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A regionalised strategy for improving motor vehicle-related highway driver deaths using a weighted averages method

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Abstract

Objective—The state of Florida has some of the most dangerous highways in the USA. In 2006, Florida averaged 1.65 fatalities per 100 million vehicle miles travelled (VMT) compared with the national average of 1.42. A study was undertaken to find a method of identifying counties that contributed to the most driver fatalities after a motor vehicle collision (MVC). By regionalising interventions unique to this subset of counties, the use of resources would have the greatest potential of improving statewide driver death.

Methods—The Florida Highway Safety Motor Vehicle database 2000–2006 was used to calculate driver VMT-weighted deaths by county. A total of 3 468 326 motor vehicle crashes were evaluated. Counties that had driver death rates higher than the state average were sorted by a weighted averages method. Multivariate regression was used to calculate the likelihood of death for various risk factors.

Results—VMT-weighted death rates identified 12 out of 67 counties that contributed up to 50% of overall driver fatalities. These counties were primarily clustered in central and south Florida. The strongest independent risk factors for driver death attributable to MVC in these high-risk counties were alcohol/drug use, rural roads, speed limit 45 mph, adverse weather conditions, divided highways, vehicle type, vehicle defects and roadway location.

Conclusions—Using the weighted averages method, a small subset of counties contributing to the majority of statewide driver fatalities was identified. Regionalised interventions on specific risk factors in these counties may have the greatest impact on reducing driver-related MVC fatalities.

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INTRODUCTION

Among people aged <40 years, motor vehicle collision (MVC) is the leading cause of death in the USA.¹ Based on data from the National Highway Traffic Safety Administration (NHTSA), Florida has some of the most dangerous highways in the USA.² In 2006 the US averaged 1.42 traffic fatalities per 100 million vehicle miles travelled (VMT),² while Florida averaged 1.65 traffic fatalities per 100 million VMT.³ With limited government resources, measures to improve the motor vehicle death rate in Florida should be directed towards regions with the greatest potential for improving statewide driver death. We hypothesised that interventions in only a few key regions may significantly reduce statewide driver death rates attributable to MVC.

Conventional methods of determining driver death incidence rates by using licensed drivers or VMT as a denominator may not identify the counties that contribute most to the overall average death rate because all events contribute equally to this arithmetic mean. We introduce the concept of weighted averages, where not all events contribute equally to the mean, and predict that the number of counties that contribute most to driver death will be few. One can then regionalise interventions specifically towards these counties and greatly impact overall driver death for the state.

The goals of this study are to identify the counties that contribute most to the driver death rate in Florida and modifiable risk factors for driver death within these highest risk counties.

METHODS

Study design

This is a population-based retrospective cohort study. The Florida Highway Safety Motor Vehicle (FHSMV) database from 2000 to 2006 was used to estimate the driver death rate for each county in Florida. These data are collected by the Florida Highway Patrol. The index population was 3 468 326 drivers involved in a MVC during this period. Survival of a driver for 30 days after a MVC was the primary outcome. For missing data (ranging between 0.0001% and 27%), Rubin's multiple imputation method was performed to complete the dataset.⁴⁵ Only five variables used in this study had more than 10% missing data: gender (13.6%), age (17.4%), alcohol/drug (15.9%), speed limit (13%) and on/off roadway (27%). To obtain 97% efficiency in estimating the true values for up to 30% of missing values, we imputed 10 data sets.⁵

VMT was calculated as 100 million vehicle miles travelled per year, and data were obtained from the Florida Department of Transportation at Automated Traffic Recorders (ATR).³ VMT is an estimate based on both traffic volume and roadway length. Approximately 300 ATRs are positioned on Florida's highway system.⁶ Data from the ATRs are submitted by states on a voluntary basis to the Federal Highway Administration to document traffic volume. We calculated the VMT death rate for each county.

To confirm that VMT-weighted death would best identify counties that contributed most to driver death, we performed an exploratory analysis of sorting counties by the following

death rate estimations: (1) overall VMT death rate (county driver deaths divided by VMT); (2) county population death rate (county driver deaths divided by population over the age of 15); (3) death rate among counties with the highest VMT; and (4) VMT-weighted death among those counties with higher than state average death rates. The VMT-weighted death method yielded the fewest counties necessary to decrease the overall state driver deaths by 50% (table 1).

Preventable risk factors for driver deaths (see statistical analysis) were examined. Driver death alone was evaluated because it was felt that drivers had uniquely modifiable and relevant risk factors such as alcohol use and speed.

Selection of high-risk counties for driver death was performed using a selection method that used VMT-weighted averages (see below).

