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Motorcycle Conspicuity and the Effect of Fleet DRL: Analysis of Two-Vehicle Fatal Crashes in Canada and the United States 2001-2007

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James W. Jenness, Frank Jenkins, Paul Zador	

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16. Abstract

This study involved testing the Fleet DRL Hypothesis that *widespread use of daytime running lights (DRL) among the motor vehicle fleet is associated with an increased risk for certain types of multi-vehicle motorcycle crashes.* This hypothesis is based on the assumption that the conspicuity of motorcycles (which normally run with their headlamp illuminated all the time) is effectively reduced during the daytime when a high proportion of other vehicles have DRL illuminated. To test the hypothesis, crash data from Canada where DRL use was mandatory were compared to crash data from 24 northern United States where DRL use was not mandatory and fleet penetration of DRL was modest. Crash data from the Fatality Analysis Reporting System (FARS) for the period of 2001 – 2007 were compared to fatal crash data from the Canadian National Collision Data Base (NCDB) for the same years. Crash scenarios that were plausibly relevant to frontal conspicuity of the involved vehicles were defined as DRL-relevant. The proportion of DRL-relevant crashes was modeled by country, year, and whether the crash involved a motorcycle. We fit separate models for crash data that occurred in four groups defined by time of day (Day, Night) and location (Rural, Urban) of the crash. The results supported seven of ten predictions indicating that the Fleet DRL Hypothesis may be true for urban roadways (but may not true for rural roadways). These results support the Fleet DRL Hypothesis for urban roadways, that widespread use of DRL in the vehicle fleet increases the relative crash risk for certain types of motorcycles crashes. This conclusion should be interpreted cautiously in light of the limitations of the analysis approach.

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Executive Summary

The annual number of motorcycle rider fatalities in the United States has more than doubled from 2294 in 1998 to 5290 in 2008 (National Highway Traffic Safety Administration, 2009). Many multi-vehicle motorcycle crashes involve right-of-way violations where another vehicle turns in front of, or crosses the path of an on-coming motorcycle. Improving the frontal conspicuity of motorcycles with forward lighting may reduce these types of crashes. On the other hand, widespread use of DRL on passenger vehicles may reduce the safety effectiveness of daytime headlamp use by motorcyclists. Research is needed to address these questions.

This study involved testing the Fleet DRL Hypothesis that *widespread use of daytime running lights (DRL) among the motor vehicle fleet is associated with an increased risk for certain types of multi-vehicle motorcycle crashes.* This hypothesis is based on the assumption that the conspicuity of motorcycles (which normally run with their headlamp illuminated all the time) is effectively reduced during the daytime when a high proportion of other vehicles have DRL illuminated. To test the hypothesis, crash data from Canada where DRL use is mandatory were compared to crash data from the northern United States where DRL use is not mandatory and fleet penetration of DRL has been modest. Based on several specific assumptions, we developed a set of ten testable predictions that follow from the hypothesis.

We compared crash data from the Fatality Analysis Reporting System (FARS) for 24 northern United States for the period of 2001 – 2007 to fatal crash data from the Canadian National Collision Data Base (NCDB) provided by Transport Canada for the same years. Crash scenarios that were plausibly relevant to frontal conspicuity of the involved vehicles were defined as DRL-relevant. The proportion of DRL-relevant crashes was modeled by country, year, and whether the crash involved a motorcycle. We fit separate models for crash data that occurred in four groups defined by time of day (Day, Night) and location (Rural, Urban) of the crash.

The results supported seven of ten predictions indicating that the Fleet DRL Hypothesis may be true for urban roadways (but may not true for rural roadways). These results suggest that there could be negative consequences for motorcycle riders of widespread DRL use in the vehicle fleet. For urban roadways especially, the proportion of two-vehicle fatal motorcycle crashes that are relevant to frontal conspicuity of the vehicles (DRL relevant) is higher in Canada than in the USA. This result and other related predictions verified by the modeling results support the Fleet DRL Hypothesis for urban roadways, that *widespread use of DRL in the vehicle fleet increases the relative risk for certain types of multi-vehicle motorcycle crashes*. This conclusion should be interpreted cautiously in light of some limitations of the analysis approach.

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Introduction

Motorcycle Conspicuity Project Overview

National Highway Traffic Safety Administration (NHTSA) issued a Task Order to Westat to investigate frontal conspicuity of motorcycles as it relates to frontal lighting treatments on motorcycles and as it relates to the use of daytime running lights (DRL) within the passenger vehicle fleet. The annual number of motorcycle rider fatalities in the United States has more than doubled from 2294 in 1998 to 5290 in 2008 (National Highway Traffic Safety Administration, 2009). Over the same period, the total number of traffic fatalities has remained relatively stable. Many multi-vehicle motorcycle crashes involve right-of-way violations where another vehicle turning in front of, or crossing the path of an on-coming motorcycle. Improving the frontal conspicuity of motorcycles may reduce the occurrence of these types of crashes. On the other hand, widespread use of DRL on passenger vehicles may reduce the safety effectiveness of daytime headlamp use by motorcyclists. Research is needed to address these questions.

The overall project objectives are to:

- Examine if the frontal conspicuity of motorcycles can be improved to reduce their chances of being struck by other motorists who may not have seen them or may not have accurately judged their approaching speed.
- Determine the impact of passenger fleet daytime running lights (DRL) on motorcycle crashes by analyzing crash data from a country that has mandated fleet use of DRL.
- Compare the response (e.g. gap size, turning speed) of motorists turning left in front of approaching passenger vehicles with DRL to those without DRL.
- Evaluate which, if any motorcycle conspicuity treatments might be most likely to improve motorcycle safety (e.g. by increasing the gaps afforded to approaching motorcycles by turning vehicles).

This report describes the work performed on Task 2 (Determine the Impact of Passenger Fleet DRL Use on Motorcycle Crashes). The study involves statistical comparisons between fatal crash data from the northern United States (where DRL use in the vehicle fleet is modest) and fatal crash data from Canada (where fleet penetration of DRL is approaching 100% and use of lights during the daytime is mandatory).

Statistical Study of Fatal Crashes

Objective

The objective of this study is to determine the impact of passenger fleet DRL use on motorcycle crashes by comparing motorcycle involved crashes in the United States, where the prevalence of DRL use within the passenger fleet has been increasing in recent years but is still only moderate (Takenobu, Schoettle, & Sivak, 2007) to motorcycle involved crashes in another country where DRL use is mandatory. The validity of this analysis depends on obtaining comparable data from the two countries and controlling for other differences between the two countries that may affect motorcycle crashes. This study is meant to provide additional insights into the work on motorcycle conspicuity and DRL that was performed under a previous NHTSA project (Pierowicz, Gawron, Wilson, & Bisantz, 2011).

Research question, hypothesis, and assumptions

The main research question for this study is the following:

- *Does widespread use of DRL among the motor vehicle fleet affect the crash risk for motorcycles?*

With widespread use of DRL, it is possible that motorcycle crashes may be reduced if motorcycle riders are able to see other vehicles better when they have DRL. However, because motorcycles are much smaller than other types of vehicles, they tend to be less conspicuous. Therefore, when crashes between motorcycles and other vehicles occur, it is more likely that the other vehicle driver failed to see the approaching motorcycle rather than that the motorcyclist failed to see the approaching other vehicle. The particular safety concern motivating the present study is that fleet use of DRL may increase the number of motorcycle crashes. Thus, the general hypothesis being addressed is that:

- *Widespread use of DRL in the vehicle fleet increases the relative risk for certain types of multi-vehicle motorcycle crashes*.

Through this report, we refer to this hypothesis as the "Fleet DRL Hypothesis."

In order to construct a set of specific predictions that could be tested by between-country comparisons of available crash data, we made several assumptions to define the causal mechanism and applicability of the Fleet DRL Hypothesis:

- Assumption 1: The primary cause for the hypothesized increase in motorcycle crash risk is that widespread use of DRL effectively reduces the frontal conspicuity of motorcycles as seen by other drivers. Several related causal hypotheses are discussed in Appendix A.
- Assumption 2: The hypothesized increase in motorcycle crash risk will be most pronounced in situations where there is more visual clutter and where more vehicles are present prior to the crash.
- Assumption 3: Fleet use of DRL does not appreciably affect the risk for certain types of motorcycle crashes, such as rear-end crashes which do not involve frontal conspicuity of the motorcycle.
- Assumption 4: The hypothesized increase in motorcycle crash risk generally does not apply to single vehicle motorcycle crashes. However, it is recognized that some single vehicle motorcycle crashes may involve a second vehicle (perhaps a "phantom vehicle" which does not stop and does not show up in the crash report) and that these incidents could be affected by fleet use of DRL. Due to this ambiguity, single vehicle crashes were not included in the analysis.
- Assumption 5: The hypothesized increase in motorcycle crash risk occurs for periods of the day when DRLs are used and does not affect the nighttime crash risk for motorcycles. We assume that during the night all vehicles drive with their headlamps illuminated, and that there are no carry-over effects from drivers being exposed to fleet DRL during the daytime.

