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Validity of Surrogate Measures of Alcohol Involvement When Applied to Nonfatal Crashes

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Abstract

Since the 1970s, nighttime fatal crashes have been used as a surrogate measure for alcohol-related fatalities for crashes for which more direct measures were absent. The validity of this approach was confirmed in 1985, but has not been re-evaluated since. Although this measure has also been applied to identify alcohol involvement in nonfatal crashes, its validity when applied to non-fatal cases has never been determined.

The objective of this study was to evaluate the appropriateness of using nighttime crashes as surrogate measures for alcohol impairment when applied to fatal and nonfatal injury and property damage only (PDO) crashes. To do so, we used data from a crash-control design study collected at the roadside in two U.S. states between 1997 and 1999, as well as from the 1997–1999, and 2004–2006 Fatality Analysis Reporting System.

The outcome of this study confirms the validity of using nighttime crashes as a surrogate measure for alcohol-related fatalities and supports the use of after-midnight crashes for measuring alcohol involvement in nonfatal and PDO crashes when the number of late-night crashes permits.

Keywords

surrogate measure; BAC measures; DWI; alcohol-related crashes; drinking and driving

1. Introduction

The last 20 years witnessed the enactment of several traffic policies and laws aimed at curbing driving while impaired (DWI). A crucial component of this success has been the availability of data-driven information on alcohol-related crashes. Science-based information is generally critical to advocacy groups, policy makers, and researchers.. Largely, this synergetic effort among scientists, advocacy groups, and policy-makers has been made possible by the availability of comprehensive state and federal crash record systems. Particularly important to that effort has been the Fatality Analysis Reporting System (FARS; <http://www.nhtsa.dot.gov/people/ncsa/fars.html>). The FARS, established by the National Highway Safety Administration (NHTSA) in 1975, has not only provided a census of fatal

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crashes, but also has stimulated the collection of blood alcohol concentration (BAC) data on drivers in fatal crashes.

Although the FARS data are useful for studies of multiple states and states with large populations, the number of fatal crashes is too limited to obtain valid results from studies of communities with small populations. For evaluations of alcohol safety laws, ordinances, or programs in small jurisdictions, an alcohol-involvement measure applicable to the more numerous injury and property-damage-only (PDO) crashes is required. Unfortunately, because participants in PDO crashes are rarely tested for BAC, information on alcohol-related incidents other than fatal crashes is usually absent. Further, although injury crashes (particularly if severe) are somewhat more likely to result in BAC tests, such testing occurs at a much lower rate than those obtained from fatal crashes. Thus, for information on alcohol involvement in nonfatal crashes, traffic safety researchers and policy-makers have relied on surrogate measures of alcohol involvement (e.g., Hingson et al., 1983; Hingson et al., 1986; Hingson et al., 1990; Holder et al., 1997; Voas et al., 1997; Wagenaar et al., 2007).

To be valid, an alcohol proxy measure in a crash population must be highly correlated with the actual presence of alcohol (BAC) in the crash population. This is true in using proxy measures for both problem identification and outcome evaluation. In problem identification, changes in the proxy measure over time or across jurisdictions can provide indices of problem magnitude and of the role of alcohol in crash causation. For outcome evaluation, changes (e.g., reduction) in the proxy following law changes and DWI countermeasures provide evidence of the program's effectiveness.

Because a proxy is never a direct measure of the attribute in question (alcohol-related crashes), some error is inevitable; that is, any proxy for alcohol involvement in crashes will likely miss some alcohol crashes (false-negatives) and include some crashes that do not involve alcohol (false-positives). Ideally, the proxy to be applied should minimize both sources of error, but in practice, this is seldom possible. Therefore, to be useful, any surrogate measure of alcohol involvement in crashes should balance the two sources of error.

In the United States, surrogate measures for alcohol impairment were first used in the 1970s when nighttime fatal crashes were used as a surrogate measure for alcohol-related fatalities in evaluations of the 35 Alcohol Safety Action Projects (ASAPs) funded by the NHTSA (Levy et al., 1977). Researchers and policy-makers needed to find reliable surrogate measures for alcohol-related fatal crashes; consequently, a few studies were conducted. One was a NHTSA-funded program to determine which vehicle maneuvers were most likely to indicate that the driver's BAC would be at .10 or greater (Harris et al., 1980). Other studies sought to identify the characteristics of alcohol-involved crashes, such as variations by time of day, day of week, and type of crash (single versus multiple vehicle; e.g., Douglass and Filkins, 1974; Heeren et al., 1985; Voas and Hause, 1987; Voas and Lacey, 1988; Rogers, 1995). These efforts supported the idea that nighttime crashes could be used as an indicator of alcohol involvement. In 1985, Heeren et al. investigated the validity of nighttime crashes (two alternative definitions were used: 8 p.m. to 4:59 a.m., and 9 p.m. to 6:59 a.m.) as a surrogate measure for alcohol-related crashes. Using fatal crash data from Delaware and Vermont and .10 BAC as an indicator of alcohol involvement, they found that alcohol involvement at nighttime (under any of the definitions considered by the authors) was closely related to fatal crashes. They also concluded that all nighttime fatal crashes would provide an appropriate surrogate measure. Using data on fatal crashes in California, Rogers (1995) agreed with Heeren et al.'s (1985) conclusion about the validity of using nighttime crashes (from 8 p.m. to 3:59 a.m.) as a proxy for alcohol involvement, although Rogers found that the 2 to 3 a.m. period (the first hour after California's 2 a.m. mandatory bar-closing time) and single-vehicle fatal crashes during nighttime were stronger indicators of alcohol involvement than the overall nighttime crash measure.