Selection method using weighted averages

This selection method is based on weighted averages. The weighted average is the same value as the arithmetic average, but instead of having each data point contributing equally to the final mean, it takes into account that some data points contribute more than others.⁷ The mathematical relationship between the average death rate and the weighted average of death by VMT is as follows:

Let the driver death in each county be represented by

$$(X_1, X_2, X_1, \dots, X_n)$$

and VMT per county be represented by

$$(V_1, V_2, V_1, \dots, V_n)$$

The statewide average death rate is then the sum of the weighted death of all counties:

$$\bar{X} = \frac{\sum_{i=1}^n V_i X_i}{\sum_{i=1}^n V_i} \text{ or } \bar{X} = \frac{V_1 X_1 + V_2 X_2 + \dots + V_n X_n}{V_1 + V_2 + \dots + V_n}$$

For our selection method (table 1), high-risk counties were defined as those whose VMT death rates were greater than the state average. These high-risk counties were adjusted by their VMT-weighted proportion (county VMT divided by state VMT). VMT-weighted death (product of county driver death and county's VMT-weighted proportion rate) was calculated. In descending order from the highest death-weighted county, we selected the number of counties which contributed to 50% of driver deaths.

Statistical analysis

Twelve out of 67 counties were selected by the VMT-weighted analysis because they contributed up to 50% of driver deaths for the state of Florida. These counties, with a total 1 600 615 driver crashes in the study period, were evaluated. Multivariate logistic regression was used to identify individual risk factors within these highest risk counties. Logistic regression was used because death was the primary outcome of interest. Additional variables were identified as potential confounders if there was an independent effect on both the exposure and outcome without influencing the pathway of interest. Multicollinearity was evaluated prior to regression analysis by examining the correlation coefficient among confounders. If the correlation coefficient was >0.8 , only one of the confounders was used in the multivariate analysis. Regression was performed to estimate the crude OR of death due to the following risk factors: alcohol/drugs, speed limit, time of day, day of the week, rural/urban location, on/off roadway, lighting conditions, weather, road surface type, road surface condition, type of shoulder, number of lanes, divided/undivided highway, miles from city, direction from city, distance from intersection, traffic, highway location, type of vehicle, direction of travel, vehicle movement, first vehicle defect and location on roadway. The final confounders adjusted for in our multivariate regression model were age, gender and insurance status. Significant risk factors for death were identified for the 12 VMT-weighted risk counties (table 2).

All data were analysed using SAS Version 9.1 of the SAS System for Unix.

RESULTS

Drivers in fatal crashes in these high-risk counties were more likely to be male and older than those involved in non-fatal crashes (table 3). Risk factors for driver deaths that were significantly higher in the unadjusted analyses were alcohol/ drugs, higher speed limits, later time of day, rural location, poor weather and off roadway location (table 3).

The range of daily VMT annually by county among all 67 counties was 453 499–57 229 314. Among the 12 high-risk counties the average daily VMT was 20 918 950 (range 8 605 081–45 806 568). Figure 1 shows the 12 high-risk counties and the remaining counties by varying degrees of death risk. These counties were primarily in central and south Florida.

After adjusting for the non-modifiable risk factors age, gender and insurance status, analysis of the 12 highest VMT-weighted risk counties revealed the following independent predictors for driver death: alcohol/drug use, speed limit >45 mph, rural versus urban roads, foggy and cloudy weather, undivided versus divided highway, type of vehicle, vehicle defects (worn tyres) and dirt roads (table 2). Significant protective factors were speed limit <35 mph, driving Monday–Saturday versus Sunday, driving between noon and 19.00 h versus 06.00 h and 09.00 h, rainy versus clear weather conditions and stone/brick/concrete versus blacktop road surface.

Alcohol/drug use in particular was a strong independent risk factor for driver death in all counties. Among the 12 counties studied, alcohol/drug use had the highest OR of death (9.16, 95% CI 9.00 to 9.32) among all risk factors.

DISCUSSION

The idea that some areas in a state will contribute more to driver death than others is intuitive. The weighted averages method is superior to the standard arithmetic mean method to report death rates. We showed that in Florida only 12 counties account for 50% of MVC-related driver deaths. Furthermore, these counties are geographically clustered in south and central Florida.

Many previous studies have provided information on significant risk factors for death and subsequently have provided global recommendations to intervene on these risk factors. These studies lack more specific recommendations for a state government to focus limited resources on target risk factors in selected counties more likely to produce a greater benefit. For example, Baker *et al* mapped county-specific motor vehicle fatalities for the 48 contiguous states of the USA.⁸ One county had >100-fold higher death rate compared with another. Risk factors for death were low population density, road characteristics, higher speeds, seatbelt non-use and vehicle type. Similar to our study, the study by Baker *et al* provided specific information on death and risk factors at the county level, but was limited by two factors: (1) the county population, which is dynamic, was the denominator for death rate; and (2) the highest risk counties were not weighted to identify the most significant contributors to the overall national death rate. Thus, intervening on the county with the highest death rate but low population density (ie, Esmeralda County, Nevada with 558 deaths/100 000 population yet only 0.2 residents/square mile) would not result in a noticeable absolute reduction in overall death rates.