- Assumption 6: Under the Fleet DRL Hypothesis, high penetration of DRL among the vehicle fleet would specifically increase motorcycles' risk for certain types of multi-vehicle crashes and would reduce or have no net effect on other vehicles' crash risk (i.e. the crash risk for non-motorcycles does not increase under the hypothesis). The rationale here is that when penetration of DRL in the vehicle fleet is low, motorcycles tend to be the only vehicles on the road with headlamps on during the daytime. Daytime headlamp use by motorcycles increases their conspicuity and may provide a safety benefit. However, the increase in conspicuity for motorcycles with lit headlamps may be reduced when DRL penetration in the passenger vehicle fleet is high. Non-motorcycles may increase their conspicuity and reduce their crash risk by adopting DRL, but as fleet penetration of DRL reaches a high level, these benefits may be reduced somewhat.
- Assumption 7: The hypothesized increase in motorcycle crash risk with fleet use of DRL does not saturate with moderate penetration of DRL within the vehicle fleet (as is the found in the United States). As penetration of DRL within the vehicle fleet increases the crash risk for motorcycles also increases such that a country with moderate penetration of DRL within the vehicle fleet would have a smaller effect of DRL on motorcycle crash rate than a country with high penetration of DRL.

We also made an assumption regarding DRL use during the study period in Canada and the United States:

- Assumption 8: The rate of DRL use in Canada was very high and relatively stable over the study period, while DRL use in the United States increased over the study period, but was always substantially less than in Canada.

Finally, we made some assumptions regarding other factors that could affect motorcycle fatalities in Canada and the United States.

- Assumption 9: Factors related to latitude, such as weather, day length, and length of the MC riding season are similar in Canada and the northern United States. Note that our classification of crashes by time of day is related to ambient lighting conditions (day, night) rather than to clock time. Crashes occurring at dusk and dawn were not included in the analysis.
- Assumption 10: Survivability rates for DRL-relevant crashes are similar in the United States and Canada and survivability rates for non DRL-relevant crashes are similar in the United States and Canada. Also, we assume that differences in the rate of motorcycle helmet use between the United States and Canada does not bias the proportion of DRL-relevant fatalities.

Based on the assumptions above we generated a list of specific testable predictions related to the Fleet DRL Hypothesis. These are given below in the Methods section below under the Predictions heading.

Method

Identification of a relevant comparison country

The first step in performing a between-countries comparison of motorcycle crashes and the possible relation to fleet DRL use was to identify a country where DRL usage on passenger vehicles is much higher than it is in the United States. Countries with laws that make DRL use mandatory on motor vehicles have much higher DRL usage than the United States, where DRL use is not mandatory. A summary of DRL usage requirements for several countries is given in Appendix B.

Similarities in traffic laws, composition of vehicle fleets, and similar seasonal weather patterns suggest that Canadian crash data may be comparable to crash data from northern regions of the United States. Canada instituted mandatory DRL for new vehicles beginning with the 1990 model year and DRL had been standard equipment on many vehicles sold in Canada for several earlier model years. In recent years, DRL use within the Canadian vehicle fleet has been very high. Approximately 94 percent of vehicles observed at London, Ontario in 2005 had DRL (Pierowicz, et al., 2011). In the U.S., some vehicle manufactures have offered DRL as optional or standard equipment, and the sales-weighted percentage of new vehicles sold each year with DRL as standard equipment has increased in recent years. For example, 32 percent of passenger cars sold in the year 2000 had DRL as standard equipment and over 60 percent of passenger cars sold in 2007 had DRL as standard equipment (Takenobu, et al., 2007). The percentage of pickup trucks, SUVs and vans sold with DRL in the U.S. is substantially lower than for passenger cars. In 2007, DRL were not available (as standard or optional equipment) on 50 percent of pickups, 41 percent of SUVs and 71 percent of vans sold in the U.S. (Takenobu, et al., 2007).

Comparing Canadian data to U.S. crash data is desirable because it enables this study to build upon previous NHTSA-sponsored empirical research that compared drivers' responses to oncoming motorcycles at sites in London, Ontario and Buffalo, New York (Pierowicz, et al., 2011). From a practical perspective, researchers from Transport Canada were willing to work with Westat on this NHTSA-sponsored project to provide crash data that is not generally accessible outside of Canada.

General strategy for analyses

The general strategy for these analyses is to compare the prevalence of motorcycle crashes in the United States and Canada that are plausibly related to the hypothesized fleet DRL effect. Overall, Canada has many fewer traffic fatalities than the United States due to large differences in the size of the vehicle fleets and total roadway miles driven in the two countries. Because we do not have good information about risk exposure of motorcycles (e.g. miles travelled by motorcycles per year in the two countries), we adopted an analysis approach that compares ratios of different types of crashes.

Variables in the two collision databases were used to define whether each two-vehicle fatal collision case involved a motorcycle, and whether each case plausibly could be affected by widespread use of DRL in the vehicle fleet. Each case was classified as DRL relevant or not based on the crash scenario as defined by certain data elements that are available in both the

Canadian and United States' databases. According to the hypothesis being tested the fatal collision types plausibly affected by fleet DRL use are those crashes where it is possible that a relative reduction frontal conspicuity of an approaching vehicle may have contributed to the crash. The prototypical example is a crash where one vehicle turns in front of, or crosses the path of an approaching vehicle (right-of-way violations) and is struck. It is reasonable to assume that some number (perhaps many) of these crashes occur because the driver of the struck vehicle fails to see the approaching vehicle or fails to correctly perceive the speed of the approaching vehicle. On the other hand, rear-end crashes that occur between two vehicles going straight would not be classified as DRL-relevant because the frontal conspicuity of the vehicles is unlikely to be a significant contributing factor in the crash.

Data

Westat staff worked with researchers at Transport Canada to obtain data from the Canadian National Collision Data Base (NCDB) on fatal crashes that occurred during 2001 to 2007. Fatal crash data for the United States were obtained from the Fatality Analysis Reporting System (FARS) for the same years. Compared to the United States, Canada has a much smaller number of fatal traffic crashes each year (e.g. 2,604 fatal crashes in year 2006 as compared to 38,648 fatal crashes in the U.S. that year).

To minimize the effects of factors related to geography and latitude such as seasonal weather, ambient lighting, day length, and length of the motorcycle riding season, only U.S. FARS data for crashes in northern states were compared to fatal crash data from Canada. The 24 northern states included in the analysis are: Alaska, Connecticut, Idaho, Illinois, Indiana, Maine, Massachusetts, Michigan, Minnesota, Montana, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, South Dakota, Vermont, Washington, Wisconsin, and Wyoming. These states correspond to NHTSA administrative Regions 1, 2 (excluding Virgin Islands and Puerto Rico), 5, 10, and half of Region 8 (excluding Nevada, Utah, and Colorado). Approximately 31 percent of the fatal motor vehicle crashes in the United States occurred in these 24 northern states in 2007.

During the years studied (2001 to 2007), eight of the northern states listed above had "universal helmet laws" requiring all motorcycle riders to wear an appropriate helmet, while the other states had less comprehensive helmet laws (e.g. helmets required for younger riders only) or no law requiring helmet use (IIHS, 2009). Canada had a universal helmet law throughout the study period.

Only fatal crashes involving two vehicles were selected for the analysis. Other data selection procedures involved:

- Eliminating crashes that involved a train, or stationary vehicle such as a parked car.
- Excluding crashes that occur during dusk or dawn (daytime and nighttime cases were retained).
- Data from multi-vehicle crashes (i.e. more than two vehicles) were excluded due to difficulties in interpreting the order of events, relative roles of involved vehicles and whether the crash scenario was DRL relevant.

We combined data from Canada and the United States in a single data file for subsequent analysis using SAS statistical software.

Variable definitions used in the analysis

For analysis purposes, we defined dichotomous variables to classify each crash case:

McCrash: Whether the two vehicle crash involved a motorcycle

1 = Motorcycle involved
2 = No motorcycle involved

DRL (relevance): Whether the crash was of a type that could be affected by DRL use in the passenger vehicle fleet (i.e. crash scenarios in which drivers were likely to have a frontal view of the other vehicle before the crash).

0 = Not fleet DRL relevant (Unlikely to be affected by fleet DRL use.)
1 = Fleet DRL relevant (Plausibly affected by fleet DRL use.)

We defined three other variables to classify the context of each crash case.

Country:

1 = United States (includes only 24 northern states); data from FARS.
2 = Canada; data from Canadian National Collision Data Base.

Urbanicity: (based on roadway functional classes)

1 = Rural
2 = Urban

Daytime: (crash cases coded as dusk, dawn, or unknown were excluded)

1 = Day
2 = Night

Year: (The year that each crash occurred)

7 years (2001 - 2007)

Motivated by Assumption 1 and Assumption 2 (given above), we used the DRL variable to categorize fatal crash cases as DRL Relevant, versus Not DRL Relevant. Classification of a crash case as DRL Relevant means that it is plausible that the crash is a type that could be affected by the use of DRL in the vehicle fleet. Not DRL Relevant means that the crash is a type that is unlikely to be affected by use of DRL in the vehicle fleet. We hypothesize that fleet DRL use affects the frontal conspicuity of vehicles (particularly motorcycles), therefore our classification of DRL Relevant versus Not DRL Relevant is aimed at separating crashes which may be caused by a driver not noticing the front of an approaching vehicle or not accurately perceiving the speed of an approaching vehicle (DRL Relevant) from crashes that are not likely to be relevant to the frontal conspicuity of the involved vehicles (Not DRL Relevant). Note that the classification of DRL Relevance does not refer to the direct effects of the crash-involved vehicles' lighting configurations (such as DRL). It refers to certain types of crashes where it is plausible that hypothesized indirect effects of DRL prevalence in the vehicle fleet may affect the frontal conspicuity of crash-involved vehicles.

