TRANSPORTATION RESEARCH SYNTHESIS

Minnesota Department of Transportation
Office of Policy Analysis, Research & Innovation
Research Services Section
(651) 366-3780
www.research.dot.state.mn.us

TRS 1009
Published November 2010

Effects of 24-Hour Headlight Use on Traffic Safety

The purpose of this TRS is to serve as a synthesis of pertinent completed research to be used for further study and evaluation by Mn/DOT. This TRS does not represent the conclusions of either CTC & Associates or Mn/DOT.

Introduction

Daytime running lights—generally low-wattage headlights that turn on automatically when a vehicle's ignition is started—are a safety feature intended to reduce multiple-vehicle crashes during daylight hours by making vehicles more conspicuous to other drivers. In some countries, such as Canada, they are required to be standard equipment on all vehicles manufactured; in the United States they are permitted but not required, and were standard equipment on about 27 percent of new vehicles manufactured in 2005 (NHTSA, 2008).

Rather than requiring an equipment modification to new or existing vehicles, some jurisdictions have explored the "behavioral option" of requiring motorists to turn on their vehicle's existing headlights 24 hours a day. The expectation is that this requirement would confer the same safety benefits as having DRLs installed in all vehicles.

The Minnesota Legislature recently directed the Minnesota Department of Public Safety to work with Minnesota DOT to study the impact of 24-hour vehicle lighting. The report is required to address the following issues:

- Potential for crash prevention
- Motorcycle, bicycle and pedestrian safety
- Application to motorcycles
- Experiences of other jurisdictions and countries
- Environmental consequences
- Cost to drivers

In support of this effort, CTC & Associates prepared this Transportation Research Synthesis to analyze the existing literature on 24-hour headlight use, especially as it applies to the issues listed above.

Summary

The impact of daytime running lights has been studied extensively by agencies around the world. The effect of 24-hour use of regular low-beam headlights (as opposed to daytime running lights) has been studied less frequently, usually as part of a larger study on DRLs. Because of this, most of the research in this Transportation Research Synthesis concerns the use of DRLs; however, many studies reference several types of DRL implementations, including both the low-wattage DRLs that are common in newer vehicles and older DRLs that are brighter, more similar to the wattage of standard low-beam headlights. This research should be applicable to Minnesota's exploration of 24-hour use of low-beam headlights.

We identified research related to the following key topic areas:

- Effectiveness at reducing crash rates
- Effect of automobile DRLs on motorcycle safety
- Effect of DRL use by motorcycles
- Effect on crashes involving pedestrians and bicyclists
- Environmental and cost issues
- Related legislation
- Implementation

Effectiveness at Reducing Crash Rates

In the considerable body of research on this topic, most studies have found that the presence of DRLs reduces daytime multiple-vehicle crashes, especially head-on and front-corner collisions where vehicle conspicuity is a concern. The magnitude of the reduction varies depending on the study and the type of crash, but many studies have found a reduction of 5 to 10 percent.

The most recent large-scale study on this topic conducted in the United States is a 2008 NHTSA study that found that DRLs had no statistically significant effects on the types of crashes studied, except for a 5.7 percent reduction in the involvement of light trucks/vans in two-vehicle crashes. A 2004 NHTSA study that used different analysis methodology found that DRLs reduced opposite-direction fatal crashes by 5 percent and opposite-direction/angle non-fatal crashes by 5 percent. That study also found a 12 percent reduction in crashes involving pedestrians and bicyclists, and a 23 percent reduction in opposite-direction crashes involving motorcyclists.

In general, the issue of research methodology seems to be a critical factor in the debate over demonstrating DRLs' effectiveness, and can make it more difficult to aggregate the results of different studies. A key European study (Elvik et al., 2003) that used statistical meta-analysis to aggregate 41 DRL studies (25 studies that evaluated the safety effects of DRL for cars, and 16 for motorcycles) found that DRL use produced a 5 to 10 percent reduction in multiparty daytime crashes for cars. In this study, all 25 of the passenger car studies evaluated in the meta-analysis found that DRL use yielded a crash reduction of some magnitude—no studies demonstrated an increase in crashes.

Finally, recent research using the Minnesota DOT Crash Database also identified reductions in the rates of various crash types when DRLs were present. The magnitudes of the reductions were greater than in other DRL studies, again likely due to differing research methodology. (In this study, the overall crash rate among vehicles without standard DRLs was 1.73 times higher than the rate for vehicles with standard DRLs [832 crashes vs. 481 crashes per 10,000 vehicles].)

Effect of Automobile DRLs on Motorcycle Safety

Minnesota law requires motorcyclists to use their headlights during daylight hours, and opponents of DRLs have argued that requiring headlight use for all vehicles could make motorcycles less conspicuous. A NHTSA study on this topic, *Motorcycle Conspicuity and the Effect of Fleet Daytime Running Lights,* is expected to be complete by the end of 2010.

The findings of the 2008 NHTSA study regarding motorcycles were not statistically significant, and the 2004 NHTSA study found that DRLs reduced daytime opposite direction fatal crashes of a passenger vehicle with a motorcycle by 23 percent.

Effect of DRL Use by Motorcycles

Since Minnesota law currently requires motorcyclists to use their headlights at al times, a 24-hour headlight use law would not represent a new requirement for motorcyclists. Elvik et al. (2003) conducted a meta-analysis of 16 studies on DRL use in motorcycles, and found that:

- The use of DRLs on motorcycles reduced the number of multiparty daytime accidents by about 32 percent. However, this estimate was highly uncertain and was based on a single study only.

- Laws or campaigns designed to encourage the use of DRL for motorcycles were associated with a 5 to 10 percent reduction in multiparty daytime accidents.

Effect on Crashes Involving Pedestrians and Bicyclists

DRLs have the potential to effect pedestrian and bicyclist safety in at least two ways. It is possible that pedestrians and bicyclists would become relatively less visible when motor vehicles have their headlights on. However, the enhanced conspicuity of motor vehicles may make them easier for pedestrians and bicyclists to observe (Elvik et al., 2003). Studies on this topic found the following:

- The Elvik et al. (2003) meta-analysis found that DRLs reduced crashes involving pedestrians, though some of the individual studies reviewed showed an increase in crashes. The report reviewed three studies that estimated DRLs' effect on crashes involving bicyclists, and all showed a reduction.

- The 2008 NHTSA study found no statistically significant results for crashes involving pedestrians or bicyclists. The 2004 NHTSA study found that DRLs reduced daytime fatal crashes involving non-motorists, pedestrians and cyclists by 12 percent.

- An experimental 2004 European study (Brouwer et al.) found no evidence of a reduced conspicuity of road users in the vicinity of a DRL-equipped vehicle.

Environmental and Cost Issues

The issues of cost and environmental impact are closely related, because factors that affect the environment, such as increased fuel use and increased use and disposal of headlight bulbs, tend to increase costs as well. Studies on this topic tend to agree that the environmental impact of DRL use or of 24-hour headlight use is relatively small, and is a relatively small portion of overall annual vehicle costs.

Several studies have conducted benefit-cost analyses, often comparing the benefit-cost ratios of dedicated DRLs vs. 24-hour headlight use. The range of benefit-cost ratios across all options varied considerably from study to study, although the ratios for 24-hour headlight use varied less:

- Elvik et al. (2003) estimated a benefit-cost ratio of 1.96 for 24-hour headlight use; this was the highest ratio across all options evaluated.
- An October 2003 study conducted in Australia calculated a 1.18 benefit-cost ratio for 24-hour headlight use; this was the lowest ratio across all options evaluated.
- A 1997 Australian study calculated a 1.27 benefit-cost ratio of requiring motorists to turn on their

A 2008 study by the California Energy Commission recommended that the state not limit DRL use as a method of reducing petroleum fuel use. The study concluded that the fuel savings from this measure would not exceed 1 percent.

Related Legislation

No current state laws requiring 24-hour headlight use were identified, but two bills requiring it have been introduced to the Illinois State Legislature in recent years. In addition, some states have made headlight use mandatory on certain corridors; a 2005 Connecticut bill is an example of this type of proposal.

Implementation

The European Union commissioned an extensive four-part research project to gather information on the effectiveness of DRLs and the most successful implementation scenarios. This project analyzed cost-benefit ratios and projected public acceptance, and recommended implementing DRLs in new vehicles and requiring 24-hour use of low-beam headlights in existing vehicles. The authors suggested that the EU consider requiring 24-hour headlight use prior to the changes in the vehicle fleet in order to receive the expected benefits of DRL use more immediately.

Following this research, the European Union decided to implement DRLs as mandatory on passenger vehicles sold in member nations beginning in 2011.

Effectiveness at Reducing Crash Rates

As countries around the world have weighed whether to mandate the installation of daytime running lights or the use of headlights during daytime, a considerable amount of research has been performed into the effectiveness of DRLs at preventing crashes. In the last decade, several studies have been performed that analyze and synthesize the large body of existing research. A 2003 meta-analysis study (Elvik et al., 2003) performed for the European Commission is the most extensive of recent syntheses in this area, and is widely cited by subsequent studies.

In the United States, two NHTSA studies (2004 and 2008) are the most recent large-scale research in this area sponsored by the federal government. In addition, a 2010 paper gives a more localized perspective on how the use of daytime running lights have affected crash rates in Minnesota, but the crash rate reductions are much higher than have been reported in much of the rest of the literature. The authors suggest that this may be due to methodological differences.

Most studies have found that the presence of DRLs reduces daytime multiple-vehicle crashes, especially head-on and front-corner collisions where vehicle conspicuity is a concern. The magnitude of the reduction varies depending on the study and the type of crash, but many studies have found a reduction of 5 to 10 percent. The Elvik et al. meta-analysis (2003) examined 25 studies of passenger cars, and found that DRL use yielded a crash reduction of some magnitude in all 25 studies.

In general, the issue of research methodology seems to be a critical factor in the debate over demonstrating DRLs' effectiveness; for example, the 2004 and 2008 NHTSA studies used different statistical analysis methodologies and yielded different results. For this reason, this Transportation Research Synthesis highlights the methodology used in key studies summarized below.

Minnesota Research

Krajicek, Michele E., and Raquel M. Schears. "Daytime Running Lights in the USA: What Is the Impact on Vehicle Crashes in Minnesota?" *International Journal of Emergency Medicine*, 2010, Vol. 3., No. 1, pages 39-43.
http://www.springerlink.com/content/l7650hx33t56n144/fulltext.pdf
Researchers used the Minnesota DOT Crash Database from 1995 to 2002 to compare the crash rates of vehicles with and without DRLs as standard equipment. They evaluated crashes involving 185,000 vehicles, 38,000 of which had standard DRLs. The crashes occurred during daylight, with optimal visibility, on a dry road surface.

The study concluded that vehicles equipped with DRLs had a statistically significant lower crash rate than vehicles without DRLs. Specific findings included:

- The overall crash rate among vehicles without standard DRLs was 1.73 times higher than the rate for vehicles with standard DRLs (832 crashes vs. 481 crashes per 10,000 vehicles).
- For fatal vehicle crashes, the crash rate ratio was 1.48 times higher (3.0 fatal crashes vs. 2.0 fatal crashes per 10,000 vehicles).
- For crashes involving pedestrians, the crash rate ratio was 1.77 times higher (5.2 crashes vs. 2.9 crashes per 10,000 vehicles).
- For crashes involving bicycles, the crash rate ratio was 1.72 times higher (7.8 crashes vs. 4.5 crashes per 10,000 vehicles).

The authors point out that these crash rate reductions are notably higher than those seen in previous studies. They hypothesize that this may be because their study was a retrospective study of all vehicle crashes in Minnesota during the time period, whereas previous studies employed a case-control methodology to compare subsets of vehicles with and without DRLs.

National and International Research: Key Studies

National Highway Traffic Safety Administration. ***The Effectiveness of Daytime Running Lights for Passenger Vehicles,*** September 2008, Report DOT HS 811 209.
http://www.regulations.gov/search/Regs/contentStreamer?objectId=090000648070b5b6&disposition=attachment&contentType=pdf
This study is U.S. DOT's most recent research on the effectiveness of DRLs. Its findings—that the presence of DRLs had no statistically significant effect on the three types of crashes studied—differ from most of the rest of the international body of research on DRLs. See page 6 of the PDF for a summary of results.

In this study, NHTSA examined data from the Fatality Analysis Reporting System from 2000 to 2005, and from nine states (Florida, Illinois, Maryland, Michigan, Missouri, Nebraska, Pennsylvania, Utah and Wisconsin) during the same time period or portions of it. Specific findings included:

- The presence of DRLs had no statistically significant effects on three types of daytime crashes: (1) two-vehicle crashes, excluding rear-end crashes; (2) single-vehicle crashes with pedestrians or cyclists; (3) single-vehicle crashes with motorcyclists.
- When passenger cars and light trucks/vans were examined separately, DRLs reduced LTVs' involvement in the two-vehicle crashes studied by 5.7 percent, a statistically significant reduction.
- Although this finding was not statistically significant, DRLs appeared to have a negative impact on LTV crashes involving pedestrians and cyclists.

Methodology
This was a control-comparison study that compared specific models of cars and LTVs that had DRLs with earlier versions of identical models without DRLs, as opposed to aggregating all vehicles with DRLs and all vehicles without. Using matched vehicle models was intended to control for vehicle-specific factors so that the presence or absence of DRLs would be the only difference between DRL and non-DRL vehicles. In addition, this study used ratio of odds ratios, rather than simple odds, as the primary statistic to estimate the magnitude of DRLs' effects. The investigators stated that the ratio of odds ratios method produces more conservative estimates, is more sensitive to sample size, and has a greater ability to control for confounding factors.

Contact: Principal investigator Jing-Shiarn Wang, NHTSA, Jing.Wang@dot.gov.

In a study performed concurrently with the NHTSA study, researchers for General Motors Corp. sought to use the same matched-pairs methodology, analyzed with two statistical methods, in examining data from slightly different sources:

> **Exponent Inc. (prepared for General Motors).** ***Matched Pair Study of the Effectiveness of Daytime Running Lights,*** February 2008. See Appendix A.
> This study sought to update the authors' previous research for General Motors using revised methodology, similar to the methods used by the 2008 NHTSA study). This study found a reduction in rates of selected two-vehicle daytime collisions of about 8 to 12 percent for vehicles equipped with DRLs. These results were based on Poisson regression analysis; a second analysis using the ratio of odds ratios approach found a reduction of 5 to 8 percent.
>
> Like the NHTSA study, this study used a matched pairs approach in analyzing the crash data; investigators used model year pairs of GM, Saab, Toyota, Subaru, Volkswagen and Volvo vehicles. Whereas the NHTSA study included crash data from FARS, this study used state data as its primary source. The authors noted that FARS contains data on fatal crashes only, which is a small subset of all crashes that occur. Their analysis of FARS data concluded:
>
> > "Analyses of fatal crashes reported in FARS showed little difference in crash rates or odds ratios for DRL and non-DRL vehicles. The lack of statistically significant results largely reflects the relatively small numbers of fatal crashes involving these particular vehicle models and years under the specified conditions of interest."

NHTSA. ***An Assessment of the Crash-Reducing Effectiveness of Passenger Vehicle Daytime Running Lamps (DRLs),*** September 2004, Report DOT HS 809 760.
http://www-nrd.nhtsa.dot.gov/Pubs/809760.pdf
This study estimated the effectiveness of passenger vehicle daytime running lights in reducing two-vehicle opposite direction crashes, pedestrian/bicycle crashes, and motorcycle crashes. The authors used generalized simple odds, a conventional statistical technique, to analyze the data. This study found that from 1995 to 2001:

- DRLs reduced opposite direction daytime fatal crashes by 5 percent.
- DRLs reduced opposite direction/angle daytime non-fatal crashes by 5 percent.
- DRLs reduced daytime single-vehicle fatal crashes involving non-motorists, pedestrians and cyclists by 12 percent.
- DRLs reduced daytime opposite direction fatal crashes of a passenger vehicle with a motorcycle by 23 percent.

The study notes that the report's reviewers required the inclusion of an analysis based on odds ratio, which is provided in Appendix B of the report. None of the results of this analysis were statistically significant. The author further discusses the difference between the two methodologies on page 27 of the PDF.

Elvik, Rune; Peter Christensen; and Svenn Fjeld Olsen. ***Daytime Running Lights—A Systematic Review of Effects on Road Safety,*** 2003.
This study was Part 2 of a four-part research project into the effects of daytime running light use sponsored by the European Commission. See Appendix B for a summary of all four parts, and see page 15 for a description of Part 4 (Commandeur et al., 2003).
http://ec.europa.eu/transport/roadsafety_library/publications/IR2_report3_ver_oct_2004.pdf

This study is the most comprehensive analysis of the existing literature on daytime running lights. The authors analyzed 25 studies that evaluated the safety effects of DRL for cars and 16 studies that evaluated the safety effects of DRL for motorcycles. Their review was a statistical meta-analysis that sought to combine the estimates of effect from each study into one summary estimate.

In their analysis, the authors distinguished between the **intrinsic effect** on safety for an individual vehicle using daytime running lights and the **aggregate effect** on the total number of accidents in a country of laws or campaigns that lead to an increased use of daytime running lights.

The results of the meta-analysis included:

- The use of DRL reduces the number of multiparty daytime accidents for cars by about 5 to 10 percent (intrinsic effect). All of the analyzed studies estimated a reduction in the number of accidents, but the size of the reduction varied from study to study.

- Laws or campaigns designed to encourage the use of DRL for cars were associated with a 3 to 12 percent reduction in multiparty daytime accidents (aggregate effect)

- The use of DRL on motorcycles reduces the number of multiparty daytime accidents by about 32 percent (intrinsic effect). However, this estimate is highly uncertain and is based on a single study only.

- Laws or campaigns designed to encourage the use of DRL for motorcycles are associated with a 5 to 10 percent reduction in multiparty daytime accidents (aggregate effect).

The robustness of these summary estimates of effect was tested for potential sources of error in the meta-analysis, including publication bias, varying quality of the studies included, the statistical weights assigned to each estimate of effect; and the contribution of a single study to the overall estimate of effect. The authors found that in general, the summary estimates of effect were very robust.

Other conclusions from the meta-analysis included:

- The effects of DRL varied according to accident severity, with DRL having the greatest effects on the most severe accidents. However, evidence concerning the effects on fatal accidents was inconsistent. In the report's cost-benefit analysis, the authors assumed that DRL would reduce fatal multiparty daytime accidents by 15%, serious injury multiparty daytime accidents by 10%, and slight injury multiparty daytime accidents by 5%.

- There was a weak relationship between geographical latitude and the effects of DRL, with the effects of DRL increasing at latitudes further from the equator.

- Evidence concerning a seasonal variation in the effects of DRL was sparse and inconclusive.

- Further study is needed regarding whether the effects of laws mandating the use of DRL tend to diminish over time.

- The authors concluded that DRL is unlikely to have any adverse effect on accidents involving pedestrians, bicyclists or motorcyclists. Some estimates indicated that DRL laws had an adverse effect on pedestrian accidents, but the summary estimate of effect indicated a reduction in pedestrian accidents.

- The authors concluded that it was likely that using low-beam headlights as DRLs could have an adverse effect on rear-end collisions, because turning on a vehicle's headlights illuminates its tail lights as well, which could make it more difficult to detect brake lights. However, the presence of a third brake light may counteract this effect, as would the use of dedicated DRLs with tail lights that are switched off.

- The authors evaluated the presence of a dose-response relationship regarding the use of DRL (that is, the greater the increase in DRL usage, the greater the effect on safety), and did not find evidence of this type of relationship. Therefore, they predicted that making DRL use mandatory in the European Union would have an effect on accidents similar to the average effect observed in previous evaluation studies.

Methodology
The authors present more detail on the methodology of their statistical meta-analysis on page 7 of the PDF (see "Concerns about meta-analysis"). In addition, in 2005 one of the study's authors published a paper in *Transportation Research Record* on the topic ("Can We Trust the Results of Meta-Analyses?: A Systematic Approach to Sensitivity Analysis in Meta-Analyses," *Transportation Research Record* vol. 1908, pages 221-229, 2005).

The UK Department for Transport sponsored a study that reviewed the results of the European Commission research:

> **Knight, I.; B. Sexton; R. Bartlett; T. Barlow; S. Latham; and I. McCrae. *Daytime Running Lights (DRL): A Review of the Reports from the European Commission,*** October 2006, sponsored by the UK Department for Transport.
> http://ec.europa.eu/transport/road_safety/vehicles/doc/consultations/drl_trl.pdf
> Commissioned by the UK Department for Transport, this review of the European Commission reports agreed with the reports' conclusion that DRL use would reduce crashes, but questioned the stated magnitude of DRLs' effect. The reviewers also agreed that the reports' estimates of fuel and emissions increases were reasonable (and possibly slightly conservative, or high). See page 42 of the PDF for additional conclusions from this review.

National and International Research: Additional Studies

United States

Farmer, C.M., and A.F. Williams (Insurance Institute for Highway Safety). "Effects of Daytime Running Lights on Multiple-Vehicle Daylight Crashes in the United States," *Accident Analysis and Prevention*, March 2002, Vol. 34, No. 2, pages 197-203.
Abstract: Involvements in multiple-vehicle daylight crashes in nine states over 4 years were analyzed for a group of passenger cars and light trucks equipped with automatic daytime running lights. On average, these vehicles were involved in 3.2% fewer multiple-vehicle crashes than vehicles without daytime running lights (P = 0.0074).

Insurance Institute for Highway Safety. "Q&As: Daytime Running Lights," October 2009.
http://www.iihs.org/research/qanda/drl.html
This online Q&A page notes that "nearly all published reports indicate DRLs reduce multiple-vehicle daytime crashes," and summarizes key results from several studies conducted in Scandinavia, Canada and the United States, including:

- A 2002 study by the Insurance Institute for Highway Safety reported a 3 percent decline in daytime multiple-vehicle crash risk in nine US states concurrent with the introduction of DRLs.
- A study examining the effect of Norway's DRL law from 1980 to 1990 found a 10 percent decline in daytime multiple-vehicle crashes.
- A Danish study reported a 7 percent reduction in DRL-relevant crashes in the first 15 months after DRL use was required and a 37 percent decline in left-turn crashes.
- In a second study covering 2 years and 9 months of Denmark's law, there was a 6 percent reduction in daytime multiple-vehicle crashes and a 34 percent reduction in left-turn crashes.
- A 1994 Transport Canada study comparing 1990 model year vehicles with DRLs to 1989 vehicles without them found that DRLs reduced relevant daytime multiple-vehicle crashes by 11 percent.

Canada
All vehicles produced for sale in Canada after December 1, 1989, are required to be equipped with daytime running lights (DRL). (See the text of the legislation at http://www.tc.gc.ca/eng/acts-regulations/regulations-crc-c1038-sch-iv-108.htm.) Transport Canada examined the effect of the law a few years after it was introduced, in the 1994 study by Arora et al., and evaluated costs and benefits of DRLs in 1995.

We contacted Transport Canada to identify whether additional research on daytime running lights had been initiated or completed. Senior Crash Avoidance & Research Engineer Vittoria Battista confirmed that there had been no additional studies undertaken beyond those listed below.

Contact: Vittoria Battista, Senior Crash Avoidance & Research Engineer, Transport Canada, (613) 998-1950, vittoria.battista@tc.gc.ca.

Arora, H.; D. Collard; G. Robbins; E.R. Welbourne; and J.G. White (Transport Canada). ***Effectiveness of Daytime Running Lights in Canada.*** December 1994, Report No. TP-12298.

Lawrence, E. (Transport Canada). ***Preliminary Economic Evaluation of the Costs and Benefits of the Daytime Running Lights Regulation,*** 1995, Report No. TP 12517.
From the abstract: This paper presents a cost-benefit analysis of the use of DRL in preventing collisions, taking into account the original equipment costs of fitting vehicles with DRL and with the fuel consumption penalties associated with fitting and use of DRL. High and low cost estimates are given, reflecting factors such as the difference between integrating DRL into existing systems or into new vehicle designs. Benefits are calculated from the collision reduction rate due to DRL as determined in a 1995 Transport Canada study, combined with previously developed estimates of the standard cost of the avoided collisions.

White, J. ***Information on Daytime Running Lights*****,** May 1998, Transport Canada Technical Memorandum TMSR 9801 (unpublished).
Key findings of this report are summarized in a 2003 literature review conducted by Australia's National Roads and Motorists Association, *A Review of Daytime Running Lights* (see http://members.optusnet.com.au/carsafety/paine_drl_nrma_racv.pdf, beginning on page 16 of the PDF).

