THE ROLE OF REDUCED VISIBILITY IN NIGHTTIME ROAD FATALITIES

D. Alfred Owens
Michael Sivak

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

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16. Abstract

Two quasi-experiments investigated the contribution of reduced visibility to fatal accidents recorded by the U.S. Fatal Accident Reporting System from 1980 through 1990. Quasi-Experiment 1 evaluated 104,235 accidents that occurred during morning and evening time periods, called Twilight Zones, during which natural illumination varied systematically in conjunction with the annual solar cycle. Fatal accidents were found to be overrepresented during darker portions of the Twilight Zones. This finding was not related to time of day, day of week, or drivers' consumption of alcohol. The contribution of reduced visibility was also indicated by higher overrepresentation of fatal accidents in low illumination under adverse atmospheric conditions and with pedestrians and pedalcyclists as opposed to all other accidents. Reduced visibility was more important than drivers' drinking as a contributor to fatal pedestrian and pedalcycle accidents, while the reverse pattern was found for all other fatal traffic accidents. Quasi-Experiment 2 assessed the role of seasonal variables other than natural illumination by comparing the monthly distributions of 337,726 accidents recorded during three time periods: the Twilight Zones plus equal-duration control periods of Daylight and Darkness. The distribution of fatal nonpedestrian accidents exhibited no substantial variation across months in any of the test periods. The incidence of fatal pedestrian/pedalcycle accidents covaried with natural illumination during the Twilight Zones, while showing no variation during Daylight and Nighttime Control periods, confirming that visibility is a key factor in pedestrian and pedalcycle accidents.

The present findings provide new evidence for both (1) the importance of visibility as a major contributing factor in fatal pedestrian and pedalcycle accidents, and (2) the relative success of previous efforts to deal with the difficulties of nighttime driving in other classes of fatal accidents.

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INTRODUCTION

Most traffic fatalities in the United States happen at night. For the past decade, fatality rates (per vehicle miles) have averaged about 3.5 times higher at night than in daylight, and there is no evidence that this situation is improving (National Safety Council, annual). In 1991, the daytime fatality rate was 1.2 per 100 million miles, while the nighttime rate was 3.7 times higher at 4.4 per 100 million miles. If the night fatality rate were lowered to match the daytime rate, the total number of road fatalities in the United States in 1991 would have been reduced by 40%, from 43,500 to 26,100 (National Safety Council, 1992).

Clearly, there is room for improvement of nighttime traffic safety. To achieve this goal, we must clarify the specific factors contributing to higher fatality rates. A number of variables are obvious candidates. It would seem that drivers are more likely to be sleepy or fatigued at night, and they are more likely to consume alcohol at night. Less obvious variables may also be important. For example, there may be more recreational driving at night, and the age mix may differ, with higher representation of young drivers at night than in daylight. It would not be surprising if all these variables contribute to the higher nighttime fatality rate. In addition, it seems plausible that reduced visibility is an important factor, which may interact with other variables like fatigue and alcohol intoxication in nighttime accidents. The present study analyzed data from the Fatal Accident Reporting System (FARS), collected over a period of eleven years (1980-1990) to evaluate the potential role of reduced visibility in nighttime road fatalities.

Driving is often described as a "visual task." Some investigators have asserted that visual input comprises 90% of the information used in driving (e.g., Rockwell, 1972; Evans, 1991). Driver licensing regulations appear universally to require screening tests of visual acuity, often specifying a minimal level of 20/40. We are not aware of any that require a test of night vision. Yet laboratory data indicate that most individuals would fail the 20/40 criterion at luminances typical of night driving, and everyone would surely fail if tested under realistic conditions with low-contrast targets and glare from oncoming headlights (e.g., Owens et al., 1992).

Ironically, there is little evidence that visual acuity is a critical factor, or a useful predictor, of traffic accidents (e.g., Burg, 1971; Leibowitz, 1993). Nevertheless, there is wide agreement that good vision is necessary for safe driving, and there is no doubt that vision is naturally impaired under conditions of ordinary nighttime driving. In addition to losses of acuity, vision in low light suffers from increased optical aberrations with dilated pupils; decreased efficiency of ocular accommodation (the eyes' autofocus system), which results in night myopia; degradation of perception of distance, depth, size, and motion because important information (e.g., interposition, texture, shadows) is weak or absent; and greatly diminished contrast sensitivity, even for large objects. Considered critically, it may seem surprising that most people are willing to drive after dark, and astonishing to see evidence that nighttime speeds are generally as high as daytime speeds (e.g., Herd, Agent, and Rizenbergs, 1980). If driving is really a "visual task" and vision is seriously degraded at night, then one would expect drivers to avoid the task or at least slow down to compensate for their visual impairment. One might suppose that the role of vision is overrated, from which it could follow that vision plays a minor role in nighttime accidents. But this supposition has little foundation, and it seems strongly counterintuitive.

A large empirical literature confirms the fact that vision is seriously degraded in nighttime driving. Since the early work of Roper and Howard (1938), we have known that drivers cannot perceive low-contrast hazards in time to avoid collision when using low-beam headlights, and advances in lighting technology have not eliminated the problem (e.g., Olson, Sivak, and Henson, 1981; Sivak, Helmers, Owens, and Flannagan, 1992). The evidence indicates that obstacles such as large animals and poorly marked vehicles (Minahan and O'Day, 1977, 1979) or pedestrians (e.g., Johansson and Rumar, 1968; Blomberg et al., 1986) are virtually impossible to see with low-beam illumination in time to stop from normal travel speeds; this is the basis of the notion that most drivers habitually "overdrive" their headlights. Other evidence indicates that nighttime accident rates decline after installation of effective stationary luminaires (Gramberg-Danielsen, 1967), and that changes of illumination associated with shifts between Standard and Daylight Savings Time influence the incidence of fatal and serious accidents, with higher accident rates in darker conditions and lower rates in lighter conditions at equivalent periods of clock-time (e.g., Green, 1980; Ferguson, et al., 1993).

One theory proposes that the apparent paradox between visual losses and night driving behavior may be understood in terms of selective degradation of visual recognition functions (Leibowitz and Owens, 1977; Leibowitz, Owens, and Post, 1982). This approach draws on research in neurophysiology and psychophysics, which provides evidence for two parallel modes of visual processing. One mode serves *focal* functions of visual recognition. These functions depend primarily on central (foveal) vision; they dominate conscious awareness and are the focus of most vision tests. The other mode serves *ambient* functions such as visual control of posture, bodily orientation, and guidance of locomotion. These functions depend heavily on peripheral vision; they are largely unconscious and are not assessed by conventional vision tests. As shown in Figure 1, visual recognition functions (e.g., acuity and contrast sensitivity) deteriorate rapidly with reduced luminance. In contrast, ambient or guidance visual functions (e.g., feelings of self-motion from a moving visual array such as *linear vection*) are essentially unaffected until luminance falls near the absolute threshold of scotopic vision.

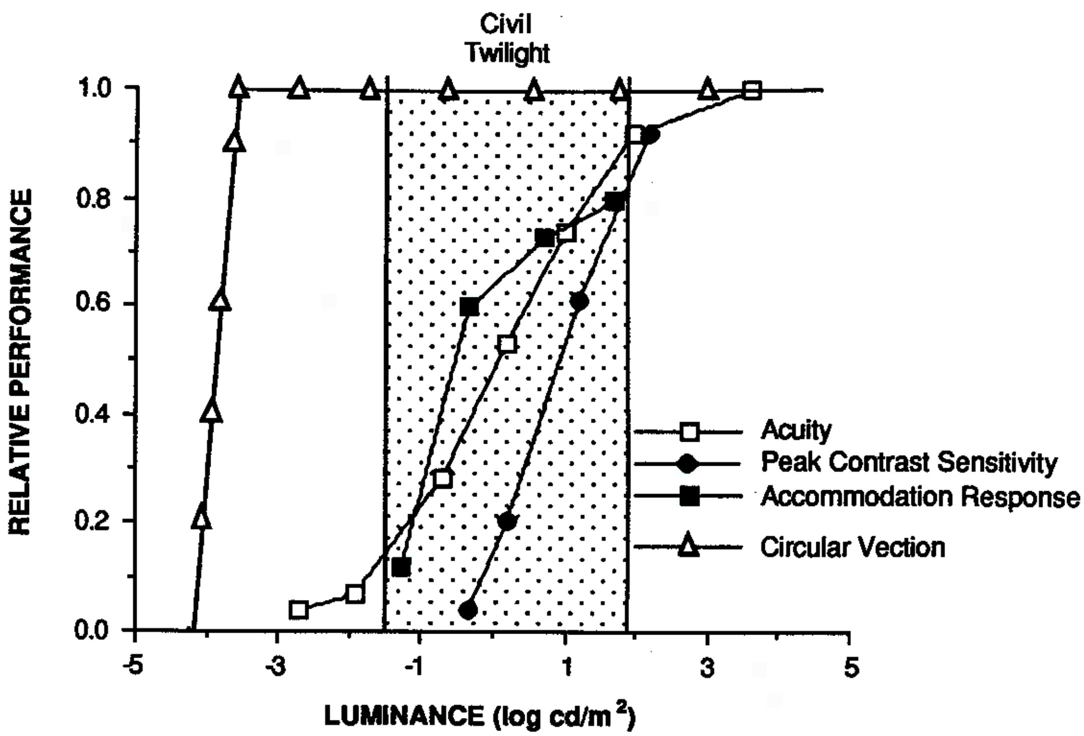

Figure 1. Relative visual performance as a function of luminance for three types of *recognition vision* and one type of *guidance vision.* Shaded area identifies range of luminances found in civil twilight. (Adapted from Owens, 1991.)

This analysis suggests that ones' ability to steer a vehicle depends on *guidance* vision, which is relatively unimpaired at night (Owens and Tyrrell, 1993). Meanwhile, actual losses of *recognition vision* (e.g., acuity and contrast sensitivity) may go unnoticed because much of the visual information used in driving is artificially enhanced through lighting or reflectorization. So according to this theory, drivers have little opportunity to observe their impairment: they can still steer efficiently and most of the things they have to see are relatively conspicuous. For the most part, the subjective difficulty of the driving task, and the driver's level of confidence, are comparable to levels found in daylight. Therefore, most drivers do not anticipate, nor are they prepared to avoid, dim low-contrast obstacles such as animals, dark-clad pedestrians, or disabled vehicles at night. Thus, the common failure of drivers to perceive their visual limitations in low illumination could contribute to the increased incidence of fatal accidents at night. But the central question remains: To what extent does reduced visibility contribute to nighttime accidents?

OUTLINE OF THE PRESENT INVESTIGATION

The working hypothesis of the present study was that reduced visibility is an important contributor to nighttime traffic accidents. Though theoretically plausible and intuitively appealing, testing this simple hypothesis is not a trivial matter. Ideally, one might contrive an experiment in which light condition is varied and other irrelevant variables—like alcohol consumption, traffic density, weather, driver age, fatigue, and sleepiness—are controlled, but that is not a practical option. An alternative approach, taken here, is to conduct quasi-experiments on data that have already been collected (Campbell and Stanley, 1963; Campbell, 1969).

The U. S. National Highway Traffic Safety Administration has acquired through the Fatal Accident Reporting System (FARS) detailed information on every fatal traffic accident in the United States since January 1, 1975. These records are regarded as census data. They include extensive and uniform information about the prevailing environmental conditions, driver and vehicle characteristics, and harmful events associated with every accident. These variables can be used as coding indices to retrieve and assemble sets of data representing the incidence of fatal accidents associated with any particular variable or group of variables. If properly examined, the FARS database can afford powerful tests of specific hypotheses without the uncertainties attached to statistical inference from limited samples. In this type of quasi-experimental research, the methodological challenge is to design criteria that can extract and "build" data sets that effectively isolate and, therefore, accurately represent the effects of selected variables on the incidence of fatal accidents.

