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THE EFFECTIVENESS OF DAYTIME RUNNING LIGHTS TO REDUCE CRASHES AND CRASH INJURIES

Fredrick M. Streff, Ph.D.

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16. Abstract

While studies of the effects of daytime running lights (DRLs) on crash outcomes have generally been lacking in experimental rigor and power necessary to specify the magnitude of the safety effect DRLs create, they are consistent in finding that DRLs have a positive effect on traffic safety. Statistically significant DRL effects found in a study of DRL implementation in a large Canadian vehicle fleet were applied to data representing the totality of U.S. crash experience for 1989. Based on these analyses, DRL implementation could be expected to prevent between 200,744 and 380,845 property-damage crashes, 98,839 to 209,052 personal-injury crashes, 165,673 to 335,630 nonfatal injuries, 42 to 3,129 fatal crashes, and 396 to 4,542 deaths each year. These ranges are based on the 95% confidence limit around the high and low reduction estimates.

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TABLE OF CONTENTS

LIST OF TABLES

Background

There is a growing literature on the effectiveness of daytime running lights for preventing crashes and crash injuries. It is important to evaluate this literature critically to assess the potential of daytime running lights (DRL) for preventing crashes and crash injuries. Toward this end, this project was designed to achieve the following objectives:

- Collect all major studies performed during the past 20 years which assess DRL effectiveness.
- Develop an independent assessment of DRL effectiveness based on a review of the literature, including a definition of the population of crashes to which DRL effectiveness estimates would apply.
- Apply the DRL-effectiveness value obtained in the prior objective to published U.S. crash statistics to obtain an estimate of the annual number of crashes, injuries, and fatalities that could be prevented if all vehicles in the U.S. were equipped with DRLs.

Review and Critique of DRL Effectiveness Literature

Although the principal goal of this project is to critically review studies of DRL effectiveness conducted in the past 20 years, notable studies conducted earlier are reviewed briefly. Perhaps the first review of the effects of DRLs on crash outcomes was published in 1964 by Allen and Clark. In this paper (the principal focus of which was a study of the effects of running lights on vehicle conspicuity), the authors described an unpublished report on the effect of Greyhound busses operating with the headlights on at all times. Allen and Clark report that the use of headlights at all times was responsible for a 7% to 15.7% reduction in daylight crashes, and that "sideswipe type accidents appear to show the most substantial decrease" (p. 2). Because the report in Allen and Clark was based on interoffice correspondence within Greyhound, there is no firm basis on which to assess the credibility of the study. However, from the available evidence this study seems to have been conducted with no experimental control. Thus, these results should be viewed with great caution.

Cantilli (1968, 1969, 1970) describes the results of a study of a DRL system used by the Port of New York Authority. This study compared the crash experience of approximately 200 vehicles in which parking lights and taillights turned on automatically with the ignition to the crash experience of about 400 unmodified vehicles over a 12-month period. Of these vehicles, 120.5 were passenger vehicles equipped with the DRL system, 242.5 were passenger vehicles not so equipped, 70.5 were light or heavy trucks equipped with the DRL system, and 134 were light or heavy trucks not so equipped[1].

The results of this study are based on a relatively small sample of crashes (72 crashes were reported during the experimental period of 12 months). Crashes included in the study were those occurring during daylight, dusk, or dawn. Backing or sideswipe collisions caused by a Port Authority vehicle were not included, nor were fixed object crashes, crashes involving objects lying in the roadway and flying objects, roll-over crashes, crashes in which the vehicle ran off the roadway, and crashes where a Port Authority vehicle struck another vehicle in the rear.

The author reports the overall crash rate per million vehicle miles of travel (VMT) was 18% lower for the DRL-equipped (parking light and taillight on with ignition) group of all vehicles, and that the DRL-equipped passenger-vehicle experience showed a 23% lower crash rate. While the author states "By t-test for statistical significance, these rates show a significant difference" (Cantilli, 1970; p. 4), it is unclear what differences were tested or how they were tested. This study also shows that the effect of the DRLs was most pronounced in rear-end crashes, and in black DRL-equipped cars (no differences were found in yellow DRL-equipped cars). Strangely, the author reports an unspecified increase in the "sideswipe" crash rate. Note, however, the majority of vehicles used in this study were not equipped with "wrap-around" or side-mounted parking lights. This explanation is offered as one reason for the lack of a decline in sideswipe crashes. No explanation is forthcoming for the observed increase in sideswipe crashes.

Cantilli's research suggests that DRLs may be effective in reducing crashes. However, much of the observed change was in rear-end crashes (which more recent studies have shown are affected by the center-high-mounted-brake light currently standard on new vehicles). Thus, it is unclear how these results may generalize to modern vehicles. A second caveat to these findings is that only the black DRL cars exhibited a positive DRL-related safety effect. Third, it is unclear if the driving experience of Port Authority vehicles was similar to that of the average driving population. Fourth, the number of crashes examined in this study was also quite small, raising further concern over the validity of the results. All-in-all, this study lends little support to the contention that DRLs are effective in preventing crashes, and provides little on which to base an estimated DRL-related crash-preventative effect. On the other hand, these results are not

[1]The exact number of vehicles used in the study varied during the experimental period, so the author reported average numbers of vehicles equipped (thus the strange half vehicle reports).

contrary to the hypothesis that DRLs are effective in preventing some crashes among some vehicles.