The following two papers present additional perspectives on DRL use in Canada:

Tofflemire, Troy C., and Paul C. Whitehead. "An Evaluation of the Impact of Daytime Running Lights on Traffic Safety in Canada," *Journal of Safety Research,* Volume 28, Issue 4, Winter 1997, pages 257-272.
Abstract: Since December 1, 1989 all new cars sold in Canada were required to be equipped with daytime running lights (DRL). This policy was expected to reduce angle and opposing collision involvement by 10% to 20% by making cars more conspicuous, thereby increasing the window of opportunity within which drivers can react. A

quasi-experimental comparative posttest design is used in this study to evaluate the impact of DRL legislation on the incidence of angle and opposing collisions for 1989 cars and 1990 cars in the 1991 calendar year. The results show that the combined incidence of the two types of collisions is reduced by 5.3% ($p < .05$), mainly due to a reduction in the incidence of opposing collisions (−15%; $p < .05$), rather than angle collisions (−2.5%; NS). An examination of each province reveals that only two small provinces display a statistically significant reduction in the incidence of opposing collisions and one province displays a statistically significant reduction in the incidence of angle collisions. The implications of these results are discussed in terms of their relevance for DRL policy theory, traffic safety, future research, and cost.

Sparks, Gordon A.; Russell D. Neudore, Anne E. Smith, Kenneth R. Wapman, and Paul L. Zador. "The Effects of Daytime Running Lights on Crashes Between Two Vehicles in Saskatchewan: A Study of a Government Fleet," *Accident Analysis and Prevention,* 1991, Vol. 25, pages 619-625.
From the abstract: Crashes of vehicles with and without daytime running lights owned by the Central Vehicle Agency of the Province of Saskatchewan were compared to a random selection of crashes drawn from provincial crash files involving vehicles without daytime running lights for the years 1982 through 1989. Daytime two-vehicle crashes involving vehicles approaching from the front or side were reduced by about 28% for the daytime running-light equipped vehicles. A 28% reduction in daytime running-light relevant daytime two-vehicle crashes corresponds to a 15% reduction in all daytime two-vehicle crashes.

Other Countries

Holló, P. "Changes in the Legislation on the Use of Daytime Running Lights by Motor Vehicles and Their Effect on Road Safety in Hungary," *Accident Analysis and Prevention*, March 1998; Vol. 30, No. 2, pages 183-199.
This paper analyzed the effects of DRL use laws implemented in Hungary in 1993 and 1994 and found a 13 percent reduction in daytime frontal and "crossing" vehicle collisions where DRL use was required.

Koornstra, M.J.; F. Bijleveld; and M. Hagenzieker. *The Safety Effects of Daytime Running Lights,* Report R-97-36. Leidschendam, The Netherlands, SWOV Institute for Road Safety Research, 1997.
http://www.landesverkehrswacht.de/fileadmin/downloads/Tagfahrlicht/Studie_Niederlande_Tagfahrlicht.pdf
This report analyzed 24 previous studies, with a focus on issues of perception of vehicles with DRLs. The authors found that DRLs generally had a positive effect on visual perception of vehicles, "particularly peripheral perception as well as perception under low levels of (daytime) ambient illumination and when not too high intensity lamps are used (to avoid glare effects)."

In addition, researchers calculated a benefit-cost ratio of 1.27 for mandatory daytime use of headlights ("behavioral obligation"). See page 10 of the PDF.

> *Note on study methodology:*
> **Stone, M. "Questions of Probability in Daytime-Running-Light Argument,"** *Accident Analysis and Prevention,* September 1999, Vol. 31, No. 5, pages 479-483.
> *Abstract:* The paper presents a revision of the formulae of Koornstra for converting "raw" daytime-running-light effects into "intrinsic" effects, based on a reworking of the underlying probability calculus.

Hansen, L.K. *Daytime Running Lights in Denmark—Evaluation of the Safety Effect.* Danish Council of Road Safety Research, Copenhagen, 1993.

Early Studies of Effectiveness

Andersson, K.; G. Nilsson; and M. Salusjarvi. *The Effect of Recommended and Compulsory Use of Vehicle Lights on Road Accidents in Finland,* 1976, Report 102A, National Road and Traffic Research Institute, Linkoping, Sweden.

Andersson, K., and G. Nilsson. *The Effect on Accidents of Compulsory Use of Running Lights During Daylight Hours in Sweden,* 1981, Report 208A, National Road and Traffic Research Institute, Linkoping, Sweden.

The following study re-examines the data in Andersson and Nilsson (1981):

Theeuwes, J., and J. Riemersma. "Daytime Running Lights as a Vehicle Collision Countermeasure: The Swedish Evidence Reconsidered," *Accident Analysis and Prevention,* October 1995, Vol. 27, No. 5, pages 633-542. TNO Human Factors Research Institute, Soesterberg, The Netherlands.
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.77.8738&rep=rep1&type=pdf
Abstract: In Sweden the use of daytime running lights (DRL) was made mandatory on 1 October 1977 for all motor vehicles at once, during all seasons and for all areas. According to a study conducted by Andersson and Nilsson (1981) [Andersson and Nilsson. VTI Swedish Road and Transport Research Institute, Report No. 208A; 1981] the introduction of DRL resulted in a reduction of 11% of multiple accidents during daytime. In many discussions on the effectiveness of DRL, these findings have been considered as the strongest evidence that the use of DRL is an effective vehicle collision countermeasure. The present study reexamines this evidence and shows that the reported 11% effect of DRL in the Swedish study is spurious. The effect is mainly the result of the application of a model that shows selective effects of DRL through modeling of unexplained changes in the number of single accidents. It is concluded that the Swedish data fail to show a clear effect of DRL.

Industry Research

Bergkvist, P. (General Motors). "Daytime Running Lights—A North American Success Story," *Proceedings of 17th Conference on the Enhanced Safety of Vehicles,* Windsor, Canada, 1998.
From the abstract: This paper begins with a brief regulatory history of DRLs in the U.S. and how General Motors Corporation (GM) introduced DRL-equipped vehicles. It also describes a DRL effectiveness study conducted by Exponent Failure Analysis Associates of San Francisco for General Motors Corporation. The study compared the collision rates of specific General Motors Corporation, Saab, Volvo and Volkswagen vehicles before and immediately after the introduction of DRLs. … Information from police accident reports and registration data shows that General Motors Corporation customers have avoided more than 25,000 vehicle collisions since General Motors Corporation began equipping vehicles with DRLs in 1995.

Other General Motors studies discussed elsewhere in this report include:

Exponent Inc. (prepared for General Motors). ***Matched Pair Study of the Effectiveness of Daytime Running Lights,*** February 2008. See Appendix A.
This study sought to update the authors' previous research for General Motors using revised methodology, similar to the methods used by the 2008 NHTSA study). This study found a reduction in rates of selected two-vehicle daytime collisions of about 8 to 12 percent for vehicles equipped with DRLs. These results were based on Poisson regression analysis; a second analysis using the ratio of odds ratios approach found a reduction of 5 to 8 percent.

Thompson, Paul A. (General Motors). ***Daytime Running Lamps (DRLs) for Pedestrian Protection,*** May 2003.
This study updated a 2000 study that reviewed crash data from 12 states, adding five additional states and more vehicle models. The abstract notes that in the 2000 study, the presence of DRLs yielded the most significant collision reductions in crashes involving pedestrians. The abstract does not give detailed results of the 2003 study.

Effect of Automobile DRLs on Motorcycle Safety

NHTSA. ***Motorcycle Conspicuity and the Effect of Fleet Daytime Running Lights,*** Contract DTNH22-05-D-01002. In progress; expected completion in 2010.

Principal investigator Stephanie Binder indicated via email that NHTSA is currently finalizing this report and expects it to be available for review by the end of the year. An undated paper and a 2005 presentation based on this research are available online; they describe the study but do not give results or conclusions.

Binder, Stephanie, Michael Perel, John Pierowicz, Valerie Gawron, and Glenn Wilson. "Motorcycle Conspicuity and the Effects of Motor Vehicle Fleet Daytime Running Lights (DRLs)," paper presented at International Motorcycle Safety Conference, undated.
http://www.msf-usa.org/imsc/proceedings/b-Binder-EffectsofMotorVehicleDRLonMotorcycleConspicuity.pdf

Binder, Stephanie, and Michael Perel. "The Effects of Motor Vehicle Fleet Daytime Running Lights (DRLs) on Motorcycle Conspicuity," presentation, Dec. 6, 2005.
http://www.nhtsa.gov/DOT/NHTSA/NVS/Public%20Meetings/Presentations/2005%20Meetings/Binder_DRLS.pdf

Contact: Principal investigator Stephanie Binder, NHTSA, stephanie.binder@dot.gov.

NHTSA. ***The Effectiveness of Daytime Running Lights for Passenger Vehicles,*** September 2008.
http://www.regulations.gov/search/Regs/contentStreamer?objectId=090000648070b5b6&disposition=attachment&contentType=pdf
This study found no statistically significant effect of DRL use on crashes involving motorcycles. Although the results were not significant, the authors found that DRLs in cars and light trucks/vans were more likely to increase fatal daytime crashes involving motorcycles, and seemed to increase overall crashes between vehicles and motorcycles. DRLs seemed to reduce crashes causing injury and overall crashes involving passenger cars and motorcycles, but seemed to have adverse effects on crashes involving light trucks/vans and motorcycles (see page 8 of the PDF). These adverse effects were not statistically significant.

NHTSA. ***An Assessment of the Crash-Reducing Effectiveness of Passenger Vehicle Daytime Running Lamps (DRLs),*** September 2004.
http://www-nrd.nhtsa.dot.gov/Pubs/809760.pdf
This study found that from 1995 to 2001, DRLs reduced daytime opposite direction fatal crashes of a passenger vehicle with a motorcycle by 23 percent.

Effect of DRL Use by Motorcycles

Minnesota law currently requires motorcyclists to turn on their headlights during daylight hours, so a 24-hour headlight use law would not represent a new requirement for motorcyclists. Several researchers studied the effectiveness of motorcycle headlight use laws during the 1980s, but less research has been performed on the topic in recent years. Elvik et al. (2003) analyzed 16 studies on DRL use in motorcycles; the results of this analysis are presented below.

Elvik, R., et al. ***Daytime Running Lights—A Systematic Review of Effects on Road Safety,*** 2003.
http://ec.europa.eu/transport/roadsafety_library/publications/IR2_report3_ver_oct_2004.pdf
This meta-analysis study identified two effects of motorcycles using DRLs:

- The use of DRL on motorcycles reduces the number of multiparty daytime accidents by about 32 percent (intrinsic effect). However, this estimate is highly uncertain and is based on a single study only.
- Laws or campaigns designed to encourage the use of DRL for motorcycles are associated with a 5 to 10 percent reduction in multiparty daytime accidents (aggregate effect).

Effect on Crashes Involving Pedestrians and Bicyclists

DRLs have the potential to effect pedestrian and bicyclist safety in at least two ways. It has been suggested that pedestrians and bicyclists become relatively less visible when motor vehicles have their headlights on. However, the enhanced conspicuity of motor vehicles may make them easier to observe for pedestrians and bicyclists (Elvik et al., 2003).

Elvik, R., et al. ***Daytime Running Lights—A Systematic Review of Effects on Road Safety,*** 2003.
http://ec.europa.eu/transport/roadsafety_library/publications/IR2_report3_ver_oct_2004.pdf
This meta-analysis study drew conclusions about the effect of DRLs on pedestrian and bicyclist safety (see page 88 of the PDF):

- This study analyzed five studies that provided estimates of the **intrinsic** effects of DRLs on crashes involving pedestrians. All studies, as well as the meta-analysis summary estimate, indicated a reduction of pedestrian accidents.
- The study analyzed nine studies that provided estimates of **aggregate** effects of DRLs on crashes involving pedestrians. Five showed an increase in the number of accidents, and four showed a reduction. However, the meta-analysis summary estimate showed a reduction in pedestrian accidents, despite the fact that a majority of the individual estimates of effect showed an increase.
- No estimates were found of the intrinsic effects of DRL on crashes involving bicyclists. There were three estimates of the aggregate effects, and all of them showed a reduction in crashes involving bicyclists.

Based on the meta-analysis, it is concluded that the DRL is unlikely to have any adverse effects on accidents involving pedestrians, cyclists or motorcyclists. Some estimates indicate an adverse effect of DRL laws for pedestrian accidents, but the summary estimate of effect, taking all individual estimates into account, indicates a reduction in pedestrian accidents.

NHTSA. ***The Effectiveness of Daytime Running Lights for Passenger Vehicles,*** September 2008.
http://www.regulations.gov/search/Regs/contentStreamer?objectId=090000648070b5b6&disposition=attachment&contentType=pdf
This study found no statistically significant effect of DRL use on crashes involving pedestrians and cyclists. Although the results were not significant, the authors found that DRLs in cars were more likely to reduce both fatal and injury crashes involving pedestrians and cyclists. For light trucks/vans, they found a large negative effect (see page 7 of the PDF), which was also not statistically significant.

NHTSA. ***An Assessment of the Crash-Reducing Effectiveness of Passenger Vehicle Daytime Running Lamps (DRLs),*** September 2004.
http://www-nrd.nhtsa.dot.gov/Pubs/809760.pdf
This study found that from 1995 to 2001, DRLs reduced daytime fatal crashes involving non-motorists, pedestrians and cyclists by 12 percent.

Brouwer, R.F.T.; W.H. Janssen; M. Duistermaat; and J. Theeuwes. ***Do Other Road Users Suffer from the Presence of Cars That Have Their Daytime Running Lights On? Investigation of Possible Adverse Effects of Daytime Running Lights,*** 2004, TNO Report TM-04-C001, TNO Human Factors, Soesterberg.
This study was part of the four-part European Commission project; see a summary at http://www.swov.nl/rapport/R-2003-29.pdf, pages 12 to 13 of the PDF.

In this experimental study, subjects viewed color slides depicting natural daylight scenes of traffic intersections. The slides contained a vehicle with or without DRL and possibly other road users such as a bicyclist, pedestrian, or motorcyclist. Subjects were instructed to determine as fast as possible whether other road users were present or not. The main result of the study is that no evidence was found of a reduced conspicuity of road users in the vicinity of a DRL-equipped vehicle. Other road users actually appeared to benefit from DRL, although the effect was small. A similar absence of adverse effects was found with respect to driver visual capacities, as measured in elderly drivers by UFOV (useful field of view) and static visual acuity scores.

Thompson, Paul A. (General Motors). ***Daytime Running Lamps (DRLs) for Pedestrian Protection,*** May 2003.
This study updated a 2000 study that reviewed crash data from 12 states, adding five additional states and more vehicle models. The abstract notes that in the 2000 study, the presence of DRLs yielded the most significant collision reductions in crashes involving pedestrians. The abstract does not give detailed results of the 2003 study.

Environmental and Cost Issues

The issues of cost and environmental impact are closely related, because factors that affect the environment, such as increased fuel use and increased use and disposal of headlight bulbs, tend to increase costs as well. Studies on this topic tend to agree that the environmental impact of DRL use or of 24-hour headlight use is relatively small, and is a relatively small portion of overall annual vehicle costs.

Several studies have conducted benefit-cost analyses, often comparing the benefit-cost ratios of dedicated DRLs vs. 24-hour headlight use. The range of benefit-cost ratios across all options varied considerably from study to study, although the ratios for 24-hour headlight use varied less:

- Elvik et al. (2003) estimated a benefit-cost ratio of 1.96 for 24-hour headlight use; this was the highest ratio across all options evaluated.
- An October 2003 study conducted in Australia calculated a 1.18 benefit-cost ratio for 24-hour headlight use; this was the lowest ratio across all options evaluated.
- A 1997 Australian study calculated a 1.27 benefit-cost ratio of requiring motorists to turn on their headlights 24 hours a day, compared with 1.76 for automatic in-vehicle DRL with low-wattage lights.

A 2008 study by the California Energy Commission recommended that the state not limit DRL use as a method of reducing petroleum fuel use. The study concluded that the fuel savings from this measure would not exceed 1 percent.

Insurance Institute for Highway Safety. "Q&As: Daytime Running Lights," October 2009.
http://www.iihs.org/research/qanda/drl.html
Excerpt: "Running vehicle lights in the daytime does not significantly shorten bulb life. Systems like those on General Motors cars that use high beams are designed to operate at half their normal power during daylight hours, thereby conserving energy and reducing the effect on a vehicle's fuel economy. The National Highway Traffic Safety Administration (NHTSA) estimates that only a fraction of a mile per gallon will be lost, depending on the type of system used. GM estimates the cost to be about $3 per year for the average driver. Transport Canada estimates the extra annual fuel and bulb replacement costs to be $3-15 for systems using reduced-intensity headlights or other low-intensity lights and more than $40 a year for DRL systems using regular low-beam headlights."

California Energy Commission. ***Option 1G: Limiting the Use of Daytime Running Lights and Optional Lamps,*** addendum to the CEC report *Options to Reduce Petroleum Fuel Use,* August 7, 2008.
http://www.energy.ca.gov/2005publications/CEC-600-2005-024/addendum_individual_files/CEC-600-2005-024-AD-1G.pdf
This analysis examines the petroleum reduction that might be achieved by limiting the use of daytime running lights, fog lamps, and other optional vehicle lights.

> *Summary:* The analysis estimates that the petroleum savings from limiting the use of DRLs would not exceed 1 percent and would defeat the more important societal safety function they provide. Daytime visibility and avoidance of head-on or sideswipe multiple car accidents is the primary function of DRLs. Additionally, a general trend towards low energy/high luminosity lamps is occurring in the automobile market. Lower energy use in these lamps may be hastened by regulatory proceedings underway to correct for unintended glare. A proposed safety regulation will limit the luminosity of DRLs used in the United States in the near future.

Elvik, et al. ***Daytime Running Lights—A Systematic Review of Effects on Road Safety,*** 2003.
http://ec.europa.eu/transport/roadsafety_library/publications/IR2_report3_ver_oct_2004.pdf
(see pages 98-99 of the PDF)
This study calculated benefit-cost ratios for five implementation options. The ratios ranged from 1.42 to 1.96, with the behavioral-only option (requiring motorists to turn on their headlights manually) yielding the highest benefit-cost ratio. (Although using a vehicle's existing headlights consumes more fuel than using low-wattage DRLs, this option requires no installation of new equipment.)

Cairney, Peter, and Tanya Styles (Australian Transport Safety Bureau). ***Review of the Literature on Daytime Running Lights (DRL),*** October 2003.
http://www.infrastructure.gov.au/roads/safety/publications/2003/pdf/Cons_Lights.pdf
This study calculated benefit-cost ratios for six implementation scenarios, and found the option that required motorists to turn on their existing headlights 24 hours a day (referred to as the "Model 2" option) had the lowest benefit-cost ratio of the six options evaluated, at 1.18. The highest benefit-cost ratio in this study was 4.59 (see Table 9, page 61 of the PDF).

In preparing the benefit-cost ratios, this study estimated the annual costs of the six options for daytime headlight use (see Table 5, page 57 of the PDF). The "Model 2" option was estimated to cause drivers to need to purchase an additional set of headlight bulbs every two years, and an additional 30 liters (8 gallons) of gasoline per year.

Koornstra, Matthijs; Frits Bijleveld; and Marjan Haganzieker. ***The Safety Effects of Daytime Running Lights*****,** 1997, Report R-97-36, SWOV Institute for Road Safety Research.
http://www.landesverkehrswacht.de/fileadmin/downloads/Tagfahrlicht/Studie_Niederlande_Tagfahrlicht.pdf
(See page 9 of the PDF for an erratum that provides revised benefit-cost ratios.)
This study calculated that the benefit-cost ratio of requiring motorists to turn on their headlights 24 hours a day was 1.27, compared with 1.76 for automatic in-vehicle DRL with low-wattage DRL lamps.

Lawrence, E. (Transport Canada). ***Preliminary Economic Evaluation of the Costs and Benefits of the Daytime Running Lights Regulation,*** 1995, Report No. TP 12517.
From the abstract: This paper presents a cost-benefit analysis of the use of DRL in preventing collisions, taking into account the original equipment costs of fitting vehicles with DRL and with the fuel consumption penalties associated with fitting and use of DRL. High and low cost estimates are given, reflecting factors such as the difference between integrating DRL into existing systems or into new vehicle designs. Benefits are calculated from the collision reduction rate due to DRL as determined in a 1995 Transport Canada study, combined with previously developed estimates of the standard cost of the avoided collisions.

National Roads and Motorists' Association [Australia] Motoring & Services and RACV, ***A Review of Daytime Running Lights,*** **June 2003.**
http://members.optusnet.com.au/carsafety/paine_drl_nrma_racv.pdf
This report discusses cost-benefit scenarios for Australia on pages 34-35 of the PDF.

Related Legislation

No current state laws requiring 24-hour headlight use were identified, but two bills requiring it have been introduced to the Illinois State Legislature in recent years. In addition, some states have made headlight use mandatory on certain corridors; a 2005 Connecticut bill is an example of this type of proposal.

Illinois
House Bill 4701, introduced January 4, 2010, by State Rep. Dan Brady
http://www.ilga.gov/legislation/BillStatus.asp?DocNum=4701&GAID=10&DocTypeID=HB&LegId=48973&SessionID=76&GA=96
This bill would require the use of headlights or daytime running lights 24 hours a day. Bill sponsor State Rep. Dan Brady was quoted about the bill in a March 2010 article in the *Daily Herald* (see http://www.dailyherald.com/story/?id=365890&src=109) as saying he introduced the bill at the request of law enforcement officials from his district as a possible way to reduce accidents.

Contact: Rep. Dan Brady, State Representative, (309) 662-1100, dan@rep-danbrady.com

State Rep. Jim Sacia introduced a similar bill in the Illinois House of Representatives last year. He indicated via e-mail that the impetus for the bill came from “an elderly lady who indicated that, in the afternoon sun, it was hard to see gray cars against gray pavement.” Sacia said resistance to the bill was significant; although most police agencies were in favor of it, he said many residents thought it was “a government intrusion.” He noted that antique car enthusiasts were also resistant to the idea.

Contact: Jim Sacia, State Representative, (815) 232-0774, jimsacia@aeroinc.net

Connecticut
Proposed Bill No. 336, introduced January 2005 by State Sen. Prague
ftp://ftp.cga.ct.gov/2005/tob/s/2005SB-00336-R00-SB.htm
This bill would have required a 24-hour “headlight use zone” on a portion of Route 169

Implementation

The European Union commissioned an extensive four-part research project to gather information on the effectiveness of DRLs and the most successful implementation scenarios. The Elvik et al. study (2003) was Part 2 of this project, and Part 4, Commandeur et al. (2003), focused on implementation.

Commandeur et al. (2003) analyzed cost-benefit ratios and projected public acceptance, and recommended implementing DRLs in new vehicles and requiring 24-hour use of low-beam headlights in existing vehicles. The authors suggested that the EU consider requiring 24-hour headlight use prior to the changes in the vehicle fleet in order to receive the expected benefits of DRL use more immediately.

Following this research, the European Union decided to implement DRLs as mandatory on passenger vehicles sold in member nations beginning in 2011 (see a fact sheet at http://www.swov.nl/rapport/Factsheets/UK/FS_DRL.pdf).

Commandeur, Jacques; René Mathijssen; Rune Elvik; Wiel Janssen; and Veli-Pekka Kallberg. ***Scenarios for the Implementation of Daytime Running Lights in the European Union,*** 2003. Part 4 of a four-part project sponsored by the European Commission.
http://www.swov.nl/rapport/R-2003-29.pdf
This study analyzed five policy options for the implementation of DRL in the European Union. The authors recommended an option that yielded the second best benefit-cost ratio, which they believed would be most widely accepted by the public: mandatory use of low-beam headlights as DRL for cars currently on the road, together with the installation of automatic dedicated DRL on new cars, both to be implemented at the same time from a certain date onwards, and preceded by a period of recommended DRL usage combined with a large-scale publicity campaign.

The authors note: “Should the technical part of the implementation take too long, however, the report recommends to start imposing the use of [low-beam] headlights as DRL as soon as possible, thus avoiding an unnecessary delay in the expected road safety benefits of DRL.”

