UMTRI-2008-33 MAY 2008

TRENDS IN FATAL U.S. CRASHES IN DARKNESS: 1990 TO 2006

JOHN M. SULLIVAN
MICHAEL J. FLANNAGAN

UMTRI
UNIVERSITY OF MICHIGAN
TRANSPORTATION RESEARCH INSTITUTE

TRENDS IN FATAL U.S. CRASHES IN DARKNESS: 1990 to 2006

John M. Sullivan
Michael J. Flannagan

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

Report No. UMTRI-2008-33
May 2008

Technical Report Documentation Page

1. Report No. UMTRI-2008-33	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Trends in Fatal U.S. Crashes in Darkness: 1990 to 2006		5. Report Date May 2008
		6. Performing Organization Code 302753
7. Author(s) John M. Sullivan and Michael J. Flannagan		8. Performing Organization Report No. UMTRI-2008-33
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, MI 48109-2150 U.S.A		10. Work Unit no. (TRAIS)
		11. Contracts or Grant No.
12. Sponsoring Agency Name and Address The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety		13. Type of Report and Period Covered
		14. Sponsoring Agency Code

15. Supplementary Notes

The Affiliation Program currently includes Alps Automotive/Alpine Electronics, Autoliv, BMW, Chrysler, Com-Corp Industries, Continental Automotive Systems, Denso, Federal-Mogul, Ford, GE, General Motors, Gentex, Grote Industries, Hella, Hitachi America, Honda, Ichikoh Industries, Koito Manufacturing, Lang-Mekra North America, Magna Donnelly, Mitsubishi Motors, Muth, Nissan, North American Lighting, OSRAM Sylvania, Philips Lighting, Renault, SABIC Innovative Plastics, Sisecam, SL Corporation, Stanley Electric, Toyota Technical Center USA, Truck-Lite, Valeo, Visteon/ACH, and 3M Visibility and Insulation Solutions. Information about the Affiliation Program is available at: http://www.umich.edu/~industry/

16. Abstract

Fatal crash trends in the United States between 1990 and 2006 were examined for changes in the ratio of crashes in darkness to crashes in daylight to determine whether recent improvements in vehicle forward headlighting might have influenced the dark/light ratio. A general decline in the ratio was observed among all fatal crashes, although partitioning of the data suggests this trend is only present among crashes involving drinking drivers. In an analysis of pedestrian crashes, an increasing trend in the dark/light ratio was observed. When the data were further partitioned based on the age of the victim, a decline was observed among adult victims and increases were observed among children and older victims. These differences in the ratio trend suggest that the dark/light ratio may be influenced by many factors and it may be difficult to associate it with any one factor, such as improved vehicle lighting.

Further analyses examined dark/light ratio trends in fatal rural and urban pedestrian crashes. Sharp declines were observed in rural crashes; no change was observed in urban crashes. A comparison of interstate and noninterstate roadways found an overall declining trend, but no difference between road types. A comparison between luxury and nonluxury makes of vehicles found no difference between vehicle types, although a trend toward sharper decline was observed among luxury vehicles.

Although some of the results could be considered consistent with the hypothesis that improvements in forward vehicle lighting have contributed to improved safety in darkness, inconsistencies in these trends suggest that other factors also affect the dark/light ratio and that caution should be used in interpreting the ratio. Moreover, the proportion of U.S. vehicles equipped with improved headlamps may be too small to influence fleet-based crash data. Additional analyses are suggested to develop more direct evidence for associating safety improvements with forward lighting.

17. Key Words Pedestrian collisions, visibility, annual trends, headlighting, darkness, dark/light ratio		18. Distribution Statement Unlimited	
19. Security Classification (of this report) None	20. Security Classification (of this page) None	21. No. of Pages 30	22. Price

Acknowledgements

Appreciation is extended to the members of the University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety for support of this research. The current members of the Program are:

Alps Automotive/Alpine Electronics	Lang-Mekra North America
Autoliv	Magna Donnelly
BMW	Mitsubishi Motors
Chrysler	Muth
Com-Corp Industries	Nissan
Continental Automotive Systems	North American Lighting
Denso	OSRAM Sylvania
Federal-Mogul	Philips Lighting
Ford	Renault
GE	SABIC Innovative Plastics
General Motors	Sisecam
Gentex	SL Corporation
Grote Industries	Stanley Electric
Hella	Toyota Technical Center, USA
Hitachi America	Truck-Lite
Honda	Valeo
Ichikoh Industries	Visteon/ACH
Koito Manufacturing	3M Visibility and Insulation Solutions

Contents

Acknowledgements ii
Introduction 1
The trend in fatal crashes using the dark/light ratio 4
The trend in fatal adult pedestrian crashes 9
The trend in fatal pedestrian crashes in rural and urban areas 14
The trend in fatal pedestrian crashes on interstate and noninterstate roadways 16
The trend among luxury and nonluxury vehicles 18
Conclusions 23
References 26

Introduction

As changes are made in vehicle designs to improve driver safety, it is reasonable to expect that the effect of such changes will eventually be observed in the vehicle crash record as a decline in crash risk. However, the simple observation of such declines can be complicated by other trends that also affect crash risk per mile over periods of several years. Thus, while it may be expected that, in the United States, vehicles have become more crashworthy over time, it is also true that there are also increasing numbers of vehicles and vehicle miles, creating more opportunities for crashes. Increasing traffic density is but one of many changes that likely influence traffic safety in the U.S. Other changes include shifts in driver population demographics, changes in roadway infrastructure design and capacity, changes in licensing policies and penalties, and increased availability of both passive and active safety improvements in vehicle design. Consequently, associating a safety benefit with a particular design change often involves a delicate process of identifying and offsetting the influence of several other factors that might affect the crash rate to varying degrees. This is frequently accomplished by selecting crash scenarios that are relevant to the design feature, and by contrasting crash rates with suitable control groups.

This report examines trends in fatal crashes in darkness in the U.S. to see whether the decline in fatal crashes at night observed in Germany between 1991 and 2002 (Lerner, Albrecht, & Evers, 2005) might also be found in the U.S. (see Figure 1). The figure shows that, in Germany, there have been declines in both daytime and nighttime fatal crashes, and that the nighttime declines appear to have been sharper than the daytime declines. The difference in the rate of decline is illustrated by a decrease in the night/day crash ratio. Of particular interest is whether the strong nighttime decline can be related to improvements over the last decade in forward vehicle lighting. For example, photometric improvements have been reported for both tungsten-halogen (TH) and high intensity discharge (HID) low beam headlamps (Sivak, Schoettle, & Flannagan, 2004). Additional improvements include the increasing availability of HID headlamps as either standard or optional equipment on more vehicle models, as well as, in the U.S., the introduction of visually aimable headlamps. The present analysis was conducted using

Fatality Analysis Reporting System (FARS) crash datasets from 1990 to 2006, provided by the National Traffic Safety Administration (NHTSA).

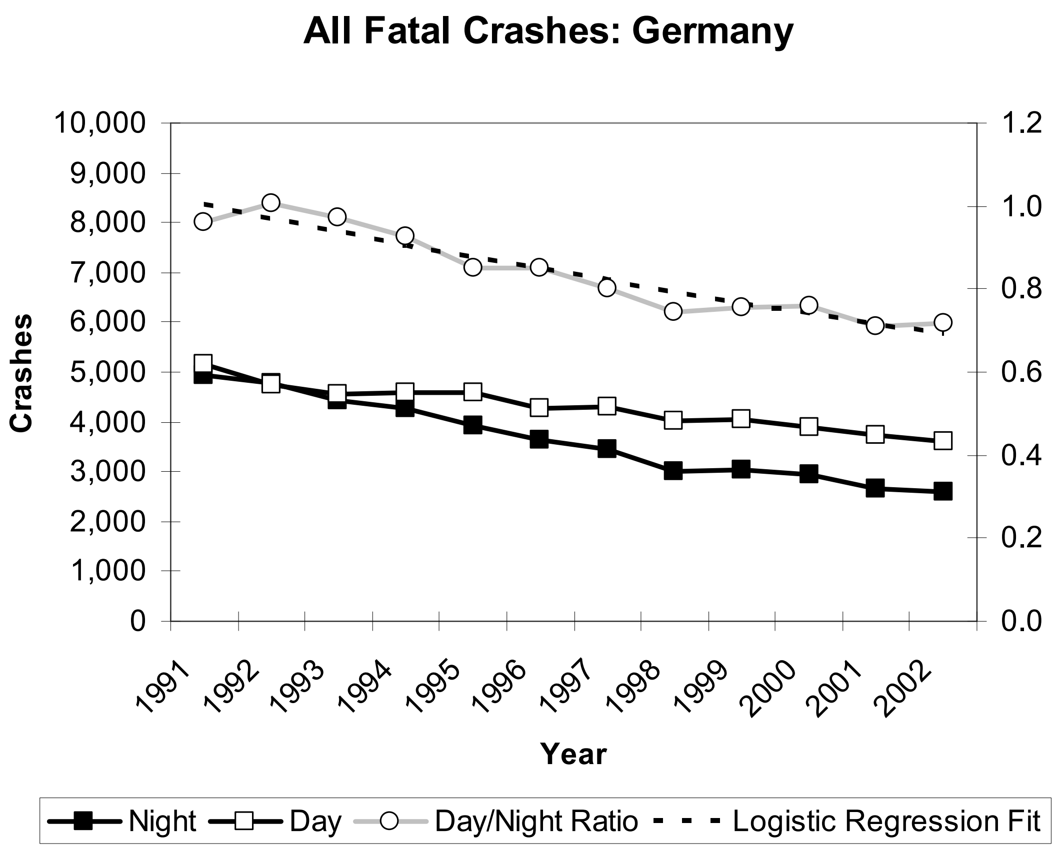

Figure 1. The number of fatal crashes in Germany in daytime (open squares) and at night (filled squares) between 1991 and 2002 (data taken from Lerner et al., 2005). The night/day ratio (open circles) is shown along with the fit from a logistic regression.