The classification scheme was based on three simple rules applied in the order shown. The descriptions below refer to FARS variables (fields) and values (codes). The classification was also applied to the Canadian data based on similar variables.

- Rule 1: If Vehicle Maneuver (V17) for BOTH vehicles = 01 (Going straight) and Manner of Collision = 02 (front-to-Front) or 08 (Sideswipe – Opposite direction) then classify as DRL Relevant.

- Rule 2: If Vehicle Maneuver (V17) for EITHER vehicle = (13 Turning Left, 14 Making a U turn) then classify crash as DRL Relevant.

- Rule 3: Classify the rest of the crashes in Analysis Set not selected by rule 1 or 2 as Not DRL Relevant.

More complex classification schemes based on other variables are possible. However, it was difficult to select a classification scheme that uses only variables available in both the U.S. and Canadian databases which do not have many missing values.

Predictions

We developed ten specific predictions related to the proportion of DRL relevant crashes. These predictions are based on the Fleet DRL Hypothesis and the related assumptions listed above. We used subscript notation to differentiate between the data groups involved in the predictions. The proportion of DRL relevant crashes out of all crashes for a particular set of conditions is given by:

$DRL_{(\underline{U}S\text{ or }\underline{C}anada)\ (\underline{U}rban\text{ or }\underline{R}ural)(\underline{N}ight\text{ or }\underline{D}ay)(\ \underline{M}otorcycle\text{ or }\underline{N}o\text{ motorcycle involved})}$.

For example, DRL_{UUNM} = proportion of DRL relevant crashes among U.S. Urban Nighttime crashes involving Motorcycles. Note that “ABS” is used to denote absolute value.

<u>Predictions for crashes occurring during the daytime (D)</u>

For crashes involving motorcycles, the proportion of DRL relevant crashes will be higher in Canada than in the United States.

D1: $DRL_{CUDM} > DRL_{UUDM}$ and

D2: $DRL_{CRDM} > DRL_{URDM}$

The difference between countries in DRL relevant crashes will be greater for urban locations than for rural locations, (assuming that the hypothesized Fleet DRL effect is most pronounced in situations where there is more visual clutter and where more vehicles are present prior to the crash.)

D3: $(DRL_{CUDM} - DRL_{UUDM}) > (DRL_{CRDM} - DRL_{URDM})$

For crashes that do not involve motorcycles, the difference between countries in proportions of DRL relevant crashes will be smaller than the difference between countries in proportions of DRL relevant crashes involving motorcycles.

D4: $(DRL_{CUDN} - DRL_{UUDN}) < (DRL_{CUDM} - DRL_{UUDM})$ and
D5: $(DRL_{CRDN} - DRL_{URDN}) < (DRL_{CRDM} - DRL_{URDM})$

For Canadian data, the difference between the proportion of DRL relevant motorcycle crashes and the proportion of DRL relevant non-motorcycle crashes will be greater (more positive) than the same difference of proportions in the United States.

D6: $(DRL_{CUDM} – DRL_{CUDN}) > (DRL_{UUDM} - DRL_{UUDN})$ and
D7: $(DRL_{CRDM} – DRL_{CRDN}) > (DRL_{URDM} - DRL_{URDN})$

Predictions for crashes occurring during the nighttime (N)

Assuming that the fleet DRL effect does not influence nighttime crashes, the proportions of DRL relevant motorcycle crashes will be more similar between the two countries at night as compared to the day.

N1: $ABS(DRL_{CUDM} - DRL_{UUDM}) > ABS(DRL_{CUNM} - DRL_{UUNM})$ and
N2: $ABS(DRL_{CRDM} - DRL_{URDM}) > ABS(DRL_{CRNM} - DRL_{URNM})$

Assuming that during the day the DRL effect is more pronounced for urban rather than rural locations and that the DRL effect does not influence nighttime crashes, we predict that for Canadian data, the proportions of DRL relevant motorcycle crashes in rural and urban locations will be more similar at night than during the day.

N3: $ABS(DRL_{CUNM} – DRL_{CRNM}) < ABS(DRL_{CUDM} - DRL_{CRDM})$

Results

Description of the sample and the analysis

Westat obtained U.S. and Canadian data for the 2001- 2007 period on fatal crashes involving either two passenger vehicles or one passenger vehicle and one motorcycle. For the purpose of our analyses, we subdivided the crash data by location (urban, rural) and time of day (day and night) into four groups of 56 cells that were defined in terms of country (USA, Canada), year (2001-2007), motorcycle involvement (or not) in the crash (McCrash), and DRL relevance (relevant, not relevant). We analyzed the data separately within four groups defined as crashes that are:

1) Rural, Nighttime
2) Rural, Daytime
3) Urban, Nighttime
4) Urban, Daytime

For each of the four groups we calculated the proportion of crashes that were DRL relevant (DRL relevance proportion), creating a total of 28 cells = 2 (country) x 2 (motorcycle involvement) x 7 (year). We estimated the probability that a crash was DRL-relevant as a function of three factors (country, motorcycle involvement, year) and investigated the effect of these factors on DRL relevance. This analysis was done separately for each of the four groups.

Table 1 presents country by motorcycle (MC) involvement counts (collapsed on Year and DRL relevance) for each of the four groups defined by crash location and time of day.

Table 1: Number of Crashes by Group, Country, and Motorcycle Involvement

Group	USA No MC	USA MC	Canada No MC	Canada MC	Group Totals	Group Pcts
Rural, Night	4,029	356	1,277	63	5,725	16.8%
Rural, Day	10,340	1,417	2,674	265	14,696	43.0%
Urban, Night	3,954	778	514	70	5,316	15.6%
Urban, Day	6,002	1,439	787	194	8,422	24.6%
Column Total	24,325	3,990	5,252	592	34,159	100%
Percent	71.2%	11.7%	15.4%	1.7%	100%	

Approximately 84% of the crashes in the sample occurred in the USA, 60% in rural locations, 68% during the daytime, 13% involved a motorcycle, and 38% were DRL relevant.

Preliminary analyses showed that location and time-of-day affected the dependence of DRL relevance on the three factors we chose to investigate. One way to account for this effect would be to include location and time-of-day as additional factors in a single-group model. However, to account for the fact that the effect of the three factors differ by group, numerous higher-order interactions would have to be included in the model. Such a model would be complex and difficult to interpret, even if cell sizes proved to be large enough to estimate all the required terms. We chose an alternative analysis strategy and fitted four separate models, one per group, each of which included only 3 predictors. The fact that regression parameters can differ among the groups shows that this approach is equivalent to having a slew of high-level interactions in a single-group analysis.

Descriptive comparison of the countries

In Table 2 we compare crash percentages between the USA and Canada by location, time of day, motorcycle involvement and DRL relevance. We see that a greater percentage of crashes were urban in the USA (43%) than in Canada (27%). About the same percentage of crashes occurred during the day in both countries (~67%), a somewhat greater percentage of crashes involved motorcycles in the USA (14%) than in Canada (10%), and a somewhat smaller percentage of crashes were DRL relevant in the USA (38%) than in Canada (42%). To summarize, crashes in the two countries are similar by time of day, are somewhat different by motorcycle involvement and DRL-relevance, and are very different by crash location (urban versus rural).

Table 2 Percentages in Various Classifications of Crashes for USA and Canada

Factor	Country	
Location	USA	Canada
Rural	57	73
Urban	43	27
Time-of-day		
Night	32	33
Day	68	67
MC Crash		
No	86	90
Yes	14	10
DRL relevant		
No	62	58
Yes	38	42

As mentioned above, the analysis involved predicting the probability that crashes are DRL relevant separately in four groups (defined by the location of the crash and time-of-day). In each group, we specified a general linear model for estimating the probability of DRL-relevance as a function of some combination of predictors and predictor interactions. We used the SAS procedure, Proc GLIMMIX (SAS Institute, 2008; Version 9.1) to estimate model parameters under the assumption that in each cell the number of DRL-relevant events was a sample from a binomial distribution B(n, p), where n is the total crash count in the cell, p is the conditional probability that in the cell each crash is DRL-relevant with probability p. This proportion, p, is transformed with a logit function. It is further assumed that the logit of the proportions is predicted as a linear function of the covariates. The models provided good fits for each of the four groups of data. Plots of the residuals are given in Appendix C.