Failure Analysis Associates

Matched Pair Study of the Effectiveness of Daytime Running Lights

Exponent®
Failure Analysis Associates®

Matched Pair Study of the Effectiveness of Daytime Running Lights

Prepared for

Brian Latouf
General Motors Corporation
Mail Code 480-111-E18
30200 Mound Road
Warren, MI 48090

Prepared by

Duane Steffey
Edmund Lau
Rose M. Ray
Exponent, Inc.
149 Commonwealth Drive
Menlo Park, CA 94025

February 2008

0703309.000 0208 ds02

Contents

List of Figures

List of Tables

Acronyms and Abbreviations

CDS	Crashworthiness Data System
DRL	Daytime Running Lights
FARS	Fatality Analysis Reporting System
GM	General Motors Corporation
MVA	Two-Vehicle (Multiple-Vehicle) Accident
NASS	National Automotive Sampling System
NHTSA	National Highway Traffic Safety Administration
ROR	Ratio of Odds Ratios

Executive Summary

There have been many studies, both of epidemiological studies of field performance and human factors experiments to estimate the effect of daytime running lights (DRLs) on improving the conspicuity of vehicles in transport. Considerable controversy remains. Both the estimated magnitude of the effect and the statistical significance the effect are seen to depend upon the data sources used and the method of measuring effectiveness and the method used for controlling potentially confounding variables. The National Highway Traffic Safety Administration (NHTSA) performed studies in 2000 and in 2004 (NHTSA 2000 and Tessmer 2004) and found evidence for effectiveness for a reduction in daytime two-vehicle crashes when using an odds-ratio method, but found that the differences were not statistically significant and sometimes counterintuitive (e.g., negative as opposed to expected positive changes) when using a ratio-of-odds-ratios (ROR) method.

The research presented here is an update of previous research on DRLs performed by Exponent for General Motors Corporation (GM) in 2002. Additional calendar years of data, non-GM vehicles and additional statistical methods have been added to the study. The pairs of DRL/non-DRL vehicles used in this study were selected to match those reported to be used by NHTSA in an ongoing study. Both the Poisson regression method for analysis of accident rates and the ratio-of-odds-ratio methods are used in this study.

Model year pairs of GM, Saab, Toyota, Subaru, Volkswagen and Volvo vehicles were identified and selected for the present study of DRL effectiveness. The set of vehicle pairs selected was chosen in conformance with the current study of DRL in progress at the NHTSA. These pairs consisted of the first two model years following the introduction of DRL and the preceding two model years (without DRL). This approach was used to minimize the effects of other design changes in the model pairs that may have contributed to crash avoidance potential and confounded the effect of DRL. As much as possible, the vehicle pair from the same product development and design cycle is used.

Motor vehicle collision data files from various states were chosen as the primary data sources for the present study. State-level files contain the largest amount of in-the-field collision data. Records are not restricted to events of a particular level of severity (e.g., fatal accidents) and constitute a complete census of all reported accidents in a given state. Thus, state files provide a sufficient volume of data to examine nearly any vehicle model in a wide variety of accident conditions, including some relatively rare events. By contrast, other commonly available sources of vehicle accident data, such as the Fatality Analysis Reporting System (FARS) or the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS), are focused on events of a specific and narrow severity (FARS) or comprise only a small sample of a larger pool of state-level data (NASS/CDS). For these reasons, a large collection of police-reported accidents from a variety of states provides the best instrument for examining the effectiveness of DRLs.

Exponent's Poisson regression analyses of 1996-2005 state motor vehicle accident and registration data found that, for both passenger cars and light trucks, rates of selected two-vehicle daytime collisions were approximately 8 to 12 percent lower for DRL-equipped vehicles than for vehicles without DRLs. These reductions were significantly greater than the corresponding decreases of no more than 4 percent observed in the rates of single-vehicle daytime and two-vehicle nighttime collisions.

Analyses using a ratio-of-odds-ratios approach corroborate these findings. Significant reductions in odds ratios of 5 to 8 percent were observed in the same types of two-vehicle daytime crashes identified in the Poisson regression analyses as having comparatively significant reductions in collision rates for DRL-equipped vehicles.

For either passenger cars, light trucks, or both types of vehicles, significant reductions were observed in the risk of daytime two-vehicle head-on crashes, daytime two-vehicle crashes in rainy or foggy conditions, and daytime two-vehicle crashes in rural areas. There is no evidence suggesting that the introduction of DRL would significantly increase the risk of motorcycle accidents or other types of crashes. These results support the conclusion of Knight, et al. (2006) that the introduction of DRL would result in a net reduction in risk of accidents and associated casualties.

Analyses of fatal crashes reported in FARS showed little difference in crash rates or odds ratios for DRL and non-DRL vehicles. The lack of statistically significant results largely reflects the relatively small numbers of fatal crashes involving these particular vehicle models and years under the specified conditions of interest.

Findings from the Poisson regression and ROR analyses generally agree well. Observed differences are likely attributable to the different components of the risk metrics. Poisson regression analyses use vehicle registration data as a measure of exposure, while the ROR analyses use daytime and nighttime single-vehicle crashes as controls.

Introduction

Daytime running lights (DRLs) were first introduced in Scandinavian countries nearly 30 years ago. In 1972, Finland was the first country to require motorists to turn on their headlamps while operating their vehicles. Over the next two decades, similar regulations were adopted by Sweden (1977), Norway (1985), Iceland (1988), and Denmark (1990). Given the northern latitude of these countries and long winter months with low ambient lights, it is not surprising that DRLs found their initial applications in these countries. In North America, Canada was the first to adopt a regulation requiring all new passenger cars manufactured after December 1, 1989, to be equipped with DRLs.

There have been many studies, both of epidemiological studies of field performance and human factors experiments to estimate the effect of DRLs on improving the conspicuity of vehicles in transport. Considerable controversy remains. Both the estimated magnitude of the effect and the statistical significance of the effect are seen to depend upon the data sources used and the method of measuring effectiveness and the method used for controlling potentially confounding variables. The National Highway Traffic Safety Administration (NHTSA) performed studies in 2000 and in 2004 (NHTSA 2000 and Tessmer 2004) and found evidence for effectiveness for a reduction in daytime two-vehicle crashes when using an odds ratio method, but found that the differences were not statistically significant and sometimes in the wrong direction when using a ratio of odds ratio method.

Knight, et al. (2006) performed a review and meta-analysis of DRL research and found statistically significant evidence of a decrease in crashes associated with the introduction of DRL, but indicated that some estimates of the magnitude of the decrease indicated that mandating DRL was not a cost effective safety strategy. In addition, conspicuity research indicated that the use of high intensity DRL by passenger vehicles may reduce the visibility of nearby motorcycles and thus increase the crash risk for motorcycles.

The British Motor Cycle Federation has published an ongoing series of reports and articles (e.g., Perlot and Prower 2003) asserting an increased risk to motor cycle drivers and criticizing the methodology of studies that found DRLs to be effective in reducing passenger vehicle crash risk. The British Association for Drivers Against Daytime Running Lights maintains a website http://www.dadrl.org.uk/index.html which lists research papers that found DRLs to be effective and provides anti-DRL criticism for each report.

The research presented here is an update of previous research on DRLs performed by Exponent for General Motors Corporation (GM) in 2002. Additional calendar years of data, non-GM vehicles and additional statistical methods have been added to the study. The pairs of DRL/non-DRL vehicles used in this study were selected to match those reported to be used by NHTSA in a current study. Both the Poisson regression method for analysis of accident rates and the ratio-of-odds-ratio methods are used in this study.

Data

Vehicle Pairs Data

Model year pairs of GM, Saab, Toyota, Subaru, Volkswagen and Volvo vehicles were identified and selected for the present study of DRL effectiveness. The set of vehicle pairs selected was chosen in conformance with the current study of DRL in progress at the NHTSA. These pairs consisted of the first two model years following the introduction of DRL and the preceding two model years (without DRL). This approach was used to minimize the effects of other design changes in the model pairs that may have contributed to crash avoidance potential and confounded the effect of DRL. As much as possible, the vehicle pair from the same product development and design cycle is used. In a few cases, only one model year prior to DRL introduction was used. Table 1 lists the specific vehicle models and their respective model years with and without DRL.

Table 1. Vehicle Model Pairs

Vehicle Make/Model	Without DRL Model Year	With DRL Model Year
Passenger Cars		
Buick Century	1995-1996	1997-1998
Buick LeSabre	1995-1996	1997-1998
Buick Park Ave	1995-1996	1997-1998
Buick Regal	1995-1996	1997-1998
Buick Riviera	1995-1996	1997-1998
Buick Skylark	1995	1996
Cadillac Deville	1994-1995	1996-1997
Cadillac Seville	1994-1995	1996-1997
Chevrolet Beretta/Corsica	1993-1994	1995-1996
Chevrolet Camaro F	1995-1996	1997-1998
Chevrolet Cavalier J	1994-1995	1996-1997
Chevrolet Corvette Y	1995-1996	1997-1998
Chevrolet GEO Metro	1994	1995
Chevrolet Lumina	1995-1996	1997-1998
Chevrolet Monte Carlo	1995-1996	1997-1997
Chevrolet Nova/Prizm	1994-1995	1996-1997
Lexus ES 300	1997-1998	1999-2000
Lexus GS 300	1997-1998	1999-2000
Lexus LS 400	1997-1998	1999-2000
Lexus SC 300/400	1997-1998	1999-2000
Oldsmobile 88	1994-1995	1996-1997

Vehicle Make/Model	Without DRL Model Year	With DRL Model Year
Oldsmobile 98	1995	1996
Oldsmobile Achieva/Alero	1994-1995	1996-1997
Oldsmobile Aurora	1995	1996
Pontiac Bonneville	1994-1995	1996-1997
Pontiac Firebird F	1995-1996	1997-1998
Pontiac Grand AM N	1994-1995	1996-1997
Pontiac Grand Prix W	1995-1996	1997-1998
Pontiac Sunbird/Fire J	1994-1995	1996-1997
Saturn SC Z	1995-1996	1997-1998
Saturn SL Z	1994-1995	1996-1997
Saturn SW Z	1994-1995	1996-1997
Subaru Legacy	1999	2000
Toyota Avalon	1997-1998	1999-2000
Toyota Celica	1999	2000
Toyota Corolla	1996-1997	1998-1999
Volvo 850	1993-1994	1995-1996
Volvo 960	1993-1994	1995-1996
VW Golf/Cabriolet	1993-1994	1995-1996
VW Jetta	1993-1994	1995-1996
VW Passat	1994-1995	1996-1997

Light Trucks

Chevrolet Astro Van	1995-1996	1997-1998
Chevrolet C/K Pick-up	1994-1995	1996-1997
Chevrolet G Van	1995-1996	1997-1998
Chevrolet GEO Tracker	1994-1995	1996-1997
Chevrolet S10 Blazer	1994-1995	1996-1997
Chevrolet S10/T10 Pick-up	1993-1994	1995-1996
Chevrolet Suburban	1994-1995	1996-1997
Chevrolet Tahoe/Blazer	1994-1995	1996-1997
GMC G10 Van	1995-1996	1997-1998
GMC Jimmy/Envoy	1994-1995	1996-1997
GMC Safari Van	1995-1996	1997-1998
GMC Sierra C/K Pick-up	1994-1995	1996-1997
GMC Sonoma/S15/T15 Pick-up	1993-1994	1995-1996
GMC Suburban	1994-1995	1996-1997
GMC Yukon	1994-1995	1996-1997
Oldsmobile Bravada	1993-1994	1996-1997*
Pontiac Transport	1995-1996	1997-1998

*Oldsmobile did not produce a Bravada in the 1995 model year.

Traffic Collision Data

Motor vehicle collision data files from various states were chosen as the primary data sources for the present study. State-level files contain the largest amount of in-the-field collision data. Records are not restricted to events of a particular level of severity (e.g., fatal accidents) and constitute a complete census of all police-reported accidents in a given state. Thus, state files provide a sufficient volume of data to examine nearly any vehicle model in a wide variety of accident conditions, including some relatively rare events. By contrast, other commonly available sources of vehicle accident data, such as the Fatality Analysis Reporting System (FARS) or the National Automotive Sampling System/Crashworthiness Data System (NASS/CDS), are focused on events of a specific and narrow severity (FARS) or comprise only a small sample of a larger pool of state-level data (NASS/CDS). For these reasons, a large collection of police-reported accidents from a variety of states provides the best instrument for examining the effectiveness of DRLs.

Data from 18 states were identified, examined, processed, and abstracted. Most data included in the present analysis cover collisions occurring from 1996 to 2005, with few exceptions (e.g., lack of VIN or unavailability). The numbers of vehicle records abstracted for the states and years used, based on the list of study vehicles, are shown in Table 2.

Table 2 State Motor Vehicle Collision Data Summary

State	Year Range	Vehicle Records
Alabama	1996-2005	141,029
Arkansas	1996	4,854
Florida	1996-2005	201,778
Georgia	1996-1997	42,600
Idaho	1996-2005	20,636
Illinois	1996-2003	296,080
Iowa	1996-2000	29,135
Maryland	1996-2005	70,320
Missouri	1996-2005	158,447
New Mexico	1996-1998	5,852
New York	1996-2005	161,694
North Carolina	1996-2005	214,376
Ohio	1996-1999	79,713
Pennsylvania	1996-2001, 2003	89,660
Texas	1996-2001	194,236
Washington	1996	2,016
Wisconsin	1997-2005	141,390
Wyoming	1996-2005	12,186

Vehicles involved in collisions were identified by their vehicle identification number (VIN)[1], and those records involving the study vehicles (as listed in Table 1) were extracted.

[1] The Texas and Washington state databases do not include the VIN. Vehicles were identified by make/model codes in these states.

Evaluating DRL effectiveness requires comparing the field experience of matched DRL and non-DRL vehicles with respect to the types of collisions that DRLs are reasonably expected to help drivers avoid. Each record in a state file contains values for a series of accident characteristics and environmental factors (e.g., light condition, urban/rural area, type of roadway) enabling the identification of different types of crashes. Interest in DRL studies centers on daytime crashes with a pedestrian, cyclist, motorcycle, or another passenger vehicle in circumstances when a DRL-equipped vehicle is expected to have greater conspicuity than a non-DRL vehicle.

The diverse set of states listed in Table 2 provides a broad spectrum of geography, demographics, and driving conditions. The set also possesses varying reporting criteria, coding systems, and associated vagaries. Although every state reports (in some form) light condition, weather condition, and type of collision, as well as other characteristics of the accident, considerable effort was required to arrive at a unified set of definitions.

Table 3. Crash Type, Light Condition, and Role in Analyses

Crash Type / Light Condition	**Role in Statistical Analyses**	
	Poisson Regression	**Ratio-of-Odds-Ratios**
Single-Vehicle (no pedestrian or cyclist) / Day	Control	Control
Single-Vehicle (no pedestrian or cyclist) / Night	—	Control
Two-Vehicle (no rear impact) / Day	Target	Target
Two-Vehicle (no rear impact) / Night	Control	Control
Two-Vehicle (no rear impact) at Dawn or Dusk	—	Target
Two-Vehicle (no rear impact) in Urban Area / Day	Target	Target
Two-Vehicle (no rear impact) in Urban Area / Night	—	Control
Two-Vehicle (no rear impact) in Rural Area / Day	Target	Target
Two-Vehicle (no rear impact) in Rural Area / Night	—	Control
Two-Vehicle (no rear impact) on Highway / Day	Target	Target
Two-Vehicle (no rear impact) on Highway / Night	—	Control
Collision with Pedestrian or Cyclist / Day	Target	Target
Collision with Pedestrian or Cyclist / Night	—	Control
Two-Vehicle Head-on / Day	Target	Target
Two-Vehicle Head-on / Night	—	Control
Two-Vehicle Angle / Day	Target	Target
Two-Vehicle Angle / Night	—	Control
Two-Vehicle Sideswipe / Day	Target	Target
Two-Vehicle Sideswipe / Night	—	Control
Collision with Motorcycle / Day	Target	Target
Collision with Motorcycle / Night	—	Control

The first column of Table 3 lists the crash types defined for use in this study. Detailed testing was performed to ensure consistency of the definitions across states and across the years within a state. Nonetheless, some information (e.g., head-on vs. angle collision) was simply not available from certain states. In these cases, some portion of the data had to be excluded from certain analyses due to the absence of the necessary information. These exceptions were identified in Appendix A.

DRLs are intended to function as a crash avoidance safety device. One cannot easily measure the numbers of collisions that have been *avoided* by using the collision data files alone. Consequently, vehicle registration data is obtained from the Polk Company in order to normalize for the number of vehicles of each model in use in each state. To objectively measure the difference in crash experience between vehicles with daytime running lights and vehicles without them, the *collision rate* was examined. The registration data provide a reliable and objective measure of the number of vehicles in use, or their “exposure”, against which the collision experience can be evaluated. Collision rate is typically expressed as numbers of collisions per 10,000 vehicles per year, or simply 10,000 *vehicle-years*. The registration data from Polk provide the basis to calculate these collision rates.

The Poisson regression method of analysis involves comparing the collision rates of DRL-equipped vehicles and non-DRL vehicles for daytime crashes of interest, identified as target crashes in the second column of Table 3. To judge its significance, any reduction in collision rates observed after DRL introduction can be compared to the corresponding change in rates for control types of crashes that are not plausibly affected by DRLs—namely, single-vehicle daytime and two-vehicle nighttime crashes.

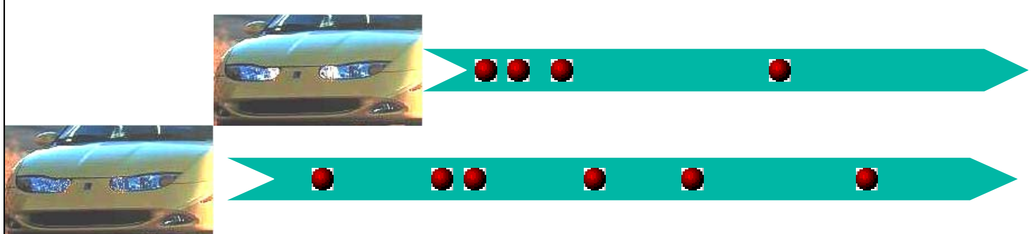
An alternative to the Poisson analyses using *vehicle-years* as the measure of exposure, the method proposed by NHTSA uses the numbers of daytime and nighttime single-vehicle crashes as control values in assessing risks of other types of crashes. This method is known as the ratio-of-odds-ratios (ROR) method.[2] As indicated in the first two entries in the third column of Table 3, single-vehicle crashes constitute the control crash type in an ROR analysis. For any other particular crash type, daytime and nighttime are the target and control light conditions, respectively.

[2] See J.M. Tessler, “An Assessment of the Effectiveness of Daytime Running Lamps (DRLS)”, NHTSA 2004, DOT HS 809 760, Appendix B.

Methods

Study Design

A “matched-pair” design is used in the present study. The study “subject” is a cohort of model pairs (see Table 1), and each “pair” consists of vehicles from the first two model years with DRL (e.g., Buick Century 1997-98) and vehicles of the same model from the two previous model years (e.g., 1995-96) immediately before the introduction of DRL. The vehicle model is “matched” in that the effect of DRL is evaluated as the “difference” in crash experience between the two halves of each model pair. The non-DRL half of each model pair, in effect, served as the control for the same model with DRL. By virtue of the matched pairing, the confounding effect due to differences in the vehicle design is largely eliminated. This study design reduces the variability in the DRL effect estimate and improves the ability to detect a DRL effect, should one exist. For each matched model pair, collision incidents that occurred during the next several calendar years were collected by the motor vehicle or highway safety departments of the relevant jurisdictions. Analyses were performed retrospectively on these historical crash data. This approach is used in many epidemiological studies. The study design is illustrated graphically in Figure 1.



$$\textit{Collision Rate} = \frac{\textit{Number of Collisions} \bullet}{\textit{Number of Vehicle-Years of Use}}$$

Figure 1 Matched Pair Design of Study

Two methods of analyses were used: Poisson regression and a ratio-of-odds-ratios method. In addition, we used both fatal crashes from the Fatality Analysis and Reporting System (FARS) and crash data of all degrees of severity from a diverse group of states as indicated in Table 2. Crossing the two data sources and two statistical methods of analysis yield the four distinct analyses performed in this study:

1. Poisson regression analysis of FARS data
2. Ratio-of-odds-ratios analysis of FARS data
3. Poisson regression analysis of state crash data
4. Ratio-of-odds-ratios analysis of state crash data

The two methods of analysis are described briefly in the following sections.

Poisson Regression Model of Crash Rates

The collision rate for a particular model is the ratio between the number of collision events observed over a certain time period (e.g., 1996-2005) and the number of such vehicles in-use over the same period of time[3]. The number of crashes was computed from FARS or state crash data files, and the number of vehicles in use was computed from the Polk registration data. The effect of DRLs can be estimated by comparing the collision rate of the models with DRL to the rate of the same model in the model pair without DRL. The ratio of their respective collision rates is:

$$\text{DRL Effect} = \frac{\textit{Collision Rate}_{\textit{with DRL}}}{\textit{Collision Rate}_{\textit{without DRL}}} = \frac{\textit{Crashes}_{\textit{DRL}} \big/ \textit{Vehicles in Use}_{\textit{DRL}}}{\textit{Crashes}_{\textit{no-DRL}} \big/ \textit{Vehicles in Use}_{\textit{no-DRL}}}$$

A rate ratio close to unity (1.0) suggests that no change occurred in the collision rate between vehicles with and without DRL. A ratio less than 1.0 would correspond to a reduction in the rate of collision for the DRL-equipped vehicle relative to its matched model pair without DRL. For example, a ratio of 0.95 is equivalent to a reduction in the collision rate of 5% relative to the same model without DRL. For each type of collision (e.g., head-on) and each collision condition (e.g., daytime) given in Table 3, this ratio can be computed from the collision data and the corresponding Polk registration data for each model and from each state.

Although this rate ratio can be computed directly from the crash data and the Polk data for each model pair in each state, our interest is in the "overall" effect of DRL, across all model pairs and across all 18 states. An accurate assessment of the DRL effect, including a formal test of the statistical significance of any observed difference, required that we construct an appropriate statistical model for the data used in this analysis. In this study, a Poisson regression model was constructed to estimate the accident rates for vehicles with and without DRLs, while accounting for the variation among model pair, state, and calendar year. For a particular model pair in a specific state, the regression model can be written as

$$\ln\left(\frac{A_{iy}}{R_{iy}}\right) = \beta_0 + \beta_1 DRL + \beta_{2y} Year_y + \beta_{3y}(DRL \times Year_y)$$

[3] The total number of vehicles in use over a period of time is a measure of the level of "exposure" generated by the group of study vehicles. This "exposure" can be termed the "vehicle years" analogues to the concept of "person years" in epidemiological studies involving human subjects.

In this model, A_{iy} is the number of crashes for model pair $\boldsymbol{i}$ in year $\boldsymbol{y}$, and R_{iy} the corresponding vehicle-years of use calculated from the Polk registration data. The number of collisions A_{iy} is assumed to follow a Poisson distribution[4], which is a discrete distribution of non-negative integers often used to describe the occurrence of rare events (e.g., hospitalizations, vehicle crashes, deaths). Thus, the equation expresses the (logarithm of) crash rate $\left(A_{iy}/R_{iy}\right)$ as a function of the presence or absence of DRL in this model pair, the calendar year, and an interaction effect between DRL and calendar year. Calendar year is included to capture year-to-year differences in crash experiences associated with changes in driver demographics, road technologies, traffic laws, and other national-level factors. The interaction term allows for variations in the effect of DRL as a function of year-to-year differences in these national-level factors.

The differences across states and differences among model pairs in this study are modeled by a hierarchical data structure superimposed on the Poisson regression model. The hierarchical structure recognized that crash rates from model pairs from the same state should have some degree of similarity reflecting the same driving condition, reporting thresholds, and other "state" factors shared by crash rates calculated from the same state. Similarly, rates from the two halves of a model pair, being of the same model, should be highly correlated, reflecting the driving habits of operators who were typically drawn to such models. A hierarchical model is appropriate for this study that includes sources of variation at different levels (e.g., between-state variations, within-state model-pair variations). In the present analysis, the DRL effect and year-to-year changes are considered "fixed," whereas state-to-state and model-to-model variations are considered "random" effects. A unique "ID" representing each model pair in the analysis represents the "model-level" variation and identified the two halves of each pair in the model.[5] Although the theory of hierarchical models has been developed for many years, only recently did software capable of addressing these complex structures with non-normal data become available in standard software packages such as SAS® and STATA®. The generalized linear mixed model in the present study is implemented using the GLIMMIX procedure, which was introduced to the SAS® (9.1.3) software in 2006. The SAS code is included in Appendix F.

The "overall" effect of DRL for this model is estimated by the average difference in the crash rates between DRL and non-DRL vehicles across different states and over the range of calendar years[6]. Two related estimates of the effect associated with the introduction of DRL

---

[4] A technical requirement in the Poisson regression model is that the mean and variance of the outcome variable are the same. In real applications, this property is often not satisfied, with the variance calculated from the data being considerably larger than its average. This condition, known as "overdispersion," may lead to a poorly fitted model if not corrected. Hauer (2001) has suggested using a similar, but more flexible, distribution—the negative binomial—in place of the Poisson in this type of regression modeling. The results presented in this report were based on regression with the negative binomial distribution.

[5] An individual intercept is allowed for each model pair.