More than 20 years after Heeren et al.'s (1985) study, the need for valid surrogate measures of alcohol impairment among drivers has increased. With the adoption by all 50 states of three key laws—the minimum legal drinking age (MLDA) law, the .08 BAC limit, and the zero-tolerance (ZT) law for underage drivers—that have been shown to be effective in reducing alcohol-related crashes, the emphasis on prevention of impaired driving is shifting to the enforcement of these laws, which is typically a state and local issue. Thus, the focus of evaluation efforts will be on smaller jurisdictions where the low number of fatal crashes will limit the usefulness of FARS data and require more reliance on injury and PDO crashes, particularly in jurisdictions in which sobriety checkpoints are either illegal or politically costly.

Unfortunately, our current knowledge about surrogate measures for alcohol impairment comes mostly from fatal crashes. The use of nighttime crashes and/or nighttime single-vehicle crashes as surrogate measures has been suggested based on data coming from fatal crashes. This leaves the increasingly relevant, but yet to be clearly answered, question: “How valid are such surrogate measures when applied to the more frequently occurring nonfatal crashes?”

In this study, we use data collected in a recent study by Blomberg et al. (2005) to evaluate the appropriateness of using nighttime and single-vehicle nighttime crashes as surrogate measures for alcohol impairment when applied to nonfatal injury and PDO crashes. Between June 1997 and September 1999, Blomberg et al. (2005) collected BAC data on 90.1% (excluding hit and runs) of 4,316 drivers involved in injury and PDO crashes in Long Beach, California, and Fort Lauderdale, Florida. That unique data set provides a basis for validating the traditional single-vehicle nighttime surrogate on nonfatal crash-involved drivers, which is more typical of the data that are available for evaluating single state and local community programs.

We further investigated the validity of the nighttime single-vehicle surrogate measure for alcohol involvement in nonfatal crashes by comparing it against contemporary data on fatal crashes (both the 1997–1999 and the 2004–2006 FARS). This comparison allowed us to validate the nighttime surrogate measure developed for crash fatalities when applied to data contemporary to the Blomberg et al.'s (2005) study (FARS 1997–1999) as well as more recent data (FARS 2004–2006). To make this study useful to today's researchers and policy-makers, we modified Heeren et al.'s (1985) criterion by using .08 rather than .10 as the definition for an alcohol-related crash (although we also run models based on the .10 BAC threshold to facilitate comparisons with Heeren et al.'s study). The validity of the nighttime surrogate measure on nonfatal crashes was investigated and adjusted for single- and multiple-vehicle crashes for drivers of different ages and genders, and for the day of the week (weekend versus weekdays).

2. Methods

This study involves two sets of data: one for nonfatal crashes and another for fatalities. Using these two data sets, we evaluated DWI involvement in two types of crashes (single vehicle and multiple vehicle) at different hours of the day. From this evaluation, we estimated the proportion of actual DWI involvement that would be correctly identified (true-positives) or incorrectly identified (false-positives) by surrogate measures based on type of crash (single vehicle versus multiple vehicle) at different times of the day.

To investigate the validity of the overall nighttime and the single-vehicle nighttime surrogate measures when applied to nonfatal data, we used data from Blomberg et al. (2005). Their study, funded by NHTSA, was a replication of the classical Borkenstein Grand Rapids study (Borkenstein et al., 1974). It included a comprehensive sampling of the drivers in nonfatal crashes and a matched set of comparison drivers in two U.S. locations: Long Beach (California) and Fort Lauderdale (Florida). Sampling in Long Beach was conducted from 4 p.m. to 2 a.m.

between June 1997 and September 1998 and, in Fort Lauderdale, from 5 p.m. to 3 a.m. between September 1998 and September 1999. In all, data were collected on 2,054 crashes in Long Beach and on 2,262 crashes in Fort Lauderdale. Of these crashes, 78% were PDOs; 21.5%, nonfatal injuries; and 0.5%, fatalities. The data were collected by a study team, an officer, and a researcher/interviewer who were dispatched to the site of a reported crash. An officer initially contacted the crash-involved drivers and requested their participation in the survey (most crashes involved two drivers). Then, data collectors administered a questionnaire and collected breath samples from the participants. If the driver or drivers were willing, the researcher interviewed them. If the driver was injured and transported to a health care center for medical treatment, research teams attempted to obtain data at the hospital. A week later, on the same day and at the same time, the survey crew returned to the same site, and two motorists (one for each driver involved in the index crash) traveling in the same direction as the crash-involved drivers were randomly selected for breath testing. The overall participation rate was very high: 90.1% for crash-involved drivers and 97.6% for the comparison drivers. From that data set, we extracted the records of 3,650 crash-involved drivers with complete BAC records and 7,578 matched control drivers. Hit-and-run crashes and fatal crashes were excluded (only nonfatal injury crashes and PDO crashes were considered). The drivers' BAC levels were measured with a handheld Alco-Sensor IV device (Intoximeters, Inc., St. Louis, Missouri), which is listed on NHTSA's qualified products for evidential breath-test devices (NHTSA, 1984).