Table 3 gives a summary of the significant effects for each group. Significance is judged by the Type III F-test probability listed in the last column. Values less than or equal to 0.05 are considered to be statistically significant. Type III tests assess for significance the additional contribution of an effect or an interaction to explaining between cell variation in DRL-relevance above and beyond the total contribution of all other effects and interactions in the model. (In contrast to type III tests, t-tests assess for significance the value of a specific parameter estimate which, in case of dependence among parameters, may depend on the ordering in which the parameters are entered.) The parameter estimate for a class variable compares the effect of class membership to the reference class so that the size of the estimate depends on reference class choice. Also, if the variable is included in an interaction, the parameter estimate and the interaction need to be interpreted jointly.

We defined the effects in the model as:

Country = Canada – USA
McCrash = Motorcycle involved – No motorcycle involved
Country*McCrash = (CanadaMC – CanadaNoMC) – (USAMC – USANoMC)
Year Trend = 2001 – 2002 – 2003 - . . . 2007

Here is a summary of the results for the four groups.

1. For crashes in Rural locations at Night:
   There was a significant effect for year. DRL relevant proportions were significantly reduced over time.

2. For crashes in Rural locations during the Day:
   There were significant effects for country and McCrash (whether the crash involved a motorcycle). Given the coding of categories the direction of effects implies that Canada had a higher proportion of DRL relevant crashes than the USA. Also, as compared to non-motorcycle crashes, motorcycle crashes included a higher proportion of DRL relevant crashes. However, there was no significant effect for the Country by McCrash interaction, which fails to confirm the DRL hypothesis (prediction D2). This suggests that the fleet DRL hypothesis may not apply to rural settings.

3. For crashes in Urban locations at Night:
   There was a significant effect for McCrash. The direction of effects implies that motorcycle crashes had higher DRL relevant proportions. While it was hypothesized that motorcycle crashes will have higher DRL relevance during the day, the positive effect for motorcycle involvement at night is not predicted by the fleet DRL hypothesis. However, this result suggests that motorcycles may be relatively less conspicuous than other vehicles in urban locations at night. There was no significant effect of Country or of Country by McCrash interaction.

4. For crashes in Urban locations during the Day:
   Country had a significant effect indicating that there was a lower proportion of DRL relevant crashes in Canada than in the USA. McCrash had a significant effect, indicating that motorcycle-involved crashes had a higher proportion of DRL relevant crashes. The Country by McCrash interaction was also significant, indicating that the McCrash effect is larger for Canada than for the USA.

This last result, the Country by McCrash interaction, speaks to the main hypothesis of the study. That is, in Canada, there is a greater proportion of DRL relevance for motorcycle crashes than in the USA (see Predictions D1 and D2). This is predicted by the greater use of DRL in Canada. However, this interaction was not significant in rural areas in the daytime. This combination of results, implying a stronger effect of fleet DRL in urban versus rural environments is consistent with our prediction (D3) for the fleet DRL hypothesis.

Another interesting result is that Country had statistically significant, but opposite effects during the day in urban and rural environments, when it would be expected that the greater use of daytime running lights in Canada would make a difference to the DRL proportions. The direction of the effect suggests that over all daytime *urban* crashes, the proportion of DRL relevant crashes in Canada was significantly less than in the USA. (But note that for daytime *rural* crashes discussed above, the proportion of DRL relevant crashes in Canada was significantly greater than in the USA.) The result for urban crashes would support the benefit of widespread use of DRL in the vehicle fleet. Although statistically significant, the size of this effect is small. For crashes not involving a motorcycle there was a 1 percentage point reduction in the proportion of DRL relevant crashes in Canada as compared to the USA (see Figure 4). However, for daytime motorcycle-involved crashes on urban roadways, Canada experienced a proportion of DRL relevant crashes that was 11 percentage points greater than the DRL relevant proportion in the USA.

Table 3: Model Estimates of Effects

Group	Effect	Estimate	Std Err	DF	t Value	Prob t	Prob F
Rural, Night							
	Intercept	-0.388	0.061	23	-6.350	0.000	********
	Country	0.302	0.065	23	4.620	0.000	0.067
	McCrash	0.239	0.113	23	2.120	0.045	0.154
	Country*McCrash	-0.061	0.282	23	-0.220	0.830	0.830
	Year	-0.044	0.014	23	-3.200	0.004	**0.004**
Rural, Day							
	Intercept	-0.591	0.039	23	-15.330	0.000	********
	Country	0.283	0.044	23	6.380	0.000	**0.003**
	McCrash	0.391	0.057	23	6.800	0.000	**0.000**
	Country*McCrash	-0.093	0.141	23	-0.660	0.519	0.519
	Year	-0.006	0.009	23	-0.740	0.464	0.464
Urban, Night							
	Intercept	-0.683	0.066	23	-10.300	0.000	********
	Country	0.117	0.098	23	1.190	0.247	0.745
	MCcrash	0.685	0.079	23	8.630	0.000	**0.001**
	Country*McCrash	-0.322	0.270	23	-1.190	0.245	0.245
	Year	-0.007	0.015	23	-0.460	0.650	0.650
Urban, Day							
	Intercept	-0.407	0.051	23	-7.950	0.000	********
	Country	-0.011	0.078	23	-0.150	0.884	**0.021**
	MCcrash	0.506	0.059	23	8.550	0.000	**0.000**
	Country*McCrash	0.460	0.176	23	2.620	0.015	**0.015**
	Year	-0.005	0.011	23	-0.410	0.689	0.689

Table 4 gives the model based logits for the model. If p is the likelihood that a crash is DRL relevant, the logit is the function Log(p/(1-p)). A larger logit implies that the mean DRL relevance proportion (p) is higher. The estimated relevance proportion (p) for each combination of group and country is given in the last column. An inspection of this table will help interpret the significance tests reported by the analysis.

Table 4 Mean Logits of DRL Relevance Likelihood

Group	Country	McCrash	Estimated Mean: Logit Metric	Estimated Mean: DRL Proportion
Rural, Night				
	Canada	MC	-0.08	0.48
	Canada	No MC	-0.26	0.44
	USA	MC	-0.32	0.42
	USA	No MC	-0.56	0.36
Rural, Day				
	Canada	MC	-0.04	0.49
	Canada	No MC	-0.33	0.42
	USA	MC	-0.23	0.44
	USA	No MC	-0.62	0.35
Urban, Night				
	Canada	MC	-0.23	0.44
	Canada	No MC	-0.59	0.36
	USA	MC	-0.02	0.49
	USA	No MC	-0.71	0.33
Urban, Day				
	Canada	MC	0.53	0.63
	Canada	No MC	-0.44	0.39
	USA	MC	0.08	0.52
	USA	No MC	-0.43	0.40

We see that in every group within each country, the McCrash effect is positive, i.e. crashes involving a motorcycle have a higher probability of DRL relevance than crashes not involving a motorcycle. This effect was significant in all but the 1st group (Rural, Night). Also, for urban daytime crashes (the last group) the effect of motorcycle involvement is much larger for Canada than for the USA. This is reflected by the statistically significant Country by McCrash interaction for this group (Table 3). The interaction may be seen by comparing the larger difference between DRL relevance for crashes involving a motorcycle and DRL relevance for the crashes not involving a motorcycle for Canada to the smaller difference between these estimates for the USA (Table 4, Urban, Day).

The year means are given in this Table 5. There was a significant year effect only for the Rural/Night group (-.044) implying that in successive years there were reduced levels of DRL relevance (by a small percent). We note that the direction of the effect was the same, but small and not significant, in every group. Since this is not a large effect and is only significant in the 1st group it will not be further discussed. Year to year trends in observed DRL relevance proportions by time of day, motorcycle involvement and crash location are shown in Appendix D.

Table 5. Estimated and Observed Proportion of DRL Relevant Crashes by Group by Year

Group	Year	Model Estimate (Logit)	Estimated Proportion DRL	Observed Proportion DRL
Rural, Night				
	2001	-0.125	0.47	0.50
	2002	-0.232	0.44	0.50
	2003	-0.305	0.42	0.41
	2004	-0.374	0.41	0.44
	2005	-0.305	0.42	0.42
	2006	-0.459	0.39	0.31
	2007	-0.371	0.41	0.40
Rural, Day				
	2001	-0.183	0.45	0.41
	2002	-0.356	0.41	0.44
	2003	-0.305	0.42	0.44
	2004	-0.388	0.40	0.40
	2005	-0.328	0.42	0.43
	2006	-0.327	0.42	0.41
	2007	-0.239	0.44	0.45
Urban, Night				
	2001	-0.292	0.43	0.53
	2002	-0.403	0.40	0.37
	2003	-0.426	0.40	0.45
	2004	-0.414	0.40	0.36
	2005	-0.394	0.40	0.44
	2006	-0.450	0.39	0.32
	2007	-0.327	0.42	0.44
Urban, Day				
	2001	-0.016	0.50	0.47
	2002	-0.105	0.47	0.50
	2003	-0.088	0.48	0.50
	2004	-0.011	0.50	0.45
	2005	-0.057	0.49	0.48
	2006	-0.078	0.48	0.50
	2007	-0.087	0.48	0.48

Based on the models' estimated DRL relevance proportions in Table 4 we evaluated the ten previously defined predictions. The first column in Table 6 contains an inequality statement to summarize each prediction with the corresponding DRL proportions estimated from the models. The second column gives an evaluation of the prediction based on the estimated DRL proportions.