[6] Technically, the "average" rate is calculated as the least squares mean. Crash rates for the DRL and non-DRL vehicles were estimated, and the difference between these two "least squares mean" rates was tested against the null hypothesis of zero difference.

were calculated. One expresses the DRL effect as the ratio between the two crash rates $\mathrm{Rate}_{\mathrm{DRL}}/\mathrm{Rate}_{\mathrm{No\text{-}DRL}}$ or, more conventionally, expresses this ratio as a percentage—namely, $\left(\frac{Rate_{DRL} - Rate_{No-DRL}}{Rate_{No\text{-}DRL}}\right) \times 100\%$. The other metric expresses the DRL effect as the arithmetic difference between the two rates: $\left(Rate_{DRL} - Rate_{No-DRL}\right)$. Both ways of representing the DRL effect have advantages and limitations. The percentage effect is a unit-less metric easily understood by non-technical audiences. However, with low crash rates, even trivially small real changes in rates may correspond to misleadingly large percentage changes.[7] The arithmetic difference in crash rates may not be as easy to understand as simple percentages, but the magnitude of this difference—in units of crashes per 10,000 vehicles per year—assists decision makers in assessing whether a statistically significant effect constitutes a real and meaningful effect. Thus, both measures of the DRL "effect" were presented. Statistical significance was evaluated using the appropriate *t*-statistics.

Regression Model for Ratio of Odds Ratios

An alternative — the ratio-of-odds-ratios (ROR) method — has been proposed and used by NHTSA in its most recently published study[8] of DRL effectiveness. Briefly, in this analysis the total number of crashes is considered fixed. Crashes are classified as either "target" (e.g., two-vehicle, not rear-end) or "control" (e.g., single-vehicle) and are also classified as to occurring in the day vs. at night. The rationale for this method is that if, for example, the addition of DRL reduces two-vehicle crashes (excluding rear-end collisions) in daylight conditions, then the odds that two-vehicle crashes occur in daylight should be smaller for vehicles equipped with DRL than for vehicles not equipped with DRL. Furthermore, this decrease in the odds of a daylight two-vehicle crash should be greater than any decrease in the corresponding odds of daylight single-vehicle crashes of DRL vehicles as compared to non-DRL vehicles. This notion is expressed algebraically as the ratio of odds ratios, or ROR, where

$$ROR = \frac{OR_{DRL}}{OR_{Non-DRL}},$$

$$OR_{DRL} = \frac{\text{Target Crash in Day}/\text{Target Crash at Night}}{\text{Control Crash in Day}/\text{Control Crash at Night}},$$

[7] For example, a change in crash rate from 0.1 to 0.2 per 10,000 vehicles per year is equivalent to 100% "effective."

[8] See Tessmer, J. M. (2004), "An Assessment of the Crash-Reducing Effectiveness of Passenger Vehicle Daytime Running Lamps (DRLs)," National Highway Traffic Safety Administration. Appendix B contains a detailed description of the methodology.

and the odds ratio for non-DRL vehicles is defined similarly.

In addition to its simple expression as the arithmetic ratio of the two odds ratios defined above, the *ROR* can be estimated by a logistic regression model. A regression model has the advantage of enabling consideration of the matched-pair nature of the study design and thus providing a more accurate estimate of the ROR. Similar to the equation shown in Appendix B of the NHTSA (2004) study, the ROR is represented by the regression coefficient β_3 associated with the interaction between DRL and crash type (target vs. control) in the regression equation:

$$\ln\left(\frac{P(L)}{1-P(L)}\right) = \beta_0 + \beta_1 DRL + \beta_2 Crash + \beta_3 (DRL \times Crash)$$

Here $P(L)$ is the probability that the collision occurred during daylight (including dawn or dusk) and therefore $\ln\left(\frac{P(L)}{1-P(L)}\right)$ is the logarithm of the odds of observing a daylight crash[9]. Two covariates, both indicator variables, were included in this logistic model: *DRL* and *Crash.* "Crash" is coded as "Yes" for a target crash and "No" for a control crash. Similarly, DRL is "Yes" for the DRL-equipped vehicles and "No" for the "non-DRL" vehicles. The estimate of the coefficient β_3 is an estimate of the ratio of odds ratios.

Similar to the Poisson regression approach, a hierarchical structure was incorporated into the logistic model[10] to account for the effects of matched vehicle pairs, state-to-state-differences, and calendar-year differences. The effectiveness (*E*) of DRL, based on the odds ratio, is then defined as $E = 1 - e^{\beta_3}$, where β_3 is the coefficient of the $(DRL \times Crash)$ interaction term in the regression equation. The SAS® software's GLIMMIX procedure was again used to perform the regression analysis and obtain estimates of DRL effectiveness based on the available data. However, in this case, a proportion (i.e., the proportion of crashes occurring during daytime) is being modeled by the regression, and therefore the distribution of the error term follows the Binomial rather than the Poisson distribution. The SAS code is provided in Appendix G.

[9] One way to prepare the data is to code an indicator variable L and assign it a value of 1 if the crash occurred in daylight and 0 in darkness. The logarithm of the odds of having a daylight crash is the "logit" of L.

[10] As in the Poisson model, state and model pairs were treated as random effects, and model pairs were "tied" together by their common ID. These variance components were incorporated into the ROR analysis. It is not clear from Tessmer (2004) whether vehicle pairs and state effects were treated in the same way in the NHTSA study.

Comparison of the Poisson Regression and ROR Methods

The Poisson regression method correctly treats crashes as a random variable that follows the Poisson distribution. The expected number of crashes is proportional to the number of vehicles in use (i.e., registered vehicle years for the vehicle). The expected number of crashes is assumed to be a function of the characteristics of each vehicle pair, including driver demographics, the calendar year, the state, and whether the vehicle was equipped with DRL or not. Within each vehicle pair, the decrease in daytime crash rate for the DRL vehicles, compared to the non-DRL vehicles, is an initial measure of the effectiveness of DRL. This is an intuitive and straightforward way to measure the effectiveness of DRL.

The validity of this measure is confounded by the fact that the DRL member of each pair is always composed of later model years than the non-DRL member of the pair. Thus, the non-DRL member of the pair is always older than the DRL member. The analysis may be controlled for vehicle age. When doing so, the DRL vehicle crashes are in later calendar years than the non-DRL vehicles. Alternatively, it is possible to control for differences in calendar-year crash rates; age and calendar year cannot be controlled simultaneously. Initial analyses indicated that differences in crash rates between calendar years are larger than differences in crash rates for different ages. Consequently, the analyses performed here were controlled for calendar year rather than for vehicle age.

As a further check that the change in daytime crash rates for DRL versus non-DRL vehicles can be attributed to the introduction of DRL, rather than some other concomitant change, two additional controls were used. The introduction of DRL would not be expected to produce any changes in nighttime crash rates. Consequently, the observed change in nighttime crash rates for DRL versus non-DRL vehicles may be considered as a baseline or estimate of the change in crash rates attributable to factors concomitant with the introduction of DRL (i.e., a negative control). Similarly, the change in single-vehicle daytime crash rates, which are not expected to be influenced by DRL, can be used as another benchmark value to judge the proportion of the change in crash rates observed with the introduction of DRL that is, in fact, attributable to DRL.

The ROR method does not directly use information on the number of vehicles in use. Rather than treating the number of crashes occurring to each vehicle as a random variable, the analysis is performed conditionally on the total of daytime and nighttime crashes. Effectiveness of DRL is then measured through the comparison of the odds of daytime crashes for target crashes to the odds of daytime crashes for control crashes. The odds ratio for DRL vehicles is then compared to the odds ratio for non-DRL vehicles. Using this method, is it not possible to distinguish a decrease in daytime two-vehicle crash rates from an increase in single vehicle crash rates or an increase in nighttime crash rates, because the relative changes of two-vehicle, single-vehicle, daytime, and nighttime crashes are all folded into the ROR.

The issues of the possibly confounding effects of calendar year or vehicle age are the same for the ROR models as for the Poisson regression models and are handled the same way in the GLIMMIX modeling.

Results

This evaluation of the effectiveness of DRLs involves two sources of data (reported crashes in state files, fatal crashes in FARS) and two methods of analysis (Poisson regression and ROR). Results are summarized in a series of figures, each of which corresponds to a particular data source, method of analysis, and type of motor vehicle (passenger cars, light trucks). In the Poisson regression analyses the effect is measured as the percent change in collision rate for vehicle models with DRLs relative to the matching models without DRLs. In the ROR analyses the effect is measured as the percent change in odds ratio for vehicle models with DRLs relative to the matching models without DRLs. For each vehicle type (DRL, non-DRL) the odds ratio expresses the odds of a daytime crash of the target type relative to the odds of a daytime single-vehicle crash. Appendices B through E provide a comprehensive set of tables with more technical details, including the 95% confidence interval and the p-value associated with the estimated effect for each combination of factors considered in the study.

Estimates of DRL Effectiveness: State-Reported Crashes

Poisson Regression Analyses

Figure 2 shows the percent reduction in crash rates associated with DRL introduction for passenger cars in various types of crashes. Note that reductions of 4.28 percent and 2.63 percent were observed for nighttime two-vehicle crashes and daytime single-vehicle crashes, respectively. (In all figures and appendices the abbreviation for multiple-vehicle accidents (MVA) refers exclusively to crashes involving only two vehicles, as listed in Table 3.) Because the presence of DRL does not plausibly affect the occurrence of crashes of these types, they serve as useful control groups and benchmarks for comparison. The observed risk reductions of 12.35 and 9.10 percent, respectively, for daytime two-vehicle head-on crashes and daytime two-vehicle crashes in rural areas are significantly greater than the reductions observed in the control crash types. Risk reductions for other crash types do not differ significantly from the control-type reductions.

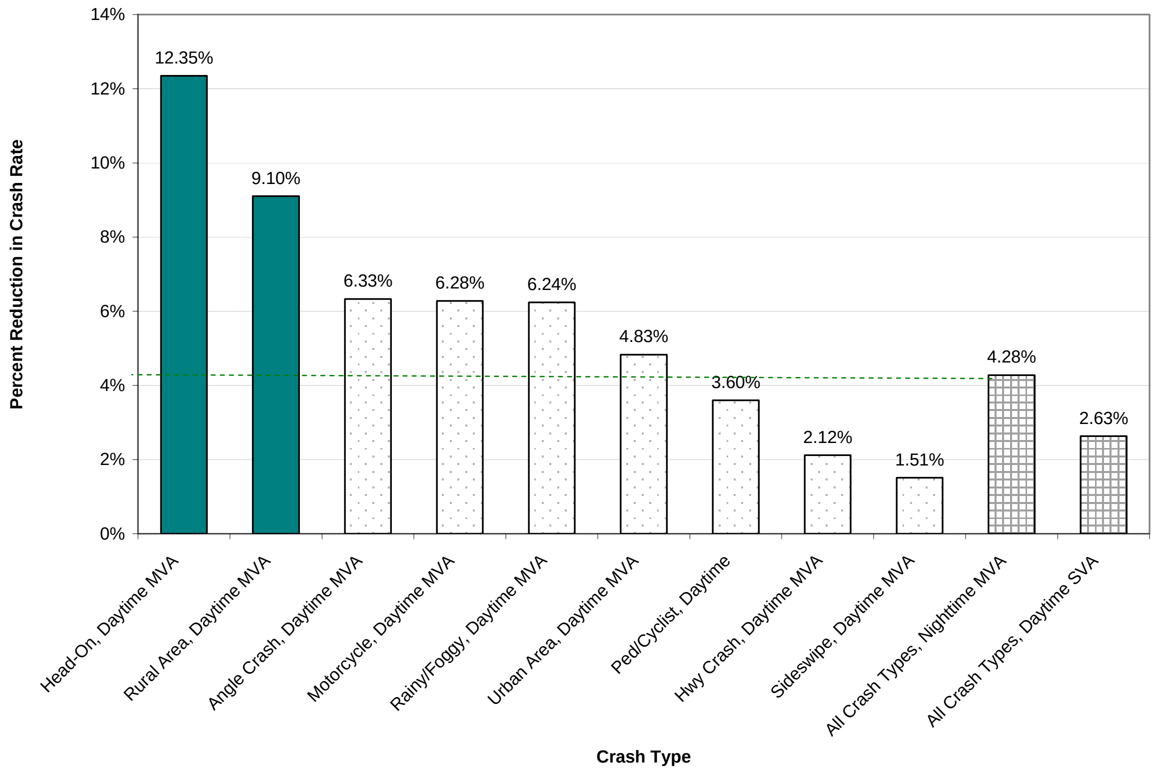


Figure 2. Estimated Effectiveness of DRL in Crash Avoidance, Passenger Cars (Poisson Regression Analysis of State Accident and Registration Data, 1996-2005)

Similar to Figure 2, Figure 3 shows the percent reduction in crash rates associated with DRL introduction for light trucks in various types of crashes. A reduction of 3.67 percent was observed for daytime single-vehicle crashes, while the rate of nighttime two-vehicle crashes increased by 0.70 percent (a reduction of -0.70 percent). The observed risk reductions of 12.30 and 7.97 percent, respectively, for daytime two-vehicle head-on crashes and daytime two-vehicle crashes in rainy or foggy conditions are significantly greater than the reductions observed in the control crash types. Risk reductions for other crash types do not differ significantly from the control-type reductions.

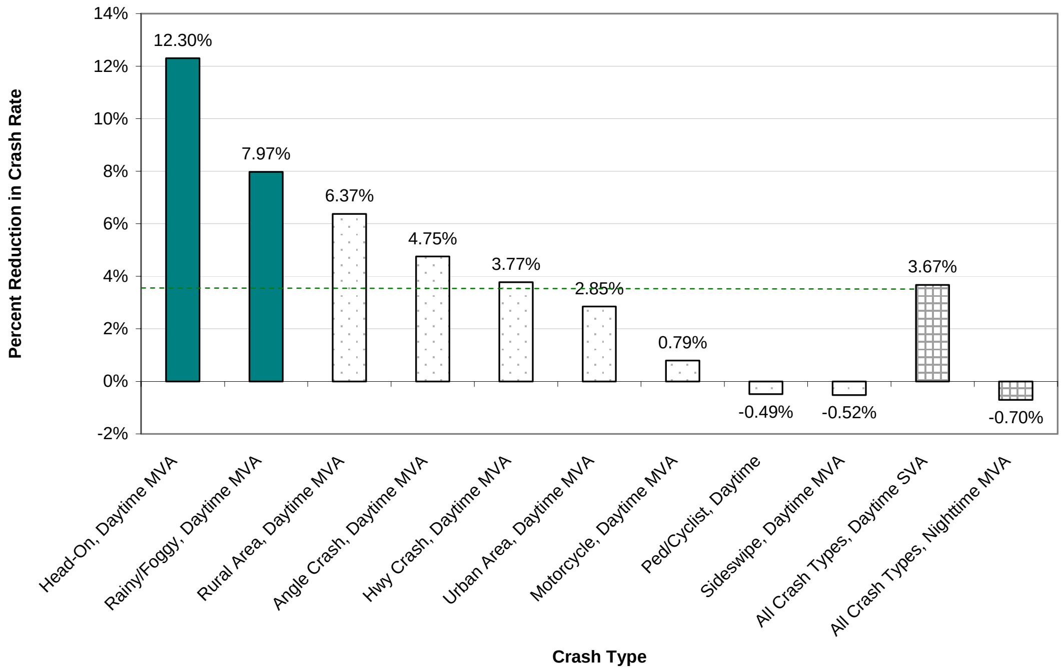


Figure 3. Estimated Effectiveness of DRL in Crash Avoidance, Light Trucks (Poisson Regression Analysis of State Accident and Registration Data, 1996-2005)

Ratio-of-Odds-Ratios Analyses

Figure 4 shows the percent reduction in odds ratio associated with DRL introduction for passenger cars in various types of crashes. The observed risk reductions of 8.82 and 4.60 percent, respectively, for daytime two-vehicle head-on crashes and daytime two-vehicle crashes in rural areas are statistically significant. The changes in odds ratio for other types of crashes are not statistically significant.

Similar to Figure 4, Figure 5 shows the percent reduction in odds ratio associated with DRL introduction for light trucks in various types of crashes. The observed risk reduction of 8.75 percent for daytime two-vehicle crashes in rainy or foggy conditions is statistically significant. The changes in odds ratio for other types of crashes are not statistically significant.

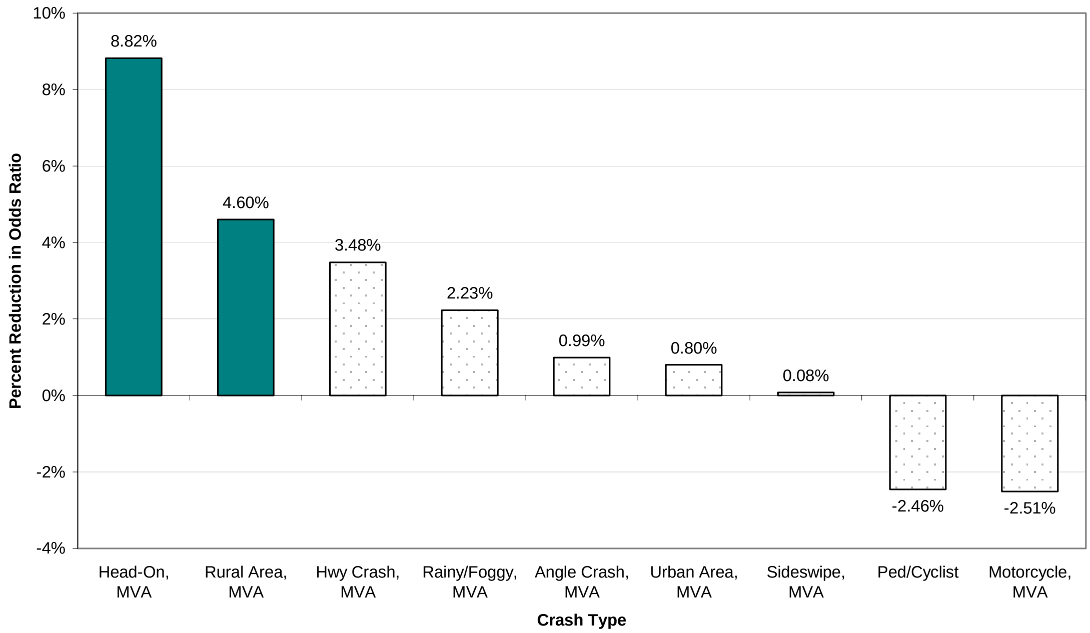


Figure 4. Estimated Effectiveness of DRL in Crash Avoidance, Passenger Cars (Ratio-of-Odds-Ratios Analysis of State Accident Data, 1996-2005)

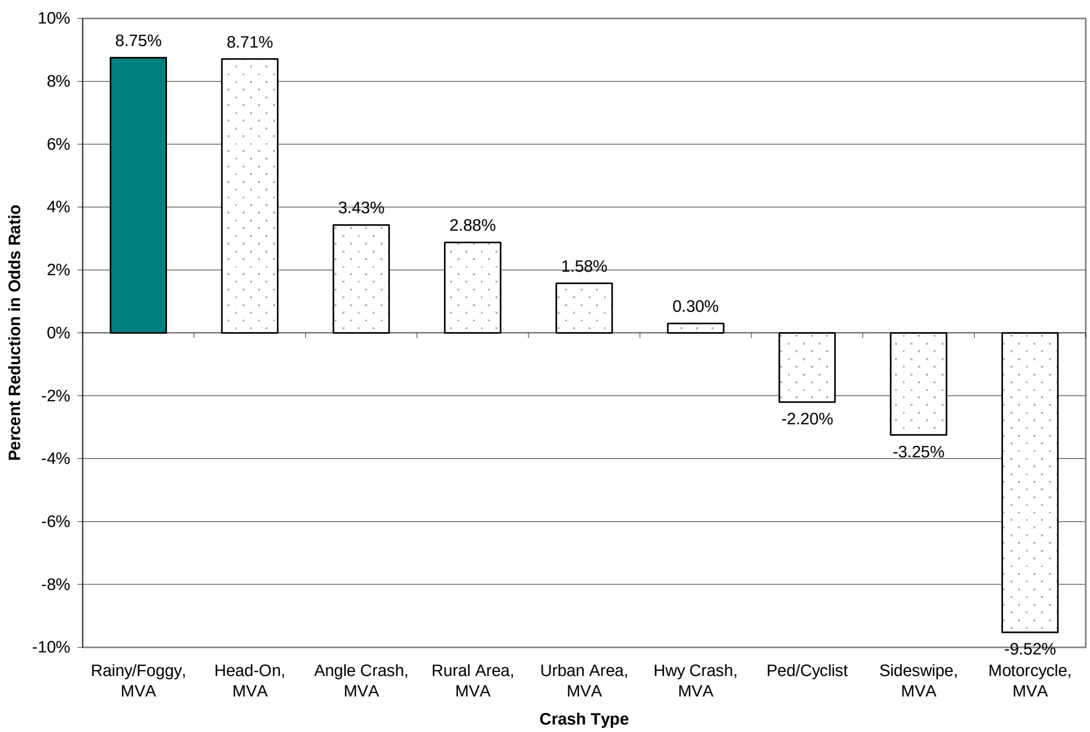


Figure 5. Estimated Effectiveness of DRL in Crash Avoidance, Light Trucks (Ratio-of-Odds-Ratios Analysis of State Accident Data, 1996-2005)

Estimates of DRL Effectiveness: Fatal Crashes

Poisson Regression Analyses

Figure 6 shows the percent reduction in crash rates associated with DRL introduction for passenger cars in various types of fatal crashes. Note that a reduction of 11.38 percent was observed for nighttime two-vehicle crashes, while the rate of daytime single-vehicle crashes increased by 1.05 percent (a reduction of -1.05 percent). Because the presence of DRL does not plausibly affect the occurrence of crashes of these types, they serve as useful control groups and benchmarks for comparison. None of the risk reductions observed for crashes types of interest differs significantly from the reductions observed in the control crash types.

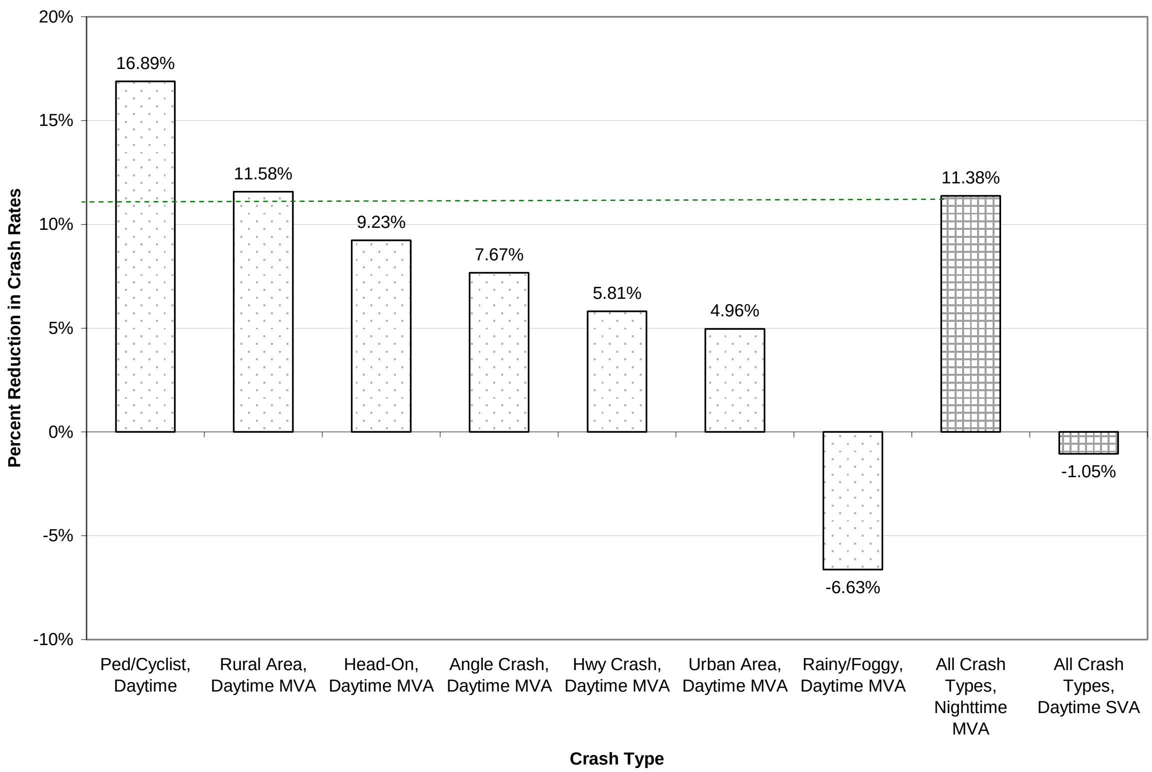


Figure 6. Estimated Effectiveness of DRL in Fatal Crash Avoidance, Passenger Cars (Poisson Regression Analysis of FARS and Registration Data, 1996-2005)

Similar to Figure 6, Figure 7 shows the percent reduction in crash rates associated with DRL introduction for light trucks in various types of fatal crashes. Reductions of 9.39 percent and 1.06 percent were observed for daytime single-vehicle crashes and nighttime two-vehicle crashes, respectively. None of the risk reductions observed for crashes types of interest differs significantly from the reductions observed in the control crash types.