The approach taken in the analyses presented here was to first examine the overall crash trends in darkness and light between 1990 and 2006 in the broadest terms, and then make successive refinements of the analysis to selectively examine crashes in which visibility in darkness is known to play a prominent role. One simple way to examine trends over time would be to look at raw crash counts during daylight and darkness; if the raw numbers drop, a decline in risk may be responsible. However, if there is also an increase in the driver population concurrent with a decline in crash risk, crash count alone may imply that no change has occurred or that risk is increasing. This appears to be the situation in the U.S. While the fatality level has been relatively flat since 1993 (filled squares in Figure 2), there has been a steady increase in both the numbers of licensed drivers and in the estimated number of vehicle miles driven since 1990. There were approximately 21% more licensed drivers and 41% more miles driven in 2006 than there were in 1990. If the number of crashes is normalized by estimates of vehicle miles traveled, there is a consistent downward trend: While the absolute number of fatalities has actually declined by only 4% (filled squares in Figure 2), the number of fatalities per miles driven has declined by about 32% (open circles). The decline in the U.S., while good news, is much lower than the decline reported in Germany (Lerner et al., 2005)—about 38% in absolute numbers between 1991 and 2002. Similar declines have also been noted in other European countries (Sivak et al., 2007).

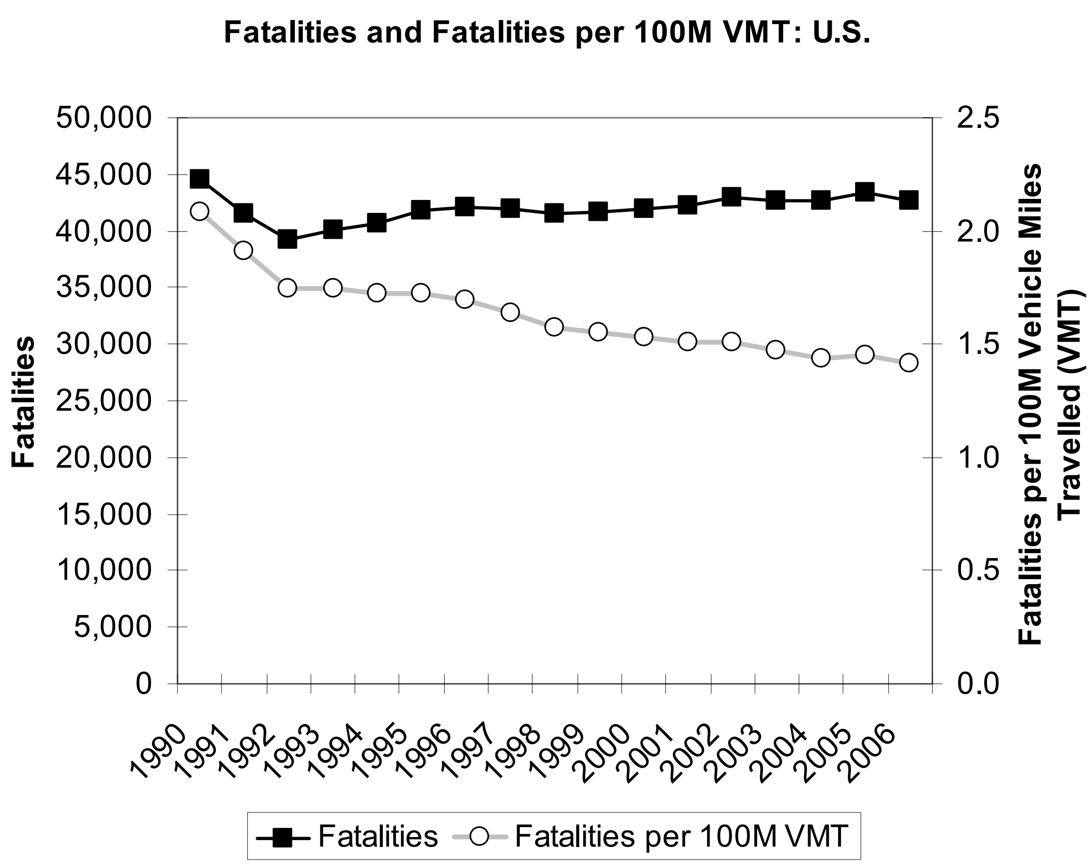

Figure 2. The number of fatalities (filled squares) and the number of fatalities per 100 million vehicle miles travelled (open circles) in the U.S. between 1990 and 2006.

The trend in fatal crashes using the dark/light ratio

One important aspect of the overall crash situation is the change in the ratio of night to day crashes on a year-by-year basis. A simple interpretation of that ratio can be based on an assumption that driver exposure levels between night and day have been proportionately stable over the years examined. That is, drivers were just as likely to drive at night in 2006 as they were in 1990; and drivers accumulated the same proportion of miles at night in 2006 as in 1990. Although it is unlikely that this assumption is completely true, it is difficult to obtain data to accurately quantify night and day exposure levels over the 17-year period examined here. For example, there is evidence that driver licensing policies have altered the dark/light exposure levels of younger drivers over this period of time. Through the 1990s, many states instituted graduated driver licensing programs that restrict the hours a novice driver is permitted to drive unaccompanied. As graduated licensing was adopted throughout the 1990s, nighttime crash rates among younger drivers declined in many states (Shope, 2007; Shope & Molnar, 2003), a likely consequence of changes in the number of young drivers on the road at night.

Thus, it should be understood that there are uncertainties about how nighttime and daytime exposure has varied over the years, and that the assumption that they are fixed is not entirely correct and may be somewhat risky. However, if it is assumed (for now) that day and night exposure levels are either unchanged, or have changed very little, the ratio of night to day crashes could help identify nighttime trends while balancing out the increase in the overall number of fatal crashes over this time. As will be shown in some later analyses, this assumption may be problematic.

For partitioning crash data, it is important to be careful about how day and night are defined. In some analyses, daytime is identified as the period of time between 6:00 a.m. and 6:00 p.m., and nighttime as 6:00 p.m. to 6:00 a.m. (e.g., Longthorne, Varghese, & Shankar, 2007). Because this report is specifically concerned with understanding how vehicle headlighting may have influenced safety, it is more helpful to distinguish periods of time in which headlighting is most likely active (i.e., in darkness) compared to periods of time in which headlighting is not likely to be active (i.e., in daylight). Especially in the summer months, when daylight lasts well into the evening, nominal nighttime could contain a substantial amount of daylight; and in winter, daytime could contain a substantial amount of darkness. Comparisons between crashes in periods of darkness versus daylight are more likely to reflect periods of headlamp use and headlamp nonuse than simple temporally-based comparisons. In the following analysis, a data field indicating light conditions present when a crash occurred (LGT_COND) in the FARS dataset is used to distinguish periods of light and dark. This field identifies ambient light conditions as: daylight, dark, dark-with-lights, dawn, dusk, and unknown. The following analyses use *daylight* to indicate the light condition and *dark* for the dark condition, and exclude *dark-with-lights, dawn, dusk,* and *unknown* from the analysis.

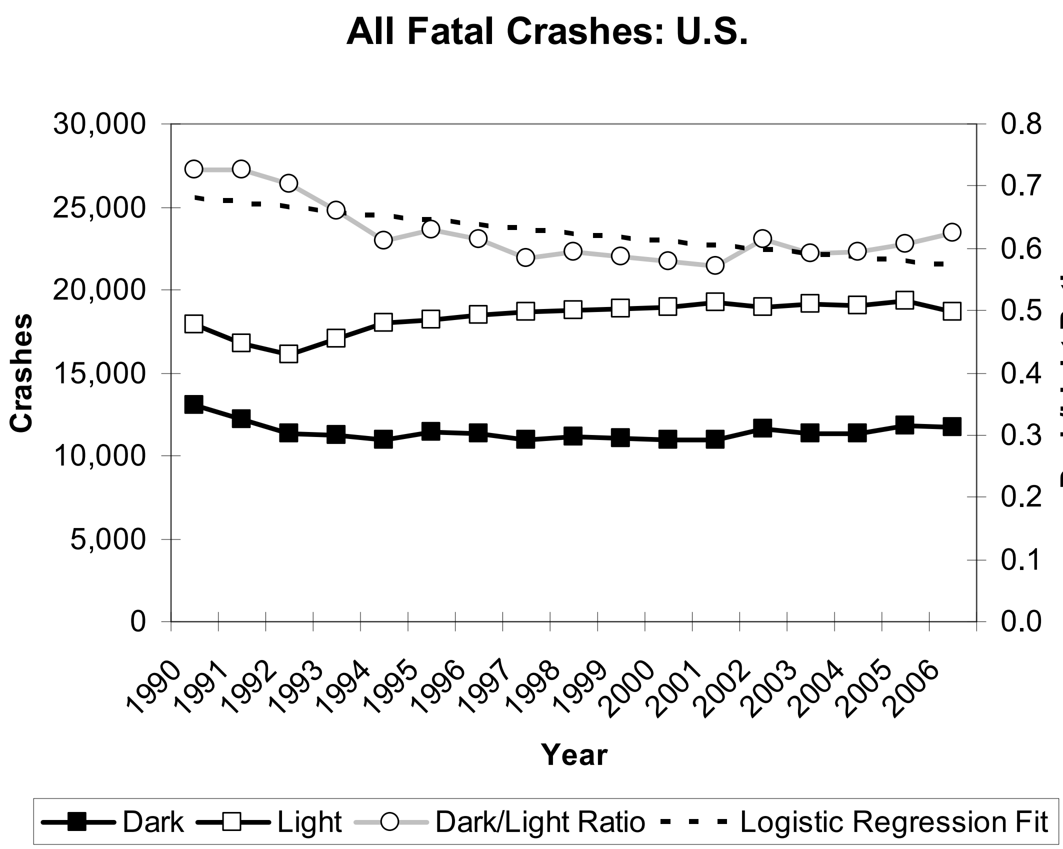

Figure 3. The number of all fatal crashes in the U.S. between 1990 and 2006 in the light (open squares) and in the dark (filled squares). The dark/light ratio is also shown (open circles), plotted on the right axis along with the fit from a logistic regression.