Table 6. Summary of Predictions

Prediction Based on Fleet DRL Hypothesis and [Model Estimates of DRL Proportions from Table 4]	Prediction Supported by Model Estimates?
D1: $DRL_{CUDM} > DRL_{UUDM}$ [.63] [.52]	Yes
D2: $DRL_{CRDM} > DRL_{URDM}$ [.49] [.44]	Yes
D3: $(DRL_{CUDM} - DRL_{UUDM}) > (DRL_{CRDM} - DRL_{URDM})$ [.63] [.52] [.49] [.44]	Yes
D4: $(DRL_{CUDN} - DRL_{UUDN}) < (DRL_{CUDM} - DRL_{UUDM})$ [.39] [.40] [.63] [.52]	Yes
D5: $(DRL_{CRDN} - DRL_{URDN}) < (DRL_{CRDM} - DRL_{URDM})$ [.42] [.35] [.49] [.44]	No
D6: $(DRL_{CUDM} – DRL_{CUDN}) > (DRL_{UUDM} - DRL_{UUDN})$ [.63] [.39] [.52] [.40]	Yes
D7: $(DRL_{CRDM} – DRL_{CRDN}) > (DRL_{URDM} - DRL_{URDN})$ [.49] [.42] [.44] [.35]	No
N1: $ABS(DRL_{CUDM} - DRL_{UUDM}) > ABS(DRL_{CUNM} - DRL_{UUNM})$ [.63] [.52] [.44] [.49]	Yes
N2: $ABS(DRL_{CRDM} - DRL_{URDM}) > ABS(DRL_{CRNM} - DRL_{URNM})$ [.49] [.44] [.48] [.42]	No
N3: $ABS(DRL_{CUNM} – DRL_{CRNM}) < ABS(DRL_{CUDM} - DRL_{CRDM})$ [.44] [.48] [.63] [.49]	Yes

Discussion

Interpretation of results

The modeling results supported predictions of the Fleet DRL Hypothesis for urban roadways (D1, D4, D6, N1) and they supported one simple prediction involving rural roadways (D2). However, they did not support three other complex predictions. One involved comparing the difference between countries in the proportion of DRL relevant crashes among rural non-motorcycles to the difference between countries for the proportion of DRL relevant crashes for rural motorcycles (D5). Another unsupported prediction involved the difference in DRL relevance proportions between motorcycle crashes and non-motorcycle crashes on rural roadways in the USA as compared to Canada (D7). The third unsupported prediction was that on rural roadways, DRL proportions for motorcycle crashes would be more similar between the two countries at night as compared to the daytime (N2). It should be noted that although prediction D2 was supported by the model estimates indicating a higher proportion of DRL relevant motorcycle crashes on rural Canadian roadways as compared to rural USA roadways, this difference in DRL relevance was also seen for rural crashes not involving motorcycles. In fact, the country by McCrash interaction was not statistically significant in the Rural/Day model (Figure 3).

Taken together, the results suggest that the Fleet DRL effect may apply primarily to urban roadways. In fact, our specific prediction that there would be a stronger Fleet DRL effect on urban versus rural roadways (D3) was supported by the results, as was the prediction that in Canada the difference between urban and rural roadways in the proportion of DRL relevant crashes for motorcycles would be reduced at night as compared to the day (N3). We speculate that these results may be explained by the fact that urban roadways tend to present the driver with a higher level of visual complexity than rural roadways. The Fleet DRL effect (reducing motorcycle conspicuity) may depend on visual clutter from other vehicles with DRL in the scene, and it is reasonable to assume that more vehicles would be present in urban versus rural scenes.

Another possible explanation for why the Fleet DRL effect is more applicable to urban roadways than rural roadways is because urban environments may have more opportunities for DRL relevant crashes than do rural environments. Drivers encounter other vehicles more often in urban environments than in rural environments because of the increased traffic, and would turn in front of other vehicles more often as well.

It is interesting to note that although Canada has widespread DRL in its vehicle fleet, the proportion of DRL relevant crashes among non-motorcycles during the day on urban roadways in Canada was only slightly less than in the USA indicating that the safety benefits of widespread DRL penetration may be small. Also, on rural roadways during the day, Canada had a higher proportion of DRL relevant crashes than the USA. If DRL helps to improve the conspicuity of vehicles with DRL and reduces their crash risk, this benefit was not reflected in our analysis of the rural crash data.

Limitations of the method

In order to test the Fleet DRL Hypothesis by comparing a country with nearly universal use of DRL to a country with only moderate penetration of DRL, we chose to use highest quality crash data available in the USA and Canada. These were data on fatal crashes. It is possible that the Canadian sample and the USA sample of fatal motorcycle crashes may differ in several ways. For example, there may be some selection bias related to survivability of motorcycle crashes. Among other things, the probability of a motorcycle crash being fatal is related to whether or not the rider was wearing a helmet. Because Canada has universal helmet laws for motorcycle riders and many of the northern states included in the USA sample have less comprehensive helmet laws, it is likely that a higher percentage of riders in Canada wear helmets. Therefore, the probability of a motorcycle crash being fatal in Canada (and included in our sample) may be somewhat lower than in the USA based on helmet use. However, there may be other factors such as EMS response, types of motorcycles in the fleet, or differences in the demographics of riders that also affect survivability. It is not clear whether any differences exist that would threaten the validity of our analysis approach. In our analysis, we compared proportions of different crash types within and between countries. A survivability-by-crash-type-by-country interaction could threaten the validity of the analysis. A related point is that we focused on fatal crashes, because we didn't have a reliable dataset of all crashes in the United States. Fatal crashes may be very different from nonfatal crashes and the effect of crash factors may be different as a result.

Our approach to testing the Fleet DRL hypothesis relied on defining crashes based on DRL relevance. Our definition of DRL relevant crashes was nonspecific in the sense that it undoubtedly selected crashes in which the two vehicle operators involved did not have any problem seeing or accurately judging the speed of the other vehicle in addition to crashes where lack of frontal conspicuity of the vehicles was a contributing factor to the crash. Despite the lack of specificity in our classification, significant differences between the two countries were found, which may mean that the Fleet DRL effect is a strong effect. Alternatively, there could be other differences between Canada and the USA that mimic the predicted effects of the Fleet DRL Hypothesis. For example, differences in urban roadway design practices between the two countries may affect the opportunities for vehicles to make left turns across the flow of oncoming traffic. A country with reduced opportunities for DRL relevant crash scenarios may naturally experience a smaller proportion of DRL relevant crashes.

Another issue related to the use of DRL relevance proportions as the unit of analysis is that observed differences in the proportions of DRL relevant crashes could be due to differences in the number of non-relevant crashes. Although we are ultimately interested in differences in the risk of DRL relevant crashes, high quality exposure data are not available. Therefore we took the approach of assessing relative crash risk by examining DRL relevant crash proportions. This approach does not allow us to estimate the absolute number of motorcycle crashes that may be attributable to the Fleet DRL effect, nor does it allow us to predict the number of additional motorcycle fatalities that would occur if DRL penetration in the USA increased 100%.

Conclusions and Recommendations

The results of this study suggest that there may be negative consequences for motorcycle riders of widespread DRL use in the vehicle fleet and they cast some doubt on the overall benefits of DRL. For urban roadways especially, the proportion of two-vehicle fatal motorcycle crashes that are relevant to frontal conspicuity of the vehicles (DRL relevant) is higher in Canada than in the USA. This result and other related predictions verified by the modeling results support the Fleet DRL Hypothesis for urban roadways, that *widespread use of DRL in the vehicle fleet increases the relative risk for certain types of multi-vehicle motorcycle crashes*.

This conclusion should be interpreted cautiously in light of the limitations of the analysis approach that are described above, however, based on our results, we recommend that:

- The safety benefits of DRL for vehicles with DRL should be clearly demonstrated before DRL use is further encouraged for use throughout the vehicle fleet.

- As DRL penetration in the vehicle fleet continues to rise in the USA, efforts to improve motorcycle conspicuity during the daytime should be undertaken. These efforts should focus on conspicuity enhancements that provide motorcycles with a unique visual signature and are not confusable with DRL commonly used on other vehicles.

Acknowledgements

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Appendix A: Supporting Hypotheses Concerning the Use of Daytime Running Lights by the Motor Vehicle Fleet and Effects on Motorcycle Crash Risk

Main hypothesis: ***Widespread use of DRL among the motor vehicle fleet is associated with an increased risk for certain types of multi-vehicle motorcycle crashes***.

Why might this hypothesis be true? The main hypothesis could be explained by one or more of the following causal explanations involving motorcycles (MCs):

Hypothesized Cause 1: ***Motorcycle crash risk is increased because the effective frontal conspicuity of MCs is reduced when MCs are seen in the context of other vehicles with DRL.*** This explanation would apply to situations where other traffic is around or behind the motorcycle. There are several possible variants to this explanation including the following:

1A) In a DRL rich context, the MC headlamp is not unique, and it may act as a camouflage feature. The MC and its lit headlamp may blend in with the background of similar lights from other vehicles. The MC loses its tendency to "pop out" visually as it would if other vehicles did not have DRL.