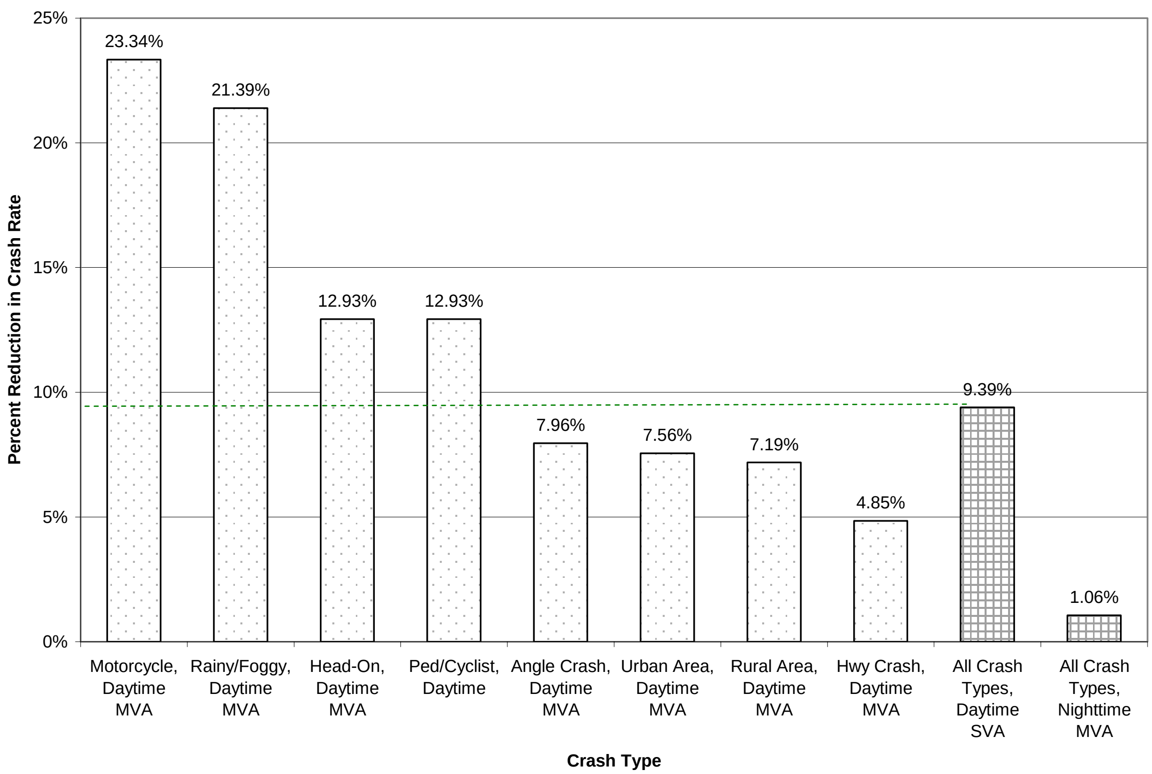


Figure 7. Estimated Effectiveness of DRL in Fatal Crash Avoidance, Light Trucks (Poisson Regression Analysis of FARS and Registration Data, 1996-2005)

Ratio-of-Odds-Ratios Analyses

Figures 8 and 9 show, for various types of fatal crashes, the percent reduction in odds ratios associated with DRL introduction for passenger cars and light trucks. None of the changes in odds ratios observed for the crash types of interest were statistically significant.

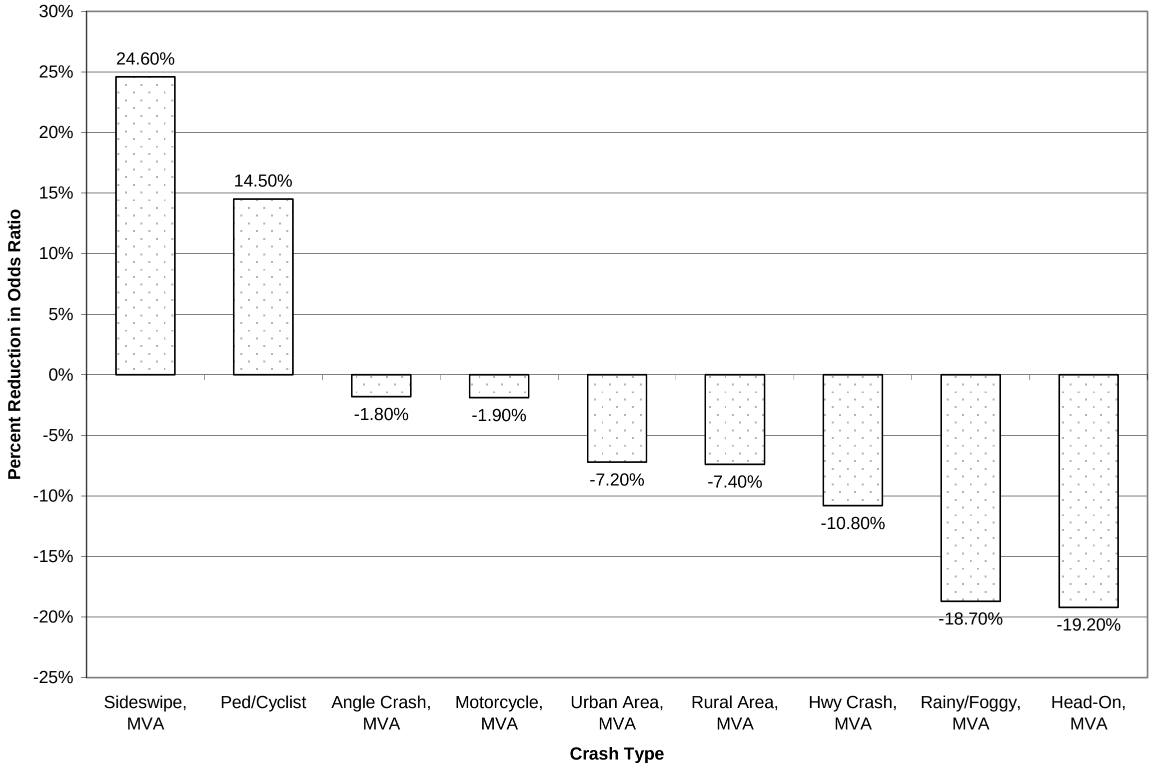


Figure 8. Estimated Effectiveness of DRL in Fatal Crash Avoidance, Passenger Cars (Ratio-of-Odds-Ratios Analysis of FARS Data, 1996-2005)

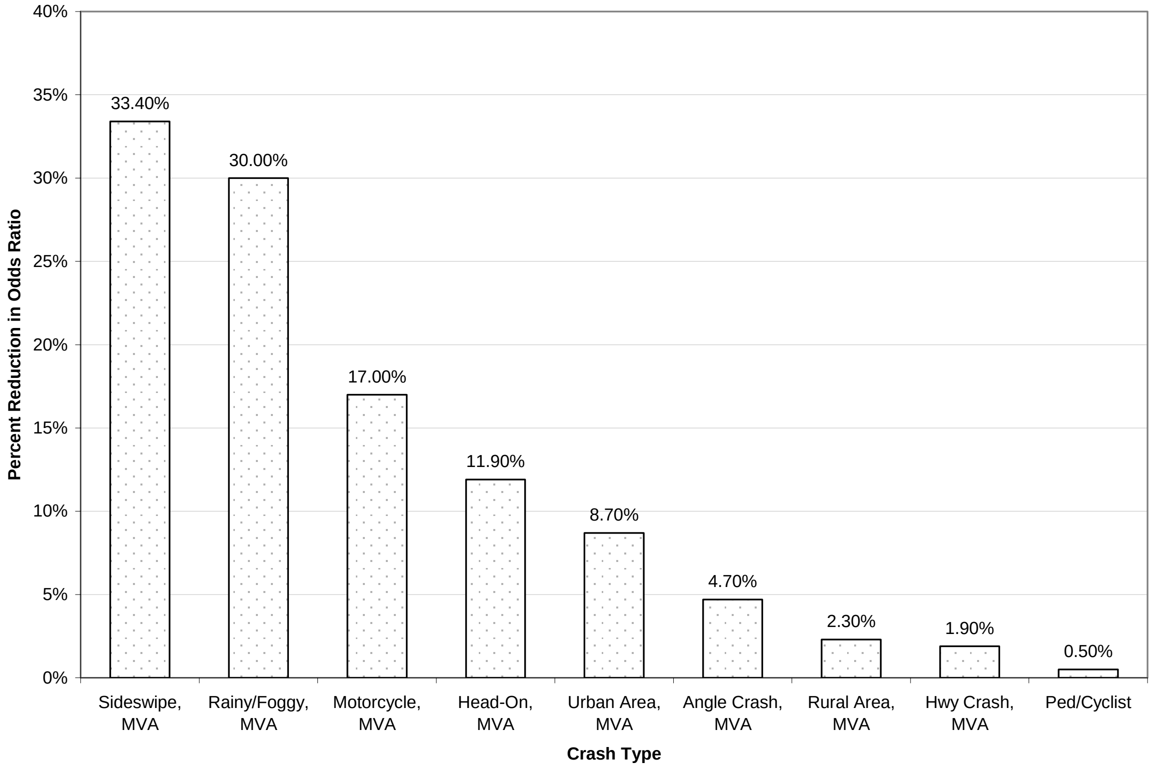


Figure 9. Estimated Effectiveness of DRL in Fatal Crash Avoidance, Light Trucks (Ratio-of-Odds-Ratios Analysis of FARS Data, 1996-2005)

Discussion

Exponent's Poisson regression analyses of 1996-2005 state motor vehicle accident and registration data found that, for both passenger cars and light trucks, rates of selected two-vehicle daytime collisions were approximately 8 to 12 percent lower for DRL-equipped vehicles than for vehicles without DRLs. These reductions were significantly greater than the corresponding decreases of no more than 4 percent observed in the rates of single-vehicle daytime and two-vehicle nighttime collisions.

Analyses using a ratio-of-odds-ratios approach corroborate these findings. Significant reductions in odds ratios of 5 to 8 percent were observed in the same types of two-vehicle daytime crashes identified in the Poisson regression analyses as having comparatively significant reductions in collision rates for DRL-equipped vehicles.

For either passenger cars, light trucks, or both types of vehicles, significant reductions were observed in the risk of daytime two-vehicle head-on crashes, daytime two-vehicle crashes in rainy or foggy conditions, and daytime two-vehicle crashes in rural areas. There is no evidence suggesting that the introduction of DRL would significantly increase the risk of motorcycle accidents or other types of crashes. These results support the conclusion of Knight, et al. (2006) that the introduction of DRL would result in a net reduction in risk of accidents and associated casualties.

Analyses of fatal crashes reported in FARS show little difference in crash rates or odds ratios for DRL and non-DRL vehicles. The lack of statistically significant results largely reflects the relatively small numbers of fatal crashes involving these particular vehicle models and years under the specified conditions of interest.

Findings from the Poisson regression and ROR analyses generally agree well. Observed differences are likely attributable to the different components of the risk metrics. Poisson regression analyses use vehicle registration data as a measure of exposure, while the ROR analyses use daytime and nighttime single-vehicle crashes as controls.

References

Andersson, K. and Nilsson G. (1981) *The effect on accidents of compulsory use of running lights during daylight in Sweden.* Report No. 208A, Swedish Road and Traffic Research Institute.

Andersson, K. and Nilsson G., and Salusjarvi, S. (1976) *The effect on traffic accidents on the recommended use of vehicle running lights in daytime in Finland.* Report No. 102, Swedish Road and Traffic Research Institute.

Aurora, H. (1994) *Effectiveness of daytime running lights in Canada.* Report No. 12298, Transport Canada, Ottawa, Canada.

Elvik, R. (1993). The effect of accidents of compulsory use of daytime running lights for cars in Norway. *Accident Analysis and Prevention*, **25** (4), 383-398.

Elvik, R. (1996). A meta-analysis of studies concerning the safety effects of daytime running lights on cars. *Accident Analysis and Prevention*, **28** (6), 685-694.

Exponent Failure Analysis Associates (2000). *Daytime running light effectiveness: A preliminary evaluation.* (Oral Presentation) 2000 SAE Government-Industry Meeting, Washington DC.

Hansen, L.K. (1993). *Daytime running lights in Denmark – evaluation of the safety effect.* Danish Council of Road Safety Research, Technical Report 2/1993.

Hauer, E. (1997). Observ*ational before-after studies in road safety*. Pergamon/Elsevier Science Inc, Terrytown, New York.

Hauer, E. (2001). Overdispersion in modeling accidents on road sections and in Empirical Bayes estimation. *Accident Analysis and Prevention*, 33, 799-808.

Henderson, R. L., Ziedman, K., Burger, W. J. and Cavey, K. E. (1983). *Motor vehicle conspicuity*. SAE Technical Report 830566.

Johnson, D. (1990). Headlight use. *Proceedings of the Human Factors Society 34th Annual Meeting*, 1086-1090.

Knight, I., Sexton, B., Bartlett, R., Barlow, T., Latham, S. and McCrae, I. (2006). Daytime Running Lights (DRL): A Review of the Reports from the European Commission, TRL Limited, Published Project Report PPR 170.

NHTSA (2000). A Preliminary Assessment of the Crash-Reducing Effectiveness of Passenger Car Daytime Running Lamps (DRLS), DOT HS 808 645, June 2000

Perel, M. (1991). Evaluation of the conspicuity of daytime running lights. *Auto & Traffic Safety*, **1** (1), 32-37.

Perlot, A. and Prower, S. (2003). *Review of the evidence for motorcycle and motorcar daytime lights*. Federation of European Motorcyclists' Associations and British Motorcyclists Federation, March 7.

Rumar, K. (1989). Vehicle conspicuity. *Proceedings of the Twelfth International Technical Conference on Experimental Safety Vehicles, 781-785.*

SAS (2001). Statistical Analysis System (SAS), Version 8.2, SAS Institute, Cary, NC.

Sparks, G. A. (1991). The effects of daytime running lights on crashes between two vehicles in Saskatchewan: a study of government fleet. *Accident Analysis and Prevention*, **25**, 619-625.

Stein, H. (1985). *Fleet experience with daytime running lights in the United States.* SAE Technical Report 851239.

Tessmer, J. M. (2004). An Assessment of the Crash-Reducing Effectiveness of Passenger Vehicle Daytime Running Lamps (DRLS), DOT HS 809 760.

Theeuwes, J. & Riemersma, J. (1995). Daytime running lights as a vehicle collision countermeasure: The Swedish evidence reconsidered. *Accident Analysis and Prevention*, **27** (5), 633-642.

Theeuwes, J. & Riemersma, J. (1996). Comment on Williams and Farmer's evaluation of daytime running lights. *Accident Analysis and Prevention*, **28** (6), 799-800.

Williams, A. F. & Farmer, C. M. (1996). Comment on Theeuwes and Riemersma's revisit of daytime running lights. *Accident Analysis and Prevention*, **28** (4), 541-542.

Acknowledgements

Financial support for this study was provided by General Motors Corp. under Purchase Order No. TCS13246. We thank Robert C. Lange, Director of Safety Engineering at GM, for his continuing interest in this issue and the invitation to perform the research reported. The research team at Exponent who participated in this study includes:

Project Managers

Duane Steffey, Ph.D.
Director, Statistical and Data Sciences

Rose M. Ray, Ph.D.
Principal Scientist

Statisticians

Edmund Lau, M.S.
Senior Managing Scientist

Ke Zhao, M.S.
Senior Staff Scientist

Madhu Iyer, M.S.
Scientist

Programmer/Analyst

Su-Wei Huang, M.S.
Lead Programmer

Appendix A: Exclusions and Limitations of State Data

Crash Type	Coded Variables	States Not Used in Analysis	Reason for Exclusion
All	Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Day Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Night Single Vehicle (no pedestrian or cyclist)- Day Single Vehicle (no pedestrian or cyclist)- Night	No Exclusions*	NA
Dawn or Dusk	Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Dawn or Dusk Single Vehicle (no pedestrian or cyclist)- - Dawn or Dusk	MO	No variable available
Urban/Rural	Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Urban - Day Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Urban - Night Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Rural - Day Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Rural - Day	No Exclusions	NA
On Highway	Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Highway - Day Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Highway - Night	No Exclusions	NA
Pedestrian or Cyclist	Single Vehicle Collision with Pedestrian or Cyclist - Day Single Vehicle Collision with Pedestrian or Cyclist - Night	No Exclusions	NA
Rain or Fog	Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Rain or Fog - Day Multiple Vehicle (two motor vehicles, no rear/unknown impact) -Rain or Fog - Night	No Exclusions	NA
Head-on Collision	Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Headon - Day Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Headon - Night	AL	No variable available
Angle Collision	Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Angle - Day Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Angle - Night	AL	No variable available
Sideswipe Collision	Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Sideswipe - Day Multiple Vehicle (two motor vehicles, no rear/unknown impact) - Sideswipe - Night	AL	No variable available
Motorcyclist	Collision with Motorcycle - Day Collision with Motorcycle - Night	No Exclusions	NA

*The following limitations apply whenever a state is not excluded from analysis:

1. Vehicle identification number (VIN) is not well coded in the Ohio 1998 data file; only 30.5% of vehicle records have VIN information.
2. Washington 1996 files contain data for passenger cars only and exclude Subaru, Toyota, and Lexus vehicles.
3. Lexus E300 (vehicle ID 810) and Lexus GS 300 (ID 813) are not included in Texas analytical files, because they can not be correctly identified by using Texas make/model codes.
4. Chevrolet S-Blazer and K-Blazer share the same make/model code in Texas.
5. Texas data files do not include a make/model code for the GMC Suburban before 1997.
6. Texas data files do not include a make/model code for the Lexus LS 400 before 1999.

Appendix B: Summary Tables from Poisson Regression Analyses of State Data, 1996-2005

Vehicle Group	*Crash Type*	*DRL per10K*	*No DRL per10K*	*Rate Ratio %*	*Eff (%)*	*Rate Change per 10K*	*t stat*	*P-value t*	*sigt*
Car	All Crash Types	255.09	267.70	0.95	4.71%	-12.60	-6.47	<.0001	*
	All Crash Types, Dawn/Dusk MVA	5.60	6.11	0.92	8.42%	-0.51	-5.18	<.0001	*
	All Crash Types, Daytime	187.10	197.11	0.95	5.07%	-10.00	-6.57	<.0001	*
	All Crash Types, Daytime MVA	151.67	160.43	0.95	5.46%	-8.76	-9.72	<.0001	*
	All Crash Types, Daytime SVA	28.22	28.98	0.97	2.63%	-0.76	-2.51	0.0123	*
	All Crash Types, MVA	187.92	198.60	0.95	5.38%	-10.68	-6.97	<.0001	*
	All Crash Types, Night Time	60.20	62.65	0.96	3.91%	-2.45	-5.13	<.0001	*
	All Crash Types, Nighttime MVA	32.87	34.34	0.96	4.28%	-1.47	-5.04	<.0001	*
	All Crash Types, Nighttime SVA	24.52	25.24	0.97	2.82%	-0.71	-2.61	0.0093	*
	All Crash Types, SVA	56.55	57.89	0.98	2.32%	-1.34	-2.67	0.0079	*
	Angle Crash, Daytime MVA	62.98	67.23	0.94	6.33%	-4.25	-8.72	<.0001	*
	Head-On, Daytime MVA	5.55	6.33	0.88	12.35%	-0.78	-7.27	<.0001	*
	Hwy Crash, Daytime MVA	27.08	27.67	0.98	2.12%	-0.59	-2.30	0.0215	*
	Motorcycle, Daytime MVA	0.99	1.06	0.94	6.28%	-0.07	-1.55	0.1229	
	Ped/Cyclist, Daytime	3.55	3.68	0.96	3.60%	-0.13	-1.87	0.0620	
	Rainy/Foggy, Daytime MVA	14.41	15.37	0.94	6.24%	-0.96	-5.68	<.0001	*
	Rural Area, Daytime MVA	21.67	23.84	0.91	9.10%	-2.17	-9.52	<.0001	*
	Sideswipe, Daytime MVA	16.30	16.55	0.98	1.51%	-0.25	-1.13	0.2573	
	Urban Area, Daytime MVA	122.24	128.45	0.95	4.83%	-6.20	-7.98	<.0001	*
Light Truck	All Crash Types	264.87	274.47	0.97	3.50%	-9.60	-4.63	<.0001	*
	All Crash Types, Dawn/Dusk MVA	6.04	6.28	0.96	3.74%	-0.23	-1.64	0.1018	
	All Crash Types, Daytime	196.23	205.34	0.96	4.44%	-9.11	-5.38	<.0001	*
	All Crash Types, Daytime MVA	156.43	163.00	0.96	4.03%	-6.58	-4.70	<.0001	*
	All Crash Types, Daytime SVA	32.93	34.19	0.96	3.67%	-1.26	-2.76	0.0058	*
	All Crash Types, MVA	191.15	197.90	0.97	3.41%	-6.74	-4.26	<.0001	*
	All Crash Types, Night Time	61.18	61.89	0.99	1.16%	-0.72	-1.02	0.3062	
	All Crash Types, Nighttime MVA	31.76	31.54	1.01	-0.70%	0.22	0.57	0.5655	
	All Crash Types, Nighttime SVA	26.79	27.29	0.98	1.84%	-0.50	-1.24	0.2169	
	All Crash Types, SVA	63.51	65.21	0.97	2.62%	-1.71	-2.31	0.0208	*
	Angle Crash, Daytime MVA	62.34	65.44	0.95	4.75%	-3.11	-4.21	<.0001	*

Vehicle Group	Crash Type	DRL per10K	No DRL per10K	Rate Ratio %	Eff (%)	Rate Change per 10K	t stat	P-value t	sigt
	Head-On, Daytime MVA	6.04	6.89	0.88	12.30%	-0.85	-5.61	<.0001	*
	Hwy Crash, Daytime MVA	30.53	31.72	0.96	3.77%	-1.20	-2.94	0.0034	*
	Motorcycle, Daytime MVA	0.91	0.92	0.99	0.79%	-0.01	-0.12	0.9020	
	Ped/Cyclist, Daytime	3.75	3.73	1.00	-0.49%	0.02	0.18	0.8610	
	Rainy/Foggy, Daytime MVA	14.74	16.01	0.92	7.97%	-1.28	-4.67	<.0001	*
	Rural Area, Daytime MVA	31.13	33.24	0.94	6.37%	-2.12	-5.54	<.0001	*
	Sideswipe, Daytime MVA	17.08	16.99	1.01	-0.52%	0.09	0.27	0.7885	
	Urban Area, Daytime MVA	117.86	121.32	0.97	2.85%	-3.46	-2.98	0.0033	*
Passenger Vehicle	All Crash Types	257.62	270.08	0.95	4.61%	-12.45	-7.77	<.0001	*
	All Crash Types, Dawn/Dusk MVA	5.75	6.17	0.93	6.78%	-0.42	-5.15	<.0001	*
	All Crash Types, Daytime	189.63	199.80	0.95	5.09%	-10.16	-8.07	<.0001	*
	All Crash Types, Daytime MVA	153.19	161.50	0.95	5.14%	-8.31	-7.82	<.0001	*
	All Crash Types, Daytime SVA	29.52	30.46	0.97	3.10%	-0.94	-3.81	0.0002	*
	All Crash Types, MVA	188.79	198.66	0.95	4.96%	-9.86	-7.92	<.0001	*
	All Crash Types, Night Time	60.49	62.42	0.97	3.09%	-1.93	-4.91	<.0001	*
	All Crash Types, Nighttime MVA	32.57	33.51	0.97	2.80%	-0.94	-3.98	<.0001	*
	All Crash Types, Nighttime SVA	25.17	25.82	0.97	2.52%	-0.65	-2.93	0.0034	*
	All Crash Types, SVA	58.49	59.98	0.98	2.48%	-1.49	-3.67	0.0003	*
	Angle Crash, Daytime MVA	62.86	66.78	0.94	5.86%	-3.91	-9.63	<.0001	*
	Head-On, Daytime MVA	5.69	6.50	0.88	12.44%	-0.81	-9.35	<.0001	*
	Hwy Crash, Daytime MVA	28.09	28.87	0.97	2.68%	-0.77	-3.58	0.0003	*
	Motorcycle, Daytime MVA	0.97	1.02	0.95	4.66%	-0.05	-1.38	0.1689	
	Ped/Cyclist, Daytime	3.61	3.69	0.98	2.34%	-0.09	-1.49	0.1357	
	Rainy/Foggy, Daytime MVA	14.54	15.58	0.93	6.66%	-1.04	-7.40	<.0001	*
	Rural Area, Daytime MVA	24.18	26.30	0.92	8.04%	-2.11	-10.88	<.0001	*
	Sideswipe, Daytime MVA	16.56	16.70	0.99	0.84%	-0.14	-0.77	0.4434	
	Urban Area, Daytime MVA	121.03	126.50	0.96	4.33%	-5.47	-6.01	<.0001	*

