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Visual assessment of pedestrian crashes

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ABSTRACT

Of the numerous factors that play a role in fatal pedestrian collisions, the time of day, day of the week, and time of year can be significant determinants. More than 60% of all pedestrian collisions in 2007 occurred at night, despite the presumed decrease in both pedestrian and automobile exposure during the night. Although this trend is partially explained by factors such as fatigue and alcohol consumption, prior analysis of the Fatality Analysis Reporting System database suggests that pedestrian fatalities increase as light decreases after controlling for other factors.

This study applies graphical cross-tabulation, a novel visual assessment approach, to explore the relationships among collision variables. The results reveal that twilight and the first hour of darkness typically observe the greatest frequency of pedestrian fatal collisions. These hours are not necessarily the most risky on a per mile travelled basis, however, because pedestrian volumes are often still high. Additional analysis is needed to quantify the extent to which pedestrian exposure (walking/crossing activity) in these time periods plays a role in pedestrian crash involvement. Weekly patterns of pedestrian fatal collisions vary by time of year due to the seasonal changes in sunset time. In December, collisions are concentrated around twilight and the first hour of darkness throughout the week while, in June, collisions are most heavily concentrated around twilight and the first hours of darkness on Friday and Saturday. Friday and Saturday nights in June may be the most dangerous times for pedestrians. Knowing when pedestrian risk is highest is critically important for formulating effective mitigation strategies and for efficiently investing safety funds. This applied visual approach is a helpful tool for researchers intending to communicate with policy-makers and to identify relationships that can then be tested with more sophisticated statistical tools.

1. Introduction

As vulnerable road users, pedestrians represent a disproportionate number of fatal crash victims. In the United States in 2007 alone, 4654 pedestrians were killed (11.3 percent of all traffic fatalities) and 70,000 pedestrians were injured (2.8 percent of all traffic injuries). The night-time hours were especially precarious, with 60 percent of all pedestrian collisions in 2007 occurring at night. It is now generally recognized that pedestrians are more likely to be involved in crashes at night. The elevated nighttime crash risk is associated with the difficulty motorists have in recognizing the presence of pedestrians at night and the associated lack of recognition and commensurate change of behavior required to accommodate this increased risk by pedestrians. Leibowitz and Owens (1977) showed that this has to do with the selective nature of the visual losses that the human vision system experiences at night. Leibowitz et al. (1998) later extended this notion by suggesting that drivers are generally not aware of their perceptual limitations at night, and that speed limits are too high for drivers to be able to avoid collisions with low-contrast obstacles. An alternate line of inquiry associated pedestrians' increased risk at night with their lack of sufficient conspicuity and their failure to appreciate the magnitude of drivers' difficulty seeing them at night (Tyrrell et al., 2004; Shinar, 1984).

The distribution of fatal crashes before and after the annual daylight saving time (DST) changes in spring and fall has also been examined to identify the increased risk to pedestrians in darkness (Sullivan and Flannagan, 2001). This analysis assumed that traffic conditions are the same in the weeks immediately before and after the changeover to DST, as traffic is principally governed by clock time rather than by the position of the sun in the sky. Thus, observed differences between these two periods in the number of accidents and their characteristics are associated with the difference in light conditions. While the research has shown a significant increase

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Table 1
Summary of single vehicle-pedestrian fatal collisions 1998–2007.

Total	43,649
Annual mean	4365
Annual minimum	4179 (2004)
Annual maximum	4758 (1998)
Annual standard deviation	169
Total pedestrian deaths	44,313

in risk to pedestrians, the method is limited to a short span of time.

The majority of past studies have considered only the pedestrian's visibility and the vehicle's speed. However, other physical, environmental and behavioral aspects may also play a role (Greene-Roesel et al., 2007). For example, the relationship between crashes and time of day, day of week, and time of year may reveal interesting and heretofore unexamined trends.