Figure 3 shows the number of fatal crashes occurring during dark and light periods along with the dark/light ratio (the odds) for each year. A logistic regression analysis modeled the odds of a crash in darkness as a function of the year of the crash. A reliable overall decline was found in the odds of a crash in darkness of about 1% per year

(Wald $\chi^2 = 334.9$, $p < .001$). The trend appears to level off in 1994—indeed an analysis spanning the years 1994 to 2006 suggests that no trend exists over those years.

A follow-up analysis examined the trend in more detail to determine whether the observed decline is the same among crash subpopulations. Crashes were partitioned into two categories based on whether any of the drivers involved were suspected of drinking (from the FARS data field, DR_DRINK), creating drinking and no-drinking crashes. The resulting trends are shown in Figure 4 and Figure 5. Among the crashes involving no drinking drivers, the annual trend is positive (Wald $\chi^2 = 5.17$, $p < .05$), increasing by about 0.2% per year. For the drinking drivers, the annual trend is negative (Wald $\chi^2 = 32.78$, $p < .01$), decreasing by about 0.6% per year. Thus it appears that there are proportionally greater declines in the number of crashes in darkness that involve drinking drivers compared to daytime over the 17-year period. Although it might be argued that the declining trend among crashes with drinking drivers is evidence for improved forward visibility in darkness, the fact that a similar effect is not also observed among crashes with no drinking drivers makes this interpretation somewhat doubtful.

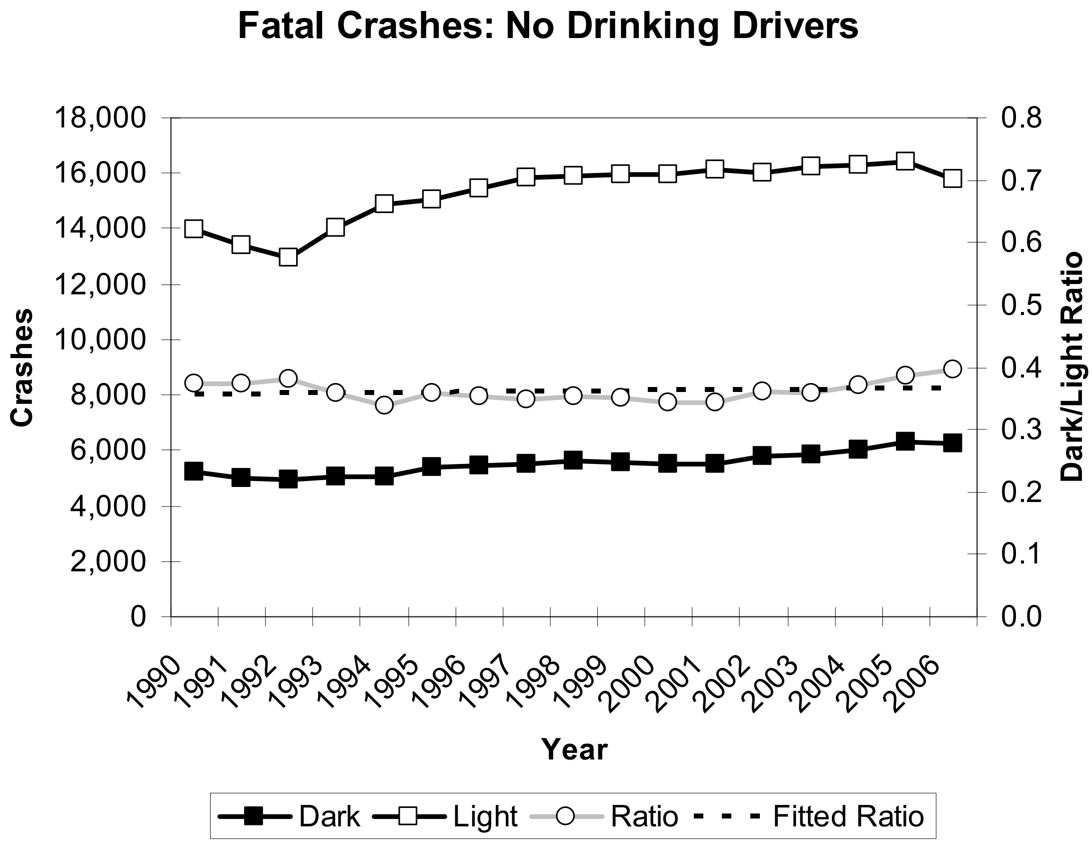

Figure 4. Trends in the dark/light distribution of fatal crashes involving no drinking drivers in darkness (filled squares) and daylight (open squares). The dark/light ratio is shown (open circles) on the right axis.

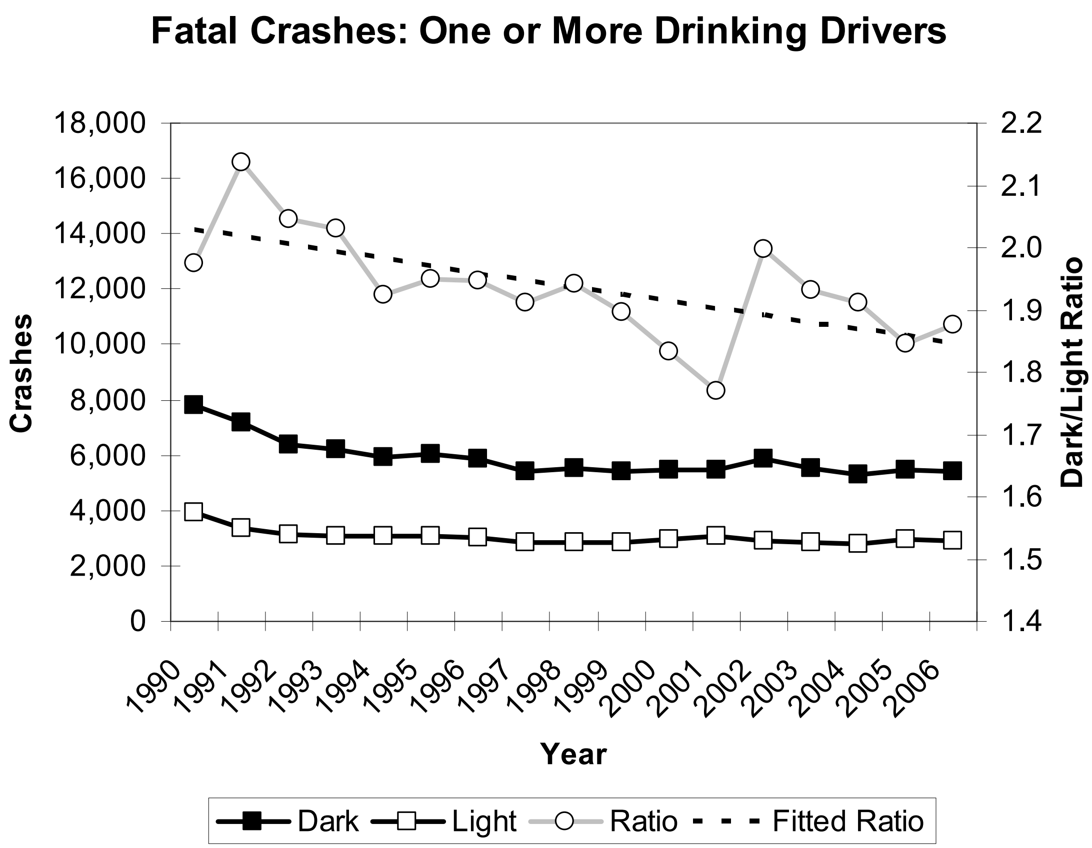

Figure 5. Trends in the dark/light distribution of fatal crashes involving at least one drinking driver in darkness (filled squares) and daylight (open squares). The dark/light ratio is shown (open circles) on the right axis.

A possible concern with this analysis is that all crashes should not benefit equally from improved forward visibility. For example, the incidence of backing collisions is presumably unrelated to forward visibility, yet they are included in the foregoing analyses. Perhaps by pooling all crashes improvements in traffic safety in darkness have been obscured. Previous reports (Sullivan & Flannagan, 1999, 2001, 2006) have shown that some crashes are substantially more sensitive to ambient light level than others. This suggests that some crashes should benefit more than others from improved forward lighting. If the analysis is restricted to include only collisions in which light level is known to play an influential role in crash risk, perhaps a more coherent picture of the trend in dark/light ratios might emerge.

In the next sections, the analysis is refined to focus on fatal pedestrian crash scenarios, which have been found to be highly reactive to ambient light conditions. First, we examine all single-vehicle fatal pedestrian crashes. If forward vehicle lighting has improved significantly over the 17-year period covered by the current analysis, it is most likely to be seen among crashes where the risk is greatest in darkness. Further pedestrian crash scenarios will compare changes in the dark/light crash odds on rural and urban roadways and on interstate and noninterstate roadways. Rural roadways are expected to be less well lit than urban roadways, and thus have an increased risk in darkness; the high speeds of interstates increase the risk in darkness because at high speeds, the limited range of low-beam headlamps allows less time to react to pedestrians suddenly revealed by a headlamp beam.

The trend in fatal adult pedestrian crashes

In this analysis, single-vehicle collisions involving pedestrian fatalities were compiled for each year from 1990 to 2006. Pedestrians of all ages were included in an initial analysis. The resulting trend in dark/light ratio appears to increase over the years, while absolute levels of both dark and light crash fatalities decline. This is shown in Figure 6. On the face of it, the increasing ratio seems to suggest that safety in darkness is getting comparatively worse than daylight safety. As before, it might be useful to partition the data to determine whether the trends observed differ among subgroups of pedestrian crashes.