The general strategy was to identify portions of the FARS database in which light condition varied systematically while other confounding variables remained relatively stable. The first step was to examine time periods called *twilight zones* during which natural illumination varies in conjunction with the annual solar cycle. The basic reasoning was simple: If light condition were *not* a contributing factor in fatal accidents, then such accidents should be distributed uniformly across the lighter and darker portions of the twilight-zone test periods. If light condition *were* a contributing factor, then fatal accidents should be overrepresented in the darker portion of the twilight zone. Assume, for example, that the time period included in the *twilight zone* is light for 50% of the year and dark for the remaining 50%. If light condition is not a contributing factor, then 50% of the fatal accidents would occur in darkness, and 50% in light. Alternatively, if light condition is a factor, then substantially more than 50% of the accidents would occur in darkness.

A key assumption of this approach is that factors other than light condition, which are associated with fatal accidents, are not systematically confounded with changes of illumination during the time periods included in the twilight zones. This seems more plausible for some variables than for others. The twilight zones include two times of day, one in the morning and one in the evening, during which variables such as traffic density, driver-age mix, fatigue, and alcohol consumption should be relatively constant. At least these factors should not covary in any obvious way with seasonal variations of the time of sunset and sunrise. On the other hand, one might anticipate variables such as atmospheric condition and pedestrian exposure to exhibit seasonal variations that are confounded with concurrent changes of natural illumination. For this reason, it was deemed necessary to conduct multiple quasi-experiments, which attempted to tease apart the role of weather and pedestrian exposure, as well as alcohol, from light condition, the variable of primary interest. The present study examined FARS data from eleven years, from 1980 through 1990, through two quasi-experiments:

(1) A Macro Examination of Fatalities in the Twilight Zone.

(2) The Distribution of Fatal Accidents in Light, Darkness, and Twilight Across Months of the Year.

Because this study was based on the data from the U.S. Fatal *Accident* Reporting System, throughout this report we will be using the term *accident* (as opposed to *collision* or *crash*).

QUASI-EXPERIMENT I:
A MACRO EXAMINATION OF FATALITIES IN THE TWILIGHT ZONE

Twice each day, illumination from the sky varies gradually as the sun reappears and disappears behind the horizon. The transitions between daylight and darkness, known as *twilight*, follow the annual solar cycle illustrated in Figure 2. The latest and earliest times of sunrise and sunset, which occur at the summer and winter solstices, appear as maxima and minima. Integrated over the year, the time period falling between the maxima and minima, approximately a 2.6-hour span in both morning and evening, represents the periods of variable natural illumination that we designated as the *twilight zone*. Over the course of the year, these periods include roughly equal portions of lighter and darker conditions. While ambient illumination varies, traffic density and driver characteristics should be relatively stable during these periods.

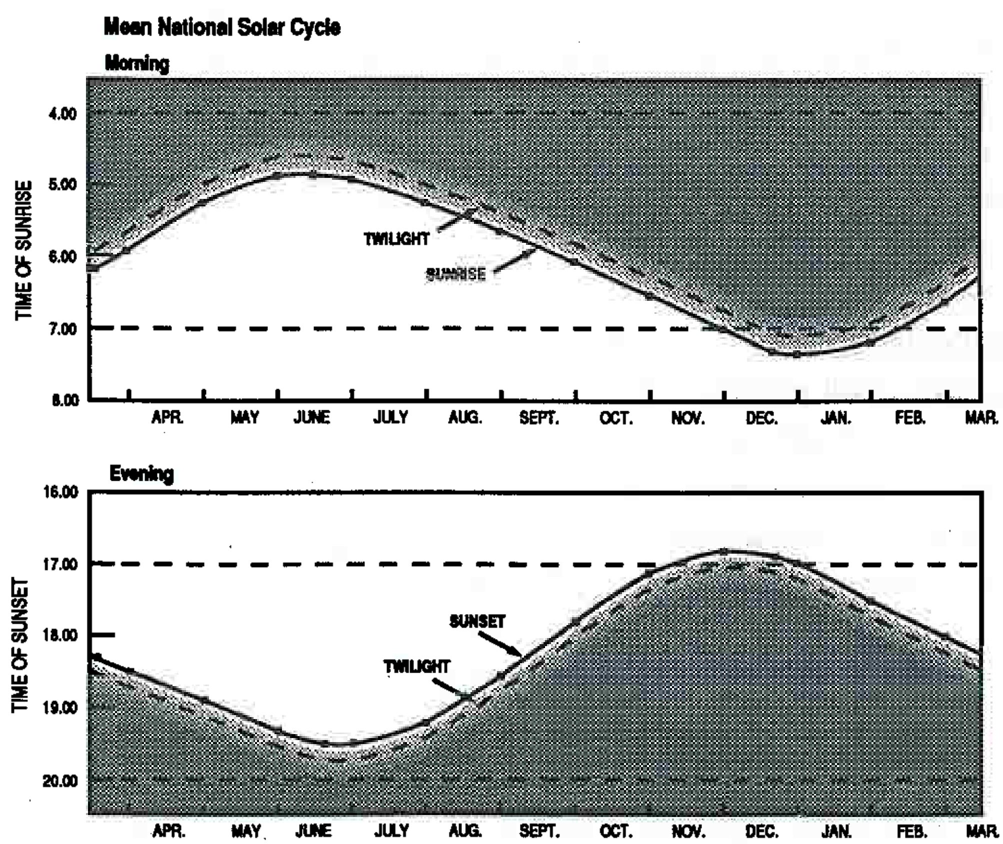

Figure 2. Mean National Solar and Twilight Cycles based on the ephemeris at mid-latitude of the United States in each of four time zones (see Appendix). Shaded areas represent darkness and unshaded, daylight; twilight curves indicate the midpoint of civil twilight. Horizontal lines indicate the standard time boundaries of the Twilight Zone test periods.

The temporal boundaries of the twilight zones were defined on the basis of visual functions during twilight rather than the times of sunrise and sunset. Early astronomers described twilight as having three phases, each defined on the basis of visual capabilities (Leibowitz, 1987). For the present purposes, the brightest phase, called *civil twilight*, is most relevant. Civil twilight occurs when the sun is from 0 to 6° below the horizon, when ambient illuminance from the sky ranges from about 330 lux to 3.3 lux in clear weather. At 40° North latitude, civil twilight lasts for 27 to 32 minutes after sunset and before sunrise (Leibowitz and Owens, 1991).

Historically, it has been assumed that "normal outdoor activities" can be carried out in ambient illuminance during civil twilight, and this standard has been incorporated into statutes regulating such activities as hunting. Recently, however, the assumption that most activities can be safely conducted in civil twilight has been challenged, particularly with respect to tasks involving dangerous mechanical devices, like power mowers, chain saws, and motor vehicles (Leibowitz and Owens, 1991). As shown in Figure 1, visual recognition capabilities decline dramatically with luminance reductions encountered in civil twilight. At the mid-point of civil twilight, ambient illuminance is about 33 lux, and an object that reflects 10% of the incident light will have a luminance of 1 cd/m^2. At this level, visual acuity is only about 50% and peak contrast sensitivity is about 33% of levels obtained in daylight (Owens, Francis, and Leibowitz, 1989).

Defining the Twilight Zone

Analyses focused primarily on two time periods, one in the morning and one in the afternoon, which were defined on the basis of the annual twilight cycle. The functions illustrated in Figure 2 represent mean values that were based on data from each of the four time zones of the lower continental U.S. (Further details are provided in the Appendix.) The latest and earliest midpoints of civil twilight, which appear as maxima and minima at the summer and winter solstices, and differ by about 2.6 hours, served as the first approximation of the *twilight zones*. Because FARS records are coded by integer hours, the test periods were expanded to comprise two three-hour intervals, from 04:00 to 06:59 hours in the morning and 17:00 to 19:59 hours in the evening.

Data Set

We analyzed data from eleven years, from 1980 through 1990, for 47 of the lower continental states, excluding Arizona. In order to obtain the desired variation of light condition, different clock times were included for Standard Time and Daylight Savings Time (DST). The former included 04:00 to 06:59 and 17:00 to 19:59 hours; the latter included 05:00 to 07:59 hours and 18:00 to 20:59 hours. The schedule of clock-times included in the data set for each year was defined with reference to the national transition into and out of DST for that year. From 1980 through 1986, DST began on the last Sunday in April and continued until the last Sunday in October. In 1987 the rule changed; thenceforth, DST extended from the first Sunday in April until the last Sunday in October. Data from Arizona were not included because that state does not shift from Standard to DST and, therefore, could not be coded accurately by the same routine used for building the data set to be investigated. Several other counties or municipalities, such as areas in Indiana near Chicago, which also do not follow the conventional national DST, were not filtered from the data set.

Within the time periods investigated, data sets were coded and analyzed according to the following variables: Time of Day (Morning vs. Evening); First Harmful Event (Pedestrian and Pedalcycle vs. All others); Atmospheric Condition (No Adverse Conditions vs. Active Rain, Snow, Sleet, Fog, etc.); Driver Drinking (Drinking Reported vs. No Drinking Reported); and Day of the Week (Weekdays vs. Weekends).

For all analyses, the dependent variable of interest was the percentage of fatal accidents occurring under two light conditions: Daylight and All Other (Dark, Dark with Lighting, Dawn, and Dusk).

Results

Over the eleven years studied (1980-1990), 104,450 fatal accidents occurred during the twilight zone test periods. Of these accidents, 104,235 (99.8%) were coded for light condition at the time of the accident, and these were the source data for this investigation. Table 1 summarizes the distribution of fatal accidents across the five variables of primary interest. Most of the fatal accidents happened in the evening (70.3%), and most occurred on weekdays (65.7%). A majority of the accidents occurred in clear atmospheric conditions (85.7%). At least one driver had been drinking in 36.8% of the accidents, while the remainder had no record of any drivers drinking. Drinking of non-drivers (e.g., pedestrians) was not evaluated. When divided into two sets according to first harmful event, 23.4% of the accidents involved pedestrians or pedalcyclists.

Table 1. Fatal accidents that occurred during the morning and evening "Twilight Zone" test intervals over the eleven year period from 1980 To 1990.

Total = 104,235

Variable	Levels	Number	Percent
Time of Day	AM	30,942	29.7
	PM	73,293	70.3
Day of Week	Saturday - Sunday	35,795	34.3
	Monday - Friday	68,440	65.7
Atmosphere	Degraded (Fog, etc.)	14,879	14.3
	Clear	89,356	85.7
Alcohol	Drinking Driver	38,361	36.8
	No Drinking Driver	65,874	63.2
Harmful Event	Pedestrian/Pedalcycle	24,372	23.4
	All Other	79,863	76.6

Light Condition. The twilight-zone test periods were lighter than the midpoint of civil twilight approximately 46.8% of the time, and darker than the midpoint of civil twilight 53.2% of the time. If fatal accidents were independent of the light condition, then the proportion of fatal accidents in the lighter and darker conditions should be equal to the proportion of total time of the respective light conditions. Thus, the "chance" prediction was that 46.8% of the fatal accidents would have been reported as occurring in daylight, and 53.2% would have been reported as occurring in dusk, dawn, or darkness.

As shown in Figure 3, the proportion of fatal accidents in the lighter portion of the twilight zones (34.7%) was lower than the chance prediction, while the proportion in the darker portion (65.3%) was 12.1% greater than the chance prediction.