Vehicle Group	Crash Type	ChiSq DF	DRL per10K	No DRL per10K	Rate Ratio %	Eff (%)	95% CI Eff(%)	Rate Change per 10K	95% CI Rate Change	t stat	P-value t	sigt
Car	All Crash Types	0.59	255.09	267.70	0.95	4.71%	(3.31% : 6.09%)	-12.60	(-16.30 : -8.85)	-6.47	<.0001	*
	All Crash Types, Dawn/Dusk MVA	0.94	5.60	6.11	0.92	8.42%	(5.32% : 11.41%)	-0.51	(-0.70 : -0.32)	-5.18	<.0001	*
	All Crash Types, Daytime	0.60	187.10	197.11	0.95	5.07%	(3.59% : 6.54%)	-10.00	(-12.89 : -7.07)	-6.57	<.0001	*
	All Crash Types, Daytime MVA	1.00	151.67	160.43	0.95	5.46%	(4.39% : 6.53%)	-8.76	(-10.47 : -7.04)	-9.72	<.0001	*
	All Crash Types, Daytime SVA	1.04	28.22	28.98	0.97	2.63%	(0.58% : 4.64%)	-0.76	(-1.35 : -0.17)	-2.51	0.0123	*
	All Crash Types, MVA	0.59	187.92	198.60	0.95	5.38%	(3.90% : 6.83%)	-10.68	(-13.57 : -7.74)	-6.97	<.0001	*
	All Crash Types, Night Time	0.99	60.20	62.65	0.96	3.91%	(2.43% : 5.36%)	-2.45	(-3.36 : -1.52)	-5.13	<.0001	*
	All Crash Types, Nighttime MVA	0.97	32.87	34.34	0.96	4.28%	(2.63% : 5.90%)	-1.47	(-2.03 : -0.90)	-5.04	<.0001	*
	All Crash Types, Nighttime SVA	1.01	24.52	25.24	0.97	2.82%	(0.71% : 4.89%)	-0.71	(-1.23 : -0.18)	-2.61	0.0093	*
	All Crash Types, SVA	1.02	56.55	57.89	0.98	2.32%	(0.62% : 3.99%)	-1.34	(-2.31 : -0.36)	-2.67	0.0079	*
	Angle Crash, Daytime MVA	0.97	62.98	67.23	0.94	6.33%	(4.94% : 7.69%)	-4.25	(-5.17 : -3.32)	-8.72	<.0001	*
	Head-On, Daytime MVA	1.01	5.55	6.33	0.88	12.35%	(9.17% : 15.43%)	-0.78	(-0.98 : -0.58)	-7.27	<.0001	*
	Hwy Crash, Daytime MVA	0.97	27.08	27.67	0.98	2.12%	(0.32% : 3.90%)	-0.59	(-1.08 : -0.09)	-2.30	0.0215	*
	Motorcycle, Daytime MVA	0.97	0.99	1.06	0.94	6.28%	(-1.78% : 13.69%)	-0.07	(-0.14 : 0.02)	-1.55	0.1229	
	Ped/Cyclist, Daytime	0.91	3.55	3.68	0.96	3.60%	(-0.19% : 7.25%)	-0.13	(-0.27 : 0.01)	-1.87	0.0620	
	Rainy/Foggy, Daytime MVA	0.93	14.41	15.37	0.94	6.24%	(4.13% : 8.30%)	-0.96	(-1.28 : -0.64)	-5.68	<.0001	*
	Rural Area, Daytime MVA	0.95	21.67	23.84	0.91	9.10%	(7.29% : 10.87%)	-2.17	(-2.59 : -1.74)	-9.52	<.0001	*
	Sideswipe, Daytime MVA	0.98	16.30	16.55	0.98	1.51%	(-1.12% : 4.06%)	-0.25	(-0.67 : 0.18)	-1.13	0.2573	
	Urban Area, Daytime MVA	1.00	122.24	128.45	0.95	4.83%	(3.67% : 5.98%)	-6.20	(-7.68 : -4.71)	-7.98	<.0001	*
Light Truck	All Crash Types	1.00	264.87	274.47	0.97	3.50%	(2.03% : 4.94%)	-9.60	(-13.56 : -5.58)	-4.63	<.0001	*
	All Crash Types, Dawn/Dusk MVA	0.94	6.04	6.28	0.96	3.74%	(-0.76% : 8.04%)	-0.23	(-0.50 : 0.05)	-1.64	0.1018	
	All Crash Types, Daytime	1.01	196.23	205.34	0.96	4.44%	(2.83% : 6.01%)	-9.11	(-12.35 : -5.82)	-5.38	<.0001	*
	All Crash Types, Daytime MVA	1.01	156.43	163.00	0.96	4.03%	(2.36% : 5.68%)	-6.58	(-9.26 : -3.85)	-4.70	<.0001	*

Vehicle Group	Crash Type	ChiSq DF	DRL per10K	No DRL per10K	Rate Ratio %	Eff (%)	95% CI Eff(%)	Rate Change per 10K	95% CI Rate Change	t stat	P-value t	sigt
	All Crash Types, Daytime SVA	1.03	32.93	34.19	0.96	3.67%	(1.08% : 6.19%)	-1.26	(-2.12 : -0.37)	-2.76	0.0058	*
	All Crash Types, MVA	1.00	191.15	197.90	0.97	3.41%	(1.84% : 4.95%)	-6.74	(-9.79 : -3.65)	-4.26	<.0001	*
	All Crash Types, Night Time	1.02	61.18	61.89	0.99	1.16%	(-1.07% : 3.34%)	-0.72	(-2.07 : 0.66)	-1.02	0.3062	
	All Crash Types, Nighttime MVA	1.00	31.76	31.54	1.01	-0.70%	(-3.13% : 1.67%)	0.22	(-0.53 : 0.99)	0.57	0.5655	
	All Crash Types, Nighttime SVA	1.04	26.79	27.29	0.98	1.84%	(-1.10% : 4.69%)	-0.50	(-1.28 : 0.30)	-1.24	0.2169	
	All Crash Types, SVA	1.04	63.51	65.21	0.97	2.62%	(0.40% : 4.78%)	-1.71	(-3.12 : -0.26)	-2.31	0.0208	*
	Angle Crash, Daytime MVA	1.01	62.34	65.44	0.95	4.75%	(2.56% : 6.88%)	-3.11	(-4.50 : -1.68)	-4.21	<.0001	*
	Head-On, Daytime MVA	0.95	6.04	6.89	0.88	12.30%	(8.18% : 16.24%)	-0.85	(-1.12 : -0.56)	-5.61	<.0001	*
	Hwy Crash, Daytime MVA	0.98	30.53	31.72	0.96	3.77%	(1.27% : 6.21%)	-1.20	(-1.97 : -0.40)	-2.94	0.0034	*
	Motorcycle, Daytime MVA	0.94	0.91	0.92	0.99	0.79%	(-12.65% : 12.62%)	-0.01	(-0.12 : 0.12)	-0.12	0.9020	
	Ped/Cyclist, Daytime	0.93	3.75	3.73	1.00	-0.49%	(-6.15% : 4.86%)	0.02	(-0.18 : 0.23)	0.18	0.8610	
	Rainy/Foggy, Daytime MVA	0.94	14.74	16.01	0.92	7.97%	(4.68% : 11.15%)	-1.28	(-1.79 : -0.75)	-4.67	<.0001	*
	Rural Area, Daytime MVA	0.98	31.13	33.24	0.94	6.37%	(4.16% : 8.52%)	-2.12	(-2.83 : -1.38)	-5.54	<.0001	*
	Sideswipe, Daytime MVA	0.98	17.08	16.99	1.01	-0.52%	(-4.42% : 3.23%)	0.09	(-0.55 : 0.75)	0.27	0.7885	
	Urban Area, Daytime MVA	1.03	117.86	121.32	0.97	2.85%	(0.97% : 4.69%)	-3.46	(-5.69 : -1.18)	-2.98	0.0033	*
Passenger Vehicle	All Crash Types	0.60	257.62	270.08	0.95	4.61%	(3.47% : 5.74%)	-12.45	(-15.51 : -9.37)	-7.77	<.0001	*
	All Crash Types, Dawn/Dusk MVA	0.94	5.75	6.17	0.93	6.78%	(4.26% : 9.24%)	-0.42	(-0.57 : -0.26)	-5.15	<.0001	*
	All Crash Types, Daytime	0.61	189.63	199.80	0.95	5.09%	(3.88% : 6.28%)	-10.16	(-12.55 : -7.74)	-8.07	<.0001	*
	All Crash Types, Daytime MVA	0.62	153.19	161.50	0.95	5.14%	(3.88% : 6.39%)	-8.31	(-10.32 : -6.27)	-7.82	<.0001	*
	All Crash Types, Daytime SVA	1.04	29.52	30.46	0.97	3.10%	(1.51% : 4.66%)	-0.94	(-1.42 : -0.46)	-3.81	0.0002	*
	All Crash Types, MVA	0.60	188.79	198.66	0.95	4.96%	(3.76% : 6.15%)	-9.86	(-12.23 : -7.47)	-7.92	<.0001	*
	All Crash Types, Night Time	1.00	60.49	62.42	0.97	3.09%	(1.87% : 4.30%)	-1.93	(-2.68 : -1.17)	-4.91	<.0001	*
	All Crash Types, Nighttime MVA	0.98	32.57	33.51	0.97	2.80%	(1.42% : 4.15%)	-0.94	(-1.39 : -0.48)	-3.98	<.0001	*

Vehicle Group	*Crash Type*	*ChiSq DF*	*DRL per10K*	*No DRL per10K*	*Rate Ratio %*	*Eff (%)*	*95% CI Eff(%)*	*Rate Change per 10K*	*95% CI Rate Change*	*t stat*	*P-value t*	*sigt*
	All Crash Types, Nighttime SVA	1.02	25.17	25.82	0.97	2.52%	(0.84% : 4.17%)	-0.65	(-1.08 : -0.22)	-2.93	0.0034	*
	All Crash Types, SVA	1.03	58.49	59.98	0.98	2.48%	(1.16% : 3.78%)	-1.49	(-2.27 : -0.70)	-3.67	0.0003	*
	Angle Crash, Daytime MVA	0.98	62.86	66.78	0.94	5.86%	(4.70% : 7.01%)	-3.91	(-4.68 : -3.14)	-9.63	<.0001	*
	Head-On, Daytime MVA	0.99	5.69	6.50	0.88	12.44%	(9.96% : 14.85%)	-0.81	(-0.97 : -0.65)	-9.35	<.0001	*
	Hwy Crash, Daytime MVA	0.97	28.09	28.87	0.97	2.68%	(1.22% : 4.12%)	-0.77	(-1.19 : -0.35)	-3.58	0.0003	*
	Motorcycle, Daytime MVA	0.96	0.97	1.02	0.95	4.66%	(-2.05% : 10.92%)	-0.05	(-0.11 : 0.02)	-1.38	0.1689	
	Ped/Cyclist, Daytime	0.92	3.61	3.69	0.98	2.34%	(-0.75% : 5.33%)	-0.09	(-0.20 : 0.03)	-1.49	0.1357	
	Rainy/Foggy, Daytime MVA	0.94	14.54	15.58	0.93	6.66%	(4.93% : 8.35%)	-1.04	(-1.30 : -0.77)	-7.40	<.0001	*
	Rural Area, Daytime MVA	0.96	24.18	26.30	0.92	8.04%	(6.64% : 9.42%)	-2.11	(-2.48 : -1.75)	-10.88	<.0001	*
	Sideswipe, Daytime MVA	0.98	16.56	16.70	0.99	0.84%	(-1.32% : 2.95%)	-0.14	(-0.49 : 0.22)	-0.77	0.4434	
	Urban Area, Daytime MVA	0.62	121.03	126.50	0.96	4.33%	(2.94% : 5.70%)	-5.47	(-7.20 : -3.72)	-6.01	<.0001	*

Appendix C: Summary Tables from Ratio-of-Odds-Ratios Analyses of State Data, 1996-2005

group	*crash*	*Ratio of OR*	*% Diff*	*t Value*	*Pr > |t|*	*sig*
Car	All Crash Types, MVA	0.985	1.50%	-0.72	0.4727	
	Angle Crash, MVA	0.990	0.99%	-0.40	0.6868	
	Head-On, MVA	0.912	8.82%	-2.84	0.0047	*
	Hwy Crash, MVA	0.965	3.48%	-1.57	0.1165	
	Motorcycle, MVA	1.025	-2.51%	0.38	0.7036	
	Ped/Cyclist	1.025	-2.46%	0.75	0.4548	
	Rainy/Foggy, MVA	0.978	2.23%	-0.88	0.3799	
	Rural Area, MVA	0.954	4.60%	-1.98	0.0485	*
	Sideswipe, MVA	0.999	0.08%	-0.03	0.9735	
	Urban Area, MVA	0.992	0.80%	-0.37	0.7134	
Light Truck	All Crash Types, MVA	0.984	1.61%	-0.47	0.6354	
	Angle Crash, MVA	0.966	3.43%	-0.88	0.3814	
	Head-On, MVA	0.913	8.71%	-1.79	0.0745	
	Hwy Crash, MVA	0.997	0.30%	-0.08	0.9348	
	Motorcycle, MVA	1.095	-9.52%	0.87	0.3830	
	Ped/Cyclist	1.022	-2.20%	0.48	0.6311	
	Rainy/Foggy, MVA	0.912	8.75%	-2.23	0.0264	*
	Rural Area, MVA	0.971	2.88%	-0.80	0.4251	
	Sideswipe, MVA	1.033	-3.25%	0.78	0.4354	
	Urban Area, MVA	0.984	1.58%	-0.45	0.6544	
Passenger Vehicles	All Crash Types, MVA	0.986	1.36%	-0.76	0.4485	
	Angle Crash, MVA	0.984	1.57%	-0.75	0.4541	
	Head-On, MVA	0.916	8.40%	-3.15	0.0017	*
	Hwy Crash, MVA	0.977	2.32%	-1.20	0.2322	
	Motorcycle, MVA	1.049	-4.86%	0.86	0.3889	
	Ped/Cyclist	1.025	-2.52%	0.94	0.3474	
	Rainy/Foggy, MVA	0.960	3.99%	-1.83	0.0676	
	Rural Area, MVA	0.960	3.97%	-2.00	0.0453	*
	Sideswipe, MVA	1.011	-1.05%	0.49	0.6255	
	Urban Area, MVA	0.992	0.84%	-0.45	0.6542	

group	crash	ChiSq DF	Ratio of OR	Low 95% Ratio	Up 95% Ratio	% Diff	Lower %	Upper %	Logit Diff	Standard Error	t Value	Pr > |t|	sig
Car	All Crash Types, MVA	1.068	0.985	0.945	1.027	1.50%	-2.65%	5.49%	-0.015	0.021	-0.72	0.4727	
	Angle Crash, MVA	1.047	0.990	0.943	1.039	0.99%	-3.93%	5.68%	-0.010	0.025	-0.40	0.6868	
	Head-On, MVA	1.071	0.912	0.855	0.972	8.82%	2.80%	14.47%	-0.092	0.033	-2.84	0.0047	*
	Hwy Crash, MVA	1.038	0.965	0.923	1.009	3.48%	-0.89%	7.66%	-0.035	0.023	-1.57	0.1165	
	Motorcycle, MVA	1.047	1.025	0.902	1.165	-2.51%	-16.46%	9.77%	0.025	0.065	0.38	0.7036	
	Ped/Cyclist	1.075	1.025	0.961	1.092	-2.46%	-9.22%	3.87%	0.024	0.033	0.75	0.4548	
	Rainy/Foggy, MVA	1.015	0.978	0.930	1.028	2.23%	-2.82%	7.02%	-0.023	0.026	-0.88	0.3799	
	Rural Area, MVA	1.041	0.954	0.910	1.000	4.60%	0.03%	8.96%	-0.047	0.024	-1.98	0.0485	*
	Sideswipe, MVA	1.017	0.999	0.952	1.049	0.08%	-4.88%	4.81%	-0.001	0.025	-0.03	0.9735	
	Urban Area, MVA	1.062	0.992	0.950	1.036	0.80%	-3.56%	4.98%	-0.008	0.022	-0.37	0.7134	
Light Truck	All Crash Types, MVA	1.045	0.984	0.920	1.052	1.61%	-5.22%	7.99%	-0.016	0.034	-0.47	0.6354	
	Angle Crash, MVA	1.028	0.966	0.893	1.044	3.43%	-4.43%	10.69%	-0.035	0.040	-0.88	0.3814	
	Head-On, MVA	1.051	0.913	0.826	1.009	8.71%	-0.91%	17.42%	-0.091	0.051	-1.79	0.0745	
	Hwy Crash, MVA	1.041	0.997	0.928	1.071	0.30%	-7.12%	7.20%	-0.003	0.037	-0.08	0.9348	
	Motorcycle, MVA	1.047	1.095	0.893	1.344	-9.52%	-34.36%	10.73%	0.091	0.104	0.87	0.3830	
	Ped/Cyclist	1.153	1.022	0.935	1.117	-2.20%	-11.72%	6.50%	0.022	0.045	0.48	0.6311	
	Rainy/Foggy, MVA	1.034	0.912	0.842	0.989	8.75%	1.07%	15.84%	-0.092	0.041	-2.23	0.0264	*
	Rural Area, MVA	1.036	0.971	0.904	1.044	2.88%	-4.36%	9.62%	-0.029	0.037	-0.80	0.4251	
	Sideswipe, MVA	1.033	1.033	0.953	1.119	-3.25%	-11.92%	4.74%	0.032	0.041	0.78	0.4354	
	Urban Area, MVA	1.044	0.984	0.918	1.055	1.58%	-5.55%	8.23%	-0.016	0.036	-0.45	0.6544	
Passenger Vehicles	All Crash Types, MVA	1.058	0.986	0.952	1.022	1.36%	-2.20%	4.80%	-0.014	0.018	-0.76	0.4485	
	Angle Crash, MVA	1.040	0.984	0.944	1.026	1.57%	-2.59%	5.56%	-0.016	0.021	-0.75	0.4541	
	Head-On, MVA	1.059	0.916	0.867	0.967	8.40%	3.26%	13.27%	-0.088	0.028	-3.15	0.0017	*

group	*crash*	*ChiSq DF*	*Ratio of OR*	*Low 95% Ratio*	*Up 95% Ratio*	*% Diff*	*Lower %*	*Upper %*	*Logit Diff*	*Standard Error*	*t Value*	*Pr > |t|*	*sig*
	Hwy Crash, MVA	1.031	0.977	0.940	1.015	2.32%	-1.52%	6.01%	-0.023	0.020	-1.20	0.2322	
	Motorcycle, MVA	1.054	1.049	0.941	1.168	-4.86%	-16.82%	5.88%	0.047	0.055	0.86	0.3889	
	Ped/Cyclist	1.098	1.025	0.973	1.080	-2.52%	-7.99%	2.67%	0.025	0.027	0.94	0.3474	
	Rainy/Foggy, MVA	1.013	0.960	0.919	1.003	3.99%	-0.29%	8.08%	-0.041	0.022	-1.83	0.0676	
	Rural Area, MVA	1.035	0.960	0.923	0.999	3.97%	0.08%	7.70%	-0.040	0.020	-2.00	0.0453	*
	Sideswipe, MVA	1.019	1.011	0.969	1.054	-1.05%	-5.40%	3.11%	0.010	0.021	0.49	0.6255	
	Urban Area, MVA	1.054	0.992	0.956	1.029	0.84%	-2.89%	4.44%	-0.008	0.019	-0.45	0.6542	

Appendix D: Summary Tables from Poisson Regression Analyses of FARS Data, 1996-2005

Vehicle Group	*Crash Type*	*DRL per100K*	*No DRL per100K*	*Rate Ratio*	*Effect (%)*	*Rate Change per100K*	*P-value t*	*sigt*
Car	All Crash Types	15.54	16.20	0.96	4.07%	-0.66	0.16	
	All Crash Types, Dawn/Dusk MVA	0.39	0.42	0.93	7.31%	-0.03	0.56	
	All Crash Types, Daytime	8.48	9.01	0.94	5.82%	-0.52	0.11	
	All Crash Types, Daytime MVA	5.26	5.74	0.92	8.32%	-0.48	0.05	*
	All Crash Types, Daytime SVA	2.65	2.63	1.01	-1.05%	0.03	0.83	
	All Crash Types, MVA	7.83	8.67	0.90	9.62%	-0.83	0.01	*
	All Crash Types, Night Time	6.71	6.82	0.98	1.66%	-0.11	0.62	
	All Crash Types, Nighttime MVA	2.49	2.81	0.89	11.38%	-0.32	0.04	*
	All Crash Types, Nighttime SVA	3.00	2.90	1.04	-3.71%	0.11	0.50	
	All Crash Types, SVA	5.82	5.67	1.03	-2.61%	0.15	0.50	
	Angle Crash, Daytime MVA	3.22	3.49	0.92	7.67%	-0.27	0.12	
	Head-On, Daytime MVA	1.58	1.74	0.91	9.23%	-0.16	0.16	
	Hwy Crash, Daytime MVA	3.65	3.88	0.94	5.81%	-0.23	0.21	
	Ped/Cyclist, Daytime	0.53	0.64	0.83	16.89%	-0.11	0.14	
	Rainy/Foggy, Daytime MVA	0.64	0.60	1.07	-6.63%	0.04	0.53	
	Rural Area, Daytime MVA	2.86	3.24	0.88	11.58%	-0.38	0.03	*
	Urban Area, Daytime MVA	2.36	2.49	0.95	4.96%	-0.12	0.39	
Light Truck	All Crash Types	21.92	23.20	0.94	5.51%	-1.28	0.02	*
	All Crash Types, Dawn/Dusk MVA	0.51	0.50	1.01	-0.65%	0.00	0.96	
	All Crash Types, Daytime	12.66	13.76	0.92	8.05%	-1.11	0.03	*
	All Crash Types, Daytime MVA	8.00	8.68	0.92	7.86%	-0.68	0.02	*
	All Crash Types, Daytime SVA	3.61	3.98	0.91	9.39%	-0.37	0.19	
	All Crash Types, MVA	11.42	12.15	0.94	5.98%	-0.73	0.14	
	All Crash Types, Night Time	9.08	9.28	0.98	2.23%	-0.21	0.54	
	All Crash Types, Nighttime MVA	3.48	3.52	0.99	1.06%	-0.04	0.88	
	All Crash Types, Nighttime SVA	4.03	4.20	0.96	4.10%	-0.17	0.49	
	All Crash Types, SVA	7.51	8.36	0.90	10.24%	-0.86	0.13	
	Angle Crash, Daytime MVA	4.54	4.94	0.92	7.96%	-0.39	0.13	
	Head-On, Daytime MVA	2.37	2.72	0.87	12.93%	-0.35	0.26	
	Hwy Crash, Daytime MVA	5.83	6.13	0.95	4.85%	-0.30	0.30	