1B) In some cases, the single MC headlamp may be perceptually grouped with headlamps from another vehicle leading to the mistaken perception that a MC in front of, or next to another vehicle is a single vehicle rather than two vehicles. The MC may be perceptually grouped with a vehicle that is further away or traveling slower that the MC.

Photo: Federation of European Motorcyclists' Association (2004)

1C) DRL-equipped vehicles compete for drivers' attention. Vehicles with DRL may have enhanced conspicuity due to having multiple DRLs and this may draw drivers' attention away from nearby MCs which have relatively less conspicuity because they are smaller and tend to have only a single headlamp.

Hypothesized Cause 2: ***MC crash risk is increased because in a jurisdiction with widespread use of DRL in the vehicle fleet, road users' search strategies adapt in some way that puts MCs at a disadvantage for being noticed.***

2A) Road users who are exposed to high usage rates of DRL may rely (or perhaps rely too much) upon the high perceptual saliency of DRL to detect approaching vehicles. This hypothesis has been discussed by Hole and Tyrrell (1995). Road uses' expectations may be developed by frequently seeing two widely spaced DRL on approaching vehicles. The typical forward lighting configuration (e.g. a single lit headlamp, or closely spaced lamps) on MCs may not be sufficiently similar to other vehicles' DRL configurations to match expectations, and therefore, road users sometimes may not notice approaching MCs.

This hypothesis predicts that MC crash risk would be increased for situations where an approaching MC is alone as well as to situations with surrounding traffic. Thus, MC crash risk would be increased for both low volume and high volume roadways.

Hypothesized Cause 3: ***Although road users may detect approaching motorcycles, they tend to overestimate motorcycles' time to arrival as compared to time to arrival estimates for larger approaching vehicles (Horswill, et al., 2005). Motorcycle crash risk may be increased by motor vehicle fleet use of DRL to the extent that the fleet use of DRL increases the difference in time to arrival judgments for motorcycles and other vehicles.***

Hypothesized Cause 4: ***Having DRL is associated with drivers acting more aggressively with respect to more vulnerable road users. Drivers who have DRL on their own vehicle may feel that they have a psychological right of way when pulling out in front of a vulnerable road user (Federation of European Motorcyclists' Associations, et al., 2001). Under this hypothesis, motorcycle crash risk (and pedestrian crash risk) is predicted to increase with widespread use of DRL in the vehicle fleet.***

Appendix B: Countries with Mandatory DRL Laws

An internet search and literature review was conducted in order to identify countries where daytime running light use is required by law. The review included studies of DRL effectiveness and safety benefits and reviews of DRL usage rates. Evaluations of DRL effectiveness have been conducted in many countries. In Europe in particular there are a number of countries with DRL regulations in one form or another and a number of evaluations have been made on their effects[1]. In the U.S. and Australia where there are no mandatory DRL laws there have also been a few evaluation studies of DRL effectiveness[2].

The European Commission indicates that there are 14 member states with DRL legislation[3]. In an effort to determine whether to introduce DRL to members of the European Union the Commission launched a public consultation in 2006 that garnered responses from a number of countries and institutions regarding their approach to DRL. The European Commission also funds the SafetyNet Project which gathered information on a number of Road Safety Performance Indicators including DRL for 27 European countries. Table 1 provides details on those countries with mandatory DRL laws. The table also details the annual number of motorcycle and powered two wheelers (PTW) fatalities per billion kilometers traveled and the ratio of fatality rate per billion km ridden by PTW riders compared to the corresponding rate for car drivers for the countries with DRL laws when available[4].

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[1] Brouwer, R.F.T. et al. Do other road users suffer from the presence of cars that have their daytime running lights on? IR3 : D R L project, October 2004; Commandeur, Jacques J.F. State of the art with respect to DRL implementations. SWOV Institute for Road Safety Research. October 2003; Daytime Running Lights: Final Report, TNO Human Factors; October 2003; Elvik, R., and T. Vaa. *Handbook of Road Safety Measures.* Amsterdam: Elsevier, 2004; Knight, I. et al. Daytime Running Lights (DRL): A review of the reports from the European Commission, TRL Limited, PPR 170, October 2006; Koornstra, Matthijs et al., The Safety Effects of Daytime Running Lights, SWOV Institute for Road Safety Research, The Netherlands, 1997;

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[3] http://ec.europa.eu/transport/roadsafety/vehicles/daytime_running_lights_en.htm accessed 11.18.08

[4] Road Safety Performance Index: Reducing motorcyclist deaths in Europe; FLASH PIN 7, ETSC December 2007.

Table 1. Countries with Mandatory DRL Laws

Country	Year DRL law initiated	Vehicle types	Road types	Season	Type of lights required	MC and PTW deaths per billion km traveled (2006)	Ratio of fatality rate per billion km ridden by MC and PTW riders compared to car drivers (2006)
Austria[5]	November 2005	All multilane vehicles and motorcycles as well as single lane motorcycles	All roads		Four options available under law: A. (normal) low beam light B. (normal) fog light C. dedicated daytime running lights D. low beam light or fog light that is constructed like daytime running lights for the use during daytime	64	10.24
Canada[6]	1989- for new vehicles	The 1989 regulation applies to all new "4-wheeled" vehicles Motorcycles required to use DRL since 1975	Requirement is not for road type but based on automatic use in vehicles	Year round	CMVSS 108 specifies the following types of DRL: • low beam headlamps at normal light intensity, • low beam headlamps at reduced light intensity, • high beam headlamps at reduced light intensity, • turn signals, • brighter parking lamps, • fog lamps, and • completely separate DRL units		
Czech Republic[6]	1982 motorcyclists 2001 all other vehicles	All motorized vehicles	All roads	Motorcyclists all year, Vehicles during winter months (Sep-Mar)		314	32.21

[5] European Commission 2006

6 Commandeur, Jacques J.F. October 2003

Country	Year DRL law initiated	Vehicle types	Road types	Season	Type of lights required	MC and PTW deaths per billion km traveled (2006)	Ratio of fatality rate per billion km ridden by MC and PTW riders compared to car drivers (2006)
Denmark[6]	1990 (had previously been in place for select vehicles)	All motorized vehicles equipped with lights	All roads	Year round	Dipped headlights, front fog lamps, dipped headlights with reduced voltage (11V or 12V for vehicles with 24V) or special DRL lamps. In all cases also the rear lamps shall be used.	36	11.21
Estonia[7]	1995	All vehicles	All roads	Year round		171	26.43
Finland[5]	1972- winter only outside urban 1982- year round outside urban 1997- all vehicles, all roads year round	All motorized vehicles	All roads	Year round	Almost all car models are sold with automatic switching-on of dipped head lights but manually operated are acceptable.	40	8.69
France[7]	DRL recommended may become compulsory					114	24.53
Germany[7]	Only Motorcycles required to use DRL					48	14.28

