky

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Acuity- far, depth recognition, muscle balance, peripheral test.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.

- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
Clear.
- **Optical conditions that current vision screening test accounts for:**
Depth perception, Eye Movement Disorder, Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"Once when you initially obtain learner's permit."
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers except for the addition of a Color Blindness Test.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official. "Affidavit for re-certification to Medical Review Board."
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together. "20/60 after referral to eye doctor."

Louisiana

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
"Wall chart and Titmus Tele-binoculars. We test for 20/40 overall vision."

- **Shortcomings:**
“Problems when applicant cannot adjust to vision test or applicants with only vision in one eye or vision impairments do not test well on machines.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Staff/ Training.
- **Instruments used in current vision screening test(s):**
Titmus Tele-Binoculars and Wall Eye Charts.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Once every four years.”
- **Data collected to identify potential vision impaired drivers:**
“Louisiana sets restrictions for vision impaired drivers that are on the driver’s license and the driver license record.”
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.

- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, On-line/ Website, Telephone/ hotline, statute/ rule/ policy. “Applicants with vision impairments are often required to re-test vision more frequently from every six months to four years.”
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Maine

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
Yes. “Visual acuity 20/ 40 best eye.”
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Visual acuity, field of vision.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.

- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"Ages 41- 45 at renewal; 52- 57 at renewal and every renewal at age 62 and older!"
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, statute/ rule/ policy, age, mandatory on-site vision testing.
- **Current visual acuity requirements:**
"20/40 with both eyes opened and examined together. Best eye and not both eyes together."

Maryland

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
Yes. "We added field of vision testing for all drivers. In addition, we now check for color deficiency in commercial drivers."
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Visual acuity, field acuity. (Nasal and peripheral.)
- **Shortcomings:**
"The plates in the machine stay the same year after year which allows the public to overhear or memorize the letters."

- **Suggested improvements for current visual acuity test methodologies:**
“To have the ability to be able to switch plates from time to time.”
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
Once every five years.
- **Data collected to identify potential vision impaired drivers:**
Vision certifications from doctor.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers except for color deficiency check (red- green-amber).
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, mandatory on-site vision testing. “Police Re-Examination Request.”

- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Massachusetts

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
Yes. "State-wide re-training of Optec 1000 Vision Screener to include peripheral vision check."
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
"Optec 1000- visual acuity 20/40 - peripheral vision 140 degrees. If applicant can't pass test then VSC (Vision Testing Certificate) completed by M.D."
- **Shortcomings:**
"Optec 1000- difficult for people with monocular vision."
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
"Computer?"
- **Authority required to modify vision testing procedures:**
Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.

- **Optical conditions that current vision screening test accounts for:**
Color blindness, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every five years.
- **Data collected to identify potential vision impaired drivers:**
“Information from the Commission for the Blind, police reports, questions concerning vision on renewal license applications, doctor reports.”
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, postal mail to our bureau, mandatory on-site vision testing.
“Massachusetts Commission for the Blind and the Registry of Motor Vehicles exchange information.”
- **Current visual acuity requirements:**
20/40 in at least one eye, a horizontal peripheral vision of at least 120 degrees and the ability to distinguish between amber, red, and green.”

Michigan

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
Yes. “The Department updated vision statements for more detailed information on bioptic/ telescopic drivers to include bioptic on-road training and potential restrictions.”
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Visual acuity and Peripheral Field of Vision.
- **Shortcomings:**
“The elderly often have difficulty with adjusting their head into the Titmus Machine. Memorization of letters has also been questionable.”
- **Suggested improvements for current visual acuity test methodologies:**
“Would like to incorporate contrast sensitivity and depth perception testing.”

- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Statute/ Policy/ Rule.
- **Instruments used in current vision screening test(s):**
Titmus vision machine, Optec 1000, and the Snellen card test.
- **Suggested instruments for adoption:**
“Would like to conduct more research, such as the Useful Field of View computer-administered and computer-scored test of visual attention, etc.”
- **Authority required to modify vision testing procedures:**
Administrative Rule, Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision. “Diseases of the eye are monitored after the Department is aware of condition.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Visual acuity is tested once every eight years, unless the driver has diseases of the eye, which would then be monitored. Visual acuity is tested at every renewal processed in the branch environment (every four years), otherwise it could occur once every eight years.”
- **Data collected to identify potential vision impaired drivers:**
“The Department collected research in the past on telescopic/ bioptic drivers.”
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.

- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, On-line/ Website, postal mail to our bureau, statute/ rule/ policy, mandatory on-site vision testing, accident report. “From a branch office or Driver Assessment Examination.”
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together. “An unrestricted driver’s license may be issued to an applicant or licensee who has visual acuity of 20/40 and a peripheral field of vision of 140. Visual acuity less than 20/40 to and including 20/50 and a peripheral field of vision of 140 or less to and including 110 may be accepted if the applicant or licensee submits a statement of examination on a form prescribed by or acceptable to the Department signed by an ophthalmologist or optometrist.”

Minnesota

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
Yes. “Check peripheral vision.”
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 1000 DMV Vision Tester.
- **Shortcomings:**
“Unable to detect cataracts and other vision problems. Peripheral- difficult to check for eye movement. Customer honesty regarding wearing contact lenses.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Statute/ Policy/ Rule, Staff/ Training.
- **Instruments used in current vision screening test(s):**
None specified.
- **Suggested instruments for adoption:**
None specified.

- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"Once every four years."
- **Data collected to identify potential vision impaired drivers:**
"The State Services for the Blind (Department of Employment and Economic Development) sends us names of persons served who are blind or visually impaired. We send a notice to each visually impaired person advising him or her to provide a vision report."
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, On-line/ Website, postal mail to our bureau, Statute/Rule/ Policy, mandatory on-site vision testing, Accident Report. "Concerned family member, neighbor- must be signed statement indicating specific problem."
- **Current visual acuity requirements:**
"20/40 with both eyes opened and examined together. 20/50 restrict to 60MPH , 20/60 restrict to 50 MPH, 20/70 restrict to 45MPH, No Freeway and daylight driving only, 20/80 refer to exam for special vision test with additional restrictions."

Mississippi

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.

- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Standard 20/40 requirements.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Staff/ Training. “More staff.”
- **Instruments used in current vision screening test(s):**
2N Vision Screeners.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, depth perception.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“New applicants and when see needed.”
- **Data collected to identify potential vision impaired drivers:**
“Medical form from optometrist.”

- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Anonymous tips, postal mail to our bureau, Telephone/ Hotline, Age, mandatory on-site vision testing.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Missouri

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 1000. "Use the acuity readings and peripheral readings."
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
"More options for the acuity readings, currently, we have letters for 20/40 readings, but if the customer fails the 20/40, the slide we then use is a landolt ring slide that sometimes confuses the customers."
- **Current plans underway to modify these tests:**
"Yes. We are checking into automated testing but funding is an issue."
- **Impediments to improvements:**
Costs, Staff Training
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
"Any automated instruments which continue to capture our current requirements."
- **Authority required to modify vision testing procedures:**
Statute.

- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
“Once every six years if ages 21- 69, every 3 years if age 70 and above, if under 21 the person falls in the graduated licensing so must have a vision each time they come in, so it could be for two or three years.”
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, postal mail to our bureau, mandatory on-site vision testing, accident report.
- **Current visual acuity requirements:**
“Must have 20/40 in either eye or both without aid to receive a non restricted license. If with aid, then require an “A” restriction (which is glasses or contacts) If cannot reach the 20/40, then must be sent to an eye doctor of the applicant's choice. If the reading is between 20/41 and 20/59 from the eye doctor, adds daylight driving only if the reading is between 20/60 and 20/74 from the eye doctor, adds restricted to 45 miles per hour if the left eye reading in 20/100 or worse, adds left outside rearview mirror. Soon to come- If the right eye reading is 20/100 or worse, adds right outside rearview mirror if the reading is between 20/75 and 20/160, the applicant receives the restrictions above, but, must also take and pass the skills test. 20/161 and worse – deny. The eye doctor can override the daylight driving only and the restricted to 45 miles per hour, but, must state that on the vision form they are completing.”

Montana

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Distance, color, depth perception for non-commercial drivers.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
“Testing that would reflect the necessary vision as it applies to driving and moving objects.”
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Statute/ Policy/ Rule, Staff/ Training.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, peripheral vision.

- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
“Upon renewal, license cycle is valid from 1 to 8 years renewal.”
- **Data collected to identify potential vision impaired drivers:**
Re-exam request, law enforcement referrals.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers “with the addition of peripheral vision testing and horizontal meridian.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, mandatory on-site vision testing, accident report. “Law enforcement request for re-exam.”
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Nebraska

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Acuity, peripheral.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 1000.

- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule, Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every five years.
- **Data collected to identify potential vision impaired drivers:**
Acuity, peripheral.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers with the addition of color blindness testing.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, on-line/ website, postal mail to our bureau, telephone/ hotline, mandatory on-site vision testing, accident report, law enforcement.
- **Current visual acuity requirements:**
Both eyes with or without corrective lenses: 20/40
Left 20/40- 50- 60; Right restrictions 20/40.

Nevada

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No
- **Vision screening test computer automated:**
No.

- **Vision screening test(s):**
Visual acuity.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Keystone and Optec 1000. Snellen chart is used as necessary.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
None specified.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified. “If the applicant fails the in-office vision test, they are referred to an eye doctor for additional testing.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“If the renewal is processed in a field office, the applicant is required to pass a vision test. If the applicant renews by mail, they are not required to submit to a vision test unless an indication is made that a change has occurred at which time a report from an eye doctor is required. An applicant must renew in a field office every other renewal cycle (every 8 years)”

- **Data collected to identify potential vision impaired drivers:**
Confidential physicians report, request for re-examination by law enforcement or family member.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, accident report.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

New Hampshire

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Titmus or Optec 1000 DMV Test, Snellen Eye Chart.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Titmus or Optec 1000 DMV Test, Snellen Eye Chart.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.

- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
Clear.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every five years. "Anytime a license is issued."
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, accident report.
- **Current visual acuity requirements:**
"20/30 with vision in one eye. 20/40 with vision in both eyes."

New Jersey

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Basic visual acuity test.
- **Shortcomings:**
"We do not check for night blindness."
- **Suggested improvements for current visual acuity test methodologies:**
More comprehensive vision screening being done.

- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Statute/ Policy/ Rule, Staff/ Training.
- **Instruments used in current vision screening test(s):**
Optec 1000 .
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule, Executive Action, Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
Clear.
- **Optical conditions that current vision screening test accounts for:**
Cataracts, color blindness.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every ten years. "This may change to one every eight years."
- **Data collected to identify potential vision impaired drivers:**
On-site testing, medical official's report.
- **Vision screening test used for commercial drivers:**
"20/40 corrected (with or without glasses) in both eyes standard and the physical required for most CDL drivers. Peripheral Vision, Depth Perception are checked at the time of the physical."
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, mandatory on-site vision testing, accident report.
- **Current visual acuity requirements:**
"20/50 with or without glasses in one eye."

New Mexico

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 1000.
- **Shortcomings:**
"Counter space."
- **Suggested improvements for current visual acuity test methodologies:**
Computer linked to physician's records. Kiosks in all offices.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
"Budget."
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
Full computer testing.
- **Authority required to modify vision testing procedures:**
"Health Advisory Board."
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.

- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"Four or eight year cycle."
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Optec 1000.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, telephone/ hotline, statute/ rule/ policy, mandatory on-site vision testing.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

New York

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
Yes. "A new chart was developed in December of 2000 to replace the Snellen chart previously used. The new chart was developed in conjunction with our Medical Advisory Board."
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
"Client is asked to stand 10-20 feet from chart (depending on which line he is asked to read). Lines 1-6 =20 feet. Lines 6-12-10 feet."
- **Shortcomings:**
"Only test for visual acuity."
- **Suggested improvements for current visual acuity test methodologies:**
"Test for peripheral vision and night vision."
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Statute/ Policy/ Rule.

- **Instruments used in current vision screening test(s):**
“No equipment is used for our vision screening.”
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“When the license/permit is renewed. Usually, every 8 years.”
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
“We do not conduct any additional testing for CDL drivers.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

North Carolina

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.

- **Vision screening test(s):**
None specified.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Keystone and Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every five years.
- **Data collected to identify potential vision impaired drivers:**
Visual acuity scores are database maintained.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.

- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, mandatory on-site vision testing, accident report. “Highway Patrol, Enforcement, physicians, family members, friends (not anonymous).”
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

North Dakota

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
Yes. “Horizontal field vision was changed from a total of 140 degrees minimum standard to a total of 105 degrees for a noncommercial applicant.”
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 1000, visual acuity, field of vision, and color vision.
- **Shortcomings:**
“Nothing significant. The field of vision maybe is not as accurate as it should be because the applicant could be moving their eyes in the machine and we would never know it.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.

- **Lighting changes that current vision screening test accounts for:**
Day. “We do not test in the night mode. If the applicant is worse than a 20/40, we send them to the eye doctor.”
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, peripheral vision. “Acuity.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Once every four years.”
- **Data collected to identify potential vision impaired drivers:**
Acuity and field of vision.
- **Vision screening test used for commercial drivers:**
Acuity, field of vision, and color vision.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, accident report. “Family member, law enforcement.”
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Ohio

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Depth perception, peripheral vision, and color blindness.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
Web-base testing.

- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Statute/ Policy/ Rule.
- **Instruments used in current vision screening test(s):**
Optec 1000 and Snellen Eye Chart.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, depth perception, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every four years.
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, accident report. "Police officer/ ticket."
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Oklahoma

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
Yes. "Peripheral vision test was added for Operator's License (Class D)."
- **Vision screening test computer automated:**
Yes.
- **Vision screening test(s):**
Distance, depth, peripheral, and color blindness.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Juno and Titmus Vision Screeners.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, peripheral vision.

- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Operator’s license is at application only. CDL license is at renewal time every four years.”
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers except for the addition of a color blindness test.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, accident report.
- **Current visual acuity requirements:**
“20/50 for Operator’s License. 20/30 for CDL License.”

Oregon

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
Yes. “We test for acuity levels. Bought OPTEC; stopped testing for anything but acuity and peripheral vision (day and night).”
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Acuity and peripheral. “They read an eye chart.”
- **Shortcomings:**
“Sometimes drivers can’t use the OPTEC machine successfully, but test well at their ophthalmologist’s office.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Keystone and Optec 1000.

- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"At renewal (every 8 years) after age 50."
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Medical doctor.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, postal mail to our bureau, statute/ rule/ policy, mandatory on-site vision testing, accident report.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Pennsylvania

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.

- **Vision screening test(s):**
Optec 1000.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"Re-exam."
- **Data collected to identify potential vision impaired drivers:**
"Attach a DL-102 (Report of Eye Exam Form)."
- **Vision screening test used for commercial drivers:**
None specified.

- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Puerto Rico

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“The vision screening test is performed by private ophthalmologist or optometrist, not at the agency.”
- **Shortcomings:**
None specified. “Since they are performed by private physicians.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs.
- **Instruments used in current vision screening test(s):**
None specified.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.

- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Vision acuity.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"One every six (6) years which is the license term."
- **Data collected to identify potential vision impaired drivers:**
"The results of the vision acuity test."
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, accident report.
- **Current visual acuity requirements:**
"20/40 for passenger vehicle drivers and motorcyclists. 20/25 for the rest of the drivers."

Rhode Island

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 1000.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
"Not automated."
- **Current plans underway to modify these tests:**
No.

- **Impediments to improvements:**
Costs.
- **Instruments used in current vision screening test(s):**
Optec 1000- no instruments.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every five years.
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, mandatory on-site vision testing.
- **Current visual acuity requirements:**
"20/100 CDL; 20/40 in each eye."

South Carolina

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.

- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Visual screener.
- **Shortcomings:**
“Need better programs for people who do not know numbers or letters.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Staff/ Training.
- **Instruments used in current vision screening test(s):**
Titmus Ortho Reader.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Depth perception, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
Once every five years.
- **Data collected to identify potential vision impaired drivers:**
None specified.

- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, postal mail to our bureau, statute/ rule/ policy, mandatory on-site vision testing.
- **Current visual acuity requirements:**
“If one eye is 200 or worse other eye must be 20/40. If one eye is 20/200 or better, good eye must be 20/70 or better.”

South Dakota

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
None specified.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, statute/ policy/ rule, staff/ training.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule, Policy.

- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Dusk.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every five years. "Unless otherwise specified by eye doctor."
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, accident report.
- **Current visual acuity requirements:**
20/60 with both eyes opened and examined together.

Tennessee

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No. "The last modifications were in 1989 for CDL to incorporate the peripheral and Color Blindness segments."
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
"For regular non-CDL applicants we screen for 20/40 vision (state minimum) in both eyes together and each eye separately using a standard vision screening machine (either Keystone or Stereo Optics)."
- **Shortcomings:**
None specified.

- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, staff/ training.
- **Instruments used in current vision screening test(s):**
Keystone and Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule, Policy. “CDL by Federal Regulations.”
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
CDL only: Color blindness, Depth perception, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Not a requirement in Tennessee for renewal.”
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
“Same as for non-CDL with the addition of Peripheral, Color blindness and Depth Perception.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, postal mail to our bureau, accident report. “DI 19 re-exam request submitted by examiner or citizen.”

- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Texas

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Snellen method of measurement. Distant visual acuity.
- **Shortcomings:**
"No provisions for an applicant who has had corrective surgery. Requires additional documentation from doctor."
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.

- **Optical conditions that current vision screening test accounts for:**
Color blindness.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
“Every six years unless they renew license by methods (i.e., web, phone, mail), then it is once every 12 years.”
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers. “Vision standards are different for commercial drivers due to federal requirements.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, statute/ policy/ rule, accident report.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together. “With corrective lenses.”

Utah

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 1000.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, statute/ policy/ rule, staff training.

- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day, Dusk.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every five years.
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, mandatory on-site vision testing, accident report.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Vermont

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.

- **Vision screening test(s):**
Titmus.
- **Shortcomings:**
“Breakage of machines.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs.
- **Instruments used in current vision screening test(s):**
Titmus.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule, Executive Action, Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision, visual acuity of 20/40.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“No vision test required to renew license, new test conducted on upgrades and addition of endorsements,”
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.

- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, telephone/ hotline, accident report.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Virginia

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Visual acuity and Horizontal Vision on desktop electric vision testers.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Statute/ Rule/ Policy.
- **Instruments used in current vision screening test(s):**
Titmus and Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Dawn, Day, Dusk.

- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Drivers must pass the vision screening test or submit a vision examination report every five years, depending upon eligibility for renewal by alternative methods (mail, internet, touch-tone telephone, etc.). The Virginia DMV Commissioner is authorized to waive the vision examination for drivers who meet certain eligibility criteria every other renewal cycle.”
- **Data collected to identify potential vision impaired drivers:**
“To obtain a license to operate a motor vehicle in Virginia, drivers must pass vision screening test (visual acuity and horizontal vision). Drivers have the option of providing a vision report from their eye practitioner instead of taking the vision screening test at a DMV Customer Service Center. The vision report must include information on visual acuity and horizontal vision.”
- **Vision screening test used for commercial drivers:**
None specified.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
“Virginia DMV relies on information from a variety of sources to help identify drivers who may be unable to safely operate a motor vehicle. Customers applying for or renewing a driver’s license are required to provide information on any physical, visual, or mental condition that may impair their ability to drive safely. On the driver’s license application, applicants are required to respond to questions that help determine if the applicant:
 - Has a physical, visual, or mental condition that requires taking medication;
 - Has ever experienced a seizure, blackout, or loss of consciousness; and
 - Has a condition that requires the use of special equipment in order to drive.

Also, DMV receives reports of impaired drivers from physicians, law enforcement, courts, relatives, DMV representatives and other reliable sources. Upon receipt of information expressing concern about a driver, Va. Code 46.2-322 authorizes DMV to require the driver to submit medical and/or vision information, and/or require the driver to pass the driver’s license knowledge and/or road tests. Once the medical review is completed, DMV may suspend or restrict the person’s driving privileges or require submission of periodic medical/

vision reports. If the information from an eye care practitioner indicates that the person's vision does not meet the vision requirements, DMV suspends the person's driving privileges."

- **Current visual acuity requirements:**

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MED 5 (Rev. 06/01)

MINIMUM VISION REQUIREMENTS

Minimum requirements may be met with or without corrective lenses.

NOTE: For Bifocal Telescopic Lens (BTL) vision requirements, see the Driver Licensing Information for Bifocal Lens Wearers form (MED44).

DRIVER'S LICENSES

VISUAL ACUITY 20/40 or better in one or both eyes

HORIZONTAL VISION 100 degrees or better

If you cannot meet the above requirements, you may be restricted to only daylight driving, provided you meet the following requirements:

VISUAL ACUITY 20/70 or better in one or both eyes

HORIZONTAL VISION 70 degrees or better -- one eye

If one eye only:
40 degrees or better temporal;
30 degrees or better nasal.

COMMERCIAL DRIVER'S LICENSE

VISUAL ACUITY 20/40 or better in EACH eye

HORIZONTAL VISION 110 degrees or better

For persons with only one eye, the above requirements can be waived if you can meet the following requirements:

VISUAL ACUITY 20/40 or better in ONE eye

HORIZONTAL VISION 70 degrees or better -- one eye

If one eye only:
40 degrees or better temporal;
30 degrees or better nasal.

If you have questions regarding these requirements call DMV at:

1-866-DMV-LINE (voice)
1-866-368-5463 or
1-800-435-5137
1-800-272-9268 (deaf or hearing impaired, ONLY)

Washington

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**

No.

- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“Test includes visual acuity, fusion, vertical and lateral phoria, depth perception, and color vision.”
- **Shortcomings:**
“Lack of variety in test options; equipment takes up too much space on counter.”
- **Suggested improvements for current visual acuity test methodologies:**
“Create a random selection of test responses and contrast sensitivity.”
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, depth perception, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
Once every five years. “Every time the customer comes for licensing services, i.e. duplicates, address or name changes, etc.”

- **Data collected to identify potential vision impaired drivers:**
“We obtain eye care professionals diagnosis (vision certificates) and maintain in file for any customer who is below the standard.”
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, statute/ rule/ policy, accident report.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

West Virginia

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 1000.
- **Shortcomings:**
“Unable to determine if other medical problems exist.”
- **Suggested improvements for current visual acuity test methodologies:**
“Upgraded system.”
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.

- **Authority required to modify vision testing procedures:**
Statute.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"Only on initial application and re-examination."
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Optec 1000 or Snellen Chart.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Wisconsin

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Acuity and peripheral.
- **Shortcomings:**
"Field can only screen basic vision."

- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Statute/ Policy/ Rule.
- **Instruments used in current vision screening test(s):**
Optec 1000.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every eight years.
- **Data collected to identify potential vision impaired drivers:**
“For drivers with a progressive eye disease and best eye worse than 20/50, we do routine follow-ups for life.”
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers. “However, standards are different.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, statute/ rule/ policy, accident report.

- **Current visual acuity requirements:**
“Minimum: 20/100 best eye, no binocular requirement, 20 degrees field of vision. At counter: Those with best eye less than 20/40 corrected need a vision report filled out.”

Wyoming

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“Visual acuity, field of vision, peripheral, and depth perception. Snellen method.”
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Keystone Vision Screener, Model DVS-3.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule, Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day. “Have special screening devices used for special tests as needed. Usually refer person to eye specialist for testing and restriction.”

- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Depth perception, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"Once every four years. Upon renewal."
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, mandatory on-site vision testing, accident report. "Law enforcement."
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together. "Must also have 120 degrees field of vision."

United Kingdom

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
"There has been no change to the acuity component of the requirements for licensing applicants over the last 10 years. However, the change in font style of number plates produced since 1 September 2001 has led to a 0.5 metre reduction in the specified distance."
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
"Driver and Vehicle Licensing Agency (DVLA) requires acuity to be expressed in terms of the 6 metre Snellen chart for Group 2 drivers' applications. It does not specify the equipment on which the acuity must be measured. A clinical examination is also carried out during the Group 2 medical examination for application purposes."

- **Shortcomings:**
“Acuity measurement is not always carried out by ophthalmic practitioners. Testing is usually carried out by General Practitioners for Group 2 applications.”
- **Suggested improvements for current visual acuity test methodologies:**
“It would obviously be helpful to have assurance of the accuracy of acuity measurements, for Group 2 applicants.”
- **Current plans underway to modify these tests:**
“A suggestion has been made that only optometrists could carry out acuity testing. Discussion is ongoing.”
- **Impediments to improvements:**
“There would be a cost implication to either the applicant or DVLA to having acuity tested only by an optometrist. There are also policy implications..”
- **Instruments used in current vision screening test(s):**

“Driver and Vehicle Licensing Agency (DVLA) requires acuity to be expressed in terms of the 6 metre Snellen chart for Group 2 drivers’ applications. It does not specify the equipment on which the acuity must be measured. A clinical examination is also carried out during the Group 2 medical examination for application purposes.”
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
“Legislation would be required to change the Group 1 eyesight requirement. Policy/ Administration could define testing process.”
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
“Number plate must be read ‘ in good light’”
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
“The number plate requirement is a non-specific measure of contrast sensitivity and glare sensitivity. Licence holders/applicants are required to notify or declare any relevant medical condition. This would include cataract, if acuity affected, field defect including peripheral defect and central scotomata, diplopia and glaucoma. The UK field requirement is for a width of 120 degrees and no

significant defect encroaching to within 20 degrees of fixation, measured using an approved perimeter with a target equivalent to a Goldmann III4e.”

- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“A Group 1 licence is issued until the 70th birthday. Renewal is every 3 years after that, based on self-declaration of the ability to meet the number plate requirement. A Group 2 licence is issued until the age of 45 and renewed every 5 years after that until the age of 65, and then annually. The acuity requirement must be met in addition to the number plate requirement. Licence holders with relevant medical condition may be reviewed more frequently.”
- **Data collected to identify potential vision impaired drivers:**
“None by DVLA.”
- **Vision screening test used for commercial drivers:**
“A Group 2 licence is issued until the age of 45 and renewed every 5 years after that until the age of 65, and then annually. The acuity requirement must be met in addition to the number plate requirement. Licence holders with relevant medical condition may be reviewed more frequently.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
“The onus is upon the driver to declare or notify a condition. Failure to do so is a criminal offence. However we also receive notification from Medical Practitioners and third parties. We would consider carefully whether an anonymous third party notification was felt to be malicious. We receive notification by post, telephone, and email. The Police will notify us of some accidents where there is felt to be a medical condition of relevance and some of these will be eyesight related. The age related renewal period is designed to improve the notification of visual conditions (and other conditions) on a regular basis. Police have the power to carry out the number plate test at the road side where visual problems are suspected and can prosecute for failure to meet the standard.”
- **Current visual acuity requirements:**
“Group 1 – number plate requirement (thought to equate to binocular acuity of 6/10). Group 1 - monocular - acuity of 6/10 (0.6) in remaining eye. Group 2 - acuity of at least 6/9 in better eye and no worse than 6.12 in other eye (corrected or uncorrected). If achieved by correction, must have uncorrected acuity of no worse than 3/60 in either eye. (There are some concessions for Group 2 drivers who were licensed prior to 1992 when more lenient standards pertained).”
- **Additional comments:**
“...UK has different acuity requirements for car drivers (Group 1 licences) and Heavy Goods/Public Service Vehicles (Group 2). Group 2 also includes smaller lorries up to 3.5 tonnes/ minibuses.

Licensing decisions for Group 1 applications are based on self-declaration of the ability to meet the eyesight requirement. This is a component of the driving test and is defined in legislation as the ability to read a car number plate under specified conditions at a specified distance. Drivers using one eye only are required under EC legislation, adopted by the UK, to have specific acuity in the remaining eye. For Group 2 drivers there is in addition a requirement for specific acuity, (corrected and uncorrected) tested in each eye.”

Canada

Alberta

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Acuity, color, depth perception, visual fields.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Stereo Optec, Keystone View, Juno, and Tracor.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Policy. “Standards are guided by the National Safety Code/ Medical Guidelines.”
- **Conducted studies measuring effectiveness of current procedures:**
No.

- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, peripheral vision. “All clients with visual acuity deficiencies are referred to a vision authority/ specialist for follow up and correction.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“At each license renewal term (maximum of 5 years).”
- **Data collected to identify potential vision impaired drivers:**
Test results.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, on-line/ website, postal mail to our bureau, telephone/ hotline, mandatory on-site vision testing, accident report. “Police.”
- **Current visual acuity requirements:**
“A minimum of 20/30 in the better eye and 20/40 in the weaker eye for commercial drivers and a minimum of 20/40 in the better eye for operators of private passenger vehicles and motorcycles.”

British Columbia

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Acuity, diplopia, color perception, stereopsis, field of vision
- **Shortcomings:**
“The gross visual field testing often does not show significant quadrantic defects, such as quadrantsopia or homonymous hemianopsia.”

- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Staff/ Training.
- **Instruments used in current vision screening test(s):**
“Keystone DVS II Vision Screener; Keystone DVSIII Vision Screener; Juno RV-123P Vision Screener; Keystone Ophthalmic Telebinocular Instrument.”
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Policy.
- **Conducted studies measuring effectiveness of current procedures:**
None specified.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, Diplopia (Double Vision), peripheral vision.
“Acuity.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Most licence holders are not visually reexamined until they reach age 80. All driver’s licences are issued subject to medical approval. If a driver is required to complete a medical report, it would include a vision screening conducted by a medical practitioner. Commercial drivers are required to complete a medical report by a medical practitioner, including vision screening, approximately every 5 years.”
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers only the standards are higher.

- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, age, accident report.
- **Current visual acuity requirements:**
20/40 with both eyes opened and examined together.

Manitoba

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“At our motor vehicle branch offices we use automated vision testers (not computer automated) for drivers who do not have a history of vision problems. If it is determined that a driver has a vision problem then a vision report with or without visual field diagrams are requested. The visual field diagrams are completed at eye care practitioners' offices and are computer automated”
- **Shortcomings:**
“The automated vision screening machines are not very accurate and are insensitive in particular to visual field defects.”
- **Suggested improvements for current visual acuity test methodologies:**
“It would be beneficial to have vision screening machines that were more sensitive.”
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs.
- **Instruments used in current vision screening test(s):**
Juno RV-123P.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Policy.

- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
“Upon application for a driver's licence or any time a driver examination is required for aberrant driving behaviour or medical reasons. Vision screenings are required for commercial drivers when the vision section of the medical report is not completed.”
- **Data collected to identify potential vision impaired drivers:**
“None. In Manitoba physicians and optometrists are required by law to report drivers whose medical condition may affect their ability to drive safely. They all have a copy of the medical standards for driving.”
- **Vision screening test used for commercial drivers:**
“If there is no vision problem then we accept the visual acuity and visual fields documented on the medical report from the family physician. If the vision section is not completed then we request a vision screening at one our offices. Commercial drivers with vision problems must file periodic vision reports completed by eye care practitioners.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, postal mail to our bureau, statute/ rule/ policy, accident report.
- **Current visual acuity requirements:**
“20/40 in better eye with both eyes opened and examined together. We are about to revise our standards to 20/50 with both eyes together for Class 5, and 20/30 both eyes together with worse eye not less than 20/100 for commercial drivers. Is based on Canadian Ophthalmological Working Group's recommendations.”

New Brunswick

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.

- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
None specified.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Juno and Titmus.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Executive Action, Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, Diplopia (Double Vision), peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"Not required."
- **Data collected to identify potential vision impaired drivers:**
None specified.

- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, postal mail to our bureau, accident report.
- **Current visual acuity requirements:**
“Class 1 or 2: no corrected visual acuity of less than 20/30 in the best eye and worse than 20/50 in the weakest eye,

Class 3 and 4: a corrected visual acuity not less than 20/30 BEST EYE ; 20/50 WEAKEST EYE

Class : 5, 6, 7, 8, 9 a corrected visual acuity not less than 20/40 in at least one eye.”

Newfoundland and Labrador

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
Yes. “Visual Acuity Standards changed from 20/40 to 20/50 for Class 05- 06 drivers.”
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“Acuity far, color identification, sign recognition and depth perception, visual fields.”
- **Shortcomings:**
“Cannot test for contrast sensitivity, binocular peripheral fields up to 150 degrees as are required standards for commercial drivers by the Canadian Medical Association.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs.

- **Instruments used in current vision screening test(s):**
Titmus, Titmus II, and Snellen Eye Chart.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day, Night.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, peripheral vision. "Heterophorias."
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"Initial and at age 75."
- **Data collected to identify potential vision impaired drivers:**
"Reports from Family Physicians, Optometrists, Ophthalmologists, and Police regarding visual acuity and fields."
- **Vision screening test used for commercial drivers:**
"Same as non-commercial drivers "but visual fields must meet 150 degree and acuity must meet a standard of 20/30 in the better eye and 20/50 in the worse eye, each eye tested separately."
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, age, accident report.
- **Current visual acuity requirements:**
"20/50 with both eyes opened and examined together. This is the acuity standard for Class 05 and 06 drivers."

Northwest Territories

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“Upon initial application a client must undergo a vision screening with the Driver Examiner. For those driver's applying for classes 1-4 (Commercial DL's), a Driver's Medical is required. If any trouble areas are noted the client is then requested to provide a report of visual functions from an Ophthalmologist. I have forwarded a copy of both forms for your information.”
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
“Complete testing for possible visual impairments when driving at dusk, dawn or night.”
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Statute/ Policy/Rule, Staff/ Training.
- **Instruments used in current vision screening test(s):**
Juno RV-123P.
- **Suggested instruments for adoption:**
“The NWT is currently in the process of replacing our vision screeners to the Titmus Vision Screeners.”
- **Authority required to modify vision testing procedures:**
Statute, Administrative Rule, Executive action, Policy.
- **Conducted studies measuring effectiveness of current procedures:**
None specified.
- **Lighting changes that current vision screening test accounts for:**
None specified.

- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Central Scotomas, Color blindness, Depth perception, peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**

“For a class 5 driver's licence (passenger vehicles) a visual screening is required upon application and then at age 75, age 80 and every two years thereafter. For classes 1-4 a vision screening is required every five years to age 45, every three years till age 65 and annually thereafter.”

- **Data collected to identify potential vision impaired drivers:**
“The information provided in the Driver's Medical Examination form and any impairment notification forms from medical professionals.”
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers, “...the only notable difference being frequency.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, mandatory on-site vision testing. “Northwest Territories Driver's Medical Report Form.”
- **Current visual acuity requirements:**
“For a class 5 driver – Binocular or Monocular Vision – Better eye 20/40
Classes 1-4 – Binocular vision – Better eye 20/30, Weaker eye 20/50.”

Nova Scotia

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“Snellen ratings.”
- **Shortcomings:**
“Unable to test above (superior) and below (inferior) horizontal meridian.”

- **Suggested improvements for current visual acuity test methodologies:**
“Advanced training for Driver Enhancement Officers, movement to computerized testing.”
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Statute/ Policy/ Rule, Staff/ Training.
- **Instruments used in current vision screening test(s):**
Keystone Telebinocular Instrument, Keystone View Model DVS N1137DC, Optec 2000.
- **Suggested instruments for adoption:**
“Computerized testing.”
- **Authority required to modify vision testing procedures:**
Statute. “Motor Vehicle Act.”
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, Diplopia (Double Vision), Glare Sensitivity, and peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
Once every ten years. “Class 2B drivers (i.e., school bus) must have a visual acuity screening test every five years and all other commercial drivers (i.e., Class 1, 2, 3 & 4) are required to submit a vision report every five years.”
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.

- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official. “Royal Canadian Mounted Police/ Police complaint, private citizen complaint, optometrists (mandatory reporting under the Optometry Act).
- **Current visual acuity requirements:**
“20/40 with both eyes opened and examined together. “The current visual acuity requirement for Class 5 drivers is 20/40 in one eye. We are reviewing new Canadian Council of Motor Transport Administrator’s (CCMTA) standards which may allow drivers to operate a motor vehicle with visual acuity of 20/50 in one eye. Vision standards for all drivers are governed by the CCMTA with the exception of Class 3 drivers which is governed by the Motor Vehicle Act.”

Nunavut

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“Juno Systems Vision Screener Model 123P-3.”
- **Shortcomings:**
“None that I am aware of other than the portability of the unit for testing in field offices.”
- **Suggested improvements for current visual acuity test methodologies:**
“We would refer to the expertise of the CCMTA Medical Advisory Group and have any recommended changes reviewed by our medical advisor.”
- **Current plans underway to modify these tests:**
Yes. “Will consider implementing any new standards recommended by the CCMTA Medical Advisory Group.
- **Impediments to improvements:**
Costs, Statute/ Policy/ Rule, Staff/ Training. “Empirical evidence of need.”
- **Instruments used in current vision screening test(s):**
“Juno System Vision Screener Model 123P-3.”
- **Suggested instruments for adoption:**
“None that I’m aware of but we’d consider the use of any superior testing units if we became aware of any.”

- **Authority required to modify vision testing procedures:**
Administrative Rule. “We try to follow the CCMTA “Medical Standards for Drivers.”
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified. “No, we rely on self-declaration or medical reporting of any such limitations at the present time.”
- **Weather conditions that current vision screening test accounts for:**
None specified. “No and I can’t say I’ve seen any diagnoses from medical practitioners specifying limitations in relation to these conditions.”
- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, Diplopia (Double Vision), peripheral vision. “We rely on self-declaration or medical reporting.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
Once every ten years. “Or as recommended by medical review, or by frequency required for medical exams under CCMTA medical guide for drivers or on demand by Registrar.”
- **Data collected to identify potential vision impaired drivers:**
“Medical reports in accordance with frequency required under the CCMTA medical guide for drivers.”
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers. “Same but periodic medicals and more frequent (CCMTA Medical Guide for Drivers).”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
“Medical official, Statute/ Rule/ Policy, Mandatory on-site vision testing.
Anonymous tips: Would not reply on this alone (would test if felt warranted).
On-line/ website: Haven’t had any but again if conveyed in this way, we might require a test. Postal mail to our bureau: Not only (test). Age: Only to the extent of age requirements for frequency of medical testing under the CCMTA Medical Guide for Drivers. Accident report: Would test if shown to be a factor. Would test if driving ability questioned by observing enforcement officer.”

- **Current visual acuity requirements:**
“20/30 with both eyes opened and examined together (20/50 in weaker eye) for classes 1, 2, 3, and 4. Must have binocular vision. For class 5 and 6, may have binocular or monocular vision and better eye must be at least 20/40.”

Ontario

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
None specified.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“Individuals are assessed by a Snellen chart for visual acuity and confrontational field assessments for visual field.”
- **Shortcomings:**
“Individuals can be tested on vision screeners and found not to be meeting the standards. When asked to file an assessment from an eye specialist, standards met in a high percentage of cases. Ontario requires a Regulation change in order to be in step with expert medical opinion and recommended vision standards. If Regulation is changed the existing vision screening devices may need to be replaced as the current screening devices can measure binocular vision but cannot measure the horizontal visual field above and below the midline.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
None specified.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
“Primarily Juno System RV 123. Acceptable: Optec 2000P and Titmus 1 and 11.”
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
“A Regulation change to vision standards is required in Ontario in order to be in step with expert medical opinion and recommended vision standards.”

- **Conducted studies measuring effectiveness of current procedures:**
None specified.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"At time of original application then:
Class G/M (Car Motorcycle) – at 80 years of age then biannually
Class D (Any truck or combination provided the towed vehicle is not over 4,600kg) – original application then annually at 80 years of age.
Other classes (A, B, C, E, F) at original application then every 5 years to 65, then annually."
- **Data collected to identify potential vision impaired drivers:**
"If a driver in Ontario does not pass the vision screening test he/she is advised that a vision report form which must be completed by an eye specialist and returned to the Ministry of Transportation within a specified time frame."
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
"Medical official, Ontario Highway Traffic Act mandatory reporting, sections 203 and 204, fax, postal mail to our Bureau, Statute/ Rule/ Policy, Mandatory Optometrists Reporting Requirement. Accident Report: Yes, if police officer indicates on accident report that the collision may have occurred due to a suspected visual problem or driver self reports a visual problem to police officer during investigation of accident."
- **Current visual acuity requirements:**
"Holders of a class G or M (Car or motorcycle) must have a minimum of 20/40 in the better eye, with or without corrective lenses and a peripheral vision total of 120 degrees.

Commercial license holders (Classes A, B, C, D, E and F) must have a minimum visual acuity of 20/30 in the better eye and 20/50 in the weaker eye, with or without corrective lenses with peripheral vision reading of 120 degrees in each eye."

Prince Edward Island

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
"Acuity, horizontal, depth, and color."
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Keystone Vision Screener.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Statute.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day, dusk.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, depth perception, peripheral vision. "Night blindness."

- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"Not required unless driver license is expired."
- **Data collected to identify potential vision impaired drivers:**
"Ophthalmologists, optometrists, and medical doctors are required to notify us."
- **Vision screening test used for commercial drivers:**
"Keystone vision tests, 20/30, 20/50, field of vision 120 degrees, must also pass color test."
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**

Medical official, accident report.
- **Current visual acuity requirements:**

20/40 with both eyes opened and examined together.

Quebec

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
"Vision screening test is concerned with visual acuity, field of vision, colour vision and muscular coordination."
- **Shortcomings:**
"The equipment is old; however, it does the work. Tests are sufficient."
- **Suggested improvements for current visual acuity test methodologies:**
"Improvements have more to do with the equipment than the test methodology. The test is used to check if the candidate meets the minimum standard."
- **Current plans underway to modify these tests:**
No. "Improvements are always in mind. However, specific modifications have not been mapped out yet."

- **Impediments to improvements:**
“In addition to being reliable, the replacement equipment must have greater advantages over that currently used.”
- **Instruments used in current vision screening test(s):**
“The trade name of the equipment is Orthorater.”
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
“None if the vision standards remain the same.”
- **Conducted studies measuring effectiveness of current procedures:**
“Yes. The report, prepared some years ago, is not available.”
- **Lighting changes that current vision screening test accounts for:**
“The test is used to check if the candidate meets the minimum standard. To take into account moments of the day or driving conditions, tests conducted by health professional are required.”
- **Weather conditions that current vision screening test accounts for:**
“The test is used to check if the candidate meets the minimum standard. To take into account moments of the day or driving conditions, tests conducted by health professional are required.”
- **Optical conditions that current vision screening test accounts for:**
“The test is used to check if the candidate meets the minimum standard . To take into account vision defects, tests conducted by health professional are required.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**

“The visual test is required when the candidate asks for a new class of license. A medical report, including results of visual tests, is required in order to renew a professional driver’s license, classes 1, 2, 3 and 4 when the driver reaches age 45, 55, 60 and 65. A medical report is required every 2 years thereafter. In other cases, a medical report, including results of visual tests, is required when we are informed that the person has a health problem.”
- **Data collected to identify potential vision impaired drivers:**
“...visual acuity, field of vision, colour vision and muscular coordination.”
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.

- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips. “Test conducted in service centre.”
- **Current visual acuity requirements:**

VISION

GROUP 1

To get a class 1, 2, 4A or 4B driver’s licence, the applicant must meet the following visual standards.

Have a binocular vision with the following characteristics:

Binocular vision:

Greater than 30% or more than 20 seconds: no impairment causing the loss of use of one eye or preventing accurate perception of objects or images.

Visual acuity: not less than 6/9 in the best eye, and not less than 6/15 in the other eye.

Visual field: 120 degrees in both eyes.

Colour vision: Distinguish red, green and yellow.

Perception of distance: 2,8,11 or 3,6,11

Horizontal muscular coordination: minimum 3, maximum 13

Vertical muscular coordination: minimum 2, maximum 8

GROUP 2

To get a class 3 or 4C driver’s licence, the applicant must meet the following visual standards.

Have a vision with the following characteristics:

Visual acuity:

Visual field:

Best eye: 120 continuous degrees.

GROUP 3

To get a class 5, 6, 6D or 8 driver's licence, the applicant must meet the following visual standards.

Have a binocular or monocular vision with the following characteristics:

- For operating any vehicle at all times
 - Visual acuity: **6/12** in the best eye.
 - Visual field: in the eye with the best visual acuity, a continuous horizontal field of **120** degrees; or a continuous horizontal field of **120** degrees in each eye.
- For operating a vehicle weighing **less than 2500 kg** for personal purposes
 - At all times:**
 - Visual acuity: **6/12** in the best eye with the **best visual field**.
 - Visual field: **100° overall or at least 30°** when measured vertically with both eyes open at once.

Daytime only, 2 possibilities:

- Visual acuity: **6/15** in the best eye, and **6/18** in the other eye.
- Visual field: **120 continuous degrees with both eyes** open at once.

OR

- Visual acuity: **6/15** in the best eye, or **6/15** with both eyes open.
- Visual field: **120 continuous degrees with both eyes** open at once.

Saskatchewan

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Acuity, color, depth perception, diplopia, peripheral vision.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.

- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
“A few old Tracors and Juno- Primary Usage.”
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, Diplopia (Double Vision), peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“We only screen on initial applications, class changes or medical requests.”
- **Data collected to identify potential vision impaired drivers:**
“Mandatory optometrist reporting.”
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers. “We use the same Juno screening instruments as we use for Class 5 drivers.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, accident report.
- **Current visual acuity requirements:**
“Class 5 drivers 20/50 with both eyes open and examined together. Class 1 to 4 not less than 20/30 with both eyes opened and examined together.”

Yukon Territory

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
Yes. "New Optec Vision Testing Machines."
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Optec 2000 vision testing device.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
Yes. "Vision standards have recently been revised per CCMTA medical standards- modifications will be made to incorporate these new standards as adopted."
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
Optec 2000 vision testing device.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
"CCMTA Medical Advisory Committee."
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
None specified.

- **Optical conditions that current vision screening test accounts for:**
Color blindness, Depth perception, Diplopia (Double Vision), peripheral vision.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
Once every ten years.
- **Data collected to identify potential vision impaired drivers:**
“Only information provided by an optometrist or ophthalmologist.”
- **Vision screening test used for commercial drivers:**
“As set out in the CCMTA medical standards. Must meet 20/30 best eye and 20/100 worst eye visual standard.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, mandatory on-site vision testing, accident report.
- **Current visual acuity requirements:**
“20/50 with both eyes opened and examined together. Per new CCMTA medical standards.”

Australia

Australian Capital Territory

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
Snellen Chart.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.

- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
“Eye test machine.”
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
“National Standards.”
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Once every five years. Every year at 75 years and over. Every year for commercial drivers.”
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
Snellen Chart.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our Bureau, Telephone/ Hotline, Accident Report.”
- **Current visual acuity requirements:**
“6/12 with both eyes opened and examined together.”

New South Wales

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
Yes. "Since 1996, customers who fail the eyesight test at a motor registry are required to provide a satisfactory report from a doctor or an optometrist."
- **Vision screening test computer automated:**
No. "In relation to driving tests, more road craft and hazard perception elements will be introduced."
- **Vision screening test(s):**
"Visual acuity using a Snellen chart."
- **Shortcomings:**
"Test is limited to checks for visual acuity, not other disorders like visual field. However, advanced aged licence applicants are subject to annual medical reviews and re-tests. See also Q2 on requirement to provide eyesight certificate which will help identify any visual disorders."
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
Costs, Statute/ Policy/ Rule, Staff/ Training.
- **Instruments used in current vision screening test(s):**
"Snellen chart on an illuminated perspex screen viewed by a mirror."
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule, Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
Day.
- **Weather conditions that current vision screening test accounts for:**
Clear.

- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**
"NSW RTA offers a choice of 1,3 or 5 year licences. An eyesight test is required on renewal or replacement, unless a test has been done in the last 12 months."
- **Data collected to identify potential vision impaired drivers:**
"The result of the eyesight test is recorded on the RTA DRIVES data base on driver licences and vehicle registrations. People who failed an eyesight test will need to provide a satisfactory eyesight report before a licence will be issued."
- **Vision screening test used for commercial drivers:**
"Visual acuity using a Snellen chart with each eye tested separately. Commercial drivers are subject to more stringent standards than private drivers."
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, postal mail to our bureau, Statute/ Rule/ Policy, Age, Mandatory On-site Vision Testing, Accident Report.

"It is a requirement for a licence holder to notify the RTA of any permanent or long-term injury or illness that may impair his or her ability to drive safely."
- **Current visual acuity requirements:**
" 6 / 12 (in metric scale) both eyes opened and examined together for private drivers.

For commercial drivers, the criteria for an unconditional licence are not met:
 - If the person's visual acuity is worse than 6/9 in the better eye; or
 - If the person's visual acuity is worse than 6/18 in either eye.
For details of national medical standards in Australia, please refer to <http://www.austroads.com.au/aftd.html>."

Northern Territory

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
Yes. "Adoption of "Assessing Fitness to Drive for Commercial and Private Vehicle Drivers - 3rd Edition" produced by Austroads in 2003. Provides guidelines for health professionals for the medical standards for licensing, and clinical management guidelines.
http://www.austroads.com.au/austroads_v2/publicationsFrame.htm?publicPublica

tion number for search: G56/03 - refer page 97 - 100 Medical Standards for Licensing - Vision and Eye Disorders.”

- **Vision screening test computer automated:**
No. “Static chart and electronic screening is used.”
- **Vision screening test(s):**
“Static visual acuity, monocularity (minimum) with low contrast acuity and peripheral field of vision.
 - a) Snellen’s Chart - standard, tumbling “E” and pictograph - used in remote areas.
 - b) Optec 2000 vision tester - metropolitan and major regional centers.”
- **Shortcomings:**
 - a) Snellen’s Chart - unable to determine low contrast acuity and peripheral vision fields
 - b) Optec 2000 vision tester - equipment is not standard across all offices, so all can perform basic binocular/monocular vision, and distance perception. Not all can perform peripheral field of vision tests or low contrast test.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified. “The screening process adequately covers the initial assessment, with the secondary assessment made by a health professional.”
- **Current plans underway to modify these tests:**
“No - these tests are used for screening purposes only. Where there is a questionable result, the customer is referred to a registered health professional for appropriate clinical assessment and diagnosis.”
- **Impediments to improvements:**
None specified. “...changes would be administrative and through policy. Functionality and authority enacted by legislation.”
- **Instruments used in current vision screening test(s):**
Optec 2000 and Snellen’s Chart.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule, Policy. “Functionality and authority enacted by Legislation.”

- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
None specified. “Testing using the electronic equipment can include low contrast acuity, however not all machines are appropriately equipped to perform these tests.”
- **Weather conditions that current vision screening test accounts for:**
Clear, and cloudiness (“if cloudiness is defined as low contrast acuity”).
- **Optical conditions that current vision screening test accounts for:**
“Screening covers (minimum for all drivers): Acuity, Monocularity (and low contrast acuity using appropriate electronic equipment where available). Health Professional Examination (Commercial and heavy vehicle drivers): Acuity, Monocularity, Diplopia, Colour blindness, Dark Adaption, and Useful Fields of Vision. Instances where a customer fails an eyesight test using the current screening methodology, require clinical diagnosis from a registered health professional using the criteria referred in the publication mentioned in 2. The health professional is required by law to report conditions where the person’s eyesight is affected. Commercial vehicle drivers are subject to a more stringent medical regime, and are required to undertake regular medical assessments in accordance with the publication referred to in 2. and therefore the screening process is not used.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“On first issue, then once every five years on renewal.”
- **Data collected to identify potential vision impaired drivers:**
None specified.
- **Vision screening test used for commercial drivers:**
“Health Professional Examination (commercial drivers): Acuity, Monocularity, Diplopia, Colour Blindness, Dark Adaptation, and Useful Field of Vision. Full medical assessment details listed in the publication referred to in 2.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, telephone, postal mail to our bureau, statue/ rule/ policy, mandatory on-site vision testing.
- **Current visual acuity requirements:**
“6/12 binocular; 6/9 in the better eye; 6/18 and in the worse eye.”

Queensland

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
Yes. "Prior to December 2001, Queensland Transport conducted eyesight tests for all driver license holders at the time of application or renewal. On the current application, there is a question "*Do you have any other vision or eye disorders*". If the applicant answers "yes" to this question, eyesight tests may be conducted. This test is designed to measure the visual acuity of an applicant."
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
"Queensland Transport uses Snellen eyesight charts. If an applicant does not meet the required vision standard they will be asked to supply an ophthalmologist or optometrist report before a driver license can be issued. For further information, you can refer to the medical guidelines "*Assessing Fitness to Drive*" for commercial and private vehicle drivers by accessing the website <http://www.austroads.com.au/aftd.html>
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
"Queensland Transport uses Snellen Eyesight Charts."
- **Suggested instruments for adoption:**
No.
- **Authority required to modify vision testing procedures:**
Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.

- **Lighting changes that current vision screening test accounts for:**
No.
- **Weather conditions that current vision screening test accounts for:**
No.
- **Optical conditions that current vision screening test accounts for:**
“Please refer to the medical guidelines “*Assessing Fitness to Drive* by accessing the website <http://www.austroads.com.au/aftd.html>”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“When a person applies/renews a driver license, they are required to answer a question about “*Do you have any other vision or eye disorders*”. If the person answers “yes” to this question, an eyesight test will be conducted. The maximum period they can renew their license for is 5 years.”
- **Data collected to identify potential vision impaired drivers:**
“This information is obtained from these driver license applications and if they have a medical condition, it is recorded on the driver license and Queensland Transport driver license system.”
- **Vision screening test used for commercial drivers:**
“The medical guideline for commercial drivers is the “*Assessing Fitness to Drive*” and you can access <http://www.austroads.com.au/aftd.html>”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official.
- **Current visual acuity requirements:**
“6/12 with both eyes opened and examined together. (Acuity should be tested using a standard visual acuity chart (Snellen chart or equivalent that includes at least 5 letters on the 6/12 line).

South Australia

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
“All eyesight testing in South Australia for the issue of a driver’s licence (if required by Transport SA) is conducted by medical practitioners, ophthalmologists or opticians.”
- **Vision screening test computer automated:**
None specified.

- **Vision screening test(s):**
None specified.
- **Shortcomings:**
None specified.
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
None specified.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
None specified.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Registrar of Motor Vehicles.
- **Conducted studies measuring effectiveness of current procedures:**
None specified.
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver's license:**

“While Transport SA does not conduct any screening eyesight tests for the issue of a driver's licence, the Registrar of Motor Vehicles may require an applicant for a learner's permit or driver's licence to undergo such tests or provide such evidence (including eyesight tests) in regard to the applicant's fitness to drive if the Registrar believe that it is reasonably appropriate. However, because there is usually a deterioration in medical fitness including eyesight as a person ages, all licence holders who turn 70 years of age or older are required to produce a

medical and eyesight certificate from their medical practitioner each year in order to retain their driver's licence."

- **Data collected to identify potential vision impaired drivers:**
Medical official.
- **Vision screening test used for commercial drivers:**
"All eyesight testing in South Australia for the issue of a driver's licence (if required by Transport SA) is conducted by medical practitioners, ophthalmologists or opticians."
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
"Any applicant for a learner's permit or driver's license, who declares that he or she wears glasses or contact lenses other than for reading, is required to provide an eyesight certificate for the initial issue of the learner's permit or driver's license. In addition, any medical practitioner, registered optician or registered physiotherapist who believes that a license holder, whom they have examined, may be suffering any illness, injury or impairment that may affect their ability to safely drive a motor vehicle, is required to notify the Registrar of Motor Vehicles of this fact and also inform the license holder. The medical professional does not incur any civil or criminal liability in carrying out this duty. There is also a legal requirement that any person, who is the holder of a driver's license and who suffers any illness, injury, disability or impairment that may affect the person's ability to drive a motor vehicle without danger to the public, is required to notify the Registrar of Motor Vehicles of this fact. In these cases, the Registrar would require the person to provide a satisfactory medical or eyesight certificate in order to continue to drive, possibly under additional license conditions depending on the medical condition."
- **Current visual acuity requirements:**
None specified.

Tasmania

- **Modification made to the visual impairment screening component of driver's license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
"Snellen Chart (from 6 metres)."

- **Shortcomings:**
“Office space constraints, consistency of applications.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
“Snellen Chart (from 3 metres).”
- **Impediments to improvements:**
“None at this stage.”
- **Instruments used in current vision screening test(s):**
None specified.
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Policy.
- **Conducted studies measuring effectiveness of current procedures:**
No.
- **Lighting changes that current vision screening test accounts for:**
“Office environment only.”
- **Weather conditions that current vision screening test accounts for:**
“Office environment only.”
- **Optical conditions that current vision screening test accounts for:**
“Office environment only.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Annually where applicant is 75 years or over.”
- **Data collected to identify potential vision impaired drivers:**
“Medical questionnaire upon application or renewal.”
- **Vision screening test used for commercial drivers:**
“Snellen chart 6/9.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, age, accident report.

- **Current visual acuity requirements:**
“6/12 with both eyes opened and examined together. 6/9 for commercial drivers.”

Victoria

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
“Yes. For private vehicle (vehicles up to 4.5 tonne) licence applicants, the monocular test was dropped. For both private and commercial (heavy vehicle) licence applicants, the colour vision test has been removed.”
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“For commercial applicants, the Snellen chart. For private vehicles, a modified Snellen chart displaying a number of lines all of which are 6/12.”
- **Shortcomings:**
“Neither peripheral vision nor acuity in varying light conditions is tested. However, if there is any evidence of poor vision, a full eyesight medical report is required.”
- **Suggested improvements for current visual acuity test methodologies:**
“This will be determined by the review....”
- **Current plans underway to modify these tests:**
“Yes. It is proposed that driver eyesight standards and assessment methods be comprehensively reviewed and an assessment be developed to replace the current acuity test. However, this work is yet to be approved and funded.”
- **Impediments to improvements:**
Costs , Staff/ Training.
- **Instruments used in current vision screening test(s):**
Commercial drivers – Snellen chart. Private drivers – modified Snellen chart.
- **Suggested instruments for adoption:**
“This will be determined by the review mentioned above.”
- **Authority required to modify vision testing procedures:**
Executive Action.
- **Conducted studies measuring effectiveness of current procedures:**
No.

- **Lighting changes that current vision screening test accounts for:**
None specified. “If an applicant has difficulty reading a chart indoors, the test can be conducted outdoors in natural light.”
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
Cataracts. “In Victoria, the licence applicant and driver is legally obliged to inform VicRoads if they suffer from a medical condition that may effect driving.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“Currently, there is no requirement for vision testing on licence renewal in Victoria.”
- **Data collected to identify potential vision impaired drivers:**
“From 2004, all drivers who are required to wear corrective lens when driving will be required to provide an eye sight report at the time of licence renewal – every 10 years.”
- **Vision screening test used for commercial drivers:**
“Visual acuity for commercial drivers is measured monocularly using a Snellen chart that includes at least 5 letters on the 6/9 and 6/18 lines.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, Anonymous Tips, Postal mail to our Bureau, Statute/ Rule/ Policy, Accident Report.
- **Current visual acuity requirements:**
“For private vehicle drivers 6/12 with both eyes opened and examined together. For commercial vehicle drivers, at least 6/9 in the better eye and at least 6/18 in the worse eye.”

Western Australia

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
No.
- **Vision screening test computer automated:**
No.
- **Vision screening test(s):**
“Snellen Chart manual testing.”