Vehicle Group	*Crash Type*	*DRL per100K*	*No DRL per100K*	*Rate Ratio*	*Effect (%)*	*Rate Change per100K*	*P-value t*	*sigt*
	Motorcycle, Daytime MVA	0.34	0.45	0.77	23.34%	-0.10	0.36	
	Ped/Cyclist, Daytime	0.85	0.98	0.87	12.93%	-0.13	0.43	
	Rainy/Foggy, Daytime MVA	0.71	0.90	0.79	21.39%	-0.19	0.03	*
	Rural Area, Daytime MVA	5.08	5.47	0.93	7.19%	-0.39	0.19	
	Urban Area, Daytime MVA	2.80	3.02	0.92	7.56%	-0.23	0.25	
Passenger Vehicle	All Crash Types	17.10	18.04	0.95	5.21%	-0.94	0.01	*
	All Crash Types, Dawn/Dusk MVA	0.43	0.45	0.96	3.60%	-0.02	0.89	
	All Crash Types, Daytime	9.52	10.25	0.93	7.13%	-0.73	0.01	*
	All Crash Types, Daytime MVA	6.01	6.51	0.92	7.66%	-0.50	0.01	*
	All Crash Types, Daytime SVA	2.88	2.97	0.97	3.23%	-0.10	0.38	
	All Crash Types, MVA	8.82	9.55	0.92	7.63%	-0.73	0.00	*
	All Crash Types, Night Time	7.31	7.45	0.98	1.89%	-0.14	0.44	
	All Crash Types, Nighttime MVA	2.79	2.97	0.94	5.86%	-0.17	0.11	
	All Crash Types, Nighttime SVA	3.24	3.25	1.00	0.30%	-0.01	0.94	
	All Crash Types, SVA	6.23	6.35	0.98	1.97%	-0.13	0.52	
	Angle Crash, Daytime MVA	3.60	3.87	0.93	6.95%	-0.27	0.05	*
	Head-On, Daytime MVA	1.80	2.01	0.90	10.29%	-0.21	0.03	*
	Hwy Crash, Daytime MVA	4.25	4.46	0.95	4.77%	-0.21	0.14	
	Motorcycle, Daytime MVA	0.27	0.32	0.85	14.91%	-0.05	0.25	
	Ped/Cyclist, Daytime	0.63	0.73	0.86	13.51%	-0.10	0.13	
	Rainy/Foggy, Daytime MVA	0.68	0.70	0.98	1.95%	-0.01	0.81	
	Rural Area, Daytime MVA	3.48	3.81	0.91	8.79%	-0.34	0.02	*
	Urban Area, Daytime MVA	2.51	2.68	0.94	6.41%	-0.17	0.14	

Vehicle Group	*Crash Type*	*ChiSq DF*	*DRL per100K*	*No DRL per100K*	*Rate Ratio*	*Effect (%)*	*95% CI Eff (%)*	*Rate Change per100K*	*95% CI Rate Change*	*t stat*	*P-value t*	*sigt*
Car	All Crash Types	1.01	15.54	16.20	0.96	4.07%	(-1.70% : 9.51%)	-0.66	(-1.54 : 0.28)	-1.44	0.16	
	All Crash Types, Dawn/Dusk MVA	0.82	0.39	0.42	0.93	7.31%	(-21.09% : 29.04%)	-0.03	(-0.12 : 0.09)	-0.58	0.56	
	All Crash Types, Daytime	0.98	8.48	9.01	0.94	5.82%	(-1.39% : 12.52%)	-0.52	(-1.13 : 0.12)	-1.64	0.11	
	All Crash Types, Daytime MVA	0.96	5.26	5.74	0.92	8.32%	(0.12% : 15.83%)	-0.48	(-0.91 : -0.01)	-2.03	0.05	*
	All Crash Types, Daytime SVA	0.99	2.65	2.63	1.01	-1.05%	(-11.79% : 8.67%)	0.03	(-0.23 : 0.31)	0.22	0.83	
	All Crash Types, MVA	0.98	7.83	8.67	0.90	9.62%	(2.52% : 16.20%)	-0.83	(-1.40 : -0.22)	-2.69	0.01	*
	All Crash Types, Night Time	0.98	6.71	6.82	0.98	1.66%	(-5.32% : 8.17%)	-0.11	(-0.56 : 0.36)	-0.50	0.62	
	All Crash Types, Nighttime MVA	0.94	2.49	2.81	0.89	11.38%	(0.80% : 20.83%)	-0.32	(-0.59 : -0.02)	-2.17	0.04	*
	All Crash Types, Nighttime SVA	0.99	3.00	2.90	1.04	-3.71%	(-15.75% : 7.07%)	0.11	(-0.20 : 0.46)	0.67	0.50	
	All Crash Types, SVA	0.99	5.82	5.67	1.03	-2.61%	(-10.82% : 5.00%)	0.15	(-0.28 : 0.61)	0.68	0.50	
	Angle Crash, Daytime MVA	0.89	3.22	3.49	0.92	7.67%	(-2.21% : 16.60%)	-0.27	(-0.58 : 0.08)	-1.57	0.12	
	Head-On, Daytime MVA	0.87	1.58	1.74	0.91	9.23%	(-4.13% : 20.88%)	-0.16	(-0.36 : 0.07)	-1.42	0.16	
	Hwy Crash, Daytime MVA	0.92	3.65	3.88	0.94	5.81%	(-3.43% : 14.23%)	-0.23	(-0.55 : 0.13)	-1.28	0.21	
	Ped/Cyclist, Daytime	0.90	0.53	0.64	0.83	16.89%	(-6.14% : 34.92%)	-0.11	(-0.22 : 0.04)	-1.50	0.14	
	Rainy/Foggy, Daytime MVA	0.87	0.64	0.60	1.07	-6.63%	(-30.90% : 13.14%)	0.04	(-0.08 : 0.19)	0.63	0.53	
	Rural Area, Daytime MVA	0.95	2.86	3.24	0.88	11.58%	(1.23% : 20.85%)	-0.38	(-0.68 : -0.04)	-2.23	0.03	*
	Urban Area, Daytime MVA	0.91	2.36	2.49	0.95	4.96%	(-7.00% : 15.59%)	-0.12	(-0.39 : 0.17)	-0.86	0.39	
Light Truck	All Crash Types	1.07	21.92	23.20	0.94	5.51%	(0.90% : 9.90%)	-1.28	(-2.30 : -0.21)	-2.36	0.02	*
	All Crash Types, Dawn/Dusk MVA	0.78	0.51	0.50	1.01	-0.65%	(-31.05% : 22.70%)	0.00	(-0.11 : 0.16)	0.05	0.96	
	All Crash Types, Daytime	0.93	12.66	13.76	0.92	8.05%	(0.95% : 14.63%)	-1.11	(-2.01 : -0.13)	-2.64	0.03	*
	All Crash Types, Daytime MVA	0.90	8.00	8.68	0.92	7.86%	(1.34% : 13.95%)	-0.68	(-1.21 : -0.12)	-2.40	0.02	*
	All Crash Types, Daytime SVA	0.97	3.61	3.98	0.91	9.39%	(-6.65% : 23.02%)	-0.37	(-0.92 : 0.26)	-1.45	0.19	
	All Crash Types, MVA	0.99	11.42	12.15	0.94	5.98%	(-3.02% : 14.19%)	-0.73	(-1.72 : 0.37)	-1.78	0.14	

Vehicle Group	*Crash Type*	*ChiSq DF*	*DRL per100K*	*No DRL per100K*	*Rate Ratio*	*Effect (%)*	*95% CI Eff (%)*	*Rate Change per100K*	*95% CI Rate Change*	*t stat*	*P-value t*	*sigt*
	All Crash Types, Night Time	1.14	9.08	9.28	0.98	2.23%	(-5.08% : 9.03%)	-0.21	(-0.84 : 0.47)	-0.62	0.54	
	All Crash Types, Nighttime MVA	0.98	3.48	3.52	0.99	1.06%	(-22.12% : 19.84%)	-0.04	(-0.70 : 0.78)	-0.16	0.88	
	All Crash Types, Nighttime SVA	1.20	4.03	4.20	0.96	4.10%	(-9.58% : 16.07%)	-0.17	(-0.67 : 0.40)	-0.72	0.49	
	All Crash Types, SVA	1.15	7.51	8.36	0.90	10.24%	(-4.65% : 23.01%)	-0.86	(-1.92 : 0.39)	-1.74	0.13	
	Angle Crash, Daytime MVA	0.94	4.54	4.94	0.92	7.96%	(-3.06% : 17.79%)	-0.39	(-0.88 : 0.15)	-1.64	0.13	
	Head-On, Daytime MVA	0.85	2.37	2.72	0.87	12.93%	(-26.03% : 39.85%)	-0.35	(-1.09 : 0.71)	-1.55	0.26	
	Hwy Crash, Daytime MVA	0.94	5.83	6.13	0.95	4.85%	(-5.49% : 14.19%)	-0.30	(-0.87 : 0.34)	-1.10	0.30	
	Motorcycle, Daytime MVA	0.93	0.34	0.45	0.77	23.34%	(-59.63% : 63.19%)	-0.10	(-0.28 : 0.27)	-1.03	0.36	
	Ped/Cyclist, Daytime	0.95	0.85	0.98	0.87	12.93%	(-28.19% : 40.86%)	-0.13	(-0.40 : 0.28)	-0.82	0.43	
	Rainy/Foggy, Daytime MVA	0.91	0.71	0.90	0.79	21.39%	(2.54% : 36.59%)	-0.19	(-0.33 : -0.02)	-2.22	0.03	*
	Rural Area, Daytime MVA	0.96	5.08	5.47	0.93	7.19%	(-4.28% : 17.39%)	-0.39	(-0.95 : 0.23)	-1.39	0.19	
	Urban Area, Daytime MVA	0.93	2.80	3.02	0.92	7.56%	(-6.27% : 19.59%)	-0.23	(-0.59 : 0.19)	-1.21	0.25	
Passenger Vehicle	All Crash Types	1.03	17.10	18.04	0.95	5.21%	(1.13% : 9.13%)	-0.94	(-1.65 : -0.20)	-2.56	0.01	*
	All Crash Types, Dawn/Dusk MVA	0.85	0.43	0.45	0.96	3.60%	((1445%) : 93.99%)	-0.02	(-0.42 : 6.51)	-0.17	0.89	
	All Crash Types, Daytime	0.98	9.52	10.25	0.93	7.13%	(2.09% : 11.92%)	-0.73	(-1.22 : -0.21)	-2.81	0.01	*
	All Crash Types, Daytime MVA	0.94	6.01	6.51	0.92	7.66%	(2.01% : 12.98%)	-0.50	(-0.85 : -0.13)	-2.69	0.01	*
	All Crash Types, Daytime SVA	1.00	2.88	2.97	0.97	3.23%	(-4.36% : 10.27%)	-0.10	(-0.31 : 0.13)	-0.89	0.38	
	All Crash Types, MVA	0.98	8.82	9.55	0.92	7.63%	(2.63% : 12.36%)	-0.73	(-1.18 : -0.25)	-3.02	0.00	*
	All Crash Types, Night Time	1.03	7.31	7.45	0.98	1.89%	(-3.21% : 6.74%)	-0.14	(-0.50 : 0.24)	-0.78	0.44	
	All Crash Types, Nighttime MVA	0.98	2.79	2.97	0.94	5.86%	(-1.56% : 12.73%)	-0.17	(-0.38 : 0.05)	-1.63	0.11	
	All Crash Types, Nighttime SVA	1.05	3.24	3.25	1.00	0.30%	(-8.04% : 8.01%)	-0.01	(-0.26 : 0.26)	-0.08	0.94	
	All Crash Types, SVA	1.05	6.23	6.35	0.98	1.97%	(-4.29% : 7.86%)	-0.13	(-0.50 : 0.27)	-0.65	0.52	
	Angle Crash, Daytime MVA	0.91	3.60	3.87	0.93	6.95%	(0.02% : 13.40%)	-0.27	(-0.52 : -0.00)	-2.01	0.05	*

Vehicle Group	*Crash Type*	*ChiSq DF*	*DRL per100K*	*No DRL per100K*	*Rate Ratio*	*Effect (%)*	*95% CI Eff (%)*	*Rate Change per100K*	*95% CI Rate Change*	*t stat*	*P-value t*	*sigt*
	Head-On, Daytime MVA	0.88	1.80	2.01	0.90	10.29%	(1.32% : 18.45%)	-0.21	(-0.37 : -0.03)	-2.30	0.03	*
	Hwy Crash, Daytime MVA	0.93	4.25	4.46	0.95	4.77%	(-1.73% : 10.86%)	-0.21	(-0.48 : 0.08)	-1.48	0.14	
	Motorcycle, Daytime MVA	0.89	0.27	0.32	0.85	14.91%	(-12.28% : 35.52%)	-0.05	(-0.11 : 0.04)	-1.14	0.25	
	Ped/Cyclist, Daytime	0.92	0.63	0.73	0.86	13.51%	(-4.38% : 28.33%)	-0.10	(-0.21 : 0.03)	-1.54	0.13	
	Rainy/Foggy, Daytime MVA	0.90	0.68	0.70	0.98	1.95%	(-15.22% : 16.56%)	-0.01	(-0.12 : 0.11)	-0.24	0.81	
	Rural Area, Daytime MVA	0.97	3.48	3.81	0.91	8.79%	(1.56% : 15.49%)	-0.34	(-0.59 : -0.06)	-2.42	0.02	*
	Urban Area, Daytime MVA	0.92	2.51	2.68	0.94	6.41%	(-2.20% : 14.29%)	-0.17	(-0.38 : 0.06)	-1.51	0.14	

Appendix E: Summary Tables from Ratio-of-Odds-Ratios Analyses of FARS Data, 1996-2005

			Car				*Light Truck*			
			Subject		*SVA Comp.*		*Subject*		*SVA Comp.*	
			#	*%*	*#*	*%*	*#*	*%*	*#*	*%*
All Crash Types, MVA	*DRL*	*Daytime*	550,718	79.96	101,955	50.89	261,915	81.29	53,340	49.44
		Night	138,038	20.04	98,407	49.11	60,275	18.71	54,556	50.56
		-Total-	688,756	100.00	200,362	100.00	322,190	100.00	107,896	100.00
	No DRL	*Daytime*	616,900	80.46	112,744	50.99	276,223	81.97	55,528	49.91
		Night	149,829	19.54	108,384	49.01	60,747	18.03	55,729	50.09
		-Total-	766,729	100.00	221,128	100.00	336,970	100.00	111,257	100.00
Angle Crash, MVA	*DRL*	*Daytime*	213,160	81.41	95,021	50.54	92,664	81.94	49,337	49.11
		Night	48,660	18.59	92,988	49.46	20,423	18.06	51,116	50.89
		-Total-	261,820	100.00	188,009	100.00	113,087	100.00	100,453	100.00
	No DRL	*Daytime*	242,909	81.92	104,343	50.65	100,287	82.94	51,395	49.63
		Night	53,617	18.08	101,678	49.35	20,622	17.06	52,171	50.37
		-Total-	296,526	100.00	206,021	100.00	120,909	100.00	103,566	100.00
Head-On, MVA	*DRL*	*Daytime*	19,627	73.20	95,021	50.54	9,929	72.89	49,337	49.11
		Night	7,185	26.80	92,988	49.46	3,692	27.11	51,116	50.89
		-Total-	26,812	100.00	188,009	100.00	13,621	100.00	100,453	100.00
	No DRL	*Daytime*	22,955	74.46	104,343	50.65	11,239	74.53	51,395	49.63
		Night	7,873	25.54	101,678	49.35	3,840	25.47	52,171	50.37
		-Total-	30,828	100.00	206,021	100.00	15,079	100.00	103,566	100.00
Hwy Crash, MVA	*DRL*	*Daytime*	132,120	77.52	101,955	50.89	71,470	79.52	53,340	49.44
		Night	38,308	22.48	98,407	49.11	18,403	20.48	54,556	50.56
		-Total-	170,428	100.00	200,362	100.00	89,873	100.00	107,896	100.00
	No DRL	*Daytime*	148,316	77.96	112,744	50.99	77,954	80.11	55,528	49.91
		Night	41,935	22.04	108,384	49.01	19,349	19.89	55,729	50.09
		-Total-	190,251	100.00	221,128	100.00	97,303	100.00	111,257	100.00

			Car				Light Truck			
			Subject		*SVA Comp.*		*Subject*		*SVA Comp.*	
			#	%	#	%	#	%	#	%
Motorcycle, MVA	*DRL*	*Daytime*	3,671	78.32	101,955	50.89	1,596	79.56	53,340	49.44
		Night	1,016	21.68	98,407	49.11	410	20.44	54,556	50.56
		-Total-	4,687	100.00	200,362	100.00	2,006	100.00	107,896	100.00
	No DRL	*Daytime*	3,959	77.51	112,744	50.99	1,599	78.89	55,528	49.91
		Night	1,149	22.49	108,384	49.01	428	21.11	55,729	50.09
		-Total-	5,108	100.00	221,128	100.00	2,027	100.00	111,257	100.00
Ped/Cyclist	*DRL*	*Daytime*	14,533	73.94	101,955	50.89	6,715	73.11	53,340	49.44
		Night	5,121	26.06	98,407	49.11	2,470	26.89	54,556	50.56
		-Total-	19,654	100.00	200,362	100.00	9,185	100.00	107,896	100.00
	No DRL	*Daytime*	16,200	74.00	112,744	50.99	6,888	72.74	55,528	49.91
		Night	5,692	26.00	108,384	49.01	2,581	27.26	55,729	50.09
		-Total-	21,892	100.00	221,128	100.00	9,469	100.00	111,257	100.00
Rainy/Foggy, MVA	*DRL*	*Daytime*	55,591	73.13	101,955	50.89	25,638	74.72	53,340	49.44
		Night	20,426	26.87	98,407	49.11	8,675	25.28	54,556	50.56
		-Total-	76,017	100.00	200,362	100.00	34,313	100.00	107,896	100.00
	No DRL	*Daytime*	63,223	73.69	112,744	50.99	28,859	77.01	55,528	49.91
		Night	22,574	26.31	108,384	49.01	8,617	22.99	55,729	50.09
		-Total-	85,797	100.00	221,128	100.00	37,476	100.00	111,257	100.00
Rural Area, MVA	*DRL*	*Daytime*	105,814	79.46	101,955	50.89	64,546	80.63	53,340	49.44
		Night	27,354	20.54	98,407	49.11	15,504	19.37	54,556	50.56
		-Total-	133,168	100.00	200,362	100.00	80,050	100.00	107,896	100.00
	No DRL	*Daytime*	120,616	80.20	112,744	50.99	71,903	81.63	55,528	49.91
		Night	29,776	19.80	108,384	49.01	16,186	18.37	55,729	50.09
		-Total-	150,392	100.00	221,128	100.00	88,089	100.00	111,257	100.00
Sideswipe, MVA	*DRL*	*Daytime*	63,746	76.43	95,021	50.54	27,594	78.17	49,337	49.11
		Night	19,659	23.57	92,988	49.46	7,705	21.83	51,116	50.89
		-Total-	83,405	100.00	188,009	100.00	35,299	100.00	100,453	100.00
	No DRL	*Daytime*	68,739	76.74	104,343	50.65	28,196	78.73	51,395	49.63
		Night	20,830	23.26	101,678	49.35	7,619	21.27	52,171	50.37
		-Total-	89,569	100.00	206,021	100.00	35,815	100.00	103,566	100.00

			Car				Light Truck			
			Subject		SVA Comp.		Subject		SVA Comp.	
			#	%	#	%	#	%	#	%
Urban Area, MVA	*DRL*	*Daytime*	431,372	80.04	101,955	50.89	189,695	81.42	53,340	49.44
		Night	107,572	19.96	98,407	49.11	43,285	18.58	54,556	50.56
		-Total-	538,944	100.00	200,362	100.00	232,980	100.00	107,896	100.00
	No DRL	*Daytime*	481,209	80.46	112,744	50.99	196,696	82.01	55,528	49.91
		Night	116,876	19.54	108,384	49.01	43,159	17.99	55,729	50.09
		-Total-	598,085	100.00	221,128	100.00	239,855	100.00	111,257	100.00

group	crash	OR w DRL	OR No DRL	Ratio OR	Eff (%)	Ratio OR Logistic	Eff (%) Logistic	Pr > |t|	sig
Car	All Crash Types, MVA	3.14	3.06	1.029	-2.9%	1.083	-8.3%	0.3357	
	Angle Crash, MVA	4.22	4.27	0.989	1.1%	1.018	-1.8%	0.8485	
	Head-On, MVA	2.80	2.50	1.121	-12.1%	1.192	-19.2%	0.1078	
	Hwy Crash, MVA	3.06	2.95	1.037	-3.7%	1.108	-10.8%	0.2701	
	Motorcycle, MVA	3.05	3.35	0.911	8.9%	1.019	-1.9%	0.9298	
	Ped/Cyclist	0.70	0.83	0.846	15.4%	0.855	14.5%	0.2488	
	Rainy/Foggy, MVA	3.25	2.90	1.119	-11.9%	1.187	-18.7%	0.2670	
	Rural Area, MVA	3.66	3.60	1.017	-1.7%	1.074	-7.4%	0.4492	
	Sideswipe, MVA	1.54	2.34	0.658	34.2%	0.754	24.6%	0.4866	
	Urban Area, MVA	2.57	2.46	1.048	-4.8%	1.072	-7.2%	0.4605	
Light Truck	All Crash Types, MVA	2.81	2.92	0.963	3.7%	0.950	5.0%	0.6176	
	Angle Crash, MVA	3.70	3.99	0.925	7.5%	0.953	4.7%	0.7124	
	Head-On, MVA	2.40	2.57	0.936	6.4%	0.881	11.9%	0.3515	
	Hwy Crash, MVA	2.83	2.84	0.998	0.2%	0.981	1.9%	0.8647	
	Motorcycle, MVA	3.03	3.46	0.875	12.5%	0.830	17.0%	0.4945	
	Ped/Cyclist	0.88	0.88	0.999	0.1%	0.995	0.5%	0.9777	
	Rainy/Foggy, MVA	2.24	3.05	0.734	26.6%	0.700	30.0%	0.0567	
	Rural Area, MVA	3.28	3.29	0.997	0.3%	0.977	2.3%	0.8286	
	Sideswipe, MVA	2.54	3.85	0.661	33.9%	0.666	33.4%	0.4026	
	Urban Area, MVA	2.17	2.36	0.920	8.0%	0.913	8.7%	0.5320	
Passenger Vehicles	All Crash Types, MVA	2.99	2.99	0.999	0.1%	1.031	-3.1%	0.6329	
	Angle Crash, MVA	3.99	4.15	0.962	3.8%	0.993	0.7%	0.9287	
	Head-On, MVA	2.62	2.53	1.035	-3.5%	1.056	-5.6%	0.5082	
	Hwy Crash, MVA	2.96	2.90	1.019	-1.9%	1.056	-5.6%	0.4372	
	Motorcycle, MVA	3.04	3.41	0.891	10.9%	0.931	6.9%	0.6640	
	Ped/Cyclist	0.78	0.86	0.912	8.8%	0.915	8.5%	0.4032	
	Rainy/Foggy, MVA	2.80	2.96	0.945	5.5%	0.957	4.3%	0.7069	
	Rural Area, MVA	3.49	3.47	1.006	-0.6%	1.027	-2.7%	0.7009	
	Sideswipe, MVA	1.96	2.83	0.690	31.0%	0.748	25.2%	0.3429	
	Urban Area, MVA	2.40	2.41	0.997	0.3%	1.011	-1.1%	0.8915	

group	*crash*	*ChiSq DF*	*Ratio of OR*	*Low 95% Ratio*	*Up 95% Ratio*	*% Diff*	*Lower %*	*Upper %*	*Logit Diff*	*Standard Error*	*t Value*	*Pr > |t|*	*sig*
Car	All Crash Types, MVA	1.092	1.083	0.919	1.276	-8.3%	-27.6%	8.1%	0.080	0.082	0.97	0.3357	
	Angle Crash, MVA	1.018	1.018	0.848	1.222	-1.8%	-22.2%	15.2%	0.018	0.092	0.19	0.8485	
	Head-On, MVA	1.101	1.192	0.961	1.479	-19.2%	-47.9%	3.9%	0.176	0.108	1.63	0.1078	
	Hwy Crash, MVA	1.104	1.108	0.921	1.334	-10.8%	-33.4%	7.9%	0.103	0.093	1.11	0.2701	
	Motorcycle, MVA	0.941	1.019	0.666	1.559	-1.9%	-55.9%	33.4%	0.019	0.215	0.09	0.9298	
	Ped/Cyclist	1.016	0.855	0.654	1.118	14.5%	-11.8%	34.6%	-0.157	0.135	-1.16	0.2488	
	Rainy/Foggy, MVA	1.110	1.187	0.876	1.609	-18.7%	-60.9%	12.4%	0.171	0.154	1.11	0.2670	
	Rural Area, MVA	1.146	1.074	0.890	1.297	-7.4%	-29.7%	11.0%	0.072	0.094	0.76	0.4492	
	Sideswipe, MVA	1.092	0.754	0.338	1.681	24.6%	-68.1%	66.2%	-0.283	0.405	-0.70	0.4866	
	Urban Area, MVA	1.049	1.072	0.890	1.290	-7.2%	-29.0%	11.0%	0.069	0.093	0.74	0.4605	
Light Truck	All Crash Types, MVA	0.952	0.950	0.774	1.167	5.0%	-16.7%	22.6%	-0.051	0.101	-0.50	0.6176	
	Angle Crash, MVA	0.997	0.953	0.732	1.240	4.7%	-24.0%	26.8%	-0.048	0.130	-0.37	0.7124	
	Head-On, MVA	0.990	0.881	0.671	1.158	11.9%	-15.8%	32.9%	-0.126	0.133	-0.95	0.3515	
	Hwy Crash, MVA	1.027	0.981	0.779	1.234	1.9%	-23.4%	22.1%	-0.019	0.113	-0.17	0.8647	
	Motorcycle, MVA	1.008	0.830	0.484	1.426	17.0%	-42.6%	51.6%	-0.186	0.270	-0.69	0.4945	
	Ped/Cyclist	1.009	0.995	0.710	1.395	0.5%	-39.5%	29.0%	-0.005	0.168	-0.03	0.9777	
	Rainy/Foggy, MVA	0.957	0.700	0.486	1.010	30.0%	-1.0%	51.4%	-0.356	0.183	-1.94	0.0567	
	Rural Area, MVA	0.897	0.977	0.787	1.212	2.3%	-21.2%	21.3%	-0.023	0.106	-0.22	0.8286	
	Sideswipe, MVA	1.178	0.666	0.253	1.751	33.4%	-75.1%	74.7%	-0.407	0.482	-0.84	0.4026	
	Urban Area, MVA	1.072	0.913	0.682	1.223	8.7%	-22.3%	31.8%	-0.091	0.144	-0.63	0.5320	
Passenger Vehicles	All Crash Types, MVA	1.059	1.031	0.910	1.167	-3.1%	-16.7%	9.0%	0.030	0.063	0.48	0.6329	
	Angle Crash, MVA	0.992	0.993	0.857	1.151	0.7%	-15.1%	14.3%	-0.007	0.074	-0.09	0.9287	
	Head-On, MVA	1.095	1.056	0.897	1.243	-5.6%	-24.3%	10.3%	0.055	0.082	0.66	0.5082	

group	crash	ChiSq DF	Ratio of OR	Low 95% Ratio	Up 95% Ratio	% Diff	Lower %	Upper %	Logit Diff	Standard Error	t Value	Pr > |t|	sig
	Hwy Crash, MVA	1.089	1.056	0.919	1.215	-5.6%	-21.5%	8.1%	0.055	0.070	0.78	0.4372	
	Motorcycle, MVA	0.973	0.931	0.673	1.287	6.9%	-28.7%	32.7%	-0.072	0.164	-0.43	0.6640	
	Ped/Cyclist	0.992	0.915	0.742	1.128	8.5%	-12.8%	25.8%	-0.089	0.106	-0.84	0.4032	
	Rainy/Foggy, MVA	1.093	0.957	0.760	1.205	4.3%	-20.5%	24.0%	-0.044	0.117	-0.38	0.7069	
	Rural Area, MVA	1.097	1.027	0.897	1.176	-2.7%	-17.6%	10.3%	0.026	0.068	0.39	0.7009	
	Sideswipe, MVA	1.120	0.748	0.409	1.367	25.2%	-36.7%	59.1%	-0.291	0.306	-0.95	0.3429	
	Urban Area, MVA	1.046	1.011	0.866	1.180	-1.1%	-18.0%	13.4%	0.011	0.078	0.14	0.8915	