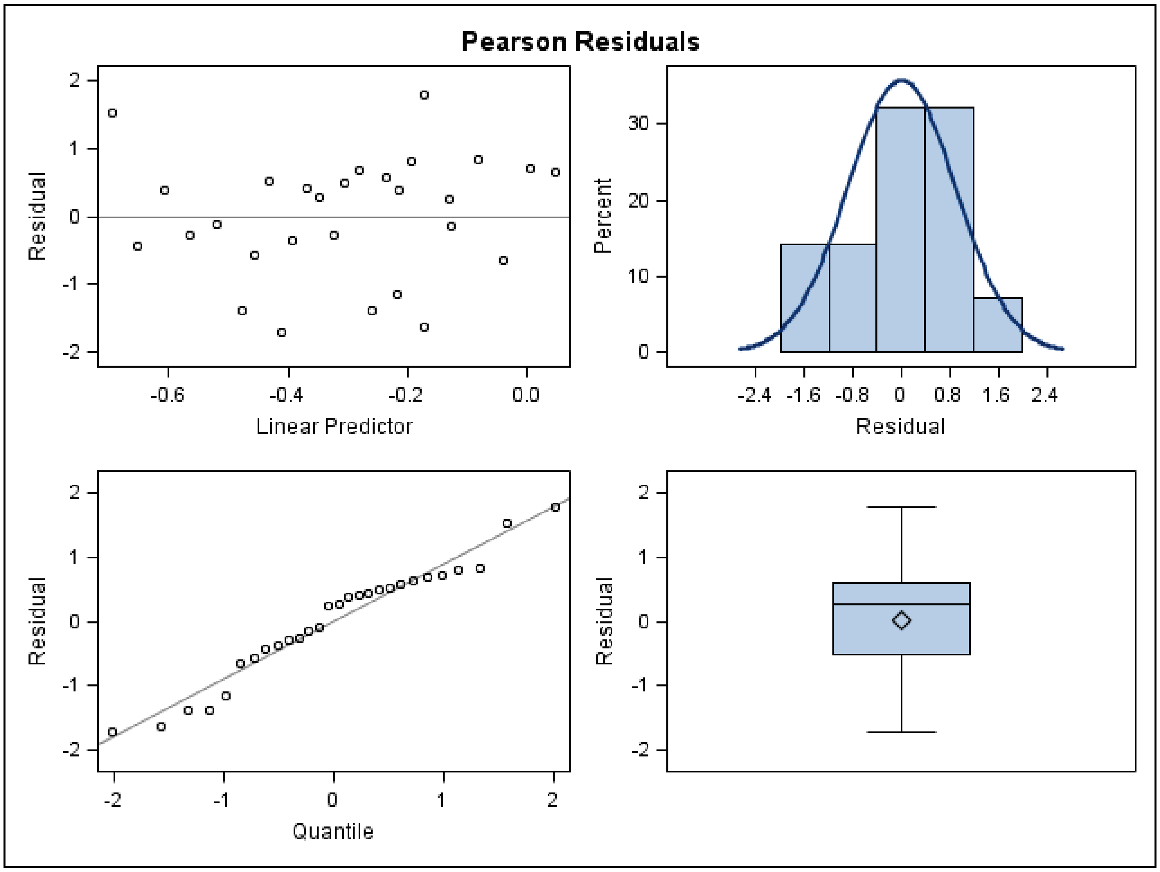
[7] Vis, M.A. and Van Gent, A.L. 2007

Country	Year DRL law initiated	Vehicle types	Road types	Season	Type of lights required	MC and PTW deaths per billion km traveled (2006)	Ratio of fatality rate per billion km ridden by MC and PTW riders compared to car drivers (2006)
Hungary[5]	1984 motorcycles 1993 for cars 1994 for other vehicles	All motorized vehicles	Outside of inhabited places (rural main roads) Motorcycles all roads.	Year round	Generally dipped beam; special daylight running bulb allowed. Lights are manually lit.	298	22.58
Israel[6]	1996	All motorized vehicles	a) For a two-wheeled vehicle, a taxi, a bus & a commercial vehicle – on all roads b) For all other vehicles – on inter-urban roads	November-March	Headlamps, dipped beams switched on manually by driver.	51	16.95
Italy[6]	June 2002	All vehicles on motorways (urban and rural) and primary rural highways. For motorcycles and scooters DRL are mandatory on all roads (urban and rural).		Year round	"Position lights"; "normal running lights" (which are the ones that you have to switch on to drive in the night or in motorways or primary rural highways); "high intensity lights (probably your straight lights)" these should never be used if another vehicle is coming towards us as he will be flashed by our lights. There are needed only for very dark roads	n/a	n/a
Latvia[7]	1996 DRL compulsory from October to April 1999 DRL compulsory at all times	All vehicle types	All roads	Year round		275	24.19

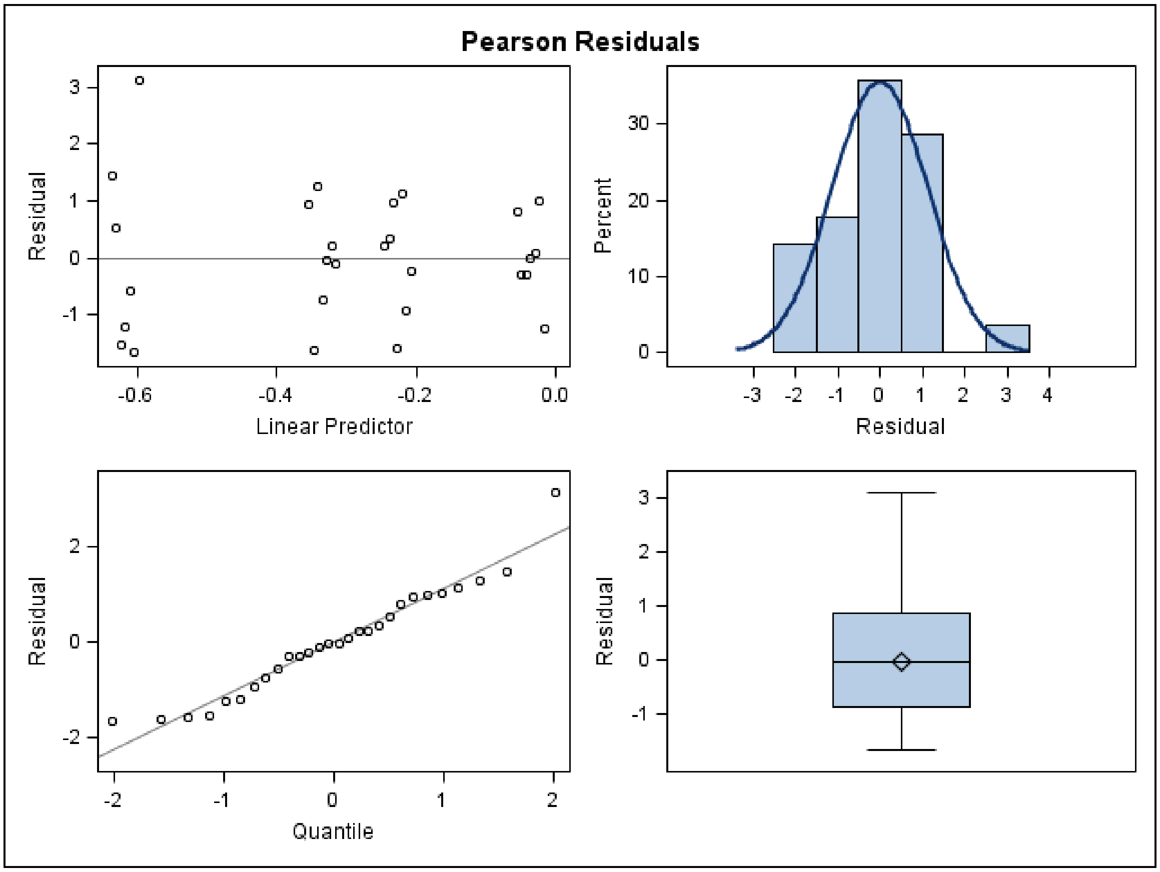
Country	Year DRL law initiated	Vehicle types	Road types	Season	Type of lights required	MC and PTW deaths per billion km traveled (2006)	Ratio of fatality rate per billion km ridden by MC and PTW riders compared to car drivers (2006)
Norway[6]	1985 new vehicles 1988 all vehicles	All motorized vehicles	All roads	Year round	Up to 1994 they had to be switched on automatically when one started the engine. Since we entering the EU in 1994 this rule was revised. Now the lights have to be lit, but they don't need to be switched on automatically	30	6.06
Poland[7]	Within in the last decade			October-February		193 (2005)	12.55 (2005)
Slovenia[7]	2005	All motorized vehicles			All new vehicles must have automated DRL	357 (2005)	51.06 (2005)
Sweden[5]	1977	All motorized vehicles	All roads	Year round	Most common DRL are standard low beams, but reduced low beams, special DRL lights and fog lights are also allowed. Manual switching is less common but allowed.	65	21.25