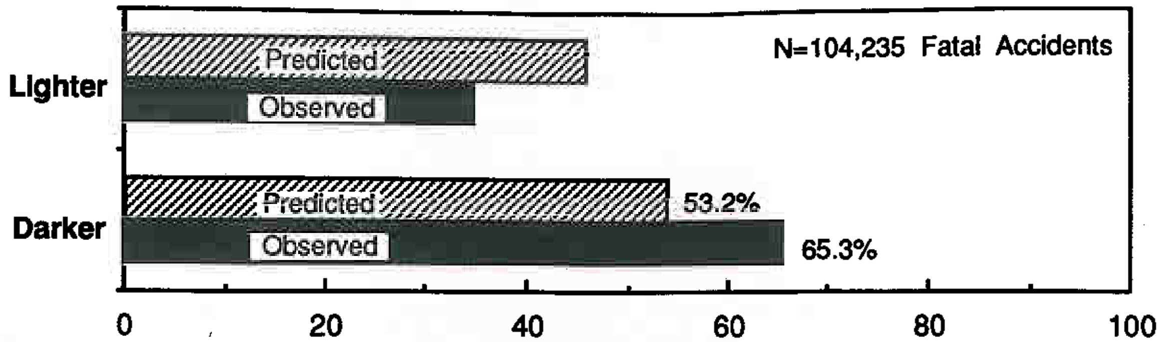

Figure 3. Comparison of predicted and observed incidence of fatal accidents in lighter and darker portions of the Twilight Zones.

The findings illustrated in Figure 3 are consistent with the hypothesis that reduced visibility is a contributing factor to nighttime traffic fatalities. But it is possible that other confounding factors, such as reporting bias, are responsible for the higher representation of fatal accidents in darker conditions. To investigate this possibility, we subdivided the main data set to look for possible differences in the distribution of fatal accidents that are related to time of day (AM vs. PM), day of the week (weekends vs. weekdays), and alcohol consumption.

Time of Day. The higher representation of fatal accidents under darker conditions seen in Figure 3 could result from a reporting bias. One can assume that investigating officers usually arrive after the event. Their later arrival could tend to bias reports of the light conditions such that events that happened in morning twilight would be reported as lighter than actual, and events that happened in evening twilight as darker than actual conditions at the time of the accident. Because more than 70% of the accidents studied occurred in the evening, this bias would distort the overall picture, indicating an overrepresentation of fatal accidents under darker conditions. Examined separately, however, the data from morning and evening should show different distributions of accidents for lighter and darker periods. Late-biased reporting in the morning would produce overrepresentation under lighter conditions; in the evening, it would produce overrepresentation under darker conditions.

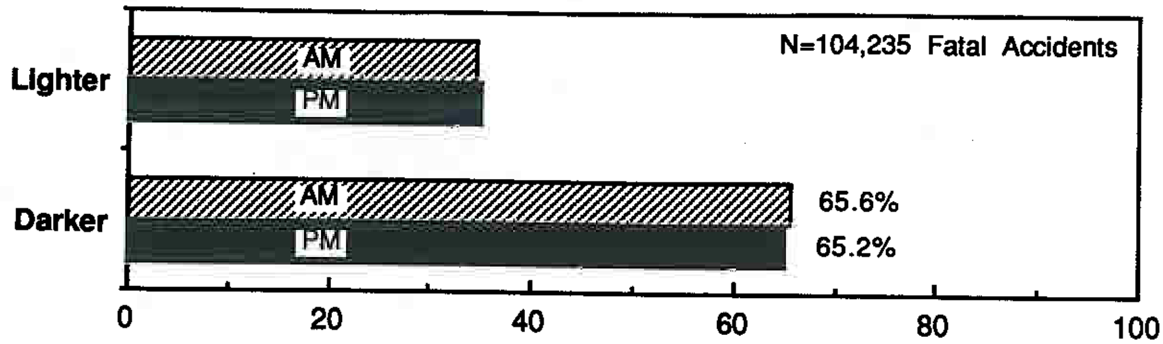

Figure 4. Incidence of fatal accidents in lighter and darker portions of the morning (AM) and evening (PM) Twilight Zones.

As shown in Figure 4, data from the morning and evening twilight zones were nearly identical; both show slightly more than 65% of the fatal accidents in darker conditions. This implies that reporting bias is not responsible for the higher incidence of fatal accidents in darker conditions.

Day of the Week. The higher representation of fatal accidents in darker conditions could also be related to variations in driving functions, such as commuting versus recreational driving. With this possibility in mind, we separated the data for weekdays and weekends as shown in Figure 5. A slightly greater overrepresentation of fatal accidents in darker conditions is evident for data from weekends (66.6%) as compared with weekdays (64.6%), but the small magnitude of this difference suggests that variations in driving function are not responsible for overall difference in light conditions seen in Figures 3 and 4.

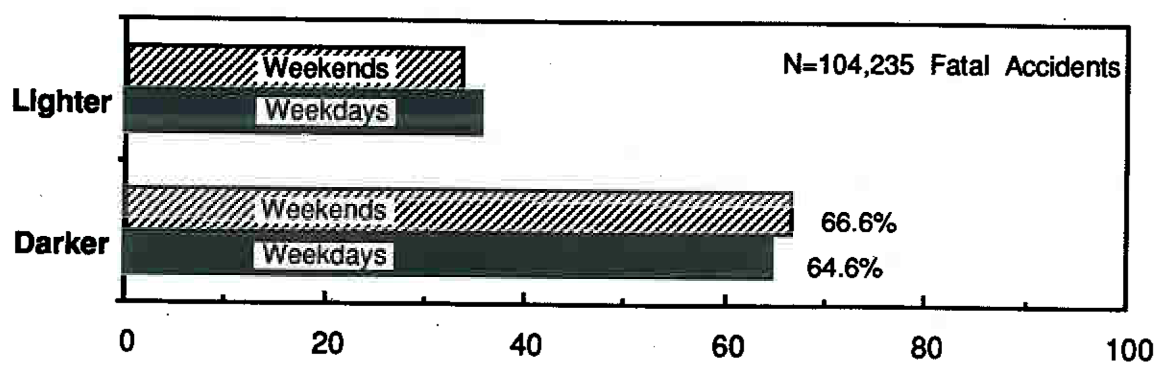

Figure 5. Incidence of fatal accidents in lighter and darker portions of the combined Twilight Zones on weekends and weekdays.

Alcohol Involvement. The high proportion of fatal accidents in darker conditions might be related to variations in the number of drivers who are intoxicated. It is widely acknowledged that alcohol consumption is a major contributor to traffic accidents. Drinking behavior might be related to season or light condition in addition to time of day. If so, the traffic mix during darker portions of the Twilight Zones could include more drinking drivers. Such variation in the condition of *drivers* then could contribute to increased incidence of fatal accidents in low-light conditions. To examine this possibility, the data set was divided into two groups: fatal accidents that involved one or more drinking drivers and those in which none of the drivers involved were reported to be drinking. Note that the criterion of drinking includes drivers who were within legally acceptable levels of alcohol consumption.

The data in Figure 6 show a 1.6% higher representation of fatal accidents in darker conditions for accidents involving drinking drivers as compared with those that involved no drinking drivers. This difference suggests either that there are more drinking drivers on the road during the darker conditions or that drinking drivers have greater risk than sober drivers of having a fatal accident in darker conditions. In either case, the difference attributable to alcohol appears to be small relative to the role of light condition, which is 11.5% greater than chance for accidents that did not involve drinking drivers.

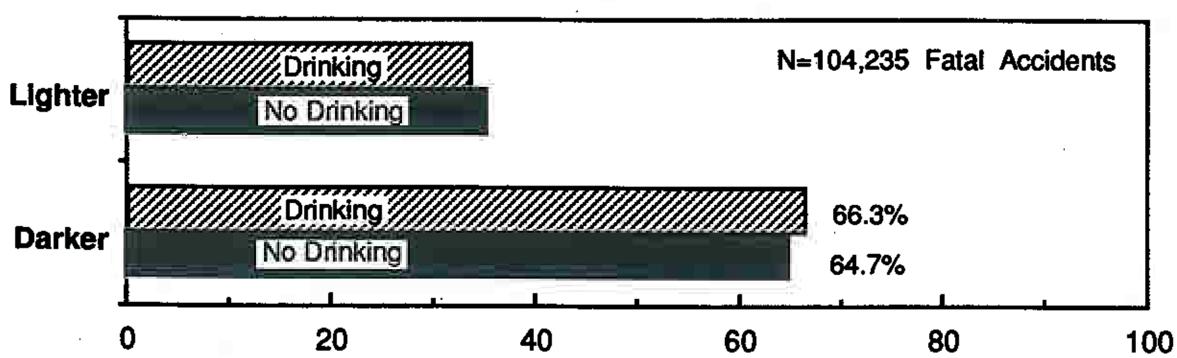

Figure 6. Incidence of fatal accidents in lighter and darker portions of the Twilight Zones with accidents divided according to whether any of the drivers involved had consumed alcohol.

Thus far, the results from the twilight zones are consistent with the hypothesis that reduced visibility contributes to increased probability of fatal accidents. In both morning and evening periods, on weekdays as well as weekends, and for sober as well as drinking drivers, fatal accidents are overrepresented during the darker portions of the twilight zone periods. This finding suggests that other variables that can exacerbate poor visibility, such as degraded atmospheric conditions, might combine with light condition to result in still greater likelihood of fatal accidents in darker conditions.

Atmospheric Conditions. The data set was divided into two subsets: one comprising all fatal accidents from the twilight zones that occurred in clear atmospheric conditions, and the other including all those that occurred when the atmosphere was degraded by active rain, snow, sleet, fog, smog, smoke, etc. These data are illustrated in Figure 7.

It is evident that the proportion of fatal accidents occurring in darker conditions is substantially higher with degraded (78.8%) than with clear (63%) atmospheric conditions. Here the representation of fatal accidents in darker conditions is higher than found with any of the preceding variables (Figures 3 through 6). The same pattern appeared after excluding all accidents that involved drinking drivers. When only no-drinking drivers were counted (N=65,874), 78% of the fatal accidents occurred in the darker portion of the twilight zone under degraded atmospheric conditions, and 62.2% happened in the darker conditions when the atmosphere was clear. This supports the hypothesis that reduced visibility contributes to increased fatal accident rates in darkness.

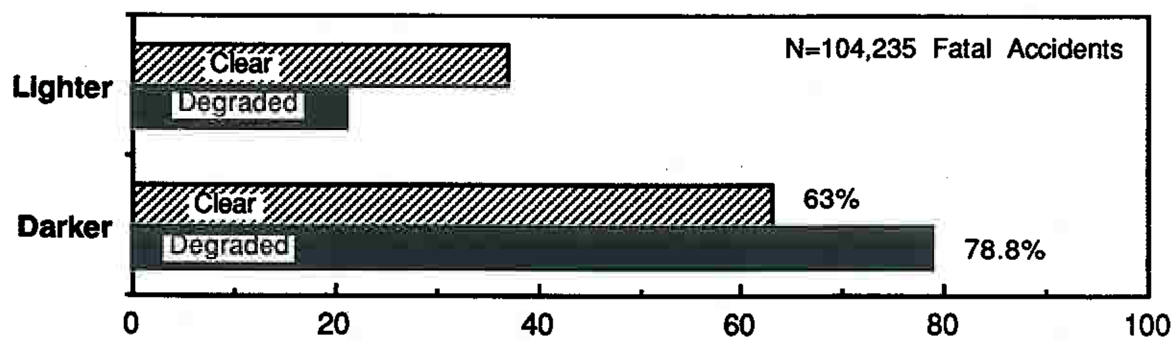

Figure 7. Incidence of fatal accidents in lighter and darker portions of the Twilight Zones during clear and degraded atmospheric conditions.