This study applies a simple visual exploratory approach to examine the relationship between fatal pedestrian crashes and time of day, day of the week, and time of year in the U.S. Also examined are time of day interactions with known risk factors—inexperienced drivers and alcohol impairment, with the intent to illuminate potential heretofore unknown effects. There are four motivations for using an exploratory visual approach. First, the analysis is exploratory in nature, and visual methods can serve data exploration well. Second, since the analysis is focused on examining time, which is continuous in nature, it is desirable to allow the data to suggest where relationship boundaries or transitions in time may exist, rather than establish cutpoints *a priori* and then examine the results. Third, the graphical method used is able to simply convey a large amount of complex and possibly highly non-linear relationships regarding crash patterns—complexity that would be largely lost if more formal methods (such as ANOVA, regression, etc.) were used. Finally, two-dimensional, color graphs highlight the interactions between different variables and can identify potential areas for formulating potential crash mitigation strategies.

Two-dimensional analysis has been used in previous safety research (e.g. Stutts et al., 1996), but it has typically been presented in tables filled with numerical values. A color graph—or colored thematic map—allows for a more intuitive visual interpretation of the relationship between variables, and is used throughout this research.

The following section presents insights derived from the data (using colored thematic maps), while the third section addresses the considerations that should be taken into account when interpreting the results of this paper. The final section presents the conclusions and recommendations.

2. Data and visual interpretations

This study examines fatal single vehicle-pedestrian collisions between 1998 and 2007 from the Fatality Analysis Reporting System (FARS), a comprehensive surveillance system of U.S. fatal collisions maintained by the National Highway Traffic Safety Administration (NHTSA). Multiple vehicle collisions were eliminated because pedestrian involvement could be incidental in these crashes. Table 1 provides summary statistics of the dataset used in the visual assessments that follow.

The initial analysis is a graphical cross-tabulation of collisions by the two variables time of day and month of year. In Fig. 1, the absolute collision counts are graphed by time of day on the *y*-axis and month on the *x*-axis. The coloring reflects a continuous scale of number of crashes, based on the range of values observed in the data. For example, the darkest red color represents 646 observed crashes for the given month-hour interval. Of course the color scaling is arbitrary and also reflects the proportion observed in a particular month-hour—with white representing a least crash intense month-hour and red the most crash intense month-hour.

The results of this analysis are shown in Fig. 1. The graph shows a steep increase in fatal pedestrian collisions after approximately twilight. This pattern would be difficult to show using quantitative methods, but is revealed clearly using this visual graphing technique. The crash intensity during twilight hours is the greatest in the late fall and winter months and relatively less intense during the middle of the year (when the daylight hours are longer). Collisions in the graph vary from a low of 52 (April, between 10 and 11 am) to a high of 646 between 6 and 7 pm in November. The peak collision intensity in June and July is from 9 to 10 pm with 436 and 390 collisions, respectively during the 10-year period. The graph also shows a slight morning peak in collisions in the fall and winter months, which may coincide with sunrise and early morning pedestrian activity.

Fig. 1 also reflects, at least to some extent, pedestrian exposure levels. However, pedestrian exposure is not likely to account for all of the trends shown. Work hours, for example, do not typically shift to a large extent from summer to winter—and thus work related pedestrian activity (i.e. exposure) should occur at nearly the same time of day but would diminish and increase with weather fluctuations. Specifically, peak work-related pedestrian exposure should occur during the morning commute, the lunch hour, and the evening commute—at least on weekdays. The trends shown in the figure, however, reveal a pattern of crash intensity that varies by time and closely track seasonal changes in sunrise and sunset times.

Because the U.S. spreads across several time zones, it is difficult to determine precisely which lighting conditions are associated with particular collisions throughout the country; locations that are at different latitudes within the same time zone will experience sunrise and sunset at different times. To explore this issue more carefully, sunset time by date for each collision record that included geographic coordinates ($N = 7618$) were extracted and examined as a subset of the larger dataset. The results are shown in Fig. 2 with the *y*-axis modified to reflect time of day relative to sunset. The figure indicates that collisions rise significantly during the first 2 h after sunset, which is twilight and the first hour of darkness. Nine hundred eighty-eight collisions, representing 13 percent of the total, occurred during the second hour after sunset. This pattern suggests that the risk of fatal pedestrian collisions is relatively higher in partial or full darkness than at any other time. As was seen in Fig. 1, the number of collisions diminishes over a few hours in the winter, but drops off more quickly during the summer months.