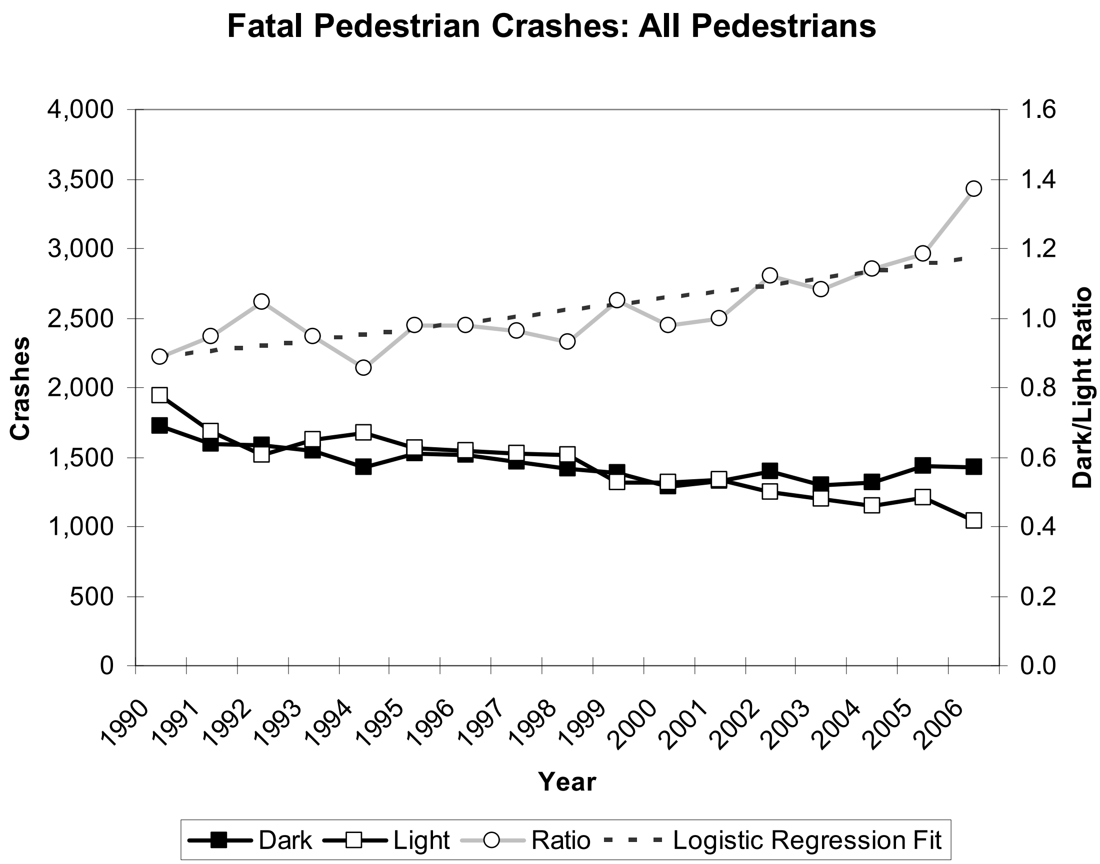

Figure 6. The number of all fatal crashes between 1990 and 2006 in the light (open squares) and in the dark (filled squares). The dark/light ratio is also shown (open circles), plotted on the right axis along with the fit from a logistic regression.

In prior analyses of pedestrian crashes using daylight saving time (Sullivan & Flannagan, 2006), it was determined that the dark/light crash risk of young (under 18 years old) pedestrians was less than that of adult (18-65 years old) and older (older then 65 years) pedestrians. One explanation for this was that children's exposure to darkness may be limited by their parents—when it is dark, children are often required by parents to go indoors regardless of clock time. Thus, the observed dark/light risk may be smaller for children, in part, because their exposure to darkness is explicitly regulated. Although it is doubtful that children's reduced exposure to darkness would directly influence changes in dark/light crash ratios over the years, the limited measurable influence of light on such crashes suggests that separating this subgroup may be reasonable. It may likewise be reasonable to separate older pedestrians, whose daily patterns of activity may be less driven by time schedules than those of younger adults.

Fatal pedestrian crashes were partitioned into three groups—young, older, and adult—based on the age of the pedestrian victim. In cases involving multiple victims, the maximum-aged victim was used. As in Sullivan and Flannagan (2006), the young group was less than 18 years of age, the adult group was between 18 and 65, and the older group over 65. A logistic regression was conducted in which the dark/light ratio was modeled as a function of crash year, age group, and the interaction between crash year and age group. The results are shown in Table 1. Notably, the three age groups show different trends. There appears to be a strong increase in the dark/light ratio among the young pedestrians (Figure 7), 5% per year; a lesser increase among older pedestrians (Figure 8), about 2% per year; and a decrease in the adult pedestrian trend (Figure 9), about 0.7% per year.

Table 1
Results of a logistic regression indicating effects of year, age group and an interaction between year and age group. The interaction indicates that the annual trend in dark/light ratio differs among the three age groups.

Parameter		***df***	**Estimate**	**S.E.**	**Wald χ^2**	**Pr > χ^2**
Intercept		1	14.808	5.113	8.388	0.0038
Year		1	-0.007	0.003	7.574	0.0059
Age Group	**(Older)**	1	-43.931	10.096	18.935	<.0001
Age Group	**(Young)**	1	-107.380	11.739	83.671	<.0001
Year*Age Group	**(Older)**	1	0.021	0.005	17.425	<.0001
Year*Age Group	**(Young)**	1	0.053	0.006	80.794	<.0001

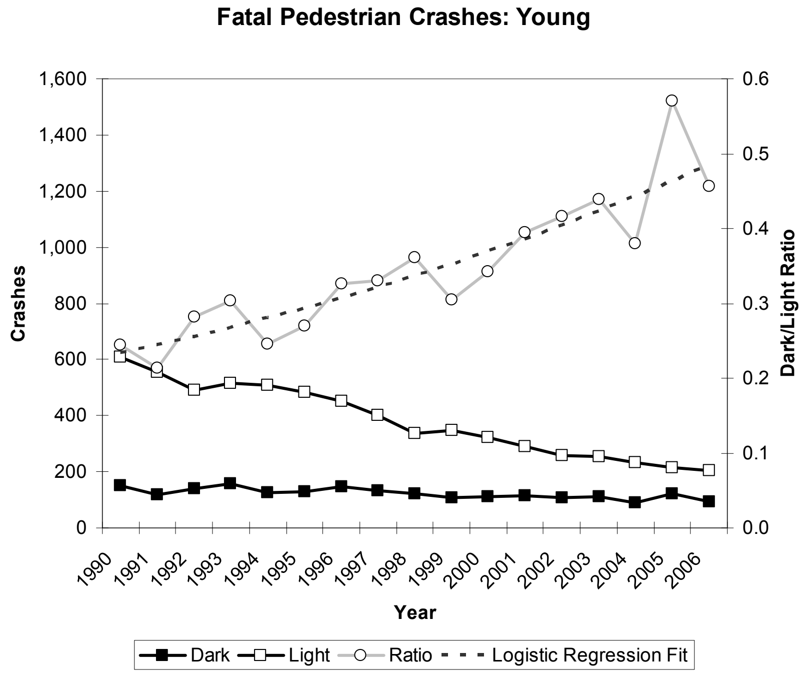

Figure 7. Annual count of fatal pedestrian crashes in darkness (closed squares) and in light (open squares) in which the pedestrian is less than 18 years of age. The dark/light ratio (open circles) is plotted on the right axis with the fit of a logistic regression.

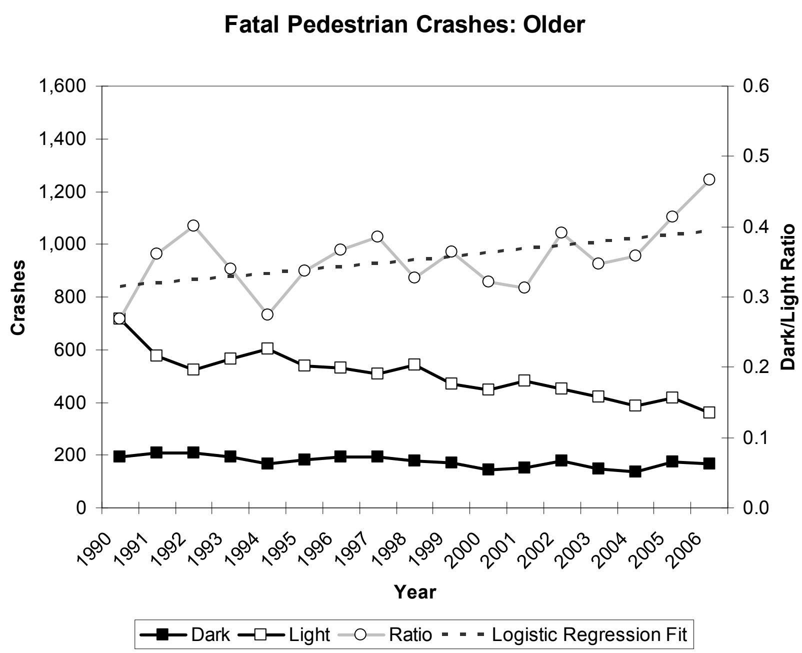

Figure 8. Annual counts of fatal pedestrian crashes in darkness (closed squares) and in light (open squares) in which the pedestrian is greater than 65 years of age. The dark/light ratio (open circles) is plotted on the right axis with the fit of a logistic regression.