Pedestrian and Pedalcycle Accidents. Previous research indicates that pedestrian visibility is seriously degraded in low illumination (e.g., Johansson and Rumar, 1968). This is due largely to the poor conspicuity of pedestrians who do not wear special retroreflective markings (Blomberg, Hale, and Preusser, 1986; Owens, Antonoff, and Francis, in press). The same problem may apply to pedalcyclists, who also are not uniformly required to utilize effective markings. Thus, it is possible that the visibility of pedestrians and pedalcyclists under low illumination is generally worse than that of motor vehicles or other roadway obstacles that are involved in fatal accidents.

To examine this possibility, the data were divided into two subsets based on the "first harmful event" (by FARS definition). One included all fatal pedestrian and pedalcycle accidents from the twilight zone periods; the other comprised all other fatal accidents from the same time periods. As illustrated in Figure 8, these data indicate that the representation of fatal accidents in darker conditions is substantially higher for incidents involving pedestrians and pedalcyclists (78.7%) than for all other fatal accidents combined (61.2%).

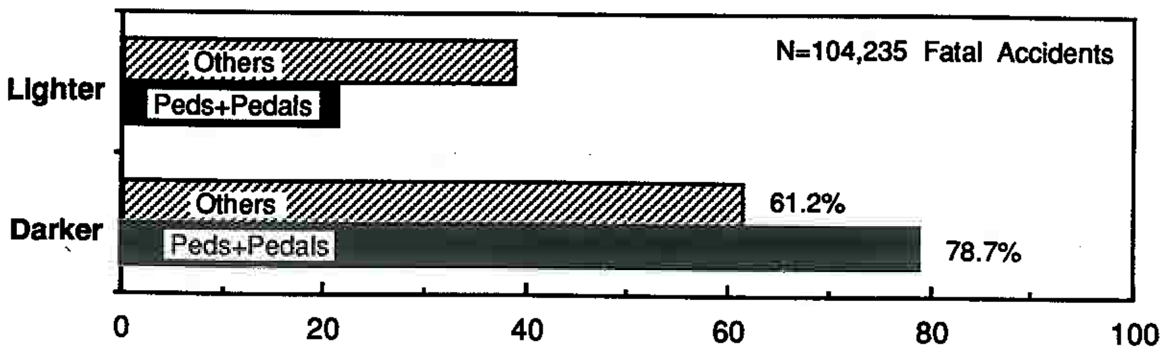

Figure 8. Incidence of fatal pedestrian and pedalcycle accidents compared with that of all other fatal traffic accidents (excluding pedestrians and pedalcyclists) in lighter and darker portions of the Twilight Zones.

In view of the higher incidence of fatal accidents in darkness for pedestrians and pedalcyclists and for degraded atmospheric conditions, it seemed appropriate to examine the interaction of these variables. Figure 9 presents the overall data subdivided by types of the accidents and atmospheric conditions.

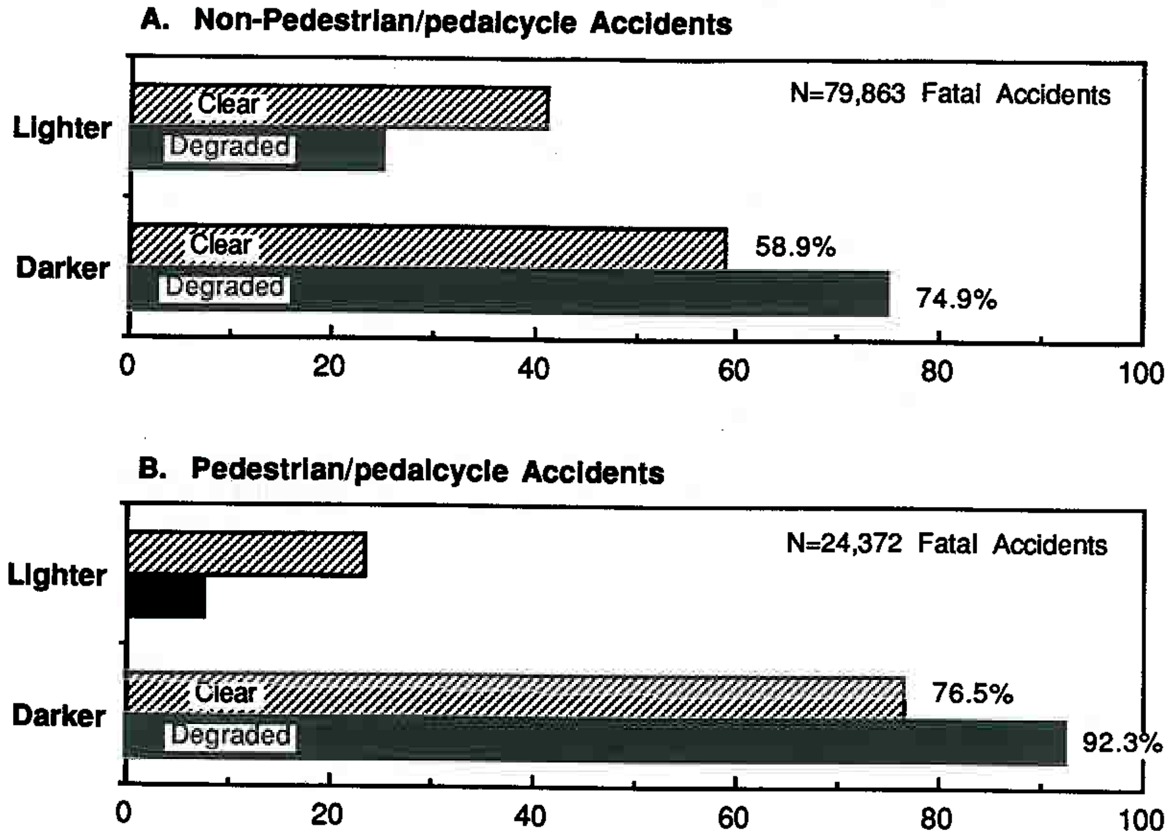

Figure 9. Distribution of fatal accidents in lighter and darker portions of the Twilight Zones under clear and degraded atmospheric conditions for the pedestrian/pedalcycle (Panel B) as compared with all other traffic fatalities (Panel A).

An interaction of all three variables that were predicted to affect visibility (light condition, atmospheric condition, and classification of accident) is clearly evident in these data. As seen in all previous figures, the proportion of fatal accidents occurring in the darker portion of the twilight zones is consistently greater than chance. The magnitude of this effect was seen to be relatively stable over time of day (Figure 4), day of the week (Figure 5), and alcohol involvement (Figure 6). In contrast, the portion of fatal accidents in darkness is strongly influenced by other concurrent variables that also affect visibility. As shown in Figure 9, the worst case is with pedestrian and pedalcycle accidents in degraded atmosphere, when 92.3% of fatal accidents occurred in darker conditions.

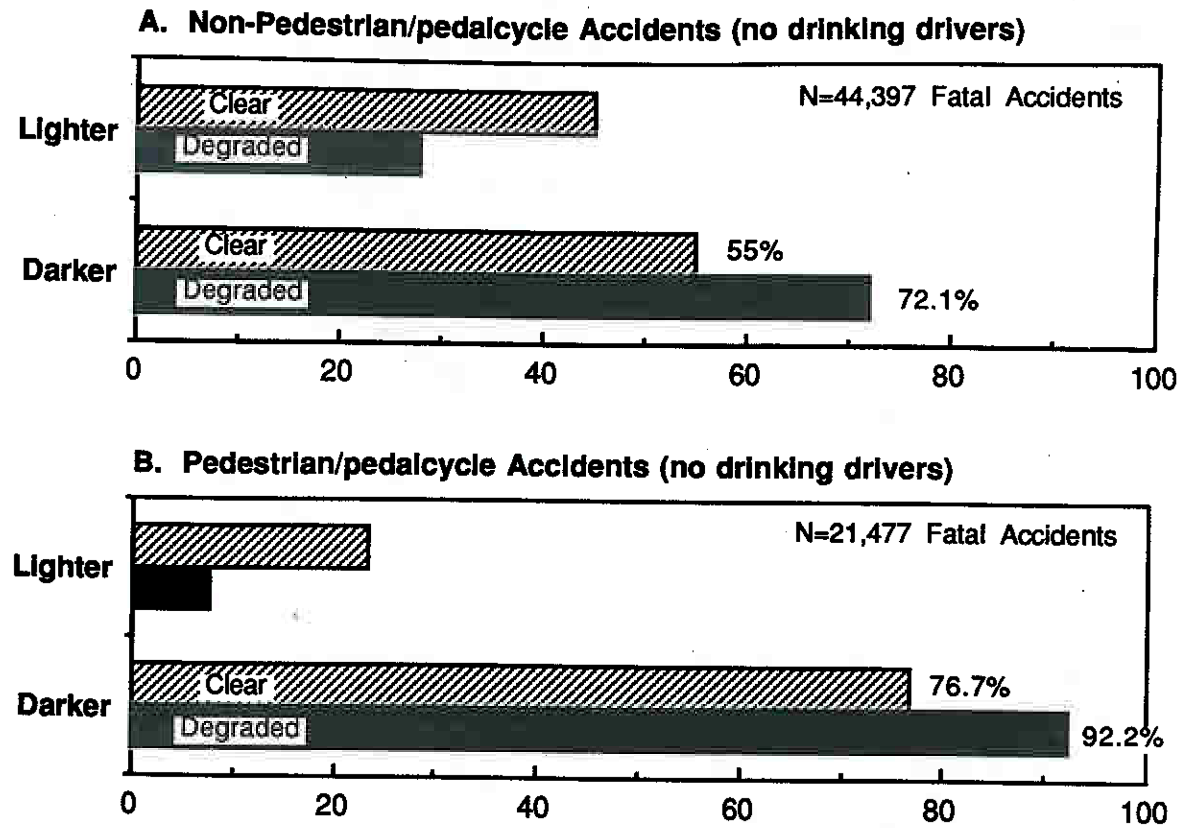

Figure 10. Distribution of fatal pedestrian/pedalcycle (Panel B) and other fatal traffic accidents (Panel A), excluding accidents involving drinking drivers.

As shown in Figure 10, the findings illustrated in Figure 9 changed little when all accidents that involved drinking drivers were excluded from the data set. This pattern of results is fully consistent with the initial hypothesis that reduced visibility contributes to higher fatality rates in darkness, and it highlights the possibility that visibility is a more important factor for some classes of accidents (e.g., pedestrian fatalities) than for others (e.g., intervehicular or single vehicle accidents).

The Contribution of Alcohol to Different Classes of Accidents. The evidence indicates that both alcohol and reduced visibility contribute to traffic accidents, but there is little information concerning the manner in which these hazardous conditions interact with other factors. The finding that alcohol had relatively little effect on patterns of fatal accidents associated with degraded visibility conditions (Figures 6 and 10) was somewhat surprising. It suggests that, to some extent, the role of alcohol and visibility may be independent contributors, or they may be contributing differentially to different classes of fatal accidents. To examine this possibility, we assessed the involvement of alcohol in pedestrian/pedalcycle accidents versus all other fatal accidents of the twilight-zone data set. These data are illustrated in Figure 11.