It is also important to examine how other known risk factors might interact with time of day, in particular, inexperienced drivers and alcohol-impaired driving—two important and well recognized factors in motor vehicle collisions. Fig. 3 shows the patterns of collisions by month and time of day for teenagers and known intoxicated drivers. Fig. 3(a) suggests that pedestrian fatal collisions involving young drivers are also concentrated around the hours after sunset, diminishing but remaining relatively intense into the early morning hours. In July, for example, pedestrian involved fatal crashes are quite intense until 3:00 am. Fatal pedestrian collisions involving alcohol-impaired drivers, shown in Fig. 3(b), reveal perhaps the most consistent pattern of all graphs examined. The highest intensity varies with sunset hours, and remains intense all the way until 3:00 am throughout the year. But continues at higher rates through the night. The intensity of alcohol-impaired driving involved fatal pedestrian collisions is relatively low during all daylight hours throughout the year. Fig. 3(c) shows that fatal pedestrian collisions with alcohol-impaired teenagers tend not to occur during daylight hours, are most intense at sunset and remain relatively intense throughout the early morning hours (3:00 am) throughout the year. Fig. 3(d) shows that when teens and alcohol-

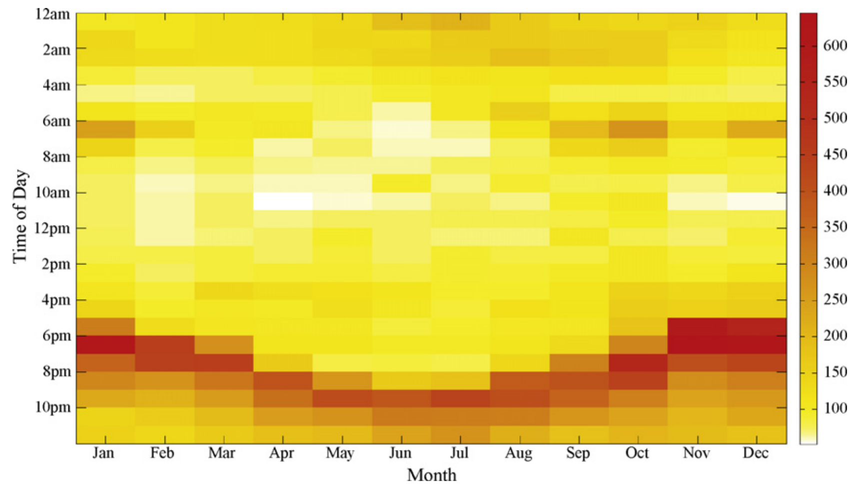

Fig. 1. Pedestrian fatal collisions by month and time of day.

impaired crashes are removed, sunrise and sunset are by far the most dominant factors associated with collisions.

As mentioned previously, the graphs so far confound exposure and time of day effects (among others), despite clear evidence that time of day effects clearly exist. Because national hourly pedestrian volume data are lacking, an attempt was made to examine this confounding using local pedestrian exposure data. In keeping, weekly pedestrian volume patterns in Alameda County, California, were collected to provide some additional insights. The University of California Safe Transportation Research & Education Center installed and monitored five automatic pedestrian counters that collected data at 13 sites in Alameda County over a 14-month period between April 2008 and June 2009. The sites included both urban and suburban locations. Fig. 4 shows composites of the pedestrian volumes at the various sites for several weeks. The gray line represents the weekly pedestrian volume pattern during several non-holiday weeks in November, December, and January and the black line represents the pedestrian volume pattern in May and June. Because the count data were collected at sites with different overall volumes, the graph shows the composite volume pattern as a percent of total weekly volume. A detailed description of the automated pedestrian counting methodology used in Alameda County has been published by Schneider et al. (2009).

Fig. 4 shows that the morning rise and the evening decline in pedestrian activity occur at roughly the same time in the winter and summer in Alameda County. This pattern confirms earlier suspicions that pedestrian activity patterns are not determined by sunrise and sunset. Fig. 4 helps to explain why the winter months have higher numbers of evening collisions than the summer months. At 6 pm in both composite graphs, the hourly pedestrian volume is between 0.8 and 1.0 percent of the weekly volume (only slightly lower on Sundays), so there are still relatively many pedestrians. At 9 pm, the hourly volume is closer to 0.4 percent of the weekly volume, representing the end of the daily peak. Although the available count data cannot be used in a direct calculation of risk, the patterns suggest that risk may not be significantly different in the first hour of darkness during different times of the year. The difference in crashes during different hours of the day may be primarily due to greater pedestrian activity after dark during the winter months. In addition, Fig. 4 suggests that pedestrian volume does not increase significantly until after 6 am, which may partially explain why the frequency of darkness and twilight collisions is much lower in the morning than the evening.