To study the nighttime and single-vehicle nighttime surrogate measures when applied to data on fatal crashes, we used two FARS data sets: one covering the same years and periods used by Blomberg et al. (2005) for nonfatal crashes, and another one covering more recent years. To match the Blomberg study periods (1997–1998 for the Florida site; 1998–1999 for the California site), we drew data from the 1997, 1998, and 1999 FARS. In their 1985 study, Heeren et al. (1985) applied their analysis to two states that had a high (75%) testing rate on all drivers in fatal crashes. This strategy was devised by Heeren et al. to avoid systematic bias due to missing alcohol information in the 1982–1983 FARS. In this study, we relied on states with a 79% or higher proportion of actual BAC measures for fatally injured drivers. Twenty-three states in the 1997–1999 FARS file met these criteria and were subsequently included in this study: California, Colorado, Connecticut, Delaware, Hawaii, Illinois, Maine, Maryland, Massachusetts, Michigan, Minnesota, Nebraska, Nevada, New Jersey, New Mexico, Oregon, Rhode Island, South Dakota, Tennessee, Washington, West Virginia, Wisconsin, and Wyoming. As mentioned, the 1997–1999 FARS data set was selected because it includes drivers contemporary to those in Blomberg et al.'s (2005) file. To investigate if results based on the 1997–1999 FARS held when based on more recent years, the 2004–2006 FARS data set was also included in this study. The following 34 states from the 2004–2006 FARS file were included in this study: Arizona, Arkansas, California, Colorado, Connecticut, Hawaii, Illinois, Louisiana, Maine, Maryland, Massachusetts, Minnesota, Missouri, Montana, Nebraska, Nevada, New Hampshire, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Carolina, South Dakota, Vermont, Virginia, Washington, West Virginia, and Wisconsin.

An alternative analytical strategy for measuring alcohol involvement is multiple imputation of BAC values, as is currently done in the FARS (Subramanian, 2002). The availability of imputed BAC values allowed us to use FARS data from all states instead of relying only on states with a high percentage of actual BAC measures. Because variables, such as the number of vehicles in the crash, are used for the BAC imputation in FARS, the use of such imputed BAC values in this evaluation of the association between BAC and single-vehicle crashes would have created a logical circularity and would have raised concerns about possible endogeneity biases.

To facilitate comparisons with the nonfatal data (i.e., data collected by Blomberg et al., 2005), we limited the data on fatal crashes to those occurring between 4 p.m. and 3 a.m. Based

on the data available in Blomberg et al. (2005), the following four time categories were created: *late afternoon* (crashes occurring between 4 p.m. and 7 p.m.), *evening* (between 7 p.m. and 9 p.m.), *early nighttime* (between 9 p.m. and midnight), and *late nighttime* (between midnight and 3 a.m.). For consistency with previous research, *late afternoon* and *evening* crashes are referred to as *daytime* crashes, and *early nighttime* and *late nighttime* crashes are referred to as *nighttime* crashes.

We used two units of analysis—the crash and the crash-involved driver—in examining the fatal and the nonfatal crash data. Estimation based on the crash as the unit of analysis is more useful to policy-makers in communities because data on traffic crashes are commonly reported by time of day and day of the week, whereas data on drivers are not. However, to study the role of covariates, such as the driver's age or gender, on the surrogate measure (particularly when applied to a multiple-vehicle crash, which involves more than one driver), we used driver as the unit of analysis. We separately examined the BACs of drivers in single- versus multiple-vehicle crashes. Of the 3,650 crash-involved drivers with BAC information in the Blomberg et al.'s file, 315 (about 9%) were involved in single-vehicle crashes. The remaining 3,335 drivers were involved in 1,963 multiple-vehicle crashes. Because a single-vehicle crash involves only one driver, crash-level estimates were based on the BAC of that driver. There was no difference between the driver and the crash unit of analysis. For a multiple-vehicle crash, the crash-level BAC estimate was based on the driver in the crash with the highest BAC. More than one driver was involved in these crashes, so the driver-level and crash-level unit of analysis differed.

The appropriateness of the nighttime and single-vehicle surrogate measure was first investigated by using the driver as the unit of analysis and testing (chi-square test) possible single variable differences in alcohol involvement in single- and multiple-vehicle crashes, on different days of the week (weekday versus weekend), during daytime or nighttime, for males and females, and by age group (15–20, 21–25, 26–34, 35–64, and 65 plus) separately for both data sets: FARS and Blomberg et al.. We also compared alcohol involvement for drivers in the crash and control (no-crash) files.

Using regression models, we investigated the possible effect of variables other than time of the day (e.g., day of the week, age, and gender) on the ability of the surrogate measures to predict alcohol involvement. More specifically, logistic regressions were applied to investigate the simultaneous contribution of the covariates under study to the likelihood that a driver record a BAC of .08 or greater, either when involved in nonfatal single- or multiple-vehicle crashes. The relative contribution of each covariate was evaluated by estimating the odds (relative to the reference levels) of impaired driving ($BAC \geq .08$) associated to each of the variables included in the model. Comparisons involving the four periods under consideration were made using *early nighttime* (between 9 p.m. and midnight) as the reference level to facilitate interpretation: we speculated that for some type of crashes, there might be substantial differences in the prevalence of $BAC \geq .08$ drivers between early nighttime and late nighttime crashes.

Finally, to determine the optimal hour intervals to be included in the surrogate measures for nonfatal crashes, we analyzed the Blomberg et al. (2005) data set to investigate alternative definitions of nighttime that would include the optimal hours for alcohol-related crashes. The proportion of true-positives ($BACs \geq .08$) that would be detected when a single-vehicle or multiple-vehicle nighttime surrogate measure was applied to nonfatal crashes was estimated for each hour, beginning at 4 p.m. and running to the end of the data set at 3 a.m.

3. Results

Table 1 shows the number of drivers and the proportion who registered a BAC of .08 or greater. Data in Table 1 are shown by type of crash (single- and multiple-vehicle crashes, and control), gender, injury severity (PDO, nonfatal injuries, and fatal injuries), and time of the day. As mentioned, prevalence of nonfatal injuries was obtained from Blomberg et al. (2005), and fatality data were drawn from the 1997–1999 and 2004–2006 FARS from the actual BACs for all drivers (unit of analysis: driver, Fatal^d) and for each fatal crash (unit of analysis: crash, Fatal^c). For single-vehicle crashes, Fatal^d = Fatal^c. For multiple-vehicle crashes with crash as the unit of analysis (Fatal^c), prevalence for driver characteristics, such as gender, was not estimated.