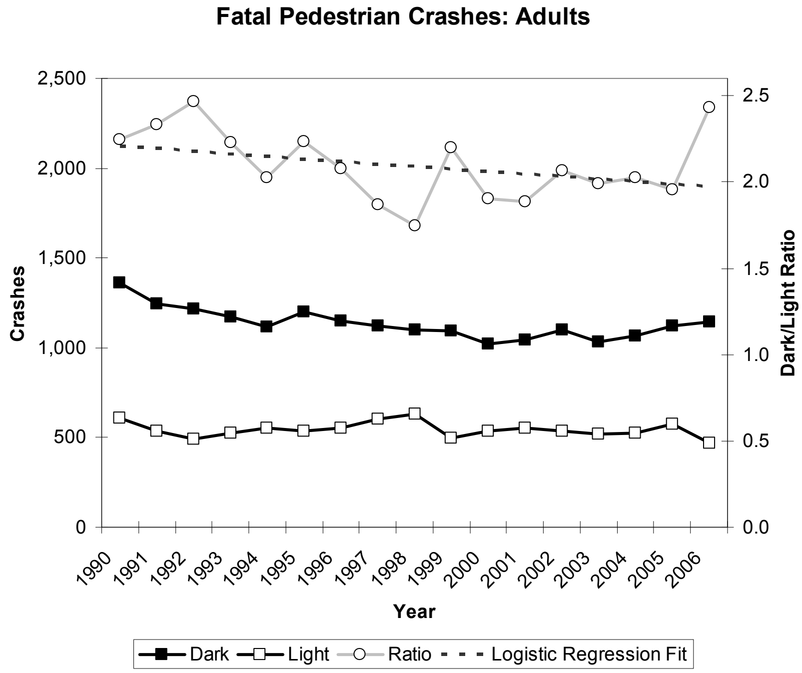

Figure 9. Annual counts of single-vehicle fatal adult (ages 18-65) pedestrian crashes occurring in darkness (closed squares) and daylight (open squares). The dark/light ratio (open circles) is plotted on the right axis along with the fit from a logistic regression.

The observed differences among the three pedestrian populations are not predicted by a simple model that associates any trends in the dark/light ratio with improvement in forward vehicle lighting. Despite narrowing the analysis to examine crashes in which light level is believed to be highly influential, it seems that other factors particular to each group influence the ratio. One admittedly *post hoc* explanation of the increase in the ratio among children is that daylight exposure to traffic is declining because fewer children walk to school (U.S. Centers for Disease Control and Prevention, 2008). There have also been indications that the proportion of time children spend in nondiscretionary activities (e.g., school/daycare, sleeping, eating, personal care) and in structured activities (e.g., sports, supervised art) has been increasing, leaving less time for unstructured play (Hofferth & Sandberg, 2000). If it assumed that such structured activities generally occur in daylight, it is possible that the decline in unstructured play in daylight may have also led to declines in children's daylight exposure to traffic. Although this explanation may account for the trend observed in children, explanations of the trends found among the older and adult populations are less clear. While changes in forward vehicle lighting might play some role in the observed trends, it is unclear why they would affect the adults and older drivers in opposite directions. More likely, the observed trends are products of myriad and complex influences associated with shifting driver-population demographics, trends in leisure-time activity, roadway infrastructure changes, and changes in law enforcement policies, to name a few. It is unclear whether the influence of broad trends in improved forward lighting across each year's vehicle fleet would be sufficiently large to dominate the influence of many of these other possible factors.

In the following analyses, pedestrian crashes involving children and older pedestrians have been excluded. Arguably, these two populations of pedestrians may have less routine patterns of exposure to traffic than adult pedestrians, whose schedule may be more restricted by employment.

The trend in fatal pedestrian crashes in rural and urban areas

Several key differences between urban and rural areas make crashes in rural areas more sensitive to light level than those in urban areas. Rural roadways are less frequently illuminated by roadway lighting or any other commercial lighting, have generally higher posted speed limits, and are often less well designed than roadways around urban areas that must sustain higher traffic volumes. Although limiting the analysis to crashes that only occur in darkness (i.e., without road lighting) may reduce some of the differences between rural and urban locales, it is likely that even unlighted roadways in urban areas enjoy some indirect lighting from nonroadway illumination. If improvement in forward vehicle lighting plays a role in reducing the dark/light ratio over time, it is more likely to be seen among crashes in rural areas than in urban areas. Thus, a logistic regression modeling year and location was conducted on crashes involving a collision between a single vehicle and an adult pedestrian in rural and urban locales.

The crash counts for dark and light periods in rural areas are shown in Figure 10 along with the observed dark/light ratio. Figure 11 shows the same data for urban areas. A logistic regression modeling the odds of a crash in darkness as function of crash year and location (rural/urban) found a main effect of locale (Wald $\chi^2 = 8.40$, $p < .01$) and an interaction between locale and year (Wald $\chi^2 = 7.9$, $p < .01$). As shown in Figures 10 and

11, in rural areas the odds that a fatal pedestrian crash occurred in darkness are much higher than in urban areas. The significant interaction indicates that in rural areas the ratio is declining, whereas in urban areas the trend is not different from zero. One troubling aspect of the rural decline is that it appears to be nonlinear: While the ratio trend seems to have declined between 1990 and 1998, it also appears to have increased between 1998 and 2006. Assuming that market penetration of improved forward lighting has been monotonically increasing, especially in more recent years, the pattern is not fully consistent with the hypothesis that the ratio is largely influenced by improved forward lighting. As was shown for different pedestrian age groups, it is likely that other factors are influencing the observed trend.

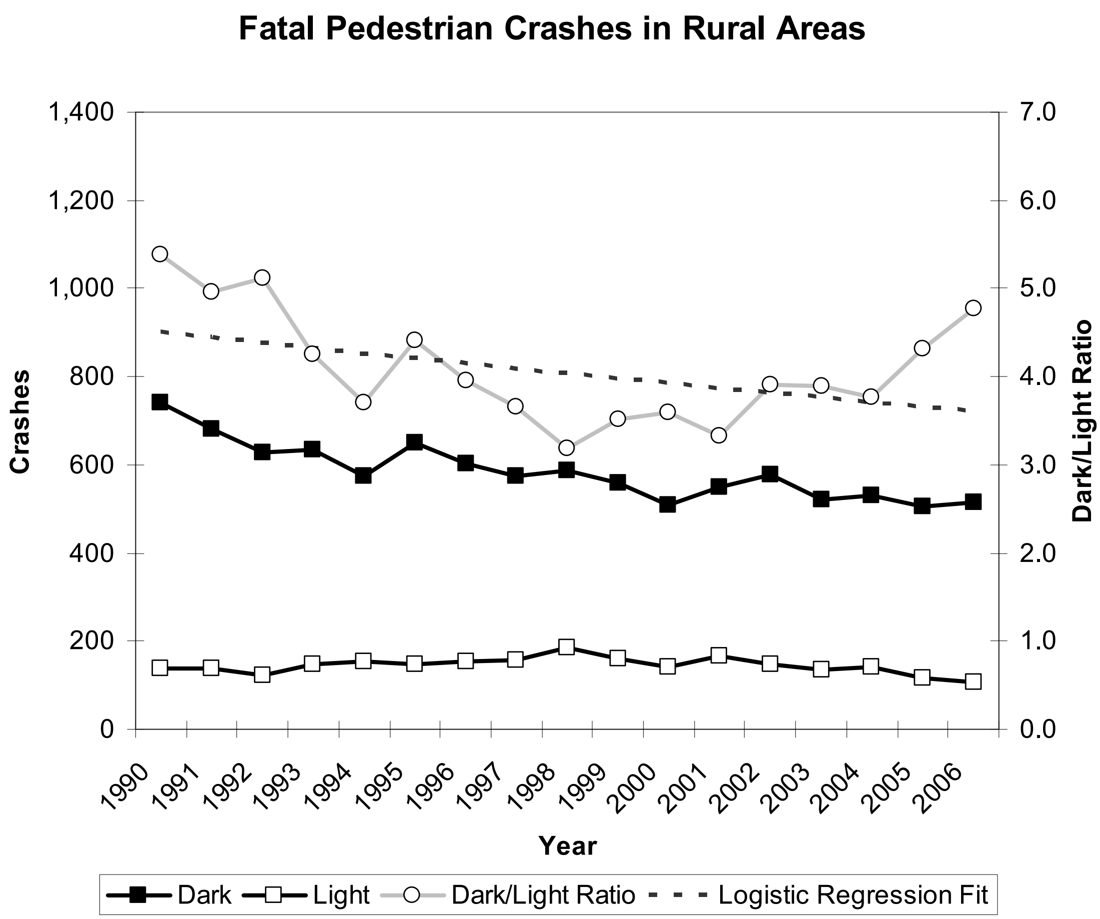

Figure 10. Annual count of fatal pedestrian crashes in rural areas occurring in darkness (closed squares) and in daylight (open squares). The dark/light ratio (open circles) is plotted along the right axis along with the fit from a logistic regression.

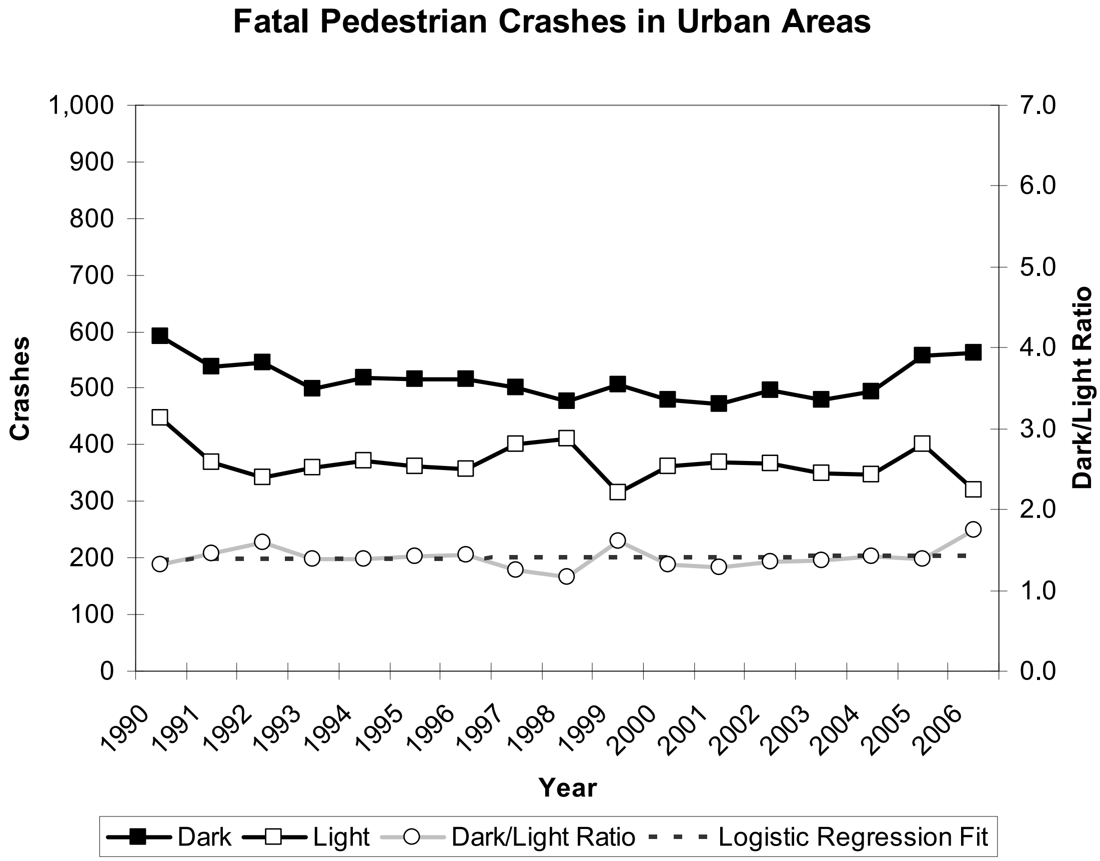

Figure 11. Annual count of fatal pedestrian crashes in urban areas occurring in darkness (closed squares) and in daylight (open squares). The dark/light ratio (open circles) is plotted along the right axis along with the fit from a logistic regression.