A study of the effects of efforts to promote daytime use of low-beam headlights during winter months in Finland was conducted by Andersson, Nilsson, and Salusjärvi (1976). In the late 1960s a variety of traffic safety and road organizations in Finland campaigned for the use of lights, particularly in the winter months. In October 1970, the Finnish Ministry of Transport issued a recommendation to all drivers of motor vehicles to use their low-beam headlights during daylight hours when traveling outside urban areas. This recommendation was in force throughout the winters of 1970-71 and 1971-72. In November 1972, the use of low-beam headlights was made mandatory outside urban areas during the period November through March by the Ministry of Transport. This regulation was extended the following year to include September and October, and in 1975 the regulation was expanded again to include April.

Finnish police assessed the frequency of vehicle lighting use during daylight hours. These assessments found that during the "baseline" period in which various traffic safety organizations campaigned for DRL use (winters of 1968-69 and 1969-70), DRL use ranged between 40% and 70%. During the period covered by the Ministry of Transport recommendation for DRL use (winters of 1970-71 and 1971-72), use averaged 87.3%, and during the period where DRL use was made compulsory by the Ministry of Transport (winters of 1972-73 and 1973-74), DRL use averaged 96.7%.

The analysis of Finnish crash data focused on the following ratio[2]:

$$\delta = \frac{mcday/mcdark}{scday/scdark}$$

The term "multiple crashes" was used to refer to crashes involving multiple motor vehicles, motor vehicles and pedestrians, cyclists, or moped riders, and motor vehicles and animals. This ratio was calculated as an attempt to partially control for influences on crash outcomes other than the DRL recommendation and mandate which could not be controlled for experimentally (e.g., a decrease in speed limits due to the 1973-74 energy crisis and differential weather between

[2] mcday = number of multiple crashes in daylight
mcdark = number of multiple crashes in darkness
scday = number of single crashes in daylight
scdark = number of single crashes in darkness

experimental periods). This ratio falls from 2.23 during the baseline period to 1.88 during the DRL recommendation period, and to 1.76 during the mandatory DRL use period. Using this "standardized ratio," daylight multiple crashes were said to have declined by 15% between baseline and the DRL recommendation period, and by 21% between the baseline and mandatory DRL use period.

The authors also examined effects of the DRL regulations on specific multiple vehicle crash configurations (i.e., crashes involving motor vehicles from opposing, crossing, and the same direction). They found that crashes involving motor vehicles in opposing directions declined by 28% from the baseline to the mandatory DRL use period. Crashes involving motor vehicles from crossing directions declined 17%, but crashes with motor vehicles travelling in the same direction increased 9%.

This review is based on an English translation of the project summary in the original paper. With the exception of the translation of the project summary, the remainder of the paper is written in Swedish. The lack of a readily available translation of the entire manuscript made a complete critique impossible. However, the Finnish experience with a DRL mandate effective only during winter months and only on rural roads is of little value in assessing potential effects of full-time DRL implementation in the U.S. A more recent analysis of a full-time Swedish law effective on all roads (conducted by the same research team using similar methods, and written in English) serves to highlight many of the strengths and weaknesses of the study of the Finnish experience.

Andersson and Nilsson (1981) examined the effects of a Swedish law mandating use of low-beam headlights or "special" auxiliary running lights during daytime hours. Effective October 1, 1977, all cars and motorcycles in Sweden were to be driven with their low-beam headlights or special DRLs illuminated during daylight hours. Unlike the law in Finland which was in effect only during the winter months and in rural areas, the Swedish law had no time or area restrictions.

Use of lights in daylight hours was observed by the Swedish Road Safety Office and the National Swedish Road and Traffic Research Institute. Before the law went into effect 50%-60% of vehicles observed in winter months had their lights on (in daylight hours, on clear days), and 25%-30% of vehicles observed in summer months used their lights during daylight hours in clear weather. When the law went into effect October 1, 1977, use increased to nearly 100%. No increase in daytime light use was reported in the months approaching the October 1 effective date. The authors report that close to 30% of all passenger cars were equipped with some kind of special DRL by the first year of the law. Based on the description in the report, these special DRLs seem to be most similar to parking lights in their size and permissible placement on the vehicle.

Data on the effects of the Swedish law on crashes is based on police-reported personal-injury crashes during the period from October 1975 through September 1979, yielding two years of data prior to and following implementation of the law. The basic assumption of the analysis is that the use of DRLs affects only the number of multiple crashes (i.e., crashes involving two or more road users) in daylight conditions, and that single-car crashes as well as the number of crashes occurring in darkness should be unaffected by changes in DRL use. To determine the selective effects of DRLs on daytime crashes, the authors use the δ-ratio described earlier. The authors point out, however, that it is improper to assume that selective effects (if found) are caused by the law because other factors with selective effects may have changed, and factors other than the DRL law may affect crashes differentially.