Table 1 shows that prevalence estimates based on the 1997–1999 and 2004–2006 FARS were very similar (statistically not different) for all four periods. Therefore, and for simplicity, only results based on the 1997–1999 FARS are presented hereafter. Table 1 also lists some well-known results. The percentage of drivers with BACs of .08 or greater is much larger for crashes than for noncrashes, for males than for females, at nighttime than at daytime, and for fatalities than for nonfatalities.

Among control (noncrash) drivers, the percentage of drivers with BACs of .08 or greater was less than 3% until midnight, when it jumped to between 7 and 8% (significantly higher, $p < .05$). There is some variation in this pattern by gender, with the percentage of male drivers with BACs of .08 or greater increasing at earlier times than for females (for males, it doubled for two periods—between 4 p.m. and 7 p.m. and between 7 p.m. and 9 p.m.—whereas it remained close to 1% for females). For both genders, however, the percentage of drivers with BACs of .08 or greater leveled off late at night (after midnight) at about 7 to 8%.

The drivers in the crash group also showed a pattern of increasing prevalence of BACs of .08 or greater from late afternoon to late nighttime. Figure 1 (based on data from Table 1) illustrates this trend (sample size constraints—small “N” as shown in Table 1—forced us to collapse nonfatal injuries and PDO crashes into a single variable in Figure 1). The prevalence of BAC $\geq .08$ increases from late afternoon to late nighttime in each of the curves in the graph. Figure 1 shows that the prevalence of BAC $\geq .08$ drivers is higher in fatal crashes than in nonfatal/PDO crashes for all four periods. The 95% confidence interval (CI) in Figure 1 shows that such difference is statistically significant, except for the late-night period, when the prevalence of single-vehicle nonfatal crashes increases and becomes statistically not different from the two types of fatal crashes under consideration. For fatal crashes, the BAC $\geq .08$ prevalence curves for single- and multiple-vehicle crashes are very similar (statistically nonsignificant). For nonfatal/PDO crashes, the prevalence curves for single- and multiple-vehicle crashes are also very similar from 4 p.m. to 9 p.m. (statistically nonsignificant). As the night progresses, the prevalence of .08 BAC in nonfatal PDO crashes increases dramatically among drivers involved in single-vehicle crashes, but the increase is not as much for those involved in multiple-vehicle crashes. At late nighttime, the prevalence of BAC $\geq .08$ among drivers involved in nonfatal/PDO single-vehicle crashes (63%) is higher than that of nonfatal/PDO multiple-vehicle crashes (40%), albeit its statistical significance occurs only at the margin ($p < .06$).

Table 2 explores the prevalence of BAC $\geq .08$ for weekdays and weekends. As indicated in Table 2, the prevalence of drivers with BACs $\geq .08$ increases from late afternoon to late nighttime on both weekdays and weekends, both for drivers in crashes and for noncrash drivers (as in Table 1, such prevalence is higher among crashes than among noncrashes both for weekdays and for weekends). The role of weekdays on the prevalence of BACs $\geq .08$ is unclear. In single-vehicle PDO/nonfatal crashes at late nighttime (after midnight), the prevalence of BACs $\geq .08$ is higher on weekdays, whereas the opposite occurs at early nighttime (9 p.m.-

midnight), albeit these differences are not statistically significant. In nonfatal multiple-vehicle crashes, the prevalence of $BAC \geq .08$ crashes is similar on weekends and weekdays, albeit slightly higher late at night on weekends. Among fatal crashes, the prevalence of $BACs \geq .08$ in single-vehicle crashes during early nighttime is slightly higher on weekends than on weekdays. None of these differences are statistically significant either.

Table 3 illustrates the role of age on the prevalence of drivers with $BACs$ of .08 or greater. Again, the prevalence of $BACs$ of .08 or greater increases from late afternoon to late nighttime. Age seems to influence $BAC \geq .08$ prevalence among fatal crashes (both single- and multiple-vehicle) at any period under consideration, with both the youngest (15–20) and the oldest (65+) age groups showing a lower prevalence of $BACs \geq .08$ drivers in fatal crashes. However, sample size limitations fail to make the observed differences among single-vehicle crashes statistically significant. The role of age on nonfatal/PDO crashes is also unclear due to small sample sizes.

Table 4 summarizes the outcome of four logistic regressions using the driver as the unit of analysis for single- and multiple-vehicle nonfatal/PDO crashes and single- and multiple-vehicle fatal crashes. The simultaneous inclusion of all factors studied revealed that among fatal crashes, as expected, $BAC \geq .08$ prevalence in nighttime crashes (from 9 p.m. to 3 a.m.) is significantly higher than during the daytime (from 4 p.m. to 9 p.m.) in both single- and multiple-vehicle crashes. This finding corroborates the overall validity of the nighttime surrogate measure when applied to fatal crashes for either single- or multiple-vehicle crashes. Table 4 also shows that, within nighttime fatal crashes, $BAC \geq .08$ prevalence is even larger at late nighttime (midnight to 3 a.m.) than at early nighttime (9 p.m. to midnight). For nonfatal/PDO crashes, however, $BAC \geq .08$ prevalence during early nighttime and late nighttime differs for single-vehicle but not for multiple-vehicle crashes (1% alpha level), suggesting that for nonfatal crashes, a modification of the nighttime surrogate measure to include only single-vehicle crashes occurring after midnight would be necessary.