When pedestrian and pedalcyclist accidents were excluded, alcohol was involved in 44.5% of the fatal accidents in the twilight zones (collapsed across atmospheric conditions). When subdivided by atmospheric condition, as shown in Panel A of Figure 11, drinking drivers were involved in a higher proportion of the fatal non-pedestrian accidents in clear (46%) than in degraded (35.2%) visibility conditions. A different pattern was found for pedestrian/pedalcycle accidents (Panel B of Figure 11). Here, drinking drivers were involved in a much smaller proportion of the fatal accidents, only 11.9% overall. When the data were subdivided by atmospheric conditions, they revealed a higher involvement of alcohol under degraded (12.4%) as compared with clear (9%) conditions. There is no reason to suppose that there were fewer drinking drivers on the road at the time of the pedestrian accidents; the data for both classes of accidents represent events that occurred in identical time periods and road environments. The data in Figure 11 indicate that, during the Twilight Zones, fatal pedestrian/pedalcycle accidents are much less likely to involve drinking drivers than are other types of fatal traffic accidents. Indeed, if we knew that 9 to 12% of the drivers on the road during the Twilight Zones had consumed alcohol, we could conclude that their involvement in fatal pedestrian and pedalcycle accidents is no higher than that of sober drivers. Together with the data in Figure 10, these findings imply that fatal pedestrian/pedalcycle accidents depend in large part on reduced visibility, while alcohol is a larger factor in other classes of the fatal traffic accidents during the same time period.

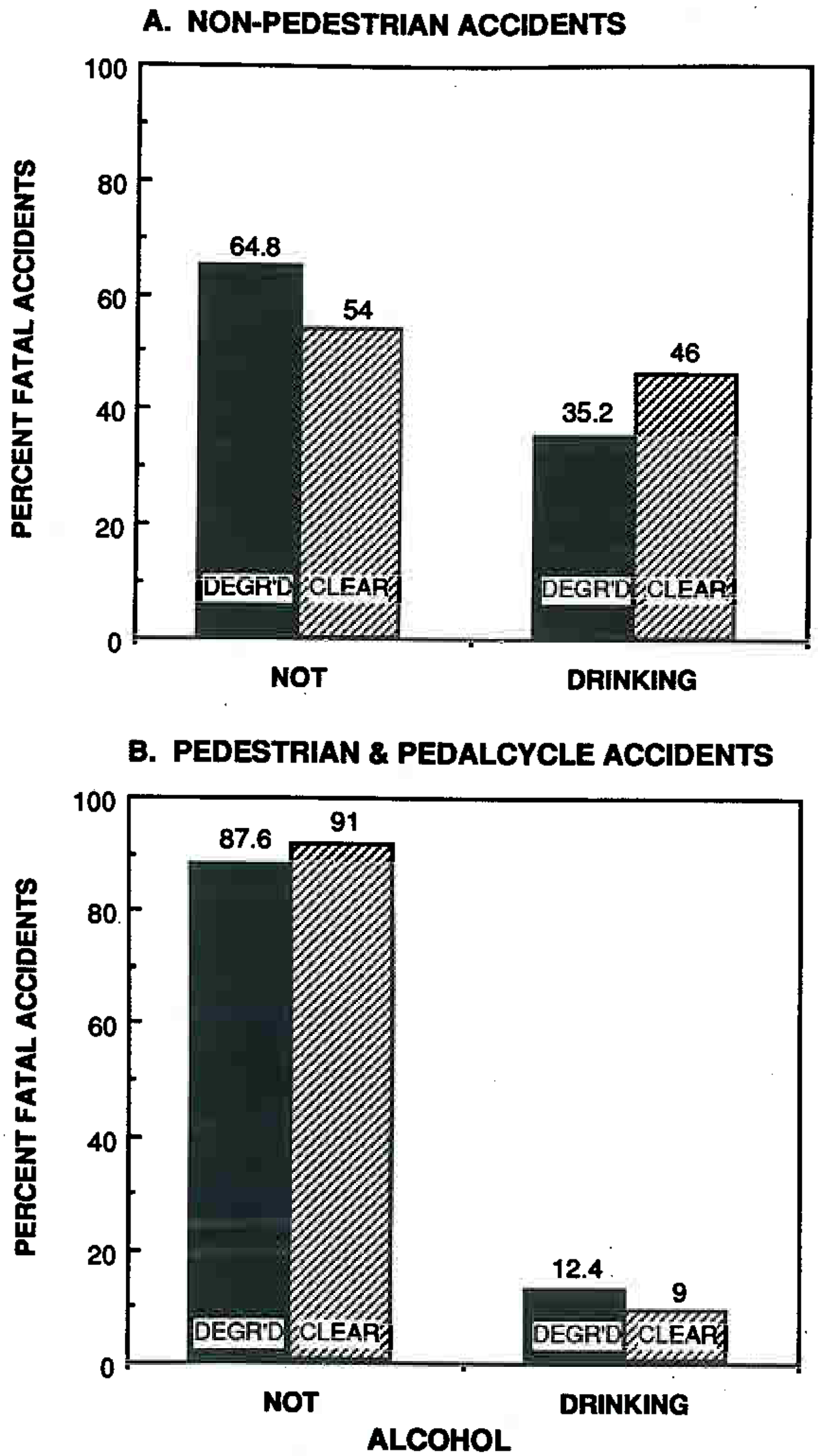

Figure 11. Alcohol involvement in pedestrian/pedalcycle (Panel B) and in all other (Panel A) fatal accidents that occurred in degraded and clear atmospheric conditions in the Twilight Zones.

QUASI - EXPERIMENT II:
THE DISTRIBUTION OF FATAL ACCIDENTS IN DAYLIGHT, DARKNESS, AND TWILIGHT ACROSS MONTHS OF THE YEAR

The findings from Quasi-Experiment I are consistent with the hypothesis that reduced visibility contributes to fatal accidents at night, particularly in situations where losses of visibility due to low illumination are exacerbated by poor atmospheric conditions and by low-contrast hazards. There is no indication that the overrepresentation of fatal accidents in degraded visibility can be attributed to time of day, day of week, or alcohol (Figures 4, 5, and 6), but another confounding variable could not be ruled out: the variations in natural illumination are directly confounded with the changing seasons. Given variations in weather and holiday travel, for example, it is possible that some hidden seasonal variable other than illumination is responsible for the higher incidence of fatal accidents in darker (winter) portions of the Twilight Zones. If this were the case, one would expect the confounding seasonal variable to exert its influence not only during the twilight-zone test periods, but also at other times of day and night. Quasi-Experiment II investigated the possible role of seasonal variables other than illumination by examining data sets from control periods of full daylight and darkness as well as the twilight zones on a month-by-month basis for the same eleven year period studied in Quasi-Experiment I.

Method

This experiment used three sets of data that were extracted from FARS records for the same 11 years and 47 states used in Quasi-Experiment I. As described in Table 2, these data included all fatal accidents occurring during three six-hour time periods: control periods of daylight and darkness, as well as the combined Twilight Zones. As in Quasi-Experiment I, the twilight zones comprised two three-hour time periods, one in the morning and one in the evening, defined on the basis of the annual twilight cycle. Over the course of a year, these time periods include ambient illumination ranging from full daylight to full darkness with 53.2% of the total time *darker* than the midpoint of civil twilight and 46.8 % of the total time *lighter* than the midpoint of civil twilight (Figure 2). The control periods were of equal total duration and included three-hour time bands immediately preceding and following morning and evening twilight. Thus, the Daylight Control period, which was always lighter than the midpoint of civil twilight, included three hours after the morning Twilight Zone plus the three hours before the evening Twilight Zone. The Nighttime Control period, which was always darker than the midpoint of civil twilight, included three hours after the evening Twilight Zone and three hours before the morning Twilight Zone. As shown in Table 2, the clock-times included in all data sets were adjusted for Daylight Savings Time relative to the solar/twilight cycle.

Table 2. Definition of test periods of Twilight, Daylight, and Nighttime for Standard and Daylight Savings Time.

Data Set	Clock-Times Included	
	Standard Time	Daylight Savings Time
Twilight Zones	0400 - 0659 hr. 1700 - 1959 hr.	0500 - 0759 hr. 1800 - 2059 hr.
Daylight Control Periods	0700 - 0959 hr. 1400 - 1659 hr.	0800 - 1059 hr. 1500 - 1759 hr.
Nighttime Control Periods	2000 - 2259 hr. 0100 - 0359 hr.	2100 - 2359 hr. 0200 - 0459 hr.

All fatal accidents within each of the three test periods were compiled by month across the eleven years from 1980 through 1990. In addition, the total numbers of fatal accidents for each month, including all 24 hours of the day, were summed over the eleven year period. The dependent variable of interest was the percentage of total accidents per month (summed across eleven years) that occurred in each of the three test periods. If fatal accidents were distributed equally across 24 hours, then each of the test periods would contain 25% of the total accidents per month, and these data sets would add up to 75% of the total fatal accidents.

The central hypothesis, that light condition contributes to increased fatality rates at night, would be supported by variation of the monthly percentage of fatal accidents in the Twilight Zones that follow a pattern similar to the annual twilight cycle. That is, higher percentages would be found in the Twilight Zones in winter months than in summer months. This hypothesis would also predict a higher percentage of accidents in the Nighttime Control than in the Daylight Control periods, but the magnitude of this effect is not so easy to predict because of likely differences in exposure.

Seasonal variables *other than light condition* would be expected to affect accident patterns in one or both of the control periods as well as the Twilight Zones. For example, if severe winter weather were responsible for increased incidence of fatal accidents in the Twilight Zones found in Quasi-Experiment I, one would expect similar increases in the daylight and dark hours that preceded and follow the Twilight Zones. In that case, the monthly percentage of fatal accidents in the Twilight Zones would *not* vary as predicted by the twilight cycle. Instead, the percentages of the three test periods might remain constant over many months, or perhaps two of the test periods (e.g., daylight and twilight) would increase together in winter months, while the percentage in darkness declined. Such seasonal variations, whether related to light condition or not, should be easy to discern when the percentage of fatal accidents for each of the three test periods are plotted as a function of months of the year.

Results

A total of 450,983 fatal accidents were recorded by FARS during the eleven years studied; 337,726 (74.9%) of these occurred during the (combined) three test periods of this experiment. Figure 12 presents the total number of fatal accidents and the sum of the three data sets as a function of months collapsed across the years from 1980-1990. The total number of fatal accidents tended to be highest in the summer months, with a peak in August at 44,132. The percentage of fatal accidents per month in the combined test sets reflects fairly accurately the overall variations in the number of accidents from month to month. This reflection of monthly variations in the total number of fatal accidents also held true for both subclasses of accidents studied, although the percentage of total fatal pedestrian and pedalcycle accidents included in the combined test periods (79.6%) was somewhat higher than that for all other fatal accidents (73.8%).

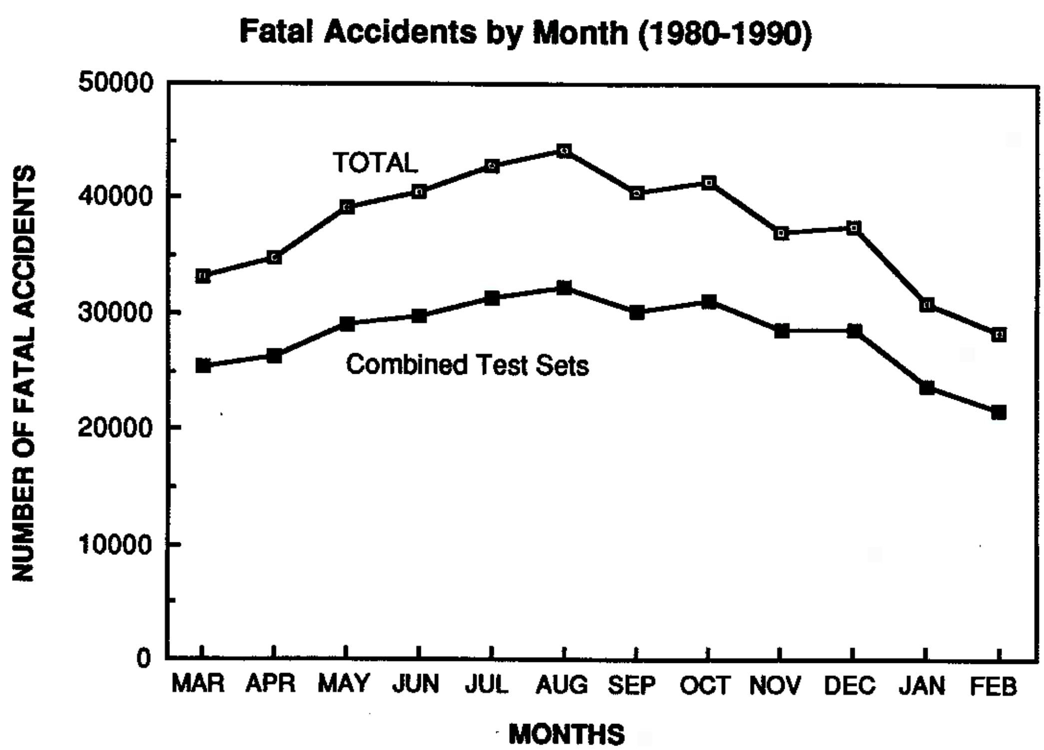

Figure 12. Total number of fatal accidents and combined test sets as functions of months. Data represent all fatal accidents reported in FARS from 1980-1990.