Based on the analyses, an 11% decrease in multiple vehicle crashes in daylight (MVD crashes) resulting in injury was estimated to be associated with the DRL law. Using the maximum-likelihood ratio test, this estimate was not statistically significant at the $p<.05$ level. However, the authors report that the estimated change was of the magnitude expected, and that the insignificant statistical results may have been due to insufficient sample size. Similar findings were reported for specific crash subgroups. The authors report a 10% decline in MVD injury crashes involving vehicles in opposing directions, a 9% decline in MVD injury crashes involving vehicles in crossing directions, and a 2% decline in MVD coincident direction crashes. As was the case in the overall reduction, none of these results was found to be statistically significant.

Some have questioned the conclusion from this study--that DRLs are effective in reducing daytime crashes--on primarily statistical grounds (e.g., Perel, 1988; Theeuwes and Riemersma, 1990). While these critiques are well founded, it is unnecessary to detail them here. Because of the lack of statistically significant results, the Andersson and Nilsson study is at best only suggestive of a positive DRL safety effect. It is by no means a conclusive study. In addition to the statistical critique, the study of Sweden's DRL law may not be indicative of the magnitude of effects that may be found in the U.S.

Some suggest that positive effects of DRLs on crash outcomes in Sweden or Finland may be higher than would be expected in the U.S. because of differences in climatic and ambient sunlight conditions. Specifically, the countries of Sweden and Finland are in higher latitudes than the U.S. Thus, there are often lower levels of ambient sunlight available for a greater proportion of the day in Scandinavian countries than would typically be found in the U.S. in winter. Because of these differences, DRLs may not produce as pronounced a detection cue in the U.S. as would be produced in Scandinavian countries. Continuing this logic, a smaller crash reduction potential would be achieved by the smaller increase in vehicle conspicuity. However, two notable studies examining the effects of DRLs on crash outcomes have been conducted in Canada and the U.S.

Stein (1985) examined the experience of three fleets totalling 2,000 vehicles (cars, vans, and pickup trucks) equipped with DRLs in the U.S. The type of DRL used was a parking light with a special bulb providing a maximum intensity of about 150-250 cd that came on with the ignition. One fleet included more than 1,700 cars and vans in Connecticut. Vehicles were randomly assigned to be equipped with the high-intensity parking lights. In this fleet, taillights were not included in the DRL system because of a concurrent study of center high-mounted brake lights. A second fleet included more than 1,500 vehicles (mostly cars and some pickup trucks) operating in the southwestern U.S. (including Texas, Oklahoma, Kansas, Colorado, Louisiana, and Mississippi). Selected vehicles were equipped with DRLs including both high-intensity parking lights and normal intensity taillights that operated automatically with the ignition. Vehicles were not randomly assigned to DRL condition in the third fleet. In this fleet (consisting of about 1,400 vehicles), vehicles from the marketing division of Dow Chemical USA were assigned to the DRL condition (high-intensity parking lights and normal intensity taillight), while the control vehicles came from the Merrell-Dow Pharmaceuticals division of Dow Chemical USA. These two divisions operated vehicles throughout the U.S. Stein notes that the driving experience of the Merrell-Dow control fleet differed somewhat from the Dow Chemical marketing fleet because the Merrell-Dow fleet was used more in urban areas.

Twenty-four months of crash data were gathered for the Connecticut fleet, five months of crash data were collected for the southwest U.S. fleet, and 15 months of crash data were collected for the Dow Chemical USA fleet. For the purposes of analysis, DRL-relevant crashes were broadly defined as any multiple-vehicle crash that occurred during daylight (including dusk and dawn) hours. All types of crash configurations (e.g., angle, head-on, sideswipe, rear-end) were included regardless of which driver may have been at fault. Collisions in which a study vehicle struck the rear end of another vehicle were not included because such collisions should not be affected by DRLs. These collisions as well as all nighttime multiple-vehicle crashes were categorized as non-DRL-relevant, and were used as a control group for analyses. For the Connecticut fleet, crashes in which the study vehicle was struck in the rear end were considered to be non-DRL-relevant, and were also included in the control group of crashes because these vehicles were not equipped with taillight DRL equipment. Single-vehicle crashes and collisions involving any parked vehicles were excluded from all analyses.

Multiple-vehicle daytime (MVD) crash experience of the experimental and control groups was compared. A total of 355 MVD crashes occurred to the fleet during the periods studied (186 involving control vehicles, 169 involving DRL-equipped vehicles). DRL-equipped vehicles were involved in 7% fewer DRL-relevant crashes than their control cohorts. When examining the crash experience of cars, the DRL-equipped vehicles were involved in 5% fewer crashes, and DRL-equipped vans and pickups were involved in 8% fewer DRL-relevant crashes. Although the statistical procedure used to calculate the statistical significance of these differences was not described, none of these differences were reported to be statistically significant.

Confidence in these results is further diminished by the lack of random assignment to DRL-condition in approximately one-third of the vehicles studied. Stein notes that there were differences in the type of travel experienced by the experimental and control groups in the Dow Chemical fleet. Results suggesting a positive safety effect from DRL installation may have been produced in part by these differences. Thus, while the Stein (1985) study provides further support for the hypothesis that DRLs are effective in reducing multiple-vehicle daytime crashes, results are far from conclusive on the magnitude of such effects.