- **Shortcomings:**
 “Eyesight testing is conducted by non-health professionals (staff), Different office lighting and test conducted in various areas. Any new office buildings now include proper eyesight testing facilities. Previously areas have been modified to incorporate test facilities which has resulted in variations to suit. People sometimes have to be referred to opticians or ophthalmologists, where they have boarder line vision. That’s doesn’t quite come up to required standards.”
- **Suggested improvements for current visual acuity test methodologies:**
 “Improved testing facilities at licensing centres and agents.”
- **Current plans underway to modify these tests:**
 “Currently reviewing driving assessment requirement for senior drivers. (annually assessed from 85 years of age onwards). Considering introducing a more appropriate driving assessment process if assessment is still required for senior drivers. Introduced new practical driving assessment in March 1999 for young drivers. Being evaluated and part of the new graduated driver training and licensing system for young drivers.”
- **Impediments to improvements:**
 Costs, policy, training.
- **Instruments used in current vision screening test(s):**
 “Snellen chart at specific area of licensing centre or referral to optometrists, ophthalmologists etc.”
- **Suggested instruments for adoption:**
 “NO. Only general eyesight assessment conducted by Licensing Centres if any problems encountered person is referred to specialist etc. “
- **Authority required to modify vision testing procedures:**
 Administrative Rule, Executive Action, Policy. “National Medical assessment guidelines are used and any variation would require national agreement form all other jurisdictions.”
- **Conducted studies measuring effectiveness of current procedures:**
 No.
- **Lighting changes that current vision screening test accounts for:**
 None specified.
- **Weather conditions that current vision screening test accounts for:**
 None specified.

- **Optical conditions that current vision screening test accounts for:**
None specified. “These may be checked or tested if referred to optometrist or ophthalmologist.”
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“First compulsory eyesight test is at 75 yrs of age then 78 and then 80 onwards however, many people are tested prior to that date. Checked earlier if subject to regular medical assessment. Eyesight testing is conducted for licence holders applying for additional classes of licence.”
- **Data collected to identify potential vision impaired drivers:**
“Records kept by department, and periodic assessments requested. Relevant licence holders have condition endorsed on licence or licence record.”
- **Vision screening test used for commercial drivers:**
“Same as for all classes of licence-general eyesight test at licensing centre unless referred to specialist. Specialist follow National guidelines.”
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
Medical official, anonymous tips, online/ website, postal mail to our bureau, statute/ rule/ policy, age, accident report. Mandatory on-site vision testing: “75, 78, and 80 years of age onwards. Family.”
- **Current visual acuity requirements:**
“6/12 private vehicles (whether the person has one or two eyes) 6/9 Commercial vehicles (both eyes).”

New Zealand

- **Modification made to the visual impairment screening component of driver’s license vision screening test over the last ten years:**
Yes. “In May 1999 New Zealand introduced photo driver licences (PDL), all existing licence holders were required to upgrade to the PDL within 12 months – part of this process was that they had to provide verification that their eyesight met the legal standard.”
- **Vision screening test computer automated:**
Yes, “90%”.
- **Vision screening test(s):**
Titmus 2a Vision Screener.

- **Shortcomings:**
“The inability to accurately screen monocular drivers or those with substandard vision in one eye.”
- **Suggested improvements for current visual acuity test methodologies:**
None specified.
- **Current plans underway to modify these tests:**
No.
- **Impediments to improvements:**
None specified.
- **Instruments used in current vision screening test(s):**
“Titmus 2a Vision Screener – If licence holder fails this screening they are required to pass a test with either a General Practitioner, Optometrist, or Ophthalmologist.”
- **Suggested instruments for adoption:**
None specified.
- **Authority required to modify vision testing procedures:**
Administrative Rule.
- **Conducted studies measuring effectiveness of current procedures:**
No. “We measure generally the amount of road crashes that are considered medically related. The latest statistic for the 12 months to July 2003 reports this as less than 2 and a half percent. This is approximately half that of May 1999 (note includes all medically related crashes).”
- **Lighting changes that current vision screening test accounts for:**
None specified.
- **Weather conditions that current vision screening test accounts for:**
None specified.
- **Optical conditions that current vision screening test accounts for:**
None specified.
- **Frequency of visual acuity screening tests to be passed in order to renew a driver’s license:**
“... Depending on the category of license, the maximum period of license renewal is 10 years. At age 80 a license holder is required to renew every 2 years. Bus and taxi drivers may choose to renew only 1 year at a time. Each time a license holder makes an application, they are required to have their eyesight screened or tested.”

- **Data collected to identify potential vision impaired drivers:**
“Statistics. Statistics are able to be produced for the percentage of drivers that fail the Titmus screener....”
- **Vision screening test used for commercial drivers:**
Same as non-commercial drivers.
- **How at-risk drivers with visual acuity problems or severe eye ailments are identified:**
None specified.
- **Current visual acuity requirements:**
“Our ratios are expressed as metres from the Snellen chart. Private licence class holders need to achieve a reading with both eyes of at least 6/12, and commercial class holders of at least 6/9.”

APPENDIX V: COPY OF THE SURVEY FORMS



Arizona Department of Transportation
Arizona Transportation Research Center

FACSIMILE TRANSMITTAL

Date: 25 February 2004

of Pages Including Cover:

To:
FAX:
Phone:

From:
FAX:
Phone:

Urgent Reply ASAP For Your Info For Your File Review and Call Me

We are undertaking research in order to identify more effective ways to screen drivers for visual acuity. We have commissioned **Environment, Safety, and Risk Associates Corporation (ESRA)** to conduct surveys and reviews of visual acuity testing methods that have been employed around the nation and the world in order to determine if Arizona Department of Transportation's (ADOT) current vision testing practices could be improved. We will also be publishing and sharing the results as part of our FHWA funded research program.



Arizona Department of Transportation
Arizona Transportation Research Center
SURVEY



1. Were any modifications made to the visual impairment screening component of your driver license vision screening test over the last ten years?

No _____ Yes _____

2. If yes, what were these modifications?

3. Are any of your vision screening tests computer automated? (If yes, please specify percentage _____ that are computer automated?)

No _____ Yes _____

4. Please specify what kind(s) of vision screening test(s) you currently use:

5. What shortcomings (if any) have you found in these tests? (Please specify.)

6. Are there any current plans underway for modifications to these tests?

No _____ Yes (Please specify) _____

7. What improvements (if any) would you like to see made to your current visual acuity test methodologies?

8. What improvements would you like to see made to your current comprehensive automated driving tests? _____

9. Are there any impediments to making improvements? Please check all that apply. Costs ___ Statute/ Policy/ Rule _____ Staff/ Training _____

Other (Please specify) _____

10. What kinds of instruments do you use in your vision screening test now?

11. Are there other instruments you would you like to see adopted?

12. What authority is required to modify your vision testing procedures?

Please check one of the following:

Statute _____ Administrative Rule _____ Executive Action _____

Policy _____ Other (Please specify.): _____

13. Have you done any studies measuring the effectiveness of your current procedures? If you have, how may we obtain a copy?

14. Does your current vision screening test account for any of the following lighting changes? Please check all that apply.

Dawn _____ Day _____ Dusk _____

15. Does your current vision screening test account for any of the following weather conditions? Please check all that apply.

Clear ___ Rain ___ Sleet ___ Snow ___ Cloudiness ___ Fog ___

Other (please specify) _____

16. Do your current vision screening tests account for any of the following (please check all that apply):

Cataracts _____ Central Scotomas _____ Color blindness _____

Contrast Sensitivity _____ Depth Perception _____ Diplopia (Double Vision) _____

Eye Movement Disorder _____ Glare Sensitivity _____ Glaucoma _____

Peripheral Vision _____ Other (Please identify.) _____

17. How frequently must visual acuity screening tests be passed in order to renew a driver's license? ___ once a year, ___ once every five years, ___ once every ten years, ___ other (please specify) _____

18. What data are collected to identify potential vision impaired drivers?

19. What vision screening test do you use for commercial drivers?

20. How are at-risk drivers with visual acuity problems or severe eye ailments identified in your state? Please check all that apply.

Medical official _____ Anonymous Tips _____

On-line / Website _____ Postal mail to our Bureau _____

Telephone/ Hotline _____ Statute/ Rule/ Policy _____

Age _____ Mandatory On-site Vision Testing _____

Accident Report _____ Other (Please specify.) _____

21. What is the current visual acuity requirement in your state?

Please identify by ratio (e.g., 20/40) : _____ / _____ with both eyes opened and examined together.

Environment, Safety, and Risk Associates Corporation (ESRA)
Fax: 520-844-8555 E-mail: surveys@esracorp.com

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