The trend in fatal pedestrian crashes on interstate and noninterstate roadways

In this analysis, fatal pedestrian crashes along interstates are compared to noninterstate crashes. In previous reports (Sullivan & Flannagan, 2001, 2007), high travel speed was identified as a factor that contributed to the sensitivity of a crash to ambient light. Based on the daylight saving time analysis, in which other nighttime factors are controlled, the ratio between fatal crashes in darkness on interstates is as much as five times that of crash levels in daylight. The cases selected in this analysis are the same as those used in the preceding rural/urban analysis; they are partitioned differently to highlight the possible role of speed as a risk factor in the analysis. It is expected that if forward visibility is improving, this might be more evident among fatal pedestrian crashes involving the high speeds that are characteristic of interstates.

Fatal pedestrian crash counts for dark and light periods on interstates and noninterstate roadways are shown in Figure 12 and Figure 13, respectively. There is a large difference in the absolute number of crashes recorded on each roadway type—over the 17-year span, only about 20% of the fatal crashes occurred on interstate roadways. Thus, pedestrian crashes on interstates are a relatively rare. Differences between the observed dark/light ratios on each roadway are less clear—while the dark/light ratios on interstates are generally higher, they are also much noisier, a likely consequence of the smaller number of crashes. A logistic regression model relating dark/light odds to year, roadway type, and the interaction found an effect of year (Wald $\chi^2 = 4.3$, $p < .05$), but no strong effect of roadway type, nor an interaction between roadway type and year. Although the observed decline in the dark/light ratio on interstates appears to be sharper than on noninterstate roadways, it is not statistically reliable.

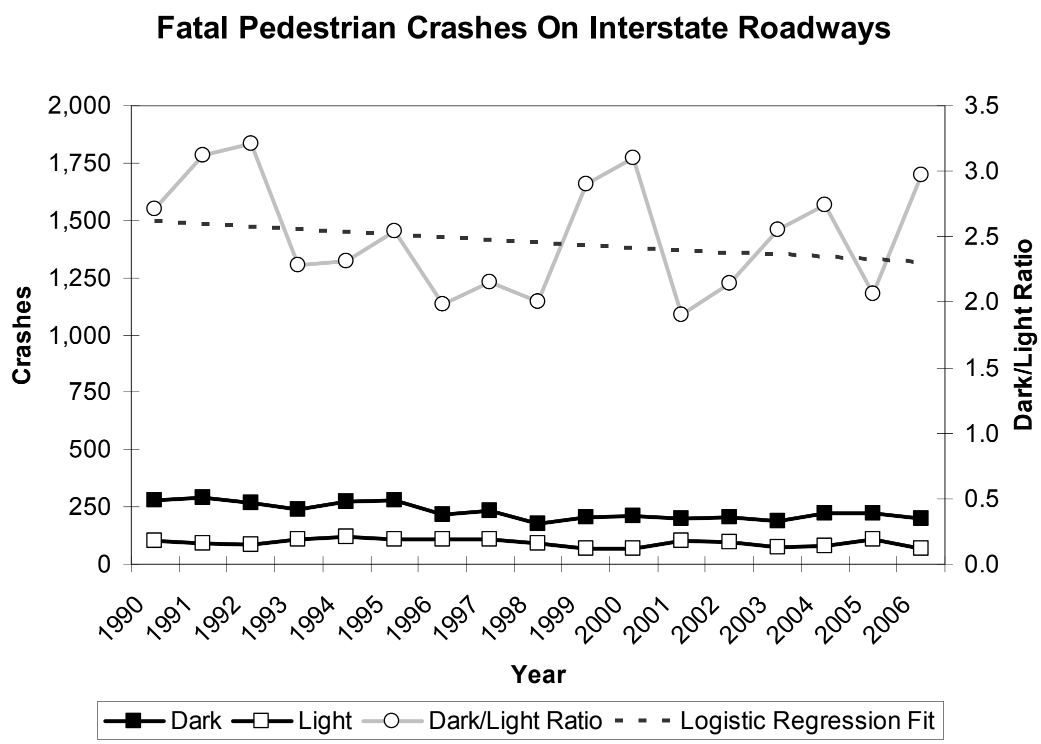

Figure 12. Annual count of fatal pedestrian crashes on interstate roadways occurring in darkness (filled squares) and in daylight (open squares). The dark/light ratio (open circles) is plotted along the right axis along with the fit from a logistic regression (dashed line).

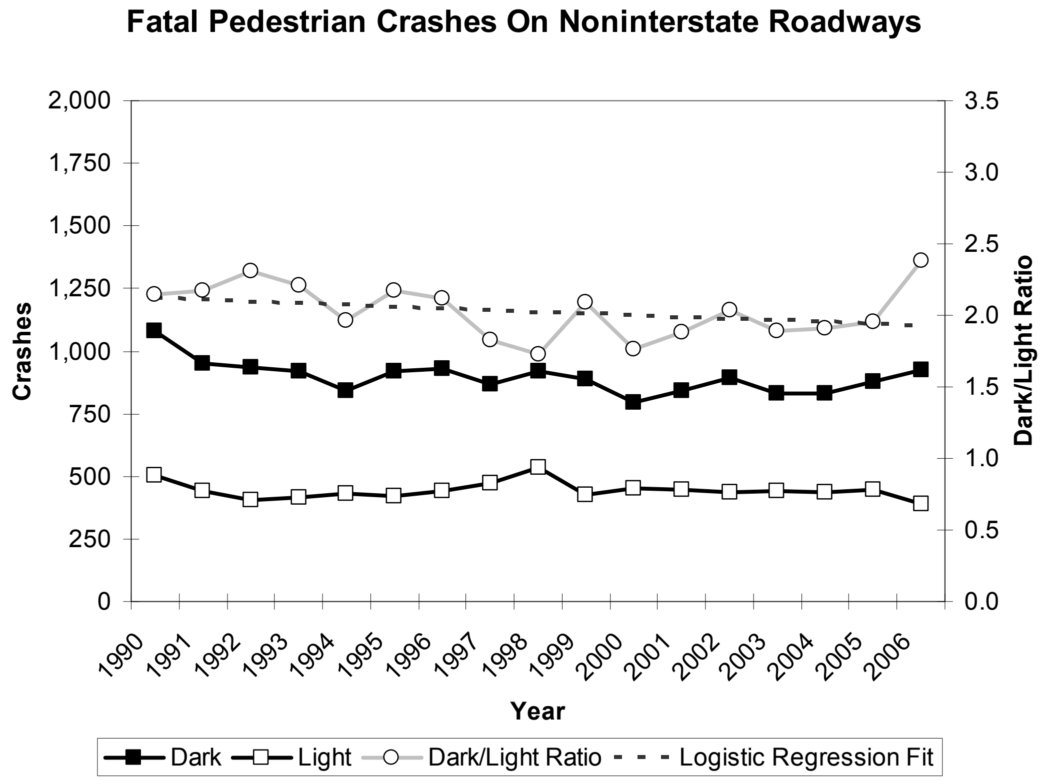

Figure 13. Annual count of fatal pedestrian crashes on noninterstate roadways occurring in darkness (filled squares) and in daylight (open squares). The dark/light ratio (open circles) is plotted along the right axis along with the fit from a logistic regression (dashed line).

The trend among luxury and nonluxury vehicles

Many vehicle design innovations are first introduced in luxury vehicle models and then gradually penetrate the rest of the vehicle market. The same is true of innovative lighting designs. Thus, HID sources are commonly offered first on luxury vehicles, and then later they might be offered on nonluxury vehicles. One possible reason that the preceding analyses show no consistent safety improvement in darkness could be that the sample of vehicles on the road includes only a small fraction with improved forward lighting. If the analysis is further focused on luxury-make vehicles, where forward lighting improvements are most likely to appear in recent years, perhaps then a stronger safety trend may be observed. The following analysis therefore narrows the focus to single-vehicle fatal pedestrian crashes that involve luxury vehicle makes.

For this analysis, passenger cars and light trucks were identified as luxury or nonluxury based on the vehicle's manufacturer. The set of vehicle maker codes used in FARS changed in 1991; consequently, different maker lists were applied to the 1990 crash data from those used for 1991 vehicles and later. The luxury makes for each period are shown in Table 2.

Table 2
Luxury vehicle makers included in the luxury vehicle analysis. Nonluxury vehicles were identified as all other passenger cars and light trucks not manufactured by a luxury maker on the list.