Appendix F: SAS Code for Poisson Regression Analyses

This appendix provides the SAS call to the GLIMMIX procedure used in the Poisson regression analyses, as well as brief descriptions of the associated arguments.

```
proc glimmix data=temp method=rspl;
     class drlx state vehid year;
     model Y = drlx year drlx*year / link=log dist=negbin offset=log_polk
                                     solution cl ddfm=kr ;
     nloptions maxiter=5000 tech=nrridg;
     random int state state*drlx / subject=vehid;
     lsmeans drlx / cl diff ilink;
run;
```

Parameter:

- data - name of the input data set
- method – estimation method (RSPL restricted maximum likelihood estimation)
- class - list of categorical variables in the model
- model – specify the fixed effect portion of the model
  - Y is the outcome variable (e.g., number of head-on crash)
  - link function is log
  - distribution is negative binomial
  - offset variable is log_polk
  - "solution" to request estimated parameters be provided
  - "cl" to request confidence intervals of parameter estimates be provided
  - ddfm – request the Kenward-Roger adjustment to the degrees of freedom be applied
- nloption - non-linear estimation parameters
- random - specify the random effect components of the model
- lsmeans - request least square means be calculated for DRL and testing for their differences

Appendix G: SAS Code for Ratio-of-Odds-Ratios Analyses

This appendix provides the SAS call to the GLIMMIX procedure used in the ratio-of-odds-ratios analyses, as well as brief descriptions of the associated arguments.

```
proc glimmix data=temp method=rspl;
     ods output parameterestimates=parm fitstatistics=fit lsmeans=ls;
     class drlx state vehid crash;
       model event/trial = drlx crash drlx*crash /link=logit dist=binomial
                                                 solution oddsratios cl
ddfm=kr;
     nloptions maxiter=500 tech=nrridg;
     random int state state*drlx*crash / subject=vehid;
run;
```

Parameter:

- data - name of the input data set
- method - estimation method (RSPL restricted maximum likelihood estimation)
- class - list of categorical variables in the model
- model – specify the fixed effect portion of the model
  - o event-trial syntax used where “event” is the number of crash during daytime and trial is the total number of crash of a particular type being studied.
  - o link function is logit
  - o distribution is binomial
  - o "solution" to request estimated parameters be provided
  - o “oddsratios” to request the parameters be presented as odds-ratios
  - o "cl" to request confidence intervals of parameter estimates be provided
  - o ddfm – request the Kenward-Roger adjustment to the degrees of freedom be applied
- nloption - non-linear estimation parameters
- random - specify the random effect components of the model

Contract No. ETU/B27020B-E3-2002-DRL-S07.18830 (TREN/E3/27-2002)

‘Daytime Running Lights’
Deliverable 3: Final Report

1. Objectives of the DRL Project

The project, which started on january 1 2003, pursued the following objectives:

(a) To assess the effectiveness of the currently legislated requirements for the use of DRL in the EU and elsewhere, and how that legislation has been implemented in these countries.

(b) To assess the various evaluations and make specific cost-effectiveness recommendations for the introduction of DRLs, taking into account the various positive and possible negative road safety impacts (casualty reduction ranges for various types of road users) and environmental impacts (increased fuel consumption and CO_2 production). To investigate possible negative environmental impacts of the use of DRLs relative to other in-vehicle electrical equipment, such as air conditioners, etc.

(c) To collate the work done under (a) and (b), and produce various implementation strategies for DRLs in the EU, as well as further specific recommendations for implementation maximising the positive effects, while minimising the negative effects.

These objectives have been elaborated as separate Workpackages, as follows:
WP 1 State-of-the-art with respect to DRL-regimes
WP 2 Review of accident analysis studies
WP 3 Investigation of (possible) adverse effects
WP 4 Development of implementation regimes

The results of these will be briefly reviewed on the basis of Internal reports (IRs) that have been produced within the Workpackages, and which are attached in full to this text.

2. Summary of results

2.1 WP 1: State-of-the-art with respect to DRL-regimes

The first objective of WP 1 was to provide an inventory of the currently legislated requirements for the use of DRL in the EU and elsewhere, and how that legislation has been implemented in these countries. Such an inventory is provided in the figure below (Commandeur, IR1).

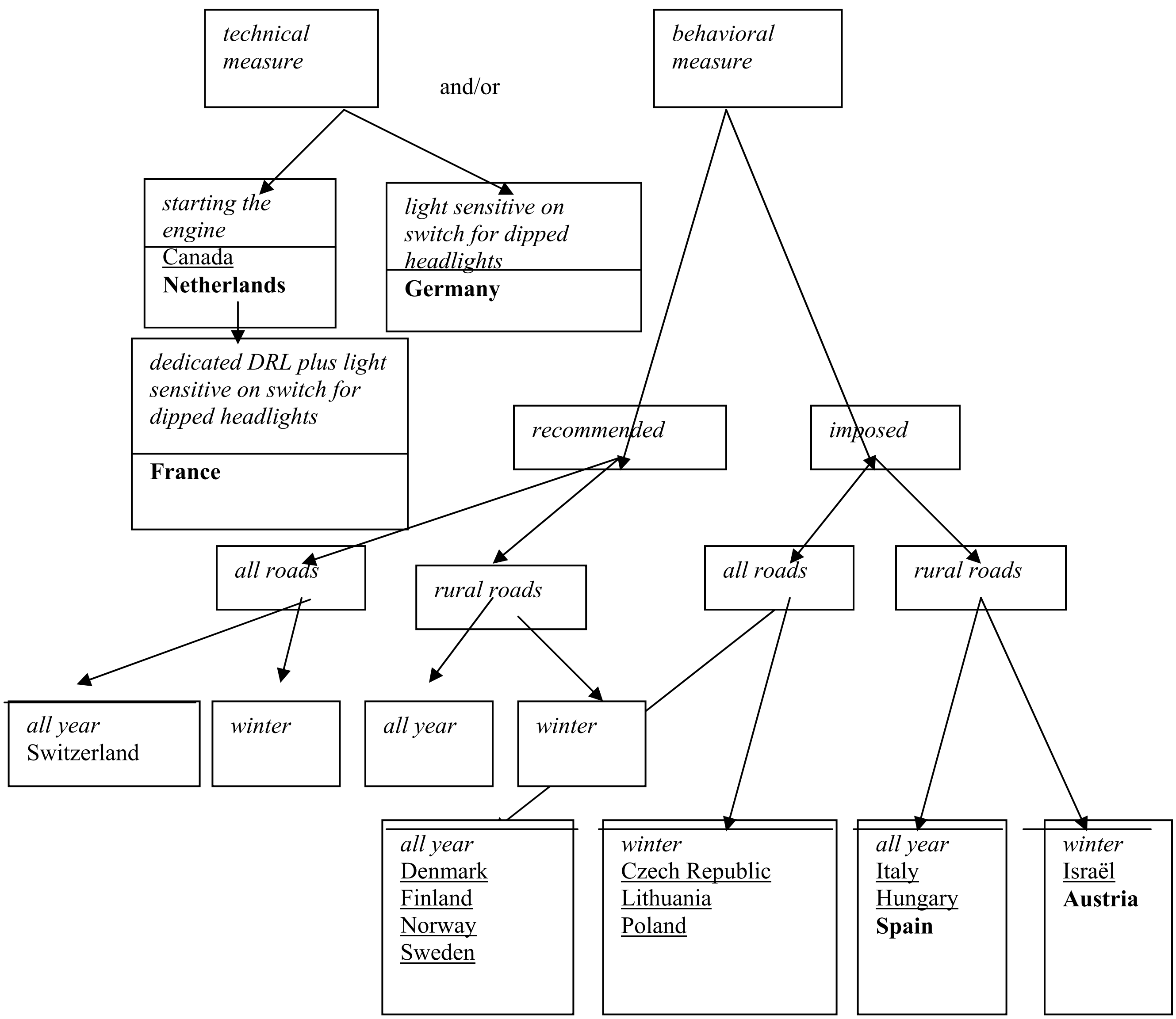


Fig. 1: Classification of DRL implementation scenarios, including countries. Underlined: countries with DRL legislation. Standard: countries without DRL legislation, but DRL recommended. **Bold**: countries without DRL legislation; plans, or expressed scenario preference if DRL proven to be effective.

The figure shows that DRL has been implemented both as a technical and as a behavioral measure. So far, the majority of DRL countries chose to impose DRL as a behavioral measure although most cars in the Scandinavian countries (Denmark, Finland, Norway and Sweden) are sold with an automatic DRL switch as well. The countries which currently have legislation on the use of DRL can be further distinguished in whether they impose DRL during the whole year or in winter time only, and on all roads or on rural roads only.

The second objective of WP 1 was to assess what can be learned under the existing DRL regimes, so as to take these findings into account in the later development of realistic implementation strategies.
It appeared that, when setting up European guidelines for the implementation of DRL, it is clear that the following issues will have to be addressed:

- pedestrians, cyclists, mopeds less conspicuous;
- motorcyclists less conspicuous;
- glare;
- increased fuel consumption;
- increased CO_2 emission;
- more frequently burned out bulbs;
- flat batteries;
- reduced conspicuity of brake lights;
- if carrying dedicated reduced intensity DRL, drivers forget to switch on dipped headlights in reduced visibility conditions;
- “masking” of unlit vehicles by lit ones in mixed daytime circulation.

In DRL countries the use of media campaigns during the introduction of DRL was found to range all the way from no media campaigns at all in Hungary to massive media campaigns in Canada. Since all DRL countries indicate not having met with much resistance and opposition against DRL after its implementation, there does not seem to be much that can be learned in terms of what type of media campaign would be optimal when introducing DRL in a non-DRL country. However, according to the person responsible for completing the questionnaire in Canada, “it is recommended that other countries intending to implement DRL policies take steps to inform their citizenry about the basic workings of visual perception relative to the driving task, since some of the comments from the Canadian public about DRL seemed to reflect a lack of understanding of the role and importance of contrast in aiding visual perception.”
Most DRL countries used a gradual approach to the implementation of DRL, either by encouraging the voluntary use of DRL before the introduction of DRL legislation, or by a gradual extension of compulsory DRL usage over more and more types of roads, over more and more months of the year, and/or for more and more types of road users.
Such gradual implementation strategies allow road users to gain personal experience in the visual workings of DRL, thus probably also contributing to obtain broader public acceptance for DRL legislation.

2.2 WP 2 Review of accident analysis studies

A meta-analysis was performed on the available accident statistics literature, aiming at answering the following questions (Elvik et al., IR 2):

1. Are the effects attributed to DRL novelty effects that are likely to erode over time?
2. What is the relationship between the usage rate for DRL and the effects on road safety (dose-response function)?
3. Do the effects of DRL vary systematically, depending on geographical latitude?
4. Do the effects of DRL vary, in terms of accident severity?
5. Do the effects of DRL vary with respect to season (winter/summer)?
6. What are the effects on accidents involving motorcyclists of requiring DRL for cars?
7. What are the effects on accidents involving pedestrians or cyclists of requiring DRL for cars?
8. Are there adverse effects of DRL on cars for other types of accident, in particular rear-end collisions?

The main findings of the systematic review of evidence concerning effects of daytime running lights on accidents can be summarised as follows:

1. A total of 41 studies that have evaluated the effects on road safety of DRL, have been retrieved. 25 of these studies have evaluated the effects for cars, 16 have evaluated the effects for motorcycles. A distinction is made between estimates of the intrinsic effects of DRL and estimates of the aggregate effects. Intrinsic effects are the effects for each car or motorcycle using DRL. Aggregate effects are the effects of an increased rate of use of DRL in a country, brought about, for example, by a law making the use of DRL mandatory.
2. The use of DRL reduces the number of multi-party daytime accidents for cars by about 5-15%. All studies that have evaluated the effects of using DRL for cars have found a reduction of the number of accidents, but the size of the estimated reduction varies from study to study.
3. Laws or campaigns designed to encourage the use of DRL for cars are associated with a 3-12% reduction in multi-party daytime accidents resulting in personal injury.
4. The use of DRL on motorcycles reduces the number of multi-party daytime accidents by about 32%. This estimate is highly uncertain and based on a single study only. Only three studies were found, but two of these studies were so poor that no confidence can be placed in their findings.
5. Laws or campaigns designed to encourage the use of DRL for motorcycles are associated with a 5-10% reduction in multi-party daytime accidents.
6. The robustness of the summary estimates of effect given above have been tested with respect to some potential sources of error in meta-analyses, including:
    a. Publication bias;
    b. Varying quality of the studies included;
    c. The statistical weights assigned to each estimate of effect; and
    d. The contribution of a single study to the overall estimate of effect.

In general, the summary estimates of effect were very robust. It is therefore concluded that the estimates of effect based on the meta-analysis are the best current estimates of the effects of DRL, given the evidence provided by the evaluation studies.

7. Various sources of variation in the effects of DRL for cars have been examined. It was concluded that:
    a. The effects of DRL are greater for fatal accidents than for injury accidents, and greater for injury accidents than for property-damage-only accidents. Evidence of effects for fatal accidents is, however, highly uncertain.
    b. The effects of DRL are likely to be greater at latitudes further away from the Equator than at latitudes close to the Equator. The evidence for such a relationship is, however, somewhat noisy.
    c. It is likely that DRL has a favourable effect on accidents involving pedestrians, cyclists or motorcyclists. An adverse effect on rear-end collisions has been found in studies of the aggregate effects of DRL. DRL combined with switched-off taillights can counteract this effect, as well as the use of high mounted brake lights.

2.3 WP 3 Investigation of (possible) adverse effects

Study on the conspicuity of vulnerable road users in the vicinity of DRL-vehicle

In this lab study (Brouwer et al., IR 3) subjects viewed colour slides depicting natural daylight scenes of traffic intersections. The slides contained a vehicle with or without DRL and possibly other road users such as a bicyclist, pedestrian or motorcyclist. Subjects were instructed to determine as fast as possible whether other road users were present or not. Search time was recorded. After each trial, subjects made a non-speeded classification indicating which other road user was present.
The effect of DRL on the conspicuity of other road users was investigated under various conditions, namely:

1. The expectancy of DRL (DRL-expectancy);
2. The expectancy of other road users (OR-expectancy);
3. The type of background;
4. The type of (other) road user; and
5. The distance between the other road user and the car.

In order to investigate the effect of expectancies about the presence of DRL (car with low beam headlights on) and the presence of other road users, the participants were assigned to one of four groups. The groups were based on the occurrence of slides with DRL and the presence of other road users (OR present/not present). Thus, the effect of expectancies was investigated between subjects. The other effects were investigated within subjects.

The main result of the study is that no evidence was found of a reduced conspicuity of road users in the vicinity of a DRL-vehicle. In fact, the evidence pointed in the opposite

direction – other road users actually benefitted from DRL -, although the effect was small. Apart from this, there were significant effects of OR-expectancy and of DRL on/off itself which were as expected, confirming the positive effects associated with them.
Although the overall effect of DRL on the conspicuity of road users was in the positive direction, this does not prevent a possible negative effect in specific situations. Inspection of the obtained significant interactions involving DRL, however, showed that such a negative effect did not occur. Therefore, it can be concluded that the absence of a negative effect on the conspicuity of other road users was a general phenomenon, at least over the range of situations studied in the experiment.

A similar absence of adverse effects was found with respect to driver visual capacities, as measured in elderly drivers by UFOV (useful field of view) and static visual acuity scores. Again, this was true both in an average sense and with respect to interactions that could have occurred in specific situations.

Environmental aspects of DRL

The following aspects of the environmental impact have been considered:
1. The effect of DRL on fuel consumption and CO_2 emission. For both aspects, an increase in the order of 0.5-1.5 % was estimated.
2. The effect on bulb lifespan, in comparison to corresponding effects of other in-vehicle electrical equipment. It was estimated that bulb replacement would be needed twice as frequently, resulting in € 6.00 extra cost per car per year.

3. Conclusions and recommendations

The results from the separate Workpackages appeared to converge to a degree that it was warranted to develop implementation regimes (in the form of policy options) for the EU. The following five policy options were investigated for the mandatory use of DRL in the European Union (Commandeur & Mathijssen, IR 4):
1. The use of DRL is required by all motor vehicles from a certain date. This is a simple behavioural measure, which does not include any new technical standards for vehicles. Drivers are simply required to turn on headlights at any time. This option will be referred to as the behavioural option.
2. The use of DRL is required by all motor vehicles from a certain date. In addition, new motor vehicles sold after the same date will be required to have an automatic switching-on of low beam headlights. This option will be referred to as the behavioural plus low beam option.
3. The use of DRL is required by all motor vehicles from a certain date. In addition, new cars sold after the same date will be required to have dedicated DRL that are switched on automatically. This option will be referred to as the behavioural plus dedicated DRL option.

4. New cars sold after a certain date are required to have an automatic switching-on of low beam headlights. Cars that do not have automatic DRL will not be required to turn on low beam headlights. This policy option will be referred to as the technical low beam option.
5. New cars sold after a certain date are required to have dedicated DRL that are turned on automatically. Cars that do not have dedicated DRL will not be required to turn on headlights. This policy option will be referred to as the technical dedicated DRL option.

A cost-benefit analysis was performed for each of these five options. The results are summarized in Table 1.

Table1. Results of cost-benefit analysis of five alternative DRL policy options.

	Alternative policy options				
Benefits and costs	**Behavioural measure**	**Behavioural + low beam**	**Behavioural + dedicated**	**Automatic low beam only**	**Automatic dedicated**
Benefits (negative amounts denote negative benefits – million Euro, present values)					
Accident reduction	47,076	49,430	49,430	38,355	38,355
Increased pollution	-12,619	-13,250	-10,252	-10,276	-6,371
Total benefit	34,458	36,181	39,178	28,059	31,964
Costs (million Euro, present values)					
Installation of automatic DRL	0	2,728	6,829	2,728	6,829
Fuel consumption	9,014	9,465	7,324	8,630	5,350
Light bulb consumption	8,562	8,990	8,562	8,436	8,436
Total costs	17,576	21,183	22,715	19,794	20,615
Ratio of benefits to costs					
Benefits/costs	1.96	1.71	1.72	1.42	1.55

For all five options, the benefits are clearly greater than the costs, but there are rather big differences between the C/B-rates of the various options.

The highest B/C-rate is that of option 1 (1.96), followed by options 2 and 3 (1.71 and 1.72, respectively). The B/C-rates for options 4 and 5 are substantially lower (1.42 and 1.55, respectively).
But the B/C-rate is not the only, and maybe not even the most important selection criterion, since the main goal of DRL implementation is road accident reduction. Another important criterion is the increase of pollution.
With regard to accident reduction, options 2 and 3 score better than option 1: an accident-related cost reduction of € 49,430 million for options 2 and 3, versus a reduction of € 47,076 million for option 1. With regard to pollution, option 3 is superior to options 1 and 2, the increased pollution of option 3 being 19% lower than that of option 1 and 23% lower than that of option 2.

Preferable policy option

The preferable policy option for DRL implementation is the technical measure of automatic dedicated DRL for new cars, combined with a behavioural measure requiring the mandatory use of low beams for existing cars. The light intensity of dedicated DRL is somewhere between the intensity of low beams and the intensity of parking lights. As a technical measure, automatic dedicated DRL are preferred above automatic low beams because dedicated DRL not only result in the highest accident reduction and the lowest increase in pollution (CO_2 emission), but also in the fairest distribution of road safety benefits over the various road user categories. For these reasons, the proposed technical measure of automatic dedicated DRL is expected to result in the highest level of public acceptance.
Defining the exact technical specifications of dedicated DRL, especially regarding light intensity, was outside the scope of this research project. It should be left over to technical specialists. The following features, however, are recommended:

- In order to prevent reduced conspicuity of unlit vehicles, the implementation of dedicated DRL on new cars should be accompanied or preceded by mandatory low beam DRL on all other motorized vehicles
- In order to prevent the possible 'masking' of brake lights, which might result in an increase of rear-end collisions, automatic dedicated DRL for headlights should be combined with switched-off taillights. This will also reduce pollution and bulb consumption.
- In order to prevent drivers from forgetting to switch-on low beams under reduced visibility conditions, automatic dedicated DRL should be combined with automatic low beam activation at a predetermined reduced level of ambient light intensity.
- In order to prevent flat batteries, both dedicated DRL and normal lights should automatically be switched on/off when starting/stopping the engine.

Implementation scenario

Since the use of DRL is controversial in some EU-countries, a gradual approach may be desirable in order to give people time to adjust to the changes and accept these as an improvement. In some countries with DRL legislation, the use of DRL was recommended before it became mandatory. In other countries, DRL was first required in winter before it became mandatory during the whole year. This implementation scenario is not feasible, though, if the *behavioural plus dedicated DRL policy option* is chosen. Another possible implementation scenario is to require automatic DRL for new cars first, and then after a while, require all cars to use it. This scenario option, however, is not very attractive since it would involve an unnecessary delay in the expected road safety benefits of DRL usage, especially if the technical part of the implementation cannot be realized within a reasonable time span. We therefore recommend to implement the behavioural part as soon as possible.

The most logical starting point for mandatory low beam DRL use is somewhere between the beginning of autumn and the beginning of winter. During a preceding period of one year maximum, it might be advisable to only recommend low beam DRL in order to allow people to adjust to the new situation and accept DRL as an improvement. This might especially be advisable in EU countries that currently have a very low degree of voluntary DRL use.

Publicity campaigns

The introduction of recommended DRL should be preceded and accompanied by a large-scale publicity campaign on TV, radio and in the newspapers, emphasizing the importance of contrast in aiding visual perception and the resulting road safety benefits. The campaign should also meet the arguments that pedestrians and two-wheeled road users would not benefit from DRL. And, finally, the campaign should stress that these road user categories will benefit even more as increasing numbers of new cars equipped with dedicated DRL emerge on the roads.
Another important element of the publicity campaign should be the placing of billboards along main roads, reminding drivers and motorized riders of recommended/mandatory low beam DRL use.