As indicated in other studies and as suggested in previous tables, nighttime is not the only factor explaining $BAC \geq .08$ prevalence in fatal crashes. Gender, age, and day of the week are also contributing factors. As shown in Table 4, $BAC \geq .08$ prevalence for fatal crashes is higher on the weekend than on weekdays. However, no such weekly difference was observed among nonfatal/PDO crashes. Regarding age and fatal crashes, the $BAC \geq .08$ prevalence was lower at the extremes of the age range; that is, lower for drivers aged 15 to 20 and 65+ than for drivers of intermediate ages (even significantly lower for drivers aged 15 to 20 than for drivers aged 65+). For nonfatal/PDO crashes, the role of age on the prevalence of $BAC \geq .08$ was nonsignificant at the 1% alpha level. Regarding gender, the prevalence of $BAC \geq .08$ was higher among males involved in fatal crashes ($p=.01$), but not among males involved in nonfatal/PDO crashes.

We also ran logistic models on the data in Table 4 but with $BAC \geq .10$ (Heeren et al.'s, 1985, criterion) as a dependent variable. The results of using $BAC \geq .10$ as the defining threshold did not change the basic outcome in Table 4. All coefficients showed the same direction and significance level as those reported in Table 4, with the exception of evening (7 p.m. to 9 p.m.), which became significant in both nonfatal models.

Table 4 includes only data from the main effect models. Results in previous tables indicate several interactions (e.g., gender by time of day). Although we tested these interactions and found some of them significant, they are not included in Table 4 because they would have made the interpretation of Table 4 unnecessarily difficult for this analysis. However, the findings of this study should alert researchers that when estimating prevalence of alcohol involvement by time of day and day of week, they might want to control for interactions.

As described, the analyses of fatal crashes (see Figure 1 and Tables 1 through 4) were based only on states with a large proportion of actual BAC measures. The alternative strategy of using imputed BAC measures from all the states was already discussed and discarded because of concerns about potential endogeneity bias; however, we did examine how the use of such alternative data set would have affected the results of this study. We found no meaningful difference between the outcomes of this alternative and our preferred analytical strategy.

Another important element for policy-makers in deciding on the adoption of a surrogate measure is the number of true- and false-positives that would be expected under different time thresholds. Table 5 shows the estimated percentage of drivers at $BAC \geq .08$ and at $BAC < .08$ that would be expected when a single- and multiple-vehicle surrogate measure is applied to nonfatal crash data at different hours. Table 5 shows that for multiple-vehicle nonfatal/PDO crashes, the number of drivers with $BAC < .08$ was always (i.e., at any hour under consideration) larger than those at $BAC \geq .08$. For single-vehicle nonfatal/PDO crashes though, $BAC \geq .08$ drivers outnumbered the $BAC < .08$ ones after midnight. Thus, according to Table 5, if the surrogate measure were based on all nonfatal/PDO crashes occurring after midnight, only 44% of the drivers identified would be truly impaired ($BAC \geq .08$). The remaining 56% would be incorrectly identified as impaired. If only multiple-vehicle nonfatal/PDO crashes were considered, the proportion of $BAC \geq .08$ drivers would also be smaller than the proportion of $BAC < .08$ drivers. For single-vehicle nonfatal/PDO crashes occurring after midnight, however, 67% of these crashes would involve $BAC \geq .08$ drivers (Table 5). If the cutoff criteria were crashes occurring after 1 a.m., then the percentage would elevate up to 75%. Thus, according to Table 5, a surrogate measure that accounts for only nonfatal late-night single-vehicle crashes would detect the maximum number of $BAC \geq .08$ drivers and the lowest proportion of $BAC < .08$ drivers.

4. Discussion

In this study, we assessed the appropriateness of applying a well-known and often-used surrogate measure to evaluate data on fatal and nonfatal crashes. Our framework for this application was more rigorous than the one applied to the analysis of fatal crashes because the nonfatal data were collected under a rigorous case-control design (Blomberg et al., 2005), whereas our analysis on fatal crashes was based on FARS, as in Heeren et al. (less than 1% of the crashes in Blomberg et al., 2005, were fatal). Regarding a surrogate for fatal crashes, our results are substantially similar to those obtained in previous studies based on fatal crashes. The similarity between the 1997–1999 and 2004–2006 FARS data regarding the prevalence of alcohol-related fatal crashes found in this study gives further evidence of the well-reported stalling in the prevalence of drunk driving over this period. Also, the percentage of drivers with high BACs in single-vehicle fatal crashes during the nighttime (shown in Table 1) is roughly consistent with the results obtained by Heeren et al. (1985). We observed between 53% and 64% of single-vehicle fatal crashes during nighttime as alcohol impaired compared to 67% in the Heeren et al. (1985) study, and between 48% and 66% as alcohol impaired in fatal multiple-vehicle crashes during nighttime compared to 61% in the Heeren et al. (1985) study. Such a close similarity of results was achieved despite the difference in the impaired criterion we used, which was a BAC of .08 or greater compared to a BAC of .10 or greater used by Heeren et al. (1985). Another difference was the use of BACs from only two states in the Heeren et al. (1985) study compared to the actual and imputed BACs from the whole United States in this study.

Unfortunately, however, the use of imputed BAC measures for this study is not free of problems: (1) BAC imputations contain an intrinsically larger error than those measured via preliminary breath testing, and the errors may be nonrandom; (2) statistical models used to yield the BAC imputations include hour or time of the day as covariates (Subramanian and

Utter, 2003), variables that are not neutral (not redundant) to this study; and (3) completeness with which BAC measures are collected in each state varies and might be responsible for some unaccounted bias. Despite these limitations, it is evident from our results that the distribution of alcohol-related crashes by time of day did not change in the decade following the Heeren et al. (1985) study. Further, the surrogate they developed apparently remains valid when applied to current fatal crash data.

Regarding nonfatal crashes (the focus of this study), we found that the nighttime measure could also be useful for evaluating alcohol policies and programs. This surrogate measure could be strengthened by including only those nonfatal crashes that occur after midnight instead of also including crashes that occur during early nighttime, as in Heeren et al. (1985). Applying such a restriction could provide researchers and policy-makers with a more accurate (smaller number of false-positives relative to the number of true-positives) surrogate measure of alcohol involvement in nonfatal crashes than the one based on the full nighttime criteria (as suggested for fatal crashes).