The most recent study of the effectiveness of DRLs for preventing crashes was conducted in Saskatchewan, Canada by Sparks, Neudorf, and Smith (1989). This study examined the crash experience of vehicles operated by the Provincial Central Vehicle Agency (CVA). Approximately 4,000 vehicles were equipped with a system that operated the low-beam headlights and parking lights with the ignition. Six years of fleet crash experience prior to the DRL installation was compared with two years of post-installation crash data. Only crashes with property damage costs of at least $500 were included in the study because this threshold had to be reached in order for a crash to be considered reportable (thus available for data analysis).

Crash data were segregated into categories representing single-vehicle crashes, multiple-vehicle crashes that occurred during darkness, and multiple-vehicle crashes that occurred during daylight. The subset of multiple-vehicle crashes occurring during daylight (MVD crashes) were further divided into categories based on injury severity and crash configuration. MVD crashes were separated into three crash severity categories: property-damage, personal injury, and fatal. MVD crashes were also divided into categories describing the crash configuration (i.e., rear-end, right angle, head-on, sideswipe, and other). Right-angle and head-on crashes were classified as

DRL-relevant crashes because it was believed that the use of DRLs would affect only these crash configurations. All other crash configurations were classified as non-DRL-relevant.

The authors examined the statistical significance of differences in the mean number of crashes that occurred in the six years prior to DRL-installation and the mean number of crashes that occurred in the two post-installation years. These tests found significantly fewer MVD crashes in the post-implementation period (11.6% fewer, $p<.05$), fewer MVD property damage crashes (10.1% fewer, $p<.05$), fewer MVD personal injury crashes (16.9% fewer, $p<.05$), and fewer "DRL-relevant" crashes (i.e., right-angle, head-on; 25.1% fewer, $p<.05$). While the estimated decline for fatal crashes approached statistical significance (75% fewer, $p<.07$), the percentage decline is based on a very small sample of crashes (an average of two per year in the pre-implementation phase and 0.5 per year in the post-implementation phase). This estimated decline in fatal crashes associated with DRL-installation is much higher than one would reasonably anticipate.

No significant differences were detected for MVD "non-DRL-relevant" crashes (i.e., rear-end, sideswipe, and other configurations), or for non-MVD crashes (i.e., single-vehicle or multiple-vehicle darkness crashes). Not only were the statistical tests nonsignificant for these groups, but the percent change from the pre-installation period approached zero (0.7% fewer MVD non-DRL relevant, and 0.3% fewer non-MVD crashes). The lack of any effects on these control conditions supports the contention that it was the DRL installation that caused the observed declines in MVD crashes and MVD subgroups. However, there was no control group of vehicles in which no DRL system was installed. Thus, the finding of significant decreases in MVD crashes and no such changes in MVD non-DRL relevant crashes or non-MVD crashes could be ascribed to some unknown factor or factors that affected only the MVD crashes and MVD subgroups. Although possible, this is unlikely, and there is no evidence to support such a conclusion.

This study also failed to examine the culpability of vehicles with respect to the causes of a crash. Thus, a DRL-equipped vehicle may have been responsible for causing a crash that may have otherwise been averted. These crashes should have been classified as non-DRL-related or omitted entirely, but they were not. The net result of these misclassifications is to reduce the apparent efficacy of DRLs by including crashes that could not have been prevented by DRL use.

Table 1 on the following pages briefly reviews the studies described in this report. Several other studies examining effects of DRLs on crash outcomes have been conducted over the last 20 years. In general, these other studies were of such small scope or used such poor experimental designs that they are available only in the "phantom press." These studies are described in a variety of literature reviews found in other DRL reports (e.g., Allen, 1979; Attwood, 1981; Kirkpatrick, Baker, and Heasley, 1987; Sparks, Neudorf, and Smith, 1989). Because only second-source reviews of these studies are readily available (and the studies are of limited utility to this project), they will not be discussed and are not included in Table 1. These reports consistently describe positive safety effects resulting from DRL implementation (these effects generally were not statistically significant or statistical significance was not calculated).

Because of the small number of studies available and the differences in DRL systems tested, a quantitative review (meta-analysis) of DRL effects is not practical. Based on the qualitative review, it is highly probable that daytime running lights are effective in reducing the occurrence of multiple-vehicle daytime crashes. All of the studies examined found positive safety effects associated with DRL use, and these effects were generally within a range of 7%-25% reductions in crashes. Unfortunately, limited sample sizes, different DRL system implementations, differences in ambient lighting and other environmental conditions, differences in relevant crash definitions, and poor experimental control make estimating a general DRL effect to apply to U.S. crash data quite difficult.

The best estimate of how DRL implementation in the U.S. would affect crashes and crash outcomes is derived from the Canadian experience described in Sparks, Neudorf, and Smith (1989). Although Canada is still somewhat north of much of the U.S., Canada is closer to the U.S. latitudes than are the Scandinavian countries. The Sparks et al. study was reasonably well controlled, and a sufficient amount of crash experience was studied to detect and estimate statistically significant differences. The Sparks et al. study was also the only study to examine separately DRL effects on property damage, personal injury, and fatal crashes, in addition to specific "DRL-relevant" crash configurations.