1990 and Earlier	**1991 to Present**
-	Acura
Alfa Romeo	Alfa Romeo
Audi	Audi
Austin Healey	Austin Healey
BMW	BMW
Cadillac	Cadillac
Infiniti	Infiniti
Jaguar	Jaguar
Lancia	Lancia
-	Land Rover
Lexus	Lexus
Lincoln	Lincoln
MG	MG
Mercedes-Benz	Mercedes-Benz
Porsche	Porsche
Saab	Saab
Sterling	Sterling
Triumph	Triumph
Volvo	Volvo

The annual trend in single-vehicle fatal pedestrian crashes involving luxury vehicles is shown in Figure 14; the comparable nonluxury trend is shown in Figure 15. A logistic regression relating dark/light ratio to year and luxury status found a main effect of year (Wald $\chi^2 = 4.7$, $p < .05$)—dark/light ratios are declining over time for luxury and nonluxury vehicles. The results are shown in Table 3. No effects of luxury status or interaction between luxury status and year were found. An interaction between luxury status and year would indicate a difference between the trend in luxury vehicles and the trend in nonluxury vehicles. A nonsignificant difference in the dark/light ratio decline was observed (Wald $\chi^2 = 1.9$, $p = .16$) in the expected direction—the slope of the decline for luxury vehicles was greater than for nonluxury vehicles. This difference is shown in Figure 16 which depicts the ratios of the luxury/nonluxury vehicle ratios. Although the decline is in the expected direction, it appears highly variable.

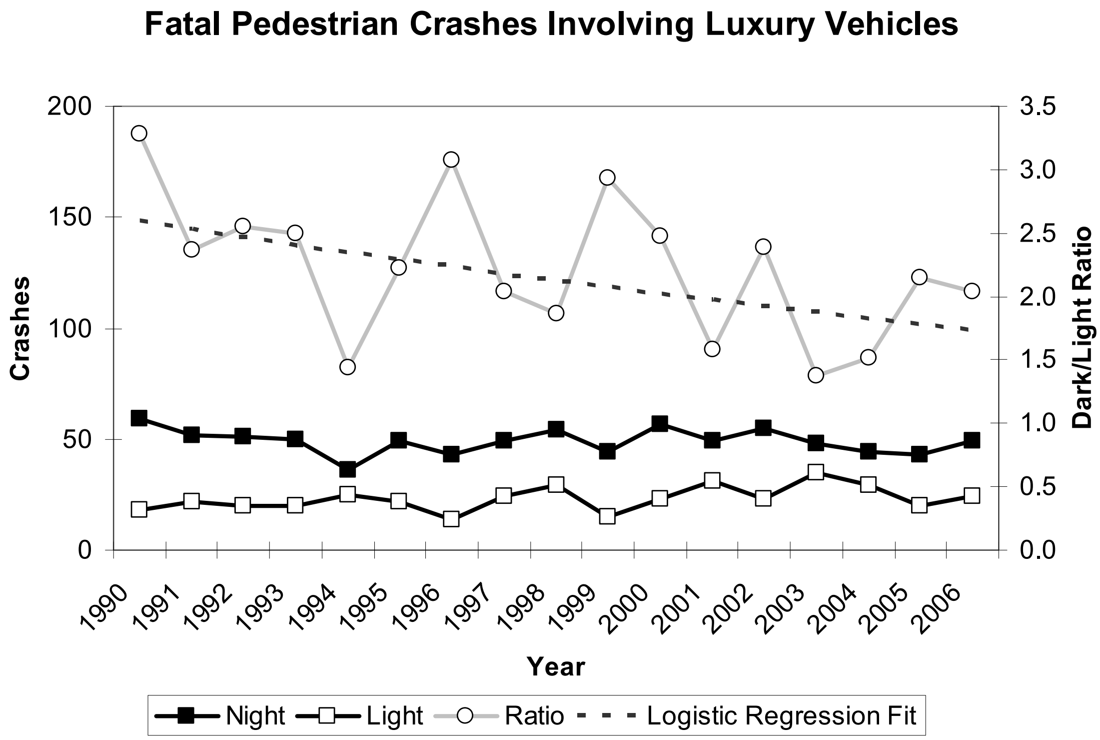

Figure 14. Annual count of single-vehicle fatal pedestrian crashes involving luxury vehicles in darkness (filled squares) and daylight (open squares). The dark/light odds ratio (open circles) is shown on the right axis along with the fit of a logistic regression (dashed line).

Table 3
Logistic regression of year and luxury status (luxury/nonluxury) on the log odds that a pedestrian crash occurred in darkness versus daylight.

Parameter		***df***	**Estimate**	**S. E.**	**Wald χ^2**	***p***
Year		1	-0.007	0.003	4.72	0.03
Luxury Status	**(Luxury)**	1	35.753	25.821	1.92	0.17
Year*Luxury Status	**(Luxury)**	1	-0.018	0.013	1.93	0.16

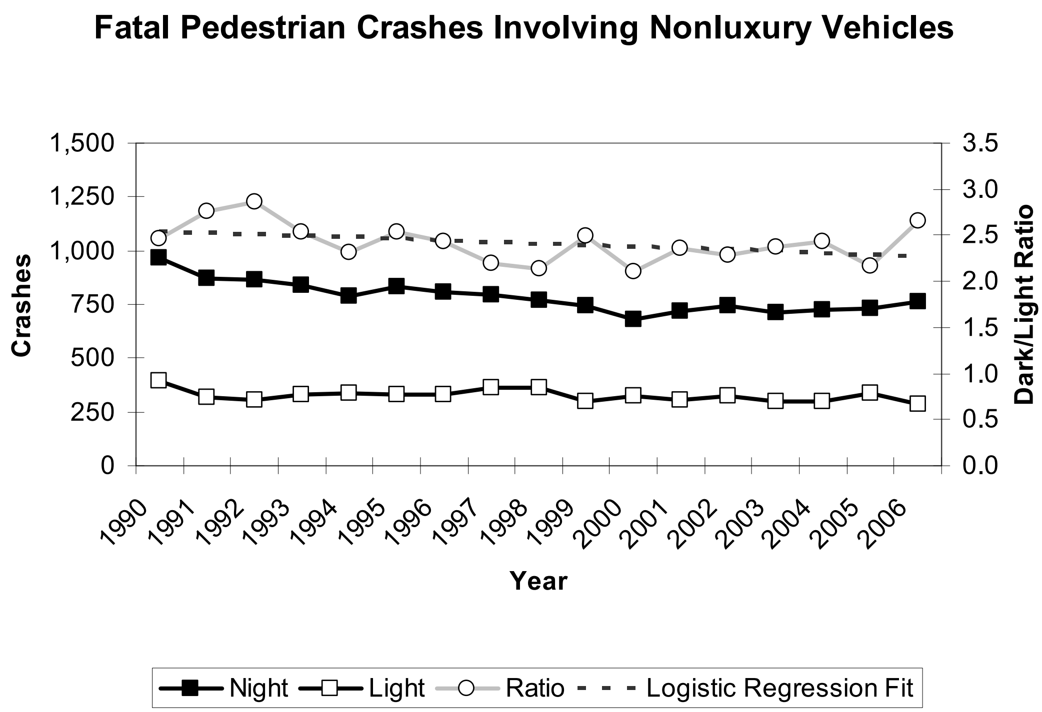

Figure 15. Annual count of single-vehicle fatal pedestrian crashes involving nonluxury vehicles in darkness (filled squares) and daylight (open squares). The dark/light odds ratio (open circles) is shown on the right axis along with the fit of a logistic regression (dashed line).

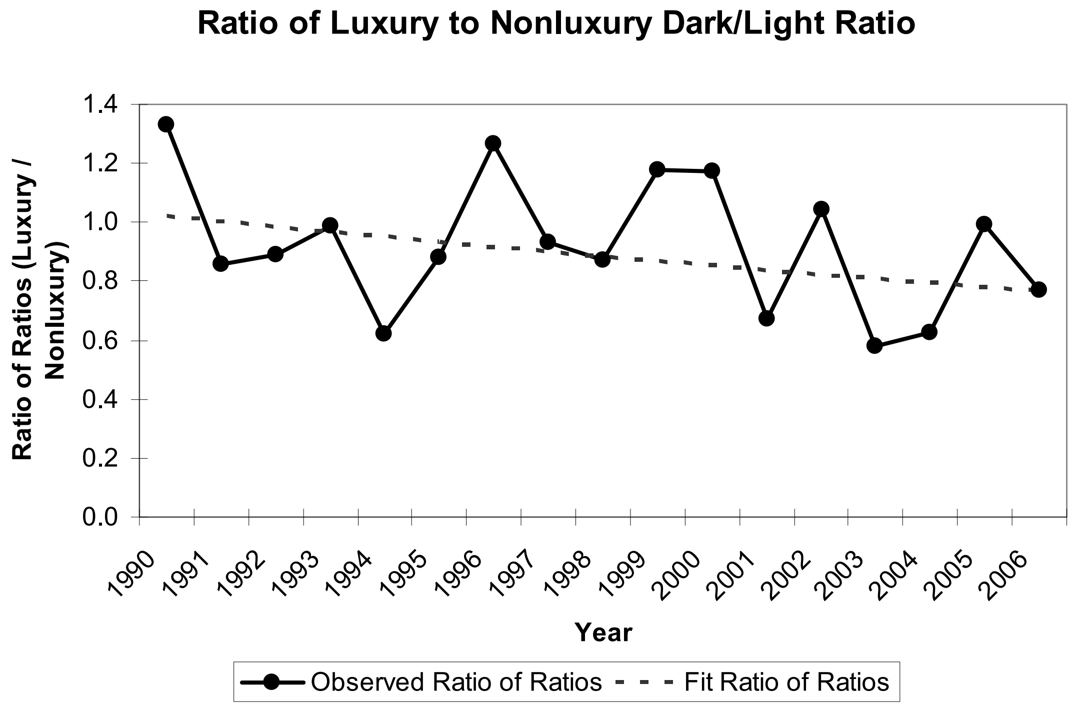

Figure 16. The observed ratio of luxury to nonluxury dark/light ratios. The dashed line is derived from the logistic regression fit and suggests that there is a trend toward a sharper decline among luxury vehicles than nonluxury.