The results shown in the tables should be used only as a loose guide for local decision-makers. The data set we used for this analysis on nonfatal crashes, albeit large, was limited to only two U.S. locations. Hourly patterns of impaired driving leading to nonfatal crashes are likely to vary in different communities. It is also likely that some crashes, particularly PDOs, were unreported and therefore were not included in the dataset we used. If concentrated at some periods, unreported PDOs might have biased some results. For instance, the spike in SV-DO/NF crashes occurring late at night might not have been as sudden (see Figure 1) if a sizable proportion of the PDO crashes occurring earlier in the day were not reported.

Further, although the participation rate in Blomberg et al.'s (2005) crash-control study was very high, a differential in refusal rates between crash-involved and non-crash-involved drivers exists (8.9% versus 3.4%). If such differential was alcohol-related, then the BAC $\geq .08$ prevalence estimates for drivers involved in nonfatal crashes would be biased down. We also detected in our analytical models several cofactors that interact in ways that still need to be investigated. These variables and their roles in alcohol involvement in nonfatal crashes need to be fully understood before a valid surrogate measure can be developed. Reliable estimates of the relative risk of involvement in an alcohol-related crash associated with different subgroups at different times of the day and days of the week need to be estimated for such surrogate measure.

5. Summary

In summary, using more recent data, (1) we confirmed Heeren et al.'s (1985) finding about the validity of a surrogate measure based on nighttime fatal crashes, but (2) we suggest that for nonfatal crashes, a more accurate surrogate measure would be achieved by using only late nighttime (after-midnight) single-vehicle crashes.

Unfortunately, this finding may present a dilemma for small communities, as using only late nighttime crashes may severely reduce the number of crashes available for analysis. Because the data for nonfatal crashes came from only two U.S. cities, a generalization of our findings involving nonfatal crashes to other locations may not be straightforward, and some adaptation to local conditions might be advisable. For some communities, applying a surrogate measure to nonfatal crashes might require an earlier threshold than the late nighttime suggested in this study. Furthermore, communities may want to consider using more than one surrogate measure if available (for instance, Rogers, 1995, found a remarkable similarity in the effect sizes of surrogate measures for fatal and serious injury crashes).

For those communities considering the adoption of surrogate measures based on time of day and number of vehicles, the analysis shown in Table 5, rather than a golden rule, can be considered as loose guide about the implications of using surrogate measures based on different cutoff hours.

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		4 p.m. – 7 p.m.	7 p.m. – 9 p.m.	9 p.m. – midnight	Midnight – 3 a.m.
SV-PDO/NF	UL(95%)	11%	31%	46%	87%
	%	4%	15%	30%	63%
	LL(95%)	1%	5%	17%	34%
MV-PDO/NF	UL(95%)	9%	23%	32%	49%
	%	7%	19%	27%	40%
	LL(95%)	6%	15%	24%	32%
SV-Fatal 9799 d	UL(95%)	29%	51%	60%	68%
	%	25%	46%	54%	64%
	LL(95%)	21%	41%	47%	59%
MV-Fatal 9799 d	UL(95%)	25%	44%	53%	68%
	%	23%	41%	50%	66%
	LL(95%)	21%	39%	47%	64%
Control	UL(95%)	1%	2%	4%	10%
	%	1%	2%	3%	8%
	LL(95%)	1%	1%	2%	6%

Figure 1.
Prevalence of Drivers with a BAC $\geq$ of .08 or Higher by Type of Crash, Injury, and Hour

Table 1

Percentage of Drivers with a BAC $\geq .08$ by Type of Crash, Gender, Injury Severity, and Time of Crash

		4 p.m. – 7 p.m.			7 p.m. – 9 p.m.			9 p.m. – midnight			midnight – 3 a.m.		
		N	% .08+		N	% .08+		N	% .08+		N	% .08+	
Crashes													
Single-vehicle drivers	Male	PDO	22	9%	24	25%		28	43%		14	64%	
		Nonfatal	57	2%	18	6%		26	19%		5	60%	
		Fatal 9799 ^d	342	31%	286	50%		205	59%		440	66%	
		Fatal 0406 ^d	462	26%	440	48%		308	56%		592	65%	
	Female	PDO	21	5%	5	20%		13	23%		4	75%	
		Nonfatal	20	5%	20	10%		12	25%		1	0%	
		Fatal 9799 ^d	156	12%	93	32%		47	32%		99	55%	
		Fatal 0406 ^d	147	16%	90	41%		67	36%		112	58%	
	Both	PDO	43	7%	29	24%		41	37%		18	67%	
		Nonfatal	77	3%	38	8%		39	23%		6	50%	
		Fatal 9799 ^d	498	25%	379	46%		252	54%		539	64%	
		Fatal 0406 ^d	609	23%	530	47%		375	53%		704	64%	
Multiple-vehicle drivers	Male	PDO	333	8%	200	20%		219	28%		77	36%	
		Nonfatal	77	12%	51	27%		65	38%		15	53%	
		Fatal 9799 ^d	1183	27%	1036	46%		713	54%		1279	68%	
		Fatal 0406 ^d	2344	25%	2145	43%		1388	56%		2538	67%	
	Female	Fatal 9799 ^e	872	24%	700	44%		486	53%		851	65%	
		Fatal 0406 ^e	1624	22%	1432	39%		917	52%		1615	64%	
	Both	PDO	291	4%	106	13%		119	21%		26	46%	
		Nonfatal	89	12%	26	12%		31	32%		11	36%	
		Fatal 9799 ^d	493	14%	306	25%		186	35%		275	58%	
		Fatal 0406 ^d	809	11%	529	25%		315	34%		556	59%	
No Crashes (Control)	Female	Fatal 9799 ^e	350	14%	219	25%		109	25%		179	56%	
		Fatal 0406 ^e	562	10%	384	22%		219	30%		370	54%	
	Both	PDO	624	6%	306	18%		338	25%		103	39%	
		Nonfatal	166	12%	77	22%		96	36%		26	46%	
		Fatal 9799 ^d	1676	23%	1342	41%		899	50%		1554	66%	
		Fatal 0406 ^d	3154	21%	2674	40%		1703	52%		3094	66%	
	Male	Fatal 9799 ^e	1222	21%	919	40%		595	48%		1030	64%	
		Fatal 0406 ^e	2187	19%	1816	36%		1136	48%		1985	62%	
	Both	PDO	2,129	1%	1,067	2%		1,299	3%		385	8%	
		Nonfatal	1,363	0%	583	1%		597	1%		155	7%	
		Fatal 9799 ^d	3,492	1%	1,652	2%		1,896	3%		540	8%	
		Fatal 0406 ^d											