While the Alameda County exposure data both confirms the suspicion that pedestrian activity is generally insensitive to time of year and explains the greater overall magnitude of collisions during winter, it fails to explain the greater magnitude of collisions between 10 pm and midnight in summer compared to winter. The consistent pedestrian volumes suggest that there is an increased risk during this time period during the summer (i.e. the number

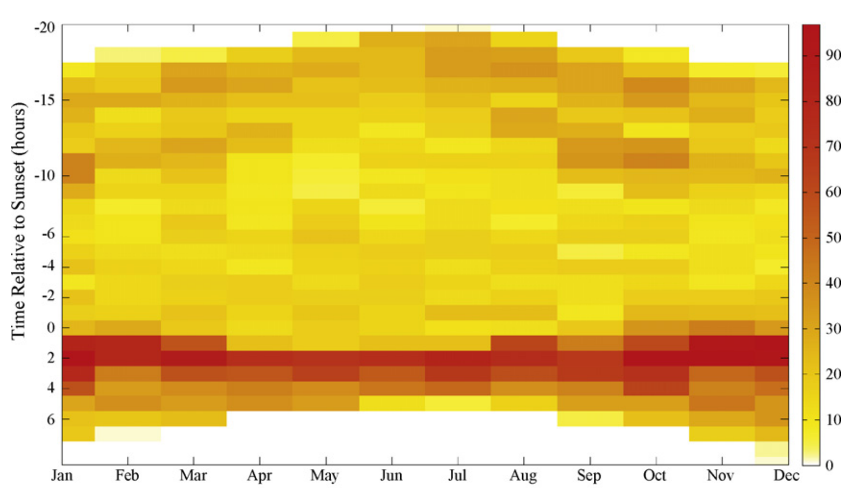

Fig. 2. Pedestrian fatal collisions by month and time of day (relative to sunset).