Appendix C: Residual Plots

1. Rural, Night

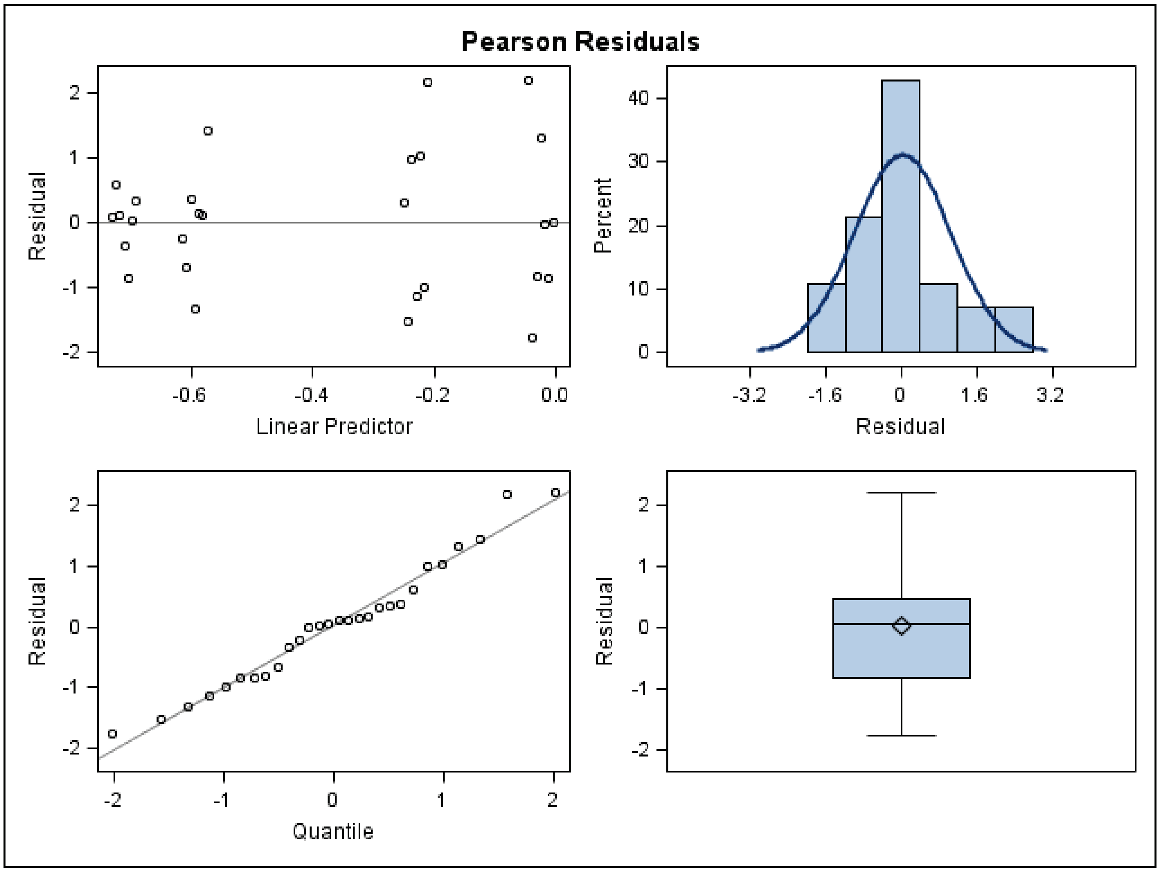


2. Rural, Day

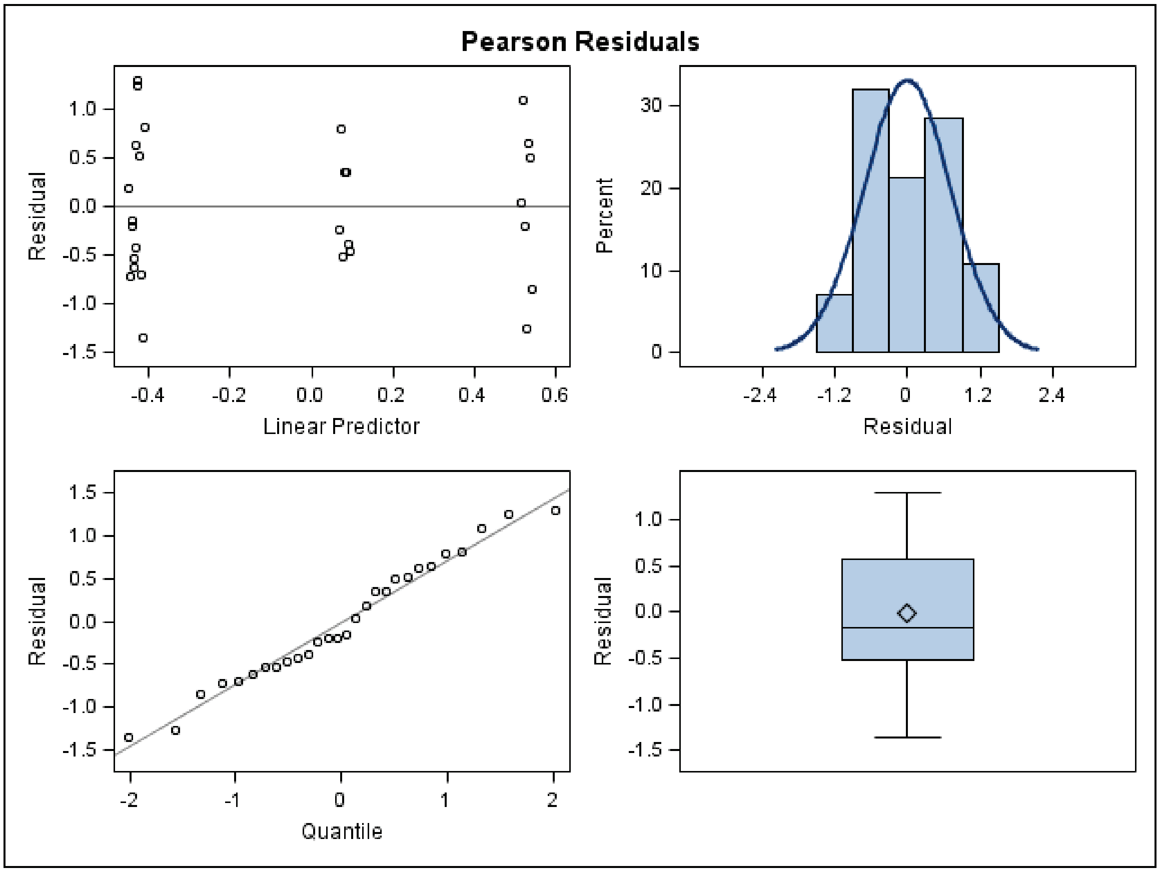


Pearson Residuals
Residual
Linear Predictor
-0.6
-0.4
-0.2
0.0
Percent
Residual
Residual
Quantile
Residual

3. Urban, Night



4. Urban, Day



Pearson Residuals
Residual
Linear Predictor
Percent
Residual
Residual
Quantile
Residual

Appendix D: Year to Year Observed DRL Relevance Proportions

Figure D1 shows the observed means by year for the four groups. The trend is slightly downward.

Figure D1. Year Trend in Observed DRL Proportions for Rural and Urban Crashes and Time of Day

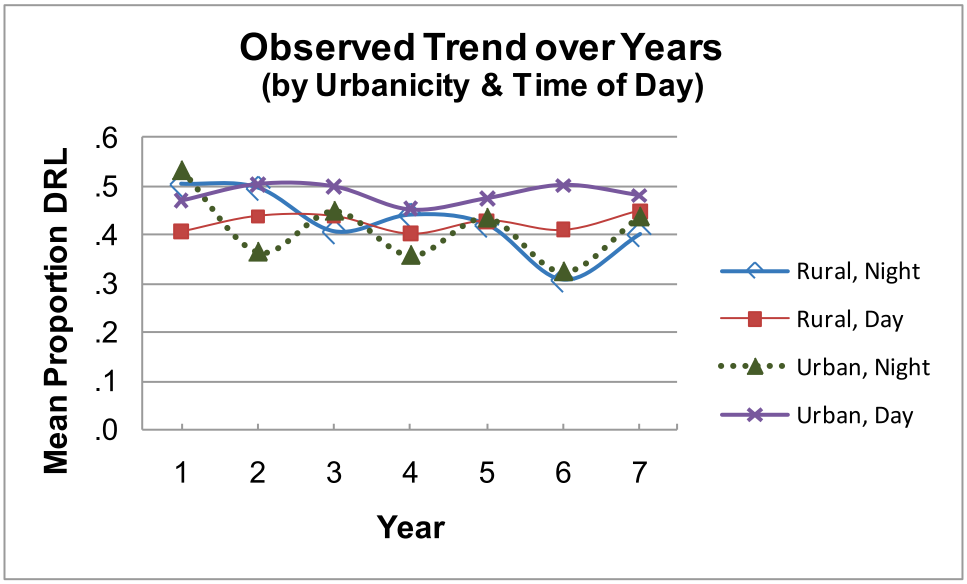
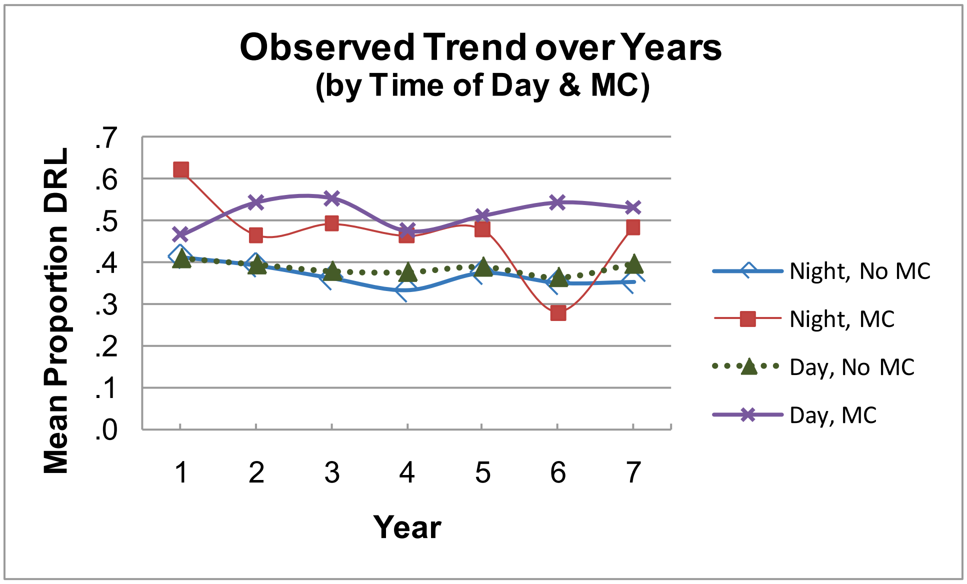


Figure D2. Year Trend in DRL Proportions for Non-Motorcycle versus Motorcycle Crashes



If we look at trends separately for crashes involving motorcycles (MC) and crashes not involving motorcycles (NoMC) by time of day, we see that the trend is flat for NonMC crashes during night or day. However, for motorcycle-involved crashes, the trend is slightly positive for daytime crashes. At night, the trend is negative.

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