Fatal^d (unit of analysis = drivers) and Fatal^e (unit of analysis = crashes) denote prevalence estimates for fatally injured drivers (unit of analysis = driver) estimated from actual BACs for all drivers (unit of analysis = driver) in the 1997–1999 and 2004–2006 FARS and from actual BACs in each fatal crash (unit of analysis = crashes) in the 1997–1999 and 2004–2006 FARS, respectively. “N” for PDO (property damage only) and nonfatal injuries from Blomberg et al. (2005); “N” for fatal injuries from selected FARS records (selection criteria described in text).

Table 2

Alcohol in Crash and Control Cases by Weekday, Injury Level, and Hour of Crash

		4 p.m. – 7 p.m.			7 p.m. – 9 p.m.			9 p.m. – midnight			midnight – 3 a.m.		
		N	%.08+	N	%.08+	N	%.08+	N	%.08+	N	%.08+	N	%.08+
Crashes													
Single-vehicle drivers	Weekday	PDO/Nonfatal	70	4%	46	17%	53	26%	10	70%	342	63%	61%
		Fatal 9799 ^d	361	24%	240	43%	145	52%	342	63%	437	61%	
		Fatal 0406 ^d	413	24%	358	46%	204	50%					
	Weekend	PDO/Nonfatal	50	4%	21	10%	27	37%	14	57%	197	64%	69%
		Fatal 9799 ^d	137	28%	139	50%	107	55%	267	69%			
		Fatal 0406 ^d	196	22%	172	48%							
Multiple-vehicle drivers	Weekday	PDO/Nonfatal	550	7%	245	16%	250	28%	65	37%	934	64%	62%
		Fatal 9799 ^d	1126	21%	896	38%	514	47%	1883	64%	1231	61%	
		Fatal 0406 ^d	2100	20%	1745	37%	980	49%	615	62%			
	Weekend	Fatal 9799 ^c	821	19%	624	37%	365	46%					
		Fatal 0406 ^c	1464	18%	1179	34%	669	46%					
		PDO/Nonfatal	245	8%	138	23%	184	28%	64	44%	620	69%	65%
Weekend	Fatal 9799 ^d	550	29%	446	48%	385	54%	1211	69%	415	67%	754	
	Fatal 0406 ^d	1054	25%	929	44%	723	55%						
	Fatal 9799 ^c	401	25%	295	46%	230	51%						
	Fatal 0406 ^c	723	21%	637	38%	467	50%						
No Crashes (Control)													
Weekday		2,374	1%	1,070	1%	1,092	2%	278	7%	262	8%		
Weekend		1,118	1%	582	2%	802	3%						

Fatal^d (unit of analysis = drivers) and Fatal^c (unit of analysis = crashes) denote prevalence estimates for fatally injured drivers (unit of analysis = driver) estimated from actual BACs for all drivers (unit of analysis = driver) in the 1997–1999 and 2004–2006 FARS and from actual BACs in each fatal crash (unit of analysis = crashes) in the 1997–1999 FARS, respectively. "N" for PDO (property damage only) and nonfatal injuries from Blomberg et al. (2005); "N" for fatal injuries from selected FARS records (selection criteria described in text). Due to missing entries, "N" in Tables 2 and 3 do not always match.