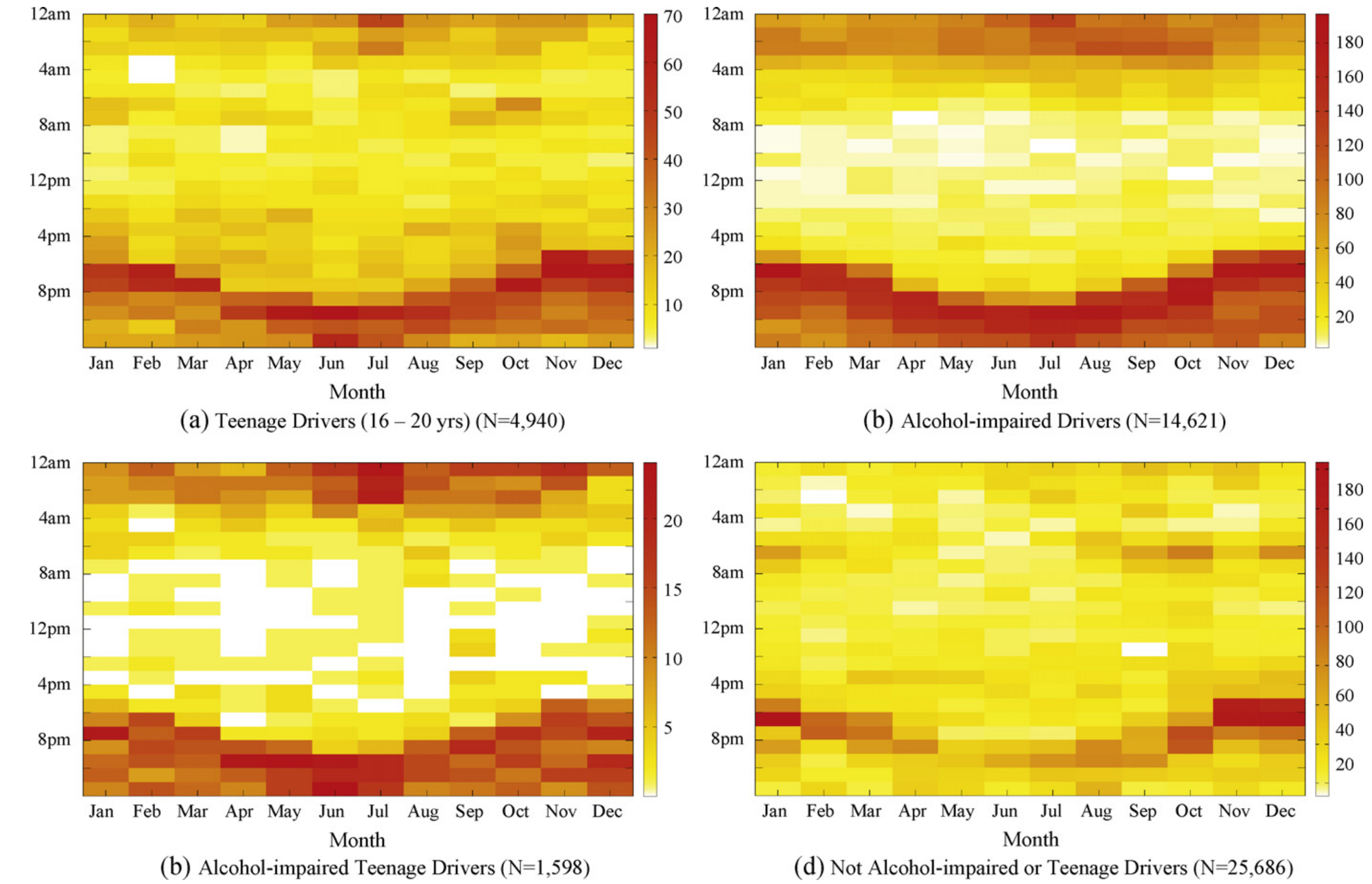

Fig. 3. Pedestrian fatal collisions by month, time of day, and covariates.

of fatalities is still relatively high even though pedestrian volumes decline steeply after 6 pm).

Examining the collision pattern by time of day and day of week in different months gives additional insight into this question. Figs. 5 and 6 show the same graph as previous for the months of June and December, respectively. In June, weekdays experience a slight peak in collisions between 9 and 10 pm, but the greatest concentration of fatal collisions is on the weekend days from 9 pm tapering into the early hours of the morning (Fig. 5). The weekday pattern is explained by the low volume of pedestrians late in the evening at any time of year. Weekend pedestrian fatalities may have several possible explanations. One possibility is that there are more pedestrians walking on Friday and Saturday evenings in the summer than the winter on a national level, even though this is not reflected in the composite Alameda County volume data. The automated counters were not placed at locations near stadiums, waterfronts, or other major nighttime pedestrian activity generators which may have had higher pedestrian volumes on weekend evenings. Another possible explanation for the higher number of pedestrian fatalities on weekends is due to more driving while intoxicated, speeding, and intoxicated pedestrians on Friday and Saturday nights during the summer. The strong concentration in late evenings on weekends seems to explain the moderate concentration shown between 10 pm and midnight in Fig. 1. In December, the concentrated area of fatal collisions is evenly distributed between 5 and 7 pm throughout the week (Fig. 6). Like June weekends, December weekends taper