Table 1. Summary of DRL Crash Effect Studies

Author	Report Date	Location	Methods	Vehicle Type	Fleet Size	DRL Type	Results
Sparks, Neudorf, & Smith	Jan. 1989	Saskatchewan, Canada	Before - After 1980-1985 -- Before 1986-1987 -- After	Central Vehicle Agency (CVA) Fleet	4000 vehicles	Low-beam headlights and parking lights (automatic with ignition on)	• 11.6% fewer multiple-vehicle daylight (MVD) crashes ($p<.05$) • 10.1% fewer MVD Property Damage crashes ($p<.05$) • 16.9% fewer MVD Personal Injury crashes ($p<.05$) • 75% fewer MVD Fatal crashes ($p<.07$) • 25.1% fewer 'DRL Affected' (Right angle, Head-on) MVD crashes ($p<.05$) • no difference in 'Non-DRL Affected' MVD crashes • no difference in single-vehicle or multiple-vehicle darkness crashes
Stein	1985	USA	Concurrent Control Group - 9 to 15 months of exposure	3 vehicle fleets - passenger cars, vans, and pick-up trucks	2000 vehicles	Higher intensity front parking lights and rear parking lights (automatic with ignition on)	Passenger Cars: • 20% fewer crashes (overall) in DRL equipped vehicles • 25% fewer DRL-relevant (MVD) crashes in DRL equipped crashes • 7% reduction in DRL relevant (MVD) crashes as proportion of total crash number Vans and Pick-up Trucks: • 18% fewer crashes (overall) in DRL equipped vehicles • 25% fewer DRL-relevant (MVD) crashes in DRL equipped crashes • 7% reduction in DRL relevant (MVD) crashes as proportion of total crash number All Vehicles: • 20% fewer crashes (overall) in DRL equipped vehicles • 22% fewer DRL-relevant (MVD) crashes in DRL equipped crashes • 8% reduction in DRL relevant (MVD) crashes as proportion of total crash number (No differences were statistically significant $p<.05$)

Author	Report Date	Location	Methods	Vehicle Type	Fleet Size	DRL Type	Results
Andersson & Nilsson	1981	Sweden	Before - After 10/1975-9/1977 -- Before 10/1977-9/1979 -- After	All Vehicles	All vehicles in Sweden	Compulsory use of low-beam headlights or auxiliary DRL	• 50% DRL use before law to 95% DRL use after law • 11% fewer MVD injury crashes • 10% fewer MVD-opposing direction injury crashes • 9% fewer MVD-crossing direction injury crashes • 2% fewer MVD-coincident direction injury crashes • 21% fewer daylight crashes involving mopeds and bicycles and motor vehicles • 17% fewer daylight crashes involving pedestrians and motor vehicles (No differences were statistically significant p<.05)
Andersson, Nilsson & Salusjarvi	1976	Finland	Before - After 7/1968-6/70 -- Publicity 7/1970-6/72 -- DRL Use Recommended 7/1972-6/74 -- DRL Use Mandated (Winter months only)	All Vehicles	All vehicles in Finland	Low-beam headlights	• 40-70% DRL use 7/1968-6/70, 87.3% DRL use 7/1970-6/72, 96.7% DRL use 7/1972-6/74 • 15% fewer MVD crashes from publicity to recommended use period • 21% fewer MVD crashes from publicity to mandated use period (Statistical significance not calculated)
Cantilli	1970	New York - USA	Concurrent control group - 12 months of experience	Autos and Trucks	191 DRL 377 control	Parking lights and taillights (automatic with ignition on)	• 18% lower MVD crash rate per million miles traveled for DRL equipped vehicles across all vehicle types • 23% lower MVD crash rate per million miles traveled for DRL equipped vehicles for passenger vehicles (Tests of statistical significance inadequately described to evaluate, no significance tests described in original 1968 report or 1969 article describing results)
Allen & Clark	1964	USA and Canada	Before - After	Busses	- NA -	Headlights	• 7% to 15.7% fewer daytime crashes (depending on fleet examined; no information on statistical significance)

Estimated Effects of DRL Implementation in the U.S.

Crash Types Affected by DRL Use

A better definition of what crashes might be affected by DRL implementation is needed before analyzing possible effects of DRL implementation on U.S. crash experience. Regardless of the type of DRL system deployed, only crashes that occur in daylight, dusk, and dawn will be affected. DRLs should also affect only multiple traffic-unit crashes. DRLs enhance vehicle conspicuity and signal vehicle presence to other traffic units that can actively respond to avoid collisions, including pedestrians and bicyclists. There is no basis to expect that single traffic-unit crashes would be affected by DRL use. There is divergent theory and research evidence, however, on the types of crash configurations that may be affected by DRL use.