Table 3

Alcohol in Crashes by Age Group, Injury Level, and Hour

		4 p.m. – 7 p.m.			7 p.m. – 9 p.m.			9 p.m. – midnight			midnight – 3 a.m.		
		N		% .08+	N		% .08+	N		% .08+	N		% .08+
		Crashes											
Single-vehicle drivers	Age 15–20	PDO/Nonfatal	16	6%	9	22%	10	40%	4	50%			
		Fatal 9799 ^d	65	15%	57	30%	50	34%	96	56%			
		Fatal 0406 ^d	75	9%	66	30%	64	25%	119	50%			
	Age 21–25	PDO/Nonfatal	18	0%	9	11%	20	30%	3	67%			
		Fatal 9799 ^d	52	13%	49	43%	46	59%	127	74%			
		Fatal 0406 ^d	57	14%	87	38%	73	58%	201	71%			
	Age 26–34	PDO/Nonfatal	29	3%	10	10%	20	15%	7	86%			
		Fatal 9799 ^d	78	29%	71	51%	65	65%	134	68%			
		Fatal 0406 ^d	100	33%	96	51%	76	72%	160	71%			
	Age 35–64	PDO/Nonfatal	46	7%	33	18%	26	42%	9	56%			
		Fatal 9799 ^d	217	33%	170	54%	84	57%	172	60%			
		Fatal 0406 ^d	280	29%	248	56%	151	53%	210	62%			
	Age 65+	PDO/Nonfatal	12	0%	6	0%	4	0%	1	0%			
		Fatal 9799 ^d	82	13%	32	25%	5	20%	7	14%			
		Fatal 0406 ^d	92	14%	32	22%	10	50%	13	23%			
Multiple-vehicle drivers	Age 15–20	PDO	48	4%	48	25%	64	27%	24	46%			
		Fatal 9799 ^d	202	6%	199	18%	147	36%	245	50%			
		Fatal 0406 ^d	378	7%	344	15%	273	33%	518	53%			
		Fatal 9799 ^c	147	5%	141	17%	94	31%	151	49%			
		Fatal 0406 ^c	265	6%	249	13%	179	29%	329	51%			
	Age 21–25	PDO	93	4%	44	20%	71	27%	23	48%			
		Fatal 9799 ^d	144	29%	148	45%	152	56%	334	73%			
		Fatal 0406 ^d	330	18%	368	40%	324	57%	776	77%			
		Fatal 9799 ^c	104	26%	100	42%	100	56%	221	67%			
		Fatal 0406 ^c	229	17%	243	37%	219	55%	483	75%			
	Age 26–34	PDO	221	12%	84	14%	110	25%	43	44%			
		Fatal 9799 ^d	276	27%	248	47%	205	66%	404	76%			
		Fatal 0406 ^d	469	26%	483	44%	289	62%	709	74%			
		Fatal 9799 ^c	195	25%	168	45%	134	62%	263	76%			
		Fatal 0406 ^c	319	22%	336	38%	177	54%	468	70%			
Age 35–64	PDO	378	6%	186	20%	176	32%	39	28%				
	Fatal 9799 ^d	768	30%	618	52%	361	47%	529	65%				
	Fatal 0406 ^d	1517	28%	1269	49%	744	55%	1022	61%				
	Fatal 9799 ^c	570	28%	421	49%	248	46%	365	63%				
	Fatal 0406 ^c	1051	26%	844	44%	505	52%	656	57%				
Age 65+	PDO	55	5%	20	5%	13	8%	0	0%				
	Fatal 9799 ^d	281	10%	126	16%	33	15%	40	23%				
	Fatal 0406 ^d	448	8%	202	14%	73	18%	66	20%				
	Fatal 9799 ^c	203	10%	88	15%	19	16%	30	20%				
	Fatal 0406 ^c	315	7%	140	14%	56	14%	47	19%				

4 p.m. – 7 p.m.		7 p.m. – 9 p.m.		9 p.m. – midnight		midnight – 3 a.m.	
N	% .08+	N	% .08+	N	% .08+	N	% .08+
Crashes							

Fatal^d denotes prevalence estimated from actual BACs for all drivers (unit of analysis = drivers) in the 1997–1999 and 2004–2006 FARS. “N” for PDO (property damage only) and nonfatal injuries from Blomberg et al. (2005); “N” for fatal injuries from selected FARS records (selection criteria described in text).

Table 4

Logistic Regression for the Likelihood of Impaired Drivers ($BAC \geq .08$) Involved in Different Types of Crashes

	Nonfatal/Property Damage Only						Fatal					
	Single Vehicle			Multiple Vehicle			Single Vehicle			Multiple Vehicle		
	Coeff	p value		Coeff	p value		Coeff	p value		Coeff	p value	
4 p.m.- 7 p.m.	-2.29	<.0001		-1.50	<.0001		-1.01	<.0001		-0.89	<.0001	
7 p.m.- 9 p.m.	-0.97	0.029		-0.51	0.003		-0.21	<.0001		-0.20	0.01	
12 a.m.-3 a.m.	1.43	0.006		0.49	0.019		0.93	<.0001		0.90	<.0001	
<i>Ref: 9 p.m.-midnight</i>												
Weekend	-0.19	0.615		0.18	0.191		0.08	<.0001		0.14	0.01	
Age 15-20	-0.14	0.794		0.07	0.728		-0.48	<.0001		-0.62	0.00	
Age 21-25	-0.87	0.140		-0.08	0.717		0.35	<.0001		0.44	0.04	
Age 26-34	-0.45	0.288		0.09	0.562		0.64	<.0001		0.68	0.00	
Age 35-64	*	*		-0.97	0.043		0.54	<.0001		0.46	0.01	
<i>Ref: Age 65+</i>												
Female	-0.03	0.945		-0.33	0.019		-0.38	<.0001		-0.40	<.0001	
Intercept	-0.42	0.274		-0.92	<.0001		-0.48	<.0001		-0.67	<.0001	

Table 5

Identification of BAC $\geq .08$; Hour-Based Percentage of Drivers at BAC $\geq .08$ Applied to Nonfatal/PDO Crashes

	All nonfatal/PDO			Single vehicle nonfatal/PDO		Multiple vehicle nonfatal/PDO	
	.08+	<.08	.08+	.08+	<.08	.08+	<.08
5 p.m.	5%	95%	4%	96%	96%	5%	95%
6 p.m.	8%	92%	5%	95%	95%	9%	91%
7 p.m.	16%	84%	13%	87%	87%	17%	83%
8 p.m.	21%	80%	17%	83%	83%	21%	79%
9 p.m.	22%	78%	26%	74%	74%	21%	79%
10 p.m.	28%	73%	24%	76%	76%	28%	72%
11 p.m.	38%	62%	40%	60%	60%	38%	63%
midnight	39%	61%	63%	38%	38%	34%	66%
1+ a.m.	52%	48%	75%	25%	25%	49%	51%
midnight+	44%	56%	67%	33%	33%	40%	60%

Nonfatal/PDO stands for nonfatal Injuries and property damage only. 1+ a.m. and midnight+ denote the 1 a.m. to 3 a.m., and the midnight to 3 a.m. periods, respectively.