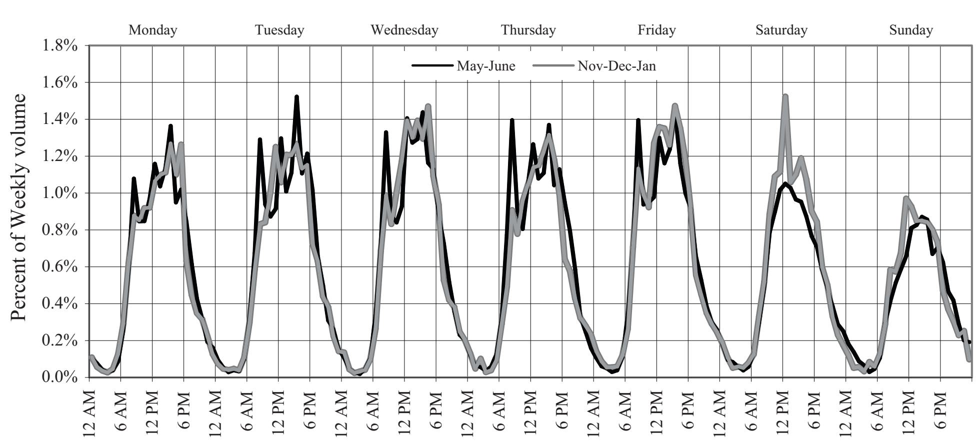

Fig. 4. Composite weekly pedestrian volume patterns by time of day.

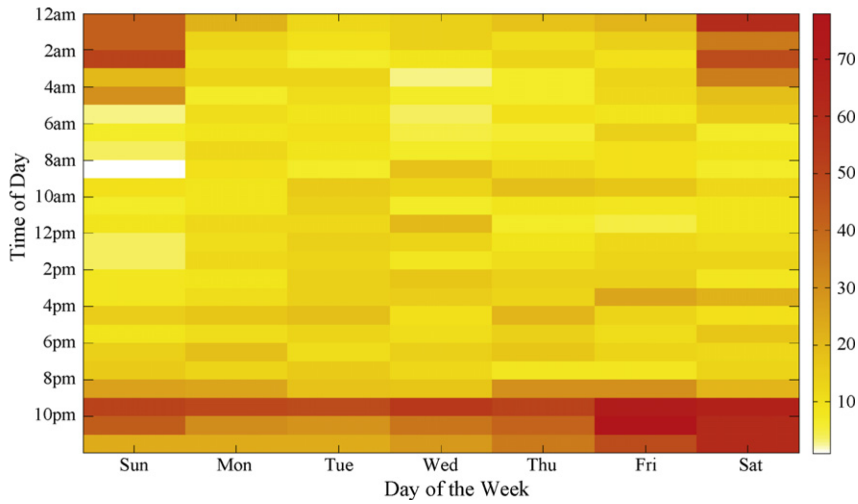

Fig. 5. June pedestrian fatal collisions by day of week and time of day.

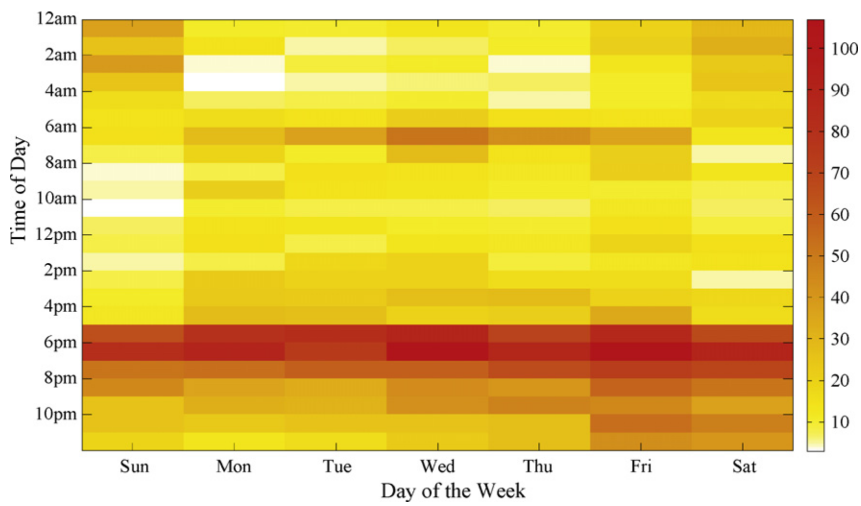

Fig. 6. December pedestrian fatal collisions by day of week and time of day.

out slowly, but unlike June, the collisions in those hours represent a smaller proportion of the total week collisions. For this reason, the December weekend nights have little effect on the month by time of day graph (Fig. 1).