DRLs theoretically affect crash outcomes through their effect on vehicle conspicuity. Thus, they should only affect crash configurations in which the signalling of vehicle presence is enhanced by the lights. These crash configurations should be determined in large part by the configuration of the DRL system. DRL systems that have been tested have generally fit into one of three basic categories: (1) low-beam (or reduced-intensity low-beam) headlights with front and rear parking lights, (2) front and rear parking lights (or similar light) systems, and (3) front parking lights (or similar light systems). If the DRL employs only frontal parking lights, one would expect that the principal effects would be in frontal collisions and perhaps some angular collisions. The reduction in angle collisions would be mediated by the luminance and maximum angle at which the parking and side-marker lights could be observed. DRL systems that employ parking lights in both the front and rear of the vehicle might be expected to reduce the number and severity of most crash configurations because the lights could be seen from nearly every angle. However, the effects should be most pronounced in the angles closest to the front and rear of the vehicle. Evidence from the Sparks et al. (1989) study suggests this may be an optimistic appraisal. Recall that Sparks et al. found a significant decrease in right-angle and head-on MVD crashes, but no change in sideswipe, rear-end, and other MVD crashes. Rear-end collisions may not be significantly affected by rear DRLs because of the safety effects produced by the center high-mounted stop lights (CHMSL). That is, rear running lights may produce little additional safety effect when used in combination with the CHMSL system. Note that over 65% of all rear-end collisions occur with a stopped vehicle, and an additional 15% with a decelerating vehicle (1989 GES data). Both of these crash configurations would probably include vehicles in which the CHMSL light was activated (although some of the decelerating vehicles may not be using their brakes and some vehicles may not be CHMSL equipped). Inclusion of low-beam or reduced-intensity low-beam headlights will likely affect the distance at which a vehicle may be detected from the front. These lights are typically brighter than the parking lights and thus extend the signalling distance of the vehicle, affecting the magnitude of expected effects.

Selection of Crash Reduction Estimates

Estimated effects of DRL implementation in the U.S. are based on effects described in the Sparks et al. (1989) study of the Saskatchewan, Canada Provincial Central Vehicle Agency fleet. For several reasons, the results from this study were selected to represent the closest approximation to possible effects of DRL implementation in the U.S. First, the Canadian experience most closely approximates the climatic conditions encountered in the U.S. Although it would be better to have data on DRL effects from a study actually conducted in the U.S., the only well controlled study of DRL effects in the U.S. was conducted with a fleet with insufficient crash experience to find statistically significant DRL effects (Stein, 1985). Thus, parameter estimates based on this study are insufficiently exact to form a foundation for an estimate of nationwide DRL-implementation effects.

Second, the Sparks et al. study was well controlled and sufficient crash experience was observed to detect statistically significant effects. This study also examined a variety of crash outcome measures increasing confidence that the effects were due to DRL implementation and not to another spurious factor. The Sparks et al. study was also the only study to examine independently effects of DRL implementation on property damage, personal injury, and fatal crashes. It is desirable to have specific effects for different crash outcome severities when attempting to estimate specific changes in crash outcomes due to possible U.S. DRL implementation. The use of multiple crash effect measures also permits a variety of analyses to be conducted to generate a range of possible effects for U.S. DRL implementation.

Data Analysis Methods

Findings of the safety effects from Sparks et al. were applied to the U.S crash experience using the 1989 NASS-GES (National Accident Sampling System - General Estimates System) crash data file established by the U.S. Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis. The GES obtains its data from a nationally representative probability sample selected from the estimated 6.6 million police-reported crashes that occur each year. These crashes include those resulting in a death or injury, and those involving "major property damage" (NASS-GES User's Manual, p. 1). In 1989, the GES obtained a sample of approximately 44,000 police crash reports. Because the GES data are from a probability sample of police-reported traffic crashes, national estimates can be made from these data. In order to calculate estimates of national-level crash characteristics, data from each crash report in the file were weighted to the national level.

GES crash data were filtered to ensure that crash configurations unlikely to be affected by DRL implementation were not included in DRL crash reduction effect estimates. Thus, only cases that occurred during daylight, dusk, or dawn (V28: 1,4-6; UMTRI NASS-GES Codebook, 1989), involving multiple traffic units (V7: 02-07), and involving collisions with motor vehicles in transport, bicycles, and pedestrians (V15: 21,22,25) were included to describe multiple-vehicle daytime (MVD) crashes in general. This definition excluded crashes occurring in darkness, those involving single-traffic units, crashes with fixed objects or noncollision events (e.g., rollovers), crashes with trains, animals, or parked motor vehicles, and cases with unknown configurations. The MVD definition also excluded cases involving pedestrian or bicycle crashes with motor vehicles in which the motor vehicle was principally responsible for the crash or the nonmotorist would probably not have been assisted by DRLs on the collision vehicle (these cases should not be affected by DRL use among motor vehicles; V31: 0008-0017,0022-0024,0027,0033-0041,0220,0620,0740,0760,1220). Additional filters were used to screen cases for the "DRL-related" crash analyses. Sparks et al. described these cases as right-angle and head-on MVD collisions. For the GES analyses, only cases of head-on and angle collision were included (V16: 2,4). Crash-level injury classifications were based on the maximum known injury severity in the crash (V32). Vehicle occupant and nonmotorist (i.e., pedestrian and bicyclist) injury frequencies were calculated with the appropriate occupant-level or nonmotorist-level data (V208 and V308 respectively).

Possible benefits from DRL implementation to the U.S. crash experience were calculated based on three estimates of DRL effects. First, the 11.6% reduction in overall multiple-vehicle daylight (MVD) crashes was applied to the GES data. Based on GES data we estimated the number of property-damage, personal injury, and fatal crashes, and the number of occupant and nonmotorist (i.e., bicyclist and pedestrian) injuries and deaths that could be prevented if there was an 11.6% reduction in MVD crashes. Second, the 25.1% reduction in DRL-related crashes (i.e., angle and head-on MVD crashes) was applied to relevant GES crash data, and effects once again segregated into property-damage, personal-injury, and fatal crashes, as well as injury and death frequencies. Finally, the 10.1% reduction in property-damage MVD crashes and the 16.9% reduction in personal injury MVD crashes were applied to relevant GES crash data to estimate crash and injury reductions. Because the 75% reduction for fatal MVD crashes found by Sparks et al. is probably an overestimate, the 16.9% reduction figure from personal-injury MVD crashes is applied to estimate the effects of DRLs on fatal MVD crashes and deaths.