Table 3 summarizes the data sets collapsed across months and years. It is evident that more fatal accidents occurred in the Nighttime Control period (29.1%) than in the Twilight Zones (23.9%) or the Daylight Control period (22%). When subdivided by accident class, however, it is evident that more pedestrian/pedalcycle accidents occurred in the Twilight Zones (30.8%) than in the Dark (29.8%) or Daylight (19%) Control periods.

Table 3. Distribution of Fatal Accidents Across Test Periods and Accident Classes.

Data Set	ACCIDENT CLASSES		
	Pedestrian/Pedal.	All Other (Non-Ped)	Combined
Twilight Zones	25,278 (30.8%)	82,161 (22.3%)	107,439 (23.9%)
Daylight Control Periods	15,575 (19%)	83,500 (22.6%)	99,075 (22%)
Nighttime Control Periods	24,458 (29.8%)	106,754 (28.9%)	131,212 (29.1%)
Excluded from Test Sets	16,719 (20.4%)	96,538 (26.2%)	113,257 (25.1%)
Total	82,030	368,953	450,983

The results of Quasi-Experiment I showed different patterns for pedestrian/pedalcycle as compared with all other fatal accidents (Figures 8, 9, 10, and 11), which suggested that light condition is a more important factor for the former class of accidents. This variable of accident classification was therefore examined further in Quasi-Experiment II. Data sets for the two classes of "first harmful event" are presented separately in Figures 13 and 14 as the percentages of fatal accidents for each month collapsed across years. All percentages were calculated using as denominators the total number of fatal accidents within the relevant category (pedestrian/pedacyclist or other) for that month. Once again, different effects of light condition are clearly evident for pedestrian and pedalcycle as compared with all other fatal accidents.

Considering first all fatal accidents *other* than those in which the first harmful event involved pedestrians or pedalcyclists, one sees no variation in the distribution of accidents across the three test periods as a function of months (Figure 13). Throughout the year, the percentage of fatal accidents occurring in the Twilight Zones and the Daylight Control periods are roughly equal, while that for the Nighttime Control period runs consistently higher. The proportion of (other) fatal accidents in the Twilight Zones ranged from 21.6% in August to 22.8% in April, with a mean of 22.3%; those in the Daylight Control period ranged from 21.7% in August to 24.2% in January, with a mean of 22.6%; and those in the Nighttime Control period ranged from 28% in October to 30.7% in March, with a mean of 28.9%. The absence of monthly variations in fatal accidents found in the Twilight Zones weighs against the hypothesis that light condition is an important contributor to these accidents for, if it were, one would expect higher proportions to occur in the winter months when the Twilight Zones are dark than in the summer months when they are light, unless changes in exposure counterbalanced the increased risk of darkness.

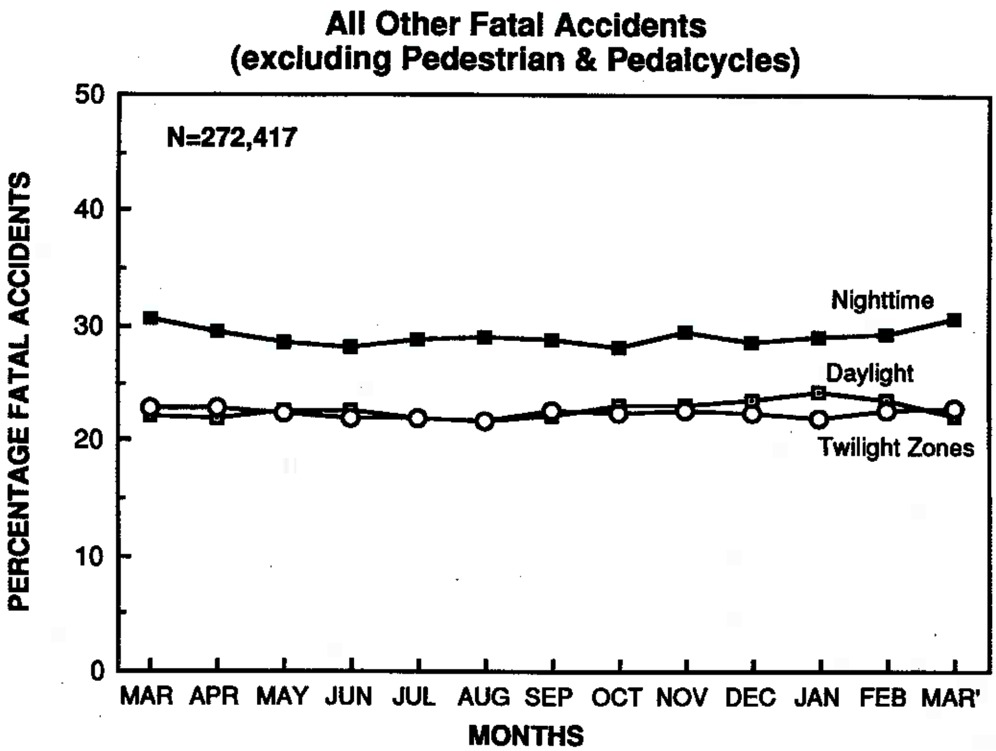

Figure 13. Percentage of fatal accidents, excluding pedestrian and pedalcycles, during Twilight Zones and Daylight and Nighttime Control Periods for each month of the year.

Turning now to the fatal pedestrian and pedalcyclist accidents (Figure 14), one sees a clear difference in the distribution of accidents across the three test periods as a function of months. Throughout the year, the percentage of fatal accidents occurring in the Daylight Control periods is relatively stable, ranging from 17.5% in November to 21.8% in May, with a mean of 19%. In contrast, the percentage of fatal accidents in the Twilight Zones is generally higher and varies widely from 18.2% in June to 41.3% in December, with a mean of 30.8%. This variation in the monthly proportion of fatal pedestrian and pedalcycle accidents is similar in form to concurrent variations in natural illumination illustrated in Figure 2. The monthly percentage of fatal accidents occurring in the Nighttime Control period is also variable, tending to be lower in the fall and winter months with a minimum of 24.2% in November, and higher in the spring and summer months with a peak of 37.7% in July.

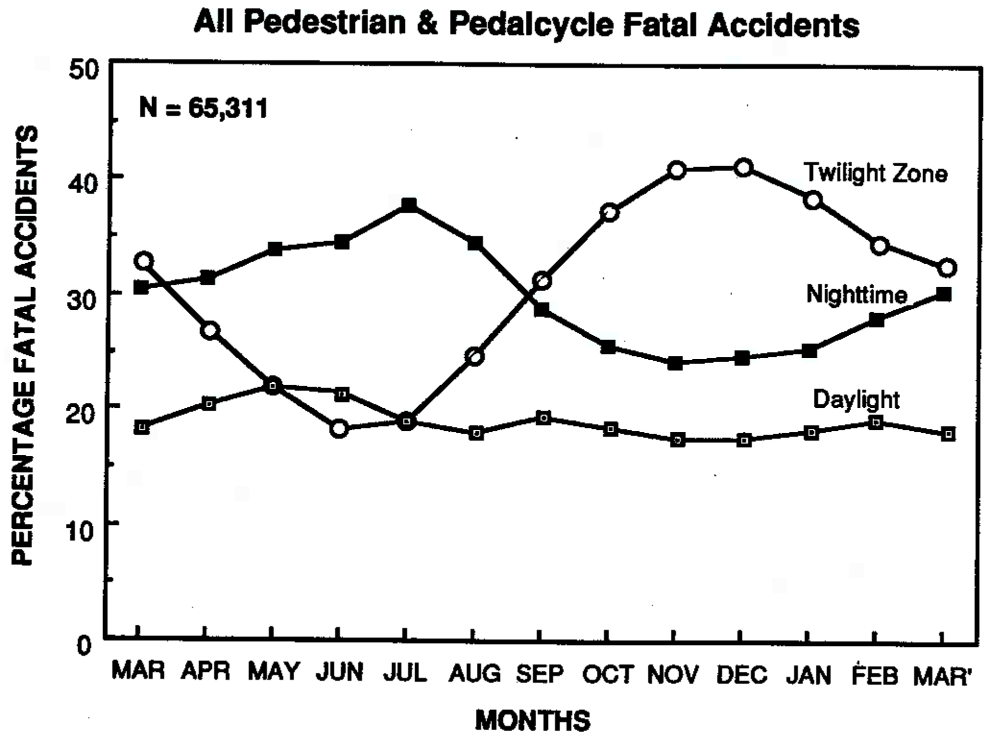

Figure 14. Percentage of fatal pedestrian and pedalcycle accidents during Twilight Zones and Daylight and Nighttime Control Periods for each month. March is repeated to permit easy comparison with Figure 2.

The monthly variations of fatal pedestrian and pedalcycle accidents in the Twilight Zones, which covaries with natural illumination, provides additional support for the hypothesis that light condition is an important contributor to these accidents. There is little indication of seasonal variations in the Daylight Control period when illumination is uniformly light. In the Nighttime Control period, when illumination is uniformly dark, the proportion of fatal accidents appears to vary across months in a manner roughly opposite to variations in the Twilight Zones, being generally higher in the summer and lower in the winter. This variation might be related to increased exposure of pedestrians and pedalcyclists at night during warmer weather. It may also be due partly to shifting proportions – as the percentage of accidents in one test period declines, the percentage in other time periods must increase. All else being equal, however, shifting proportions from the Twilight Zones would tend to inflate the percentages for both Daylight and Nighttime equally in the summer and deflate them both in winter, which is not the case. So interpretation of variations in the Nighttime data remains equivocal. Nevertheless, there is no indication in either the Daylight or Nighttime data of some hidden seasonal variable that would account for covariation of illumination and fatal pedestrian/pedalcycle accidents in the Twilight Zones. These data imply that light condition is a primary contributor to this class of accidents.

In addition to differences in the role of light condition, the results of Quasi-Experiment I suggested a differential role of alcohol in pedestrian/pedalcycle accidents versus all other fatal traffic accidents. At least in the Twilight Zones, the representation of drinking drivers was much lower in pedestrian/pedalcycle accidents than in other fatal accidents (Figure 11). In order to examine the differential role of alcohol more closely, the data sets presented in Figures 13 and 14 were subdivided into fatal accidents for which there was no reported evidence of drivers' consumption of alcohol ("No Drinking Drivers") and those in which it was reported that one or more drivers had consumed alcohol ("Drinking Drivers"). These data, collapsed across months, are summarized in Table 4. Again, this classification does *not* represent *intoxication* by legal standards, but rather indicates just that either no alcohol or some alcohol (potentially a low level) was known to have been consumed. It is possible, therefore, that these data underestimate the negative effects of alcohol intoxication. Figure 15 presents these results broken down by month for all fatal accidents other than pedestrian and pedalcyclists, and Figure 16 presents those for pedestrian/pedalcycle accidents.