Conclusions

Compared to the large overall decline in traffic fatalities reported in Germany between 1991 and 2002 (Lerner et al., 2005), the decline observed in the U.S. is substantially weaker. Indeed, absolute U.S. fatality levels appear to be flat since 1994 and only show a declining trend when the data are normalized by vehicle miles traveled (see Figure 2 on page 3). While the decline in the night/day crash ratio found in Germany suggests that nighttime safety is improving rapidly, a much weaker decline is observed in the U.S. spanning the years 1990 and 2006. Indeed, there seems to have been relatively little change in the U.S. since 2000 (see Figure 3 on page 5). Thus, it appears that there are significant differences between the U.S. and Germany with respect to declines in nighttime fatal crashes. While there have been some arguments to suggest that German reunification may have created conditions unique to Germany (e.g, Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, 2006; Winston, Rineer, Menon, & Baker, 1999), fatality declines like those in Germany have also been observed in other European countries as well as in Japan (see Figure 17), suggesting that Germany is not simply rebounding from the effects of reunification. Instead, it appears that the U.S. has made smaller gains than other countries in improving traffic safety over the last 17 years (Sivak et al., 2007).

Arguably, the kind of safety improvements one might expect to see from improvements in forward headlighting may not be readily evident from a gross analysis of the U.S. dark/light crash ratio that pools all fatal crashes. In many fatal nighttime crashes, poor visibility may play little or no role. Moreover, trends among many other factors (apart from improved forward lighting) are likely to contribute to changes in the observed dark/light ratio. For example, when the crashes were partitioned into those involving drinking drivers and those in which no drivers were drinking, the observed crash trends moved in opposite directions—increasing among the crashes with no drinking drivers, and decreasing among crashes involving drinking drivers. One *post hoc* explanation for the decline among crashes involving drinking drivers might be that selective and increasing nighttime enforcement of the drunk-driving laws through the years has reduced the relative numbers of drunk drivers on the road at night. While plausible, this explanation is one of many other possible explanations that could be offered. Without additional supporting data, such conjectures should be considered fairly weak.

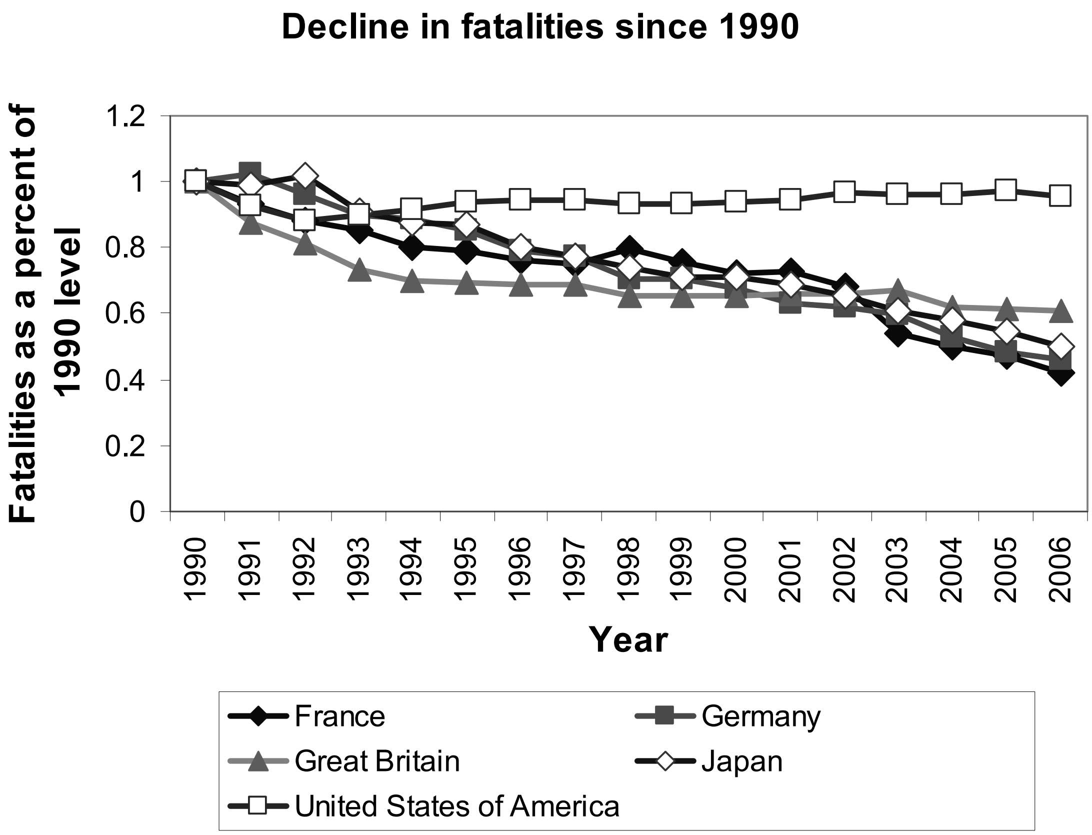

Figure 17. Relative declines in traffic fatalities since 1990 (International Road Traffic and Accident Database (IRTAD), 2008).

When the analyses were redirected to examine pedestrian crashes, in which ambient light level appears to play a strong role, the observed dark/light ratio increased over the years examined, suggesting that safety in darkness is declining relative to daylight safety. With further partitioning of this trend, it was found that the ratio has been increasing among pedestrian crashes involving children and older victims, and decreasing among crashes involving adult victims. Although a plausible explanation was offered to explain changing trends in children's exposure to traffic, the fact that the dark/light trends can reverse based on alternate partitioning of the data suggests that the dark/light ratio measure may be easily influenced by many factors. It may thus be imprudent to presume that improvements in vehicle lighting would necessarily be the strongest factor influencing the dark/light ratio.

In an analysis of rural pedestrian crashes with adult victims, greater dark/light ratio declines were observed in rural areas compared to urban areas. An analysis comparing interstate to noninterstate collisions found similar declines for the two road types, although the small number of interstate cases may have limited the precision of the estimated interstate decline. Finally, an analysis comparing luxury and nonluxury vehicles did not find reliable differences between the two vehicle types, although the estimated decline was steeper for luxury vehicles than for nonluxury vehicles.

Although some of the results might be considered consistent with the hypothesis that improvements in forward lighting have reduced dark/light ratios, changes in the direction of this trend when the data are partitioned into subgroups suggests that other factors also affect the dark/light ratio. Indeed, the evidence tying any general trends to the dark/light ratio is weak. Moreover, the proportion of U.S. vehicles equipped with HID headlamps may be (as of 2006) too small to register among the entire fleet of active vehicles in a given crash year, although, in terms of photometry, improvements have been noted for both TH and HID headlamps (Sivak et al., 2004). One way to address this problem would be to separate the year of a collision from the model year of the vehicle involved. Assuming that model-year equipment is relatively fixed while various characteristics of the roadway environment change over the years, it may be possible to determine the relative influence of vehicle equipment versus roadway environment. A second strategy might be to examine the crash records of vehicle lines that have upgraded forward vehicle lighting as standard equipment, so that a before/after comparison of crash involvement in darkness can be made.

References

Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH. (2006). Traffic safety - the German experience after the reunification [Electronic Version], 8 pages. Retrieved April 10, 2008 from http://www.gtz.de/de/dokumente/en-traffic-safety-reunification-2006.pdf.

Hofferth, S. L., & Sandberg, J. F. (2000). Changes in American children's time, 1981-1997. In T. Owens & S. L. Hofferth (Eds.), *Children at the Millennium: Where have we come from; where are we going?* New York: Elsevier Science.

International Road Traffic and Accident Database (IRTAD). (2008). Retrieved April 20, 2008, from IRTAD: http://irtad.bast.de

Lerner, M., Albrecht, M., & Evers, C. (2005). *Das Unfallgeschehen bei Nacht* (Technical Report No. M 172). Bergisch Gladbach, Germany: Bundesanstalt für Straßenwesen.

Longthorne, A., Varghese, C., & Shankar, U. (2007). *Fatal two-vehicle motorcycle crashes.* (NHTSA Technical Report No. DOT HS 810 834). Washington, D.C.: National Highway Traffic Safety Administration.

Shope, J. T. (2007). Graduated driver licensing: Review of evaluation results since 2002. *Journal of Safety Research, 38*(2), 165-175.

Shope, J. T., & Molnar, L. J. (2003). Graduated driver licensing in the United States: evaluation results from the early programs. *Journal of Safety Research, 34*(1), 63-69.

Sivak, M., Luoma, J., Flannagan, M. J., Bingham, C. R., Eby, D. W., & Shope, J. I. (2007). Traffic safety in the U.S.: Re-examining major opportunities. *Journal of Safety Research, 38*(3), 337-355.

Sivak, M., Schoettle, B., & Flannagan, M. (2004). *Recent trends in the performance of tungsten-halogen and HID low beams in the U.S.* (Technical Report No. UMTRI-2004-25). Ann Arbor: The University of Michigan Transportation Research Institute.

Sullivan, J. M., & Flannagan, M. J. (1999). *Assessing the potential benefit of adaptive headlighting using crash databases* (Technical Report No. UMTRI-99-21). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Sullivan, J. M., & Flannagan, M. J. (2001). *Characteristics of pedestrian risk in darkness* (Technical Report No. UMTRI-2001-33). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Sullivan, J. M., & Flannagan, M. J. (2006). *Implications of fatal and non-fatal crashes for adaptive headlighting* (Technical Report No. UMTRI -2006-1). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Sullivan, J. M., & Flannagan, M. J. (2007). Determining the potential safety benefit of improved lighting in three pedestrian crash scenarios. *Accident Analysis & Prevention, 39*(3), 638-647.

U.S. Centers for Disease Control and Prevention. (2008). Kids walk to school: Then and now—barriers and solutions [Electronic Version]. Retrieved April 20, 2008 from http://www.cdc.gov/nccdphp/dnpa/kidswalk/then_and_now.htm.

Winston, F. K., Rineer, C., Menon, R., & Baker, S. P. (1999). The carnage wrought by major economic change: ecological study of traffic related mortality and the reunification of Germany. *British Medical Journal, 318*(7199), 1647-1649.