Results

As expected, the analyses estimating effects of DRL implementation in the U.S. generated a range of effects on crash and injury outcomes. Table 2 describes the subset of crashes from the 1989 GES data that met the criteria for multiple-vehicle daylight (MVD) crashes described earlier. Table 3 describes the subset of crashes from the 1989 GES data that met the criteria for DRL-related MVD crashes. In Tables 2-6, the "crashes" row refers to the number of crashes for a given category, the "occupants" row refers to the number of vehicle occupants injured or killed in crashes for a given category, and the "nonmotorists" row refers to the number of pedestrians or bicyclists injured or killed in crashes for a given category. Results from the application of the Sparks et al. crash reduction estimates to the 1989 GES data are organized by crash severity (i.e., effects on property-damage, personal-injury, and fatal crashes).

Table 2. MVD Crashes 1989 GES Data

	Property Damage	Personal Injury	Fatal	Total
Crashes	2,384,594	1,051,948	11,715	3,448,257
Occupants		1,710,806	13,568	
Nonmotorists		3,148	29	
Total Injuries		1,713,954	13,597	

Table 3. DRL-Related MVD Crashes 1989 GES Data

	Property Damage	Personal Injury	Fatal	Total
Crashes	1,309,925	613,310	10,078	1,933,313
Occupants		1,041,492	11,580	
Nonmotorists		880	0	
Total Injuries		1,042,372	11,580	

Table 4 describes the results of the analyses on property-damage crashes. According to the GES data, about 2 million property-damage crashes occurred in the U.S. in 1989. Because the GES system is based on a sample of crashes, standard errors and 95% confidence bands can be calculated around estimates generated from the crash data. In the case of property-damage crashes, the GES data show that there were 2,384,594 MVD property-damage crashes with a 95% confidence band of ±317,365, and 1,309,925 DRL-related MVD crashes with a 95% confidence band of ±178,887 in the U.S. in 1989. Table 4 shows that about 241,000 to 329,000 property-damage crashes might be prevented each year by DRL implementation in the U.S. When the

95% confidence band is calculated for these crash data, the range is 200,744 to 380,845 property-damage crashes that might be prevented annually by DRL implementation in the U.S.

Table 4. Estimated Reduction in Property-damage Crashes due to DRL Implementation			
	10.1% decrease in MVD-Property-damage crashes	11.6% decrease in MVD crashes	25.1% decrease in DRL-related MVD crashes
Crashes	240,844	276,613	328,791

Analyses of personal injury data are described in Table 5. In 1989, there were 1,051,948±145,818 MVD personal-injury crashes resulting in 1,713,954±246,801 nonfatal injuries. In the same year, there were 613,310±89,503 DRL-related MVD crashes resulting in 1,042,372±150,710 nonfatal injuries. Table 5 shows that about 122,000 to 178,000 personal-injury crashes might be prevented annually by DRL implementation, preventing from 199,000 to 290,000 nonfatal injuries each year. When the 95% confidence band is calculated for these reductions, the range is 98,839 to 209,052 personal-injury crashes and 165,673 to 335,630 nonfatal injuries that might be prevented annually by DRL implementation in the U.S.

Table 5. Estimated Reduction in Personal-injury Crashes and Injuries due to DRL Implementation			
	11.6% decrease in MVD crashes	16.9% decrease in MVD-Inj. crashes	25.1% decrease in DRL-related MVD crashes
Crashes	122,026	177,779	153,941
Occupants	198,453	289,126	261,415
Nonmotorists	365	532	221
Total Injuries	198,819	289,658	261,635

Analyses of fatality data are described in Table 6. In 1989, there were 11,715±4,486 MVD fatal crashes resulting in 13,597±4,892 deaths. In the same year, there were 10,078±4,133 DRL-related MVD fatal crashes resulting in 11,580±4,457 deaths[3]. Table 6 shows that about 1,400 to 2,500 fatal crashes might be prevented each year by DRL implementation, preventing from 1,600 to 2,900 deaths annually. When the 95% confidence band is calculated for these

[3]The fatal crash and fatality frequencies generated from the 1989 GES data are quite similar to data generated from the 1989 Fatal Accident Reporting System (FARS) data using the same filters. FARS is a census of all fatal crashes occurring in the U.S. In 1989, FARS recorded 10,177 fatal crashes resulting in 12,010 deaths in MVD crashes, and 8,680 fatal crashes resulting in 10,309 deaths in DRL-related MVD crashes.

reductions, the range is 42 to 3,129 fatal crashes and 396 to 4,542 deaths that might be prevented each year by DRL implementation in the U.S.