Table 4. Distribution of fatal accidents involving alcohol across test periods and accident classes.

	Pedestrian and Pedalcycle Accidents			**All Other Accidents**		
Test Period	**No Drinking**	**Drinking**	**All**	**No Drinking**	**Drinking**	**All**
Twilight	22,260 (88.1%)	3018 (11.9%)	25,278 (100%)	45,609 (55.5%)	36,552 (44.5%)	82,161 (100%)
Daylight	14,645 (94%)	930 (6%)	15,575 (100%)	63,380 (75.9%)	20,120 (24.1%)	83,500 (100%)
Nighttime	19,138 (78.2%)	5320 (21.8%)	24,458 (100%)	35,633 (33.4%)	71,121 (66.6%)	106,754 (100%)
All	56,043 (85.8%)	9268 (14.2%)	65,311 (100%)	144,622 (53.1%)	127,793 (46.9%)	272,415 (100%)

Considering first the larger group of all "other" (non-pedestrian) fatal accidents, note that nearly half (46.9%) of the accidents in the *combined* test periods involved at least one drinking driver. The proportion of alcohol-related accidents varies widely in the separate test periods, however (Table 4). In Daylight, less than one-quarter of the fatal accidents involved drinking drivers, while in Nighttime fully two-thirds of the *non-pedestrian* accidents involved drinking drivers. Drinking drivers were involved in 44.5% of the fatal non-pedestrian accidents in Twilight. Figure 15 reveals no appreciable monthly variation in the distribution of fatal non-pedestrian accidents, although the predominance of alcohol-related accidents at night is clearly evident. Among accidents with drinking drivers, the highest percentage of fatalities occurred at night, while among accidents involving no drinking drivers, the *lowest* percentage of fatalities occurred at night. Consistent with previous research (Evans, 1991), these results confirm that a large proportion of fatal nighttime (non-pedestrian) accidents involve at least one drinking driver. One cannot help but speculate that the overall nighttime fatality rate could be dramatically reduced if drinking drivers were eliminated from the traffic mix!

As found in Quasi-Experiment I (Figure 11), involvement of drinking drivers was substantially lower in fatal pedestrian/pedalcycle accidents (Table 4), including only 14.2% over the combined test periods. Again, the lowest proportion of drinking drivers was found in Daylight (6%). The highest percentage of drinking drivers was found in the Nighttime Control period (21.8%), but this level of involvement was still lower than the lowest percentage of drinking drivers (in daylight) for all other fatal accidents. Drinking drivers were involved in 11.9% of the fatal pedestrian/pedalcycle accidents in the Twilight Zones, which matches the proportion found in Quasi-Experiment I.

Figure 16 shows that monthly distribution of fatal pedestrian/pedalcycle accidents with no drinking drivers followed a pattern similar to that found with no-drinking and drinking drivers combined (Figure 14). (This is not surprising since 85.8% of the combined data involved no drinking driver.) Fatal pedestrian accidents in the Daylight Control period were relatively stable over the year, with a slight tendency toward higher values in May and June. In contrast, the percentage of accidents in the Twilight Zones varied from 15.1% in June to 37.5% in December, which paralleled concurrent variations in natural illumination. Data in the Nighttime Control period again show a tendency toward higher percentages in the summer months, which may be related to increased exposure. The data from accidents that involved drinking drivers show no appreciable monthly variations. Percentages of alcohol-related pedestrian accidents during the Twilight Zones, which are of primary interest here, are uniformly low, ranging from 2.6% in July to 4.6% in September, and show no correlation with the annual solar/twilight cycle of ambient illumination. Similar to the results from non-pedestrian accidents, the highest percentages of alcohol-related pedestrian/pedalcycle occurred in the Nighttime Control period.

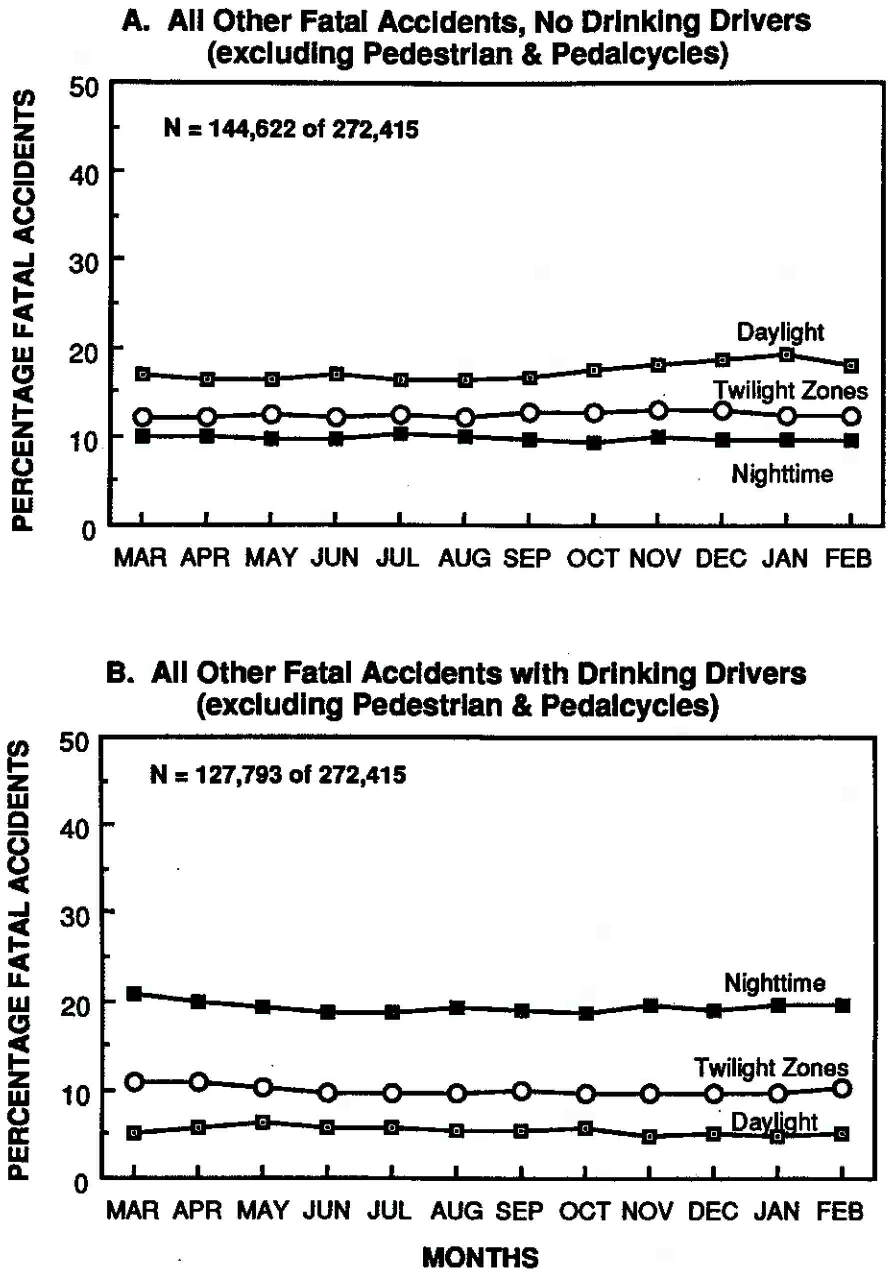

Figure 15. Percentage of fatal accidents, excluding pedestrians and pedalcycles, which involved no drinking drivers (Panel A) or one or more drinking drivers (Panel B).

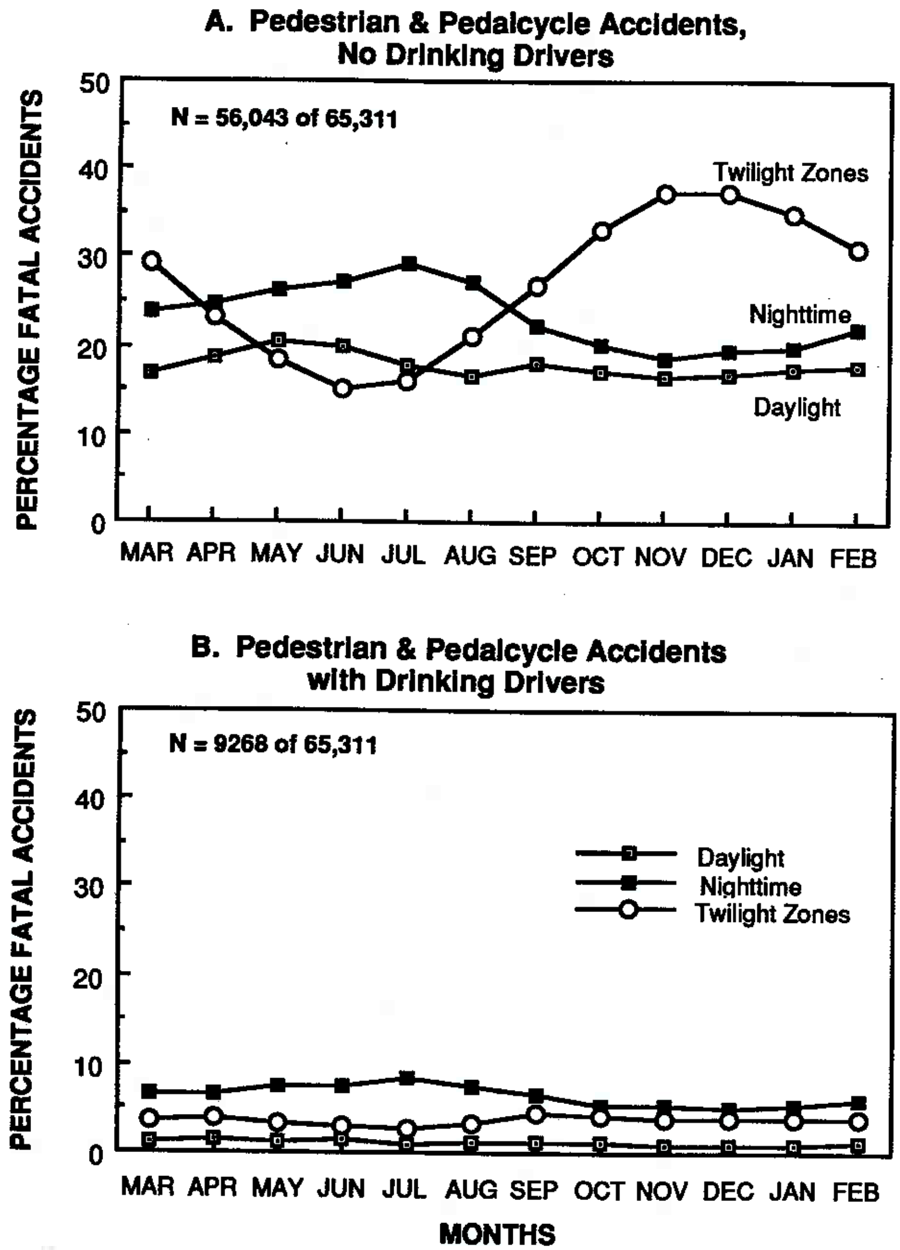

Figure 16. Percentage of fatal pedestrian and pedalcycle accidents which involved no drinking drivers (Panel A) or one or more drinking drivers (Panel B).