3. Considerations

There are several caveats to consider when examining and interpreting the graphs presented in this paper. The FARS data and graphs based on them are highly aggregated, making it impossible to take into account all of the factors that can influence the occurrence of a fatal collision. Local factors like surrounding land uses, urban or rural location, street lighting, and walkability for example can all play significant roles. This analysis does not account for vehicle speed at impact or blood alcohol level of the pedestrian, which has been shown to contribute to pedestrian fatal collisions (Davis, 2001; Johnson, 1997)—although these effects are likely being seen in the graphs. In addition, the pedestrian count data are taken from only one area of Northern California, where seasonal weather changes are relatively mild, so the pedestrian volume patterns may not be generalizable to the entire nation. Other regions with extreme changes in weather may have more striking changes in pedestrian volume patterns. Another useful estimate of exposure would have been hourly motor vehicle volumes, which were not available for this study.

4. Conclusions and recommendations

The results of this exploratory visual analysis show that the first hour of darkness typically has the greatest frequency of pedestrian fatal collisions. Careful examination of the evidence suggests that the twilight hour and transition from light to dark has its own negative effect on fatal pedestrian crashes, quite separate from pedestrian exposure effects. The most plausible explanations for this observed phenomenon are that: (1) dusk is a time when glare and associated reduced visibility occurs for both drivers and pedestrians westerly facing; (2) reduced visual contrast during the transition form daytime to darkness makes headlights less effective; (3) vision adapts more easily outside of a car, so that pedestrians are less aware of the reduced visibility of drivers; (4) pedestrians and/or drivers do not compensate appropriately for the reduced visibility and increased crash risk of pedestrians during these times.

Weekly patterns of pedestrian fatal collisions vary by time of year due to the seasonal changes in sunset time. In December, collisions are concentrated around twilight and the first hour of darkness throughout the week while, in June, collisions are most heavily concentrated around twilight and the first hours of darkness on Friday and Saturday. Friday and Saturday nights in June may be the most dangerous times for pedestrians.

Inspection of known risk factors—teens and alcohol-impaired driving—suggests that these risk are greatest on weekends in summer and from sunset until the early morning hours. In fact teen drivers and alcohol impairment seem to be weighted dramatically towards twilight and the early morning hours.

Although the exact risk of fatal collisions by time of day is unclear (due to lack of exposure data), the relative fatal collision frequencies by time of day indicate when crashes are occurring. Examination of the graphs suggests areas where mitigation strategies might be considered:

1. In the winter months, increased enforcement of speed limits and drivers yielding to pedestrian right of way could be particularly effective during the evening commute hours when many cars and pedestrians are traveling.
2. In the summer, enforcement may be most effective in the late evening hours on weekends.
3. Pedestrian and driver education campaigns could be designed to increase awareness about times when pedestrian crashes are most common. Specific driver education messages could focus more on the dangers to pedestrians of speeding at night and of the dangers present during twilight and dusk.
4. Possible engineering solutions include installation of street lighting or traffic calming elements that slow down speed or improve visibility of pedestrians, such as in-pavement crosswalk lighting. The concentration of collisions in the early evening hours also suggests that extending daylight savings time throughout the year could save many lives, as has been recommended by some researchers (Ferguson et al., 1995).
5. Graduated driver licensing programs that restrict teen drivers during late night and early morning driving is supported by these data.
6. Alcohol impairment as far as pedestrians fatalities are concerned occurs even during twilight and dusk. Sobriety checkpoints earlier in the evening may be warranted.

The exploratory visual cross-tabulation technique employed in this research is able to convey information that would not be possible with more formal methods. The intent was not to quantify the relationships described, but instead to shed light on the complexity of trends with fatal pedestrian crashes that have heretofore not been thoroughly examined. The sheer size of the dataset (all of U.S. for 10 years) suggests that the patterns are stable and not subject to significant fluctuations. Even subsets of the data produced similar trends. While crosstabulation methods have been used before, the striking presentation of the data as presented herein could be effective for convincing policy-makers of the need for targeted mitigation or for use in educational campaigns for the public—providing an extremely useful communication tool for researchers. Additionally, researchers can use this approach as an exploratory tool to easily identify potential crash relationships that can then be tested with more sophisticated statistical analyses. For example, the graphs might lend insight into where breakpoints of time of day are important for inclusion in statistical models.

Finally, this paper demonstrates a method that is extremely useful for conveying complex information to decision makers. This contribution is important in the context of the often extreme difficulties associated with conveying complex information to inform transportation investment decisions.

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