Table 6. Estimated Reduction in Fatal Crashes and Deaths due to DRL Implementation			
	11.6% decrease in MVD crashes	16.9% decrease in MVD-Inj. crashes	25.1% decrease in DRL-related MVD crashes
Crashes	1,359	1,980	2,529
Occupants	1,574	2,293	2,907
Nonmotorists	3	5	0
Total Injuries	1,577	2,298	2,907

Discussion

While studies of the effects of DRLs on crash outcomes have generally been lacking in experimental rigor and power necessary to specify the magnitude of the safety effect DRLs create, they are consistent in finding that DRLs have a positive effect on traffic safety. No study was found to have a result which indicated that DRLs have a negative effect on safety (i.e., caused more crashes than they prevented). However, most were ambiguous with respect to the crash reduction potential of DRL implementation and use. The notable exception to this trend was the Sparks et al. (1989) study. Sparks et al. found statistically significant reductions in crashes and injuries associated with DRL installation in a large fleet of vehicles in Canada.

Because the Sparks et al. study examined the effects of a DRL system that employed both low-beam headlights and parking lights in the front and rear of vehicles, it is likely that the results of the study represent the upper bound in expected DRL effects on crash prevention. DRL systems that use reduced-intensity low-beam headlights, or do not use headlights at all will probably be less effective in crash reduction than the system studied by Sparks et al. This hypothesis is based on the theoretical basis of DRL effects as signals of vehicle presence. As the luminance of the lighting system decreases, the distance the light will be detected by an observer will decrease (given consistent ambient illumination), and thus the effectiveness of the light to serve as a signal of vehicle presence also decreases.

With respect to the analyses described in the current application of the Sparks et al. results to the U.S. crash experience, some caveats are in order. Most important, the crash experience of the fleet used in the Sparks et al. study differs somewhat from that of the 1989 GES data (nationwide U.S. crash data estimates) used to estimate possible DRL effects in the U.S. The crashes in the Sparks et al. study involved crashes resulting in at least $500 (Canadian) of property-damage. Reporting thresholds in the U.S. vary a great deal from state to state, but the GES specification of personal-injury or "major property damage" for inclusion in the data set probably means that the GES data are comparable to the CVA fleet crash data with respect to reporting threshold. More substantively, the crash experience in the CVA fleet used by Sparks et al. had a higher proportion of property-damage crashes (and fewer personal-injury and fatal crashes) than the GES data. The CVA fleet experienced 82.8% to 87.3% property-damage crashes versus 66.8% property-damage crashes for the GES data, and the CVA fleet experienced 11.7% to 16.4% personal-injury crashes versus 32.7% for the GES data. The crash data also differed with respect to the proportions of crashes occurring during daylight hours and with respect to single- versus multiple-vehicle involvement. The CVA fleet experienced 87.2% of their crashes in daylight versus 69.5% for the GES data. Nearly 78% of the CVA fleet crashes involved multiple traffic units while only 67.6% of the GES crashes involved multiple traffic units.

These differences are important to note, but the most important issue is whether or not these differences are likely to affect the estimated effects of daytime running lights on the U.S. crash experience. While the parameter estimates of the effects of DRLs in the CVA fleet study may have differed somewhat had the crash experience of the fleet differed, it is impossible to judge precisely how the results might have been affected. It is possible that DRL effects are more pronounced in crashes of minor severity (i.e., property-damage and minor-injury crashes) where vehicle speeds are likely to be low and that these effects dominated the CVA fleet analyses and subsequent effect estimates. If this is the case, then the estimates probably represent the upper bound of possible effects of DRL implementation in the U.S. On the other hand, the vehicle-presence signalling improvement generated by the use of daytime running lights might be more useful in crashes involving higher vehicle speeds, and subsequently higher crash severities. If this is the case, then the Sparks et al. study probably underestimates the beneficial effects of DRLs. There is some limited evidence to support this hypothesis. Note that the estimated DRL crash reduction effect from the CVA fleet study was greater for personal-injury MVD crashes than for property-damage MVD crashes (16.9% versus 10.1%). However, this difference is most likely not statistically significant.

It is also true that the GES data is built upon a base of only about 44,000 crashes. Thus, it might be argued that any effects based on this data are subject to substantial sample error and would not represent reality. Being aware of the nature of the data, confidence bands for each DRL-effect estimate were calculated based on the standard errors provided in the NASS-GES User's Guide. Data from the GES, the FARS, and census crash data from three states (i.e., Michigan, Texas, and Washington state) were also examined to determine if GES data deviated substantially from census crash data. While some deviation between GES and these census data sets was found, it was typically small and was within the confidence bounds established for the GES data set. It can be concluded from these analyses that the DRL-effect estimates based on the GES data are an accurate reflection of the magnitude of crash and injury reduction effects that can be expected from implementation of a low-beam headlight and parking light DRL system in the U.S.

Summary

While studies of the effects of DRLs on crash outcomes have generally been lacking in experimental rigor and power necessary to specify the magnitude of the safety effect DRLs create, they are consistent in finding that DRLs have a positive effect on traffic safety. Statistically significant DRL effects found in a study of DRL implementation in a large Canadian vehicle fleet were applied to data representing the totality of U.S. crash experience for 1989. Based on these analyses, DRL implementation could be expected to prevent between 200,744 and 380,845 property-damage crashes, 98,839 to 209,052 personal-injury crashes, 165,673 to 335,630 nonfatal injuries, 42 to 3,129 fatal crashes, and 396 to 4,542 deaths each year. These ranges are based on the 95% confidence limit around the high and low reduction estimates.

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