CONCLUSIONS

The FARS data from the *Twilight Zones* provide new evidence that reduced visibility is indeed an important contributor to higher road fatality rates in darkness. But the picture is not as simple as initially anticipated, for the role of degraded visibility appears not to be equally important for all classes of accidents.

The evidence from Quasi-Experiment I shows that 12.1% more road fatalities occur during the darker portion of the Twilight Zones than is predicted by chance (Figure 3). Finer analyses confirmed that the contribution of reduced visibility cannot be attributed to other situational variables. The overrepresentation of fatal accidents in darker conditions is evident in both morning and evening test periods, on weekdays as well as weekends, and in accidents that involve no drinking drivers as well as those involving drinking drivers (Figures 4, 5, and 6).

The role of reduced visibility became clearer upon examination of more difficult visual conditions. Under good atmospheric conditions, the overall proportion of fatal accidents in darker conditions was only 9.8% greater than chance, while under degraded atmospheric conditions this proportion was 25.6% greater than chance (Figure 7). When the data were divided according to accident classification, the proportion of pedestrian and pedalcycle accidents in darker conditions was substantially higher than that of all other fatal accidents (Figure 8). Examining these two classes of fatal accidents under clear and degraded atmospheric conditions (Figure 9) showed that the lowest proportion of fatal accidents in darker conditions was obtained for non-pedestrian accidents in clear atmospheric conditions — 58.9%, which is 5.7% greater than chance. The highest proportion was obtained with pedestrian/pedalcycle accidents for which 92.3% occurred in darkness when the atmosphere was degraded (i.e., 39.1% greater than chance). The latter result, for pedestrian and pedalcycle accidents, did not change when all events that involved drinking drivers were excluded (Figure 10 B). For *other* (non-pedestrian) fatal accidents, however, when drinking drivers were excluded, the overrepresentation of fatal accidents in darker conditions decreased to only 1.8% greater than chance in clear weather, while it remained higher, 18.9% greater than chance, in degraded atmospheric conditions (Figure 10 A). This suggests that, unlike pedestrian and pedalcycle accidents, visibility is a minor contributor to *other* fatal nighttime accidents in clear weather, but visibility remains an important factor for this class of accidents when vision is degraded further by inclement weather.

Quasi-Experiment I also revealed differential involvement of drinking drivers in different classes of fatal accidents. Consistent with earlier reports (e.g., Evans, 1991), we found that a substantial portion (36.8%) of fatal accidents in the Twilight Zones involved at least one drinking driver. When divided according to accident classification, however, the data revealed that drinking drivers were much less likely to be involved in pedestrian and pedalcycle accidents than in other fatal accidents. Only 11.9% of the fatal pedestrian and pedalcycle accidents involved one or more drinking drivers, in contrast to 44.5% of all other fatal accidents (Table 4). To our knowledge, this discrepancy has not been previously reported. In fact, it seems contrary to the account offered by Evans (1991, p. 185-186). Alcohol consumption and involvement in mishaps clearly varies as a function of time of day. So we would emphasize that, with respect to alcohol, the present results reflect only the situation encountered in the Twilight Zones; higher levels of alcohol involvement are likely in time periods closer to midnight, and lower levels in time periods closer to noon. The present data indicate that, during the Twilight Zone test periods, reduced visibility is more important than alcohol as a contributor to pedestrian and pedalcycle fatalities, while the converse is true of other fatal traffic accidents that occurred in identical time periods and road environments (Figure 11).

Quasi-Experiment II investigated the possibility that some hidden seasonal variable other than visibility is responsible for the higher incidence of fatal accidents in darker portions of the Twilight Zones. Consistent with the hypothesized role of visibility, variations in the monthly rate of fatal pedestrian/pedalcycle accidents were found to be closely correlated with variations in natural illumination in the Twilight Zones, while there were no parallel variations of the fatality rates in daylight and nighttime control periods (Figure 14). Again, these results, which imply that visibility is a key contributor to pedestrian and pedalcycle accidents, held true when all events that involved drinking drivers were excluded from analysis (Figures 15 A and 16 A). This pattern of results confirms that variations of natural illumination, and neither some other seasonal variable nor alcohol, is responsible for increases in pedestrian and pedalcycle fatalities in the darker (winter) months. A similar analysis of all other fatal accidents (excluding pedestrian and pedalcycle accidents) revealed a different picture. There was virtually no concurrent variation in the monthly distribution of other (non-pedestrian/pedalcycle) fatal accidents in the twilight-zone test periods (Figure 13). This suggests that fatal non-pedestrian accidents are *not* notably influenced by increased darkness during the winter twilight-zone test periods, a finding that weighs against the hypothesized contribution of reduced visibility. The occurrence of non-pedestrian fatal accidents is apparently unrelated to natural illumination.

This null finding cannot be taken as the whole story, however, because there is other evidence that reduced visibility does contribute to certain subclasses of fatal non-pedestrian/ pedalcycle accidents. As seen in Quasi-Experiment I (Figure 10A), the incidence of fatal non-pedestrian accidents in darker conditions is 18.9% greater than chance when visibility is degraded further by poor atmospheric conditions (and all accidents involving drinking drivers have been excluded). Moreover, earlier research has shown that poor visibility (i.e., low conspicuity) is an important contributor to some types of intervehicle accidents, such as nighttime car-into-truck underride accidents (Allen, 1970; Minahan and O'Day, 1977; Sivak, 1979; Henderson et al., 1983). Reduced visibility almost certainly contributes to *some* fatal intervehicular accidents for the same reasons that apply in pedestrian and pedalcycle accidents. As reviewed in the introduction, driving behavior commonly exceeds the limits of human perception and lighting technology for inadequately marked hazards. A dim, low-contrast obstacle cannot be perceived in time to avoid collision at normal travel speeds (Roper and Howard, 1938; Johansson and Rumar, 1968; Owens, Francis, and Leibowitz, 1989). Most vehicles and roadway obstacles are well enough marked with lights or retroreflective materials to provide adequate visibility at long distances, at least in clear atmospheric conditions. The present findings suggest that, aside from pedestrians and pedalcyclists, accidents with inadequately marked obstacles comprise a relatively small portion of the total number of fatal accidents in the Twilight Zones.

In summary, the outcome of both Quasi-Experiments provides new evidence for
(1) the important role of visibility as a contributing factor in fatal traffic accidents, and
(2) the success of past efforts to deal with the visual difficulties of nighttime driving.

Our results confirm that poor visibility is a major factor in fatal accidents with inconspicuous hazards, such as pedestrians, joggers, and bicyclists. Indeed, for this class of accidents, the evidence indicates that visibility is a more important contributing factor than drivers' consumption of alcohol. But the present results also indicate that reduced visibility does not play a dominant role in all classes of nighttime accidents. Specifically, it appears that natural illumination (i.e., from the sky) bears little relation to the incidence of fatal accidents *other than* those involving pedestrians and pedalcyclists. This difference can be attributed to the effectiveness of widespread use of marker lights and reflective materials on vehicles and fixed obstacles near the roadway. By virtue of appropriate regulations and lighting technology, these hazards are generally highly visible after dark and, therefore, fatal accidents with such hazards are more likely to be associated with factors like alcohol than with natural ambient illumination.

While it is encouraging to consider the benefits of existing marking systems, the problem of poor visibility in night driving remains serious. Because of economic and technical constraints, these accidents are not likely to be eliminated soon through either universal lighting of all roadways or enhancement of low-beam headlight systems (Sivak, Helmers, Owens, and Flannagan, 1992). Rather, wider use of well-designed reflective markings, in conjunction with more effective public information about the special hazards of the night traffic environment, appear more promising (Blomberg, et al., 1986; Olson, 1992; Owens, Antonoff, and Francis, in press).

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APPENDIX
DERIVATION OF LIGHTER AND DARKER PORTIONS OF THE TWILIGHT ZONE

The empirical strategy of Quasi-Experiment I was to determine whether the incidence of fatal accidents in the Twilight Zones differed between lighter and darker portions of the test periods. Thus, the null hypothesis was that the proportion of fatal accidents under dark (or light) conditions would be equal to the proportion of the total time included in the Twilight Zones that conditions were darker (or lighter) than the midpoint of civil twilight. This null or "chance" prediction was derived through the following analysis of the annual twilight cycle.

1. The Mean National Solar Cycle. The mean solar cycle was computed using a program written in *Mathematica* to obtain times of sunrise and sunset for each day of 1992 at the following four locations. Accuracy of the program was confirmed to be within one minute by comparison with the Naval Observatory's 1993 Astronomical Almanac.

Eastern Time Zone: 36°N, 78°W
Central Time Zone: 37°30'N, 92°W
Mountain Time Zone: 40°N, 108°W
Pacific Time Zone: 40° 30'N, 119°W.

These locations were selected to represent points near the geographic center (in latitude and longitude) of states included in each of the four time zones of the lower continental states.

2. The Time Range of Morning and Evening Twilight. At 40°N latitude, which is the approximate central latitude of the lower continental United States, the duration of civil twilight varies from 27 to 32 minutes after sunset and before sunrise, depending on the season (Leibowitz and Owens, 1991). So on the average, the midpoint of civil twilight occurs 15 minutes after sunset and 15 minutes before sunrise. Taking the midpoint of civil twilight as the dividing point between lighter and darker portions of the Twilight Zones, the annual twilight cycle was derived by plotting functions parallel to, but 15 minutes later than, sunset and 15 minutes earlier than sunrise (Figure 2).

3. The Twilight Zone Test Periods. The earliest and latest standard times of these mean national twilight cycles, which occur at the summer and winter solstices, are the natural boundaries of the mean annual twilight cycle for the lower continental U.S. The amplitude of this cycle is 2.64 hours, ranging from 4.49 to 7.13 decimal hours in the morning and from 17.05 to 19.81 decimal hours in the evening. Because the FARS data are coded for integer hours, it was not possible to select data sets that conformed exactly to the natural Twilight Zones. Our experimental approximation of the natural twilight zones was therefore defined as two three-hour time bands: between 04:00 to 06:59 hours in the morning, and between 17:00 and 19:59 hours in the evening (Standard Time).

4. The Light/Dark Portions of the Twilight Zone Test Periods. Because the experimental test periods exceeded the amplitude of the natural twilight cycle, they included darker portions that exceeded 50% of the total time. In order to determine the portions of the morning and evening experimental Twilight Zones that were darker than the midpoint of civil twilight, each test period was represented as a rectangle, which was three hours by one year in dimensions and, thus, comprised an area of three year-hours. The darker area of this rectangle for both morning and evening Twilight Zones was then determined for each of the four lower continental US time zones (i.e., at the locations listed above). The darker portions of morning and evening Twilight Zone test periods at each location were as follows:

	Proportion of Time Darker Than Mid-Twilight	
Location	**AM**	**PM**
36° N, 78° W	.616	.486
37° 30′ N, 92° W	.593	.508
40° N, 108° W	.604	.484
40° 30′ N, 119° W	.527	.563
National Mean	.585	.510

5. Weighting the Light/Dark Portions for Unequal Sample Sizes. Most of the recorded fatal accidents (70.3%) occurred in the evening Twilight Zone. Therefore, the amount of darkness in the evening Twilight Zone should be weighted proportionately more heavily than that of the morning Twilight Zone. This was accomplished by the following formula:

$$\text{Weighted Darker Portion} = \text{PM Dark Portion}\ (0.703) + \text{AM Dark Portion}\ (0.297)$$
$$\text{i.e., } .510\ (0.703) + .585\ (0.297) = .532$$

Thus, if fatal accidents were distributed uniformly across the Twilight Zone test periods with no relation to variations in natural illumination, 53.2% of the total fatal accidents (collapsed across geographic regions for both morning and evening) would have happened in the darker portion of the Twilight Zone test periods. This was the null hypothesis for Quasi-Experiment I.