Our analysis is also unique because it accounts for an open driving population (drivers from other geographical areas). Studies have used the number of licensed drivers in an attempt to capture the population at risk of MVC-related deaths. However, not all drivers who die in MVCs are from the region in question. Use of population density itself—a dynamic figure—is thus not accurate. Drivers found in a particular county may not necessarily live in that county, especially in a tourist state such as Florida. Several studies have used VMT as a denominator for motor vehicle death rates.^{9–11} However, no studies have also accounted for VMT-weighted death rates to account for the proportion of all miles driven in an area. Although the concept of weighted averages is not new,⁷ it is a novel method to better identify high-risk counties for driver deaths.¹²

Among the top weighted risk counties, alcohol use remained the strongest predictor of driver death. Prevention programmes such as decreasing the legal blood alcohol limit, increasing traffic fines and increasing convictions for drunk driving have been shown to decrease alcohol-related MVC fatalities.¹³ If resources are limited, a focused county-based intervention to prevent driving under the influence would have a major impact on MVC-attributable driver deaths.

Higher speed is a well-known risk factor for MVC deaths. Speed enforcement detection devices including speed cameras, radar and laser devices have demonstrated benefit in reducing speed, traffic injuries and deaths.^{14,15} Implementing such devices in the highest weighted risk counties of Florida may significantly improve overall driver death.

There are few data regarding associations between motor vehicle deaths and road surface type, location on roadway (ie, off roadway, on the shoulder or on the median) or divided versus undivided highway. The protective effect of slag/gravel/stone or dirt roads compared with blacktop roads may be due to higher 'traction' or coefficient of friction. Drivers are also more likely to drive more slowly on these surfaces. Finally, road slickness is a known but understudied risk factor for motor vehicle death due to both loss of control and increased braking distance.¹⁶ Lie *et al* demonstrated the effectiveness of the electronic stability control device, an on-board safety system that helps maintain control of the vehicle during critical manoeuvring in different road (including low friction) conditions.¹⁷ The reason for the higher death risk with off roadway location is unknown. Regarding the median-divided highway, one study suggested that the association with higher driver death is due either to loss of control on soft-surface shoulders, ejection of occupants or median crossover and collision with oncoming vehicle.¹⁸ Further study is needed on the reason for increased driver death risk associated with road surface type, roadway location and highway dividers.

Driver death was more likely on rural roads than on urban roads, and previous studies have suggested this higher death is due to less access to or lower quality of emergency medical services (EMS) in rural settings.^{8,19} Clark *et al* proposed a model in which motor vehicle death in an area was directly proportional to some power of the mean distance between hospitals, a measure of access to EMS.²⁰ Gonzalez *et al* showed that higher overall EMS prehospital time was associated with higher mortality rates in rural settings.²¹ Measures to improve access to and quality of EMS in rural or high-risk areas may significantly reduce driver fatalities.

Vehicle defects (ie, worn or smooth tyres) were associated with driver death, especially in the top 12 weighted risk counties. Data are lacking on outcomes after interventions to improve awareness and maintenance of tyres and further study is needed. Perhaps providing a rebate on tyre checks and tyre replacement in the highest risk counties may improve vehicle defect-associated driver fatalities.

Our study has several limitations. Data in the FHSMV are collected by highway patrol officers arriving at the scene of a MVC and are susceptible to incomplete data collection. To account for missing data we performed multiple imputation. Most of our variables from the FHSMV dataset had less than 10% missing data. Only one variable had more than 20% missing data. We imputed 10 datasets and achieved 97% efficiency for missing data up to 30%.⁵ The open driving population of Florida poses another limitation. For example, interventions such as drinking and driving prevention programmes at a county level may have limited effect on visiting drivers. Florida has over 15 million registered drivers,²² but over 39.8 million visitors who do not arrive by air.²³ The proportion of Florida visitors involved in fatal driver crashes is unknown and would be an important future study. In light of this limitation, this study highlights the importance of statewide enforcement of zero tolerance for driving under the influence of alcohol and drugs. Fortunately, many of the risk factors identified can be targeted at a county level, such as improving roadway conditions, greater presence of highway law enforcement during evening hours and limiting the speed limit in certain areas.

Using VMT as the weighted proportion can be a limitation since not all road traffic is captured. There are over 300 ATR in the state of Florida; however, these may not be located outside main arteries of traffic. This could underestimate the true proportion of some counties with fewer main roadways.

Although we found county-specific targets for intervention, the potential reduction in overall death is still theoretical. Additionally, although we identified ‘high-yield’ targets for intervention, we have yet to understand the reason for the association between some risk factors and driver death (ie, why gravel/stone/slag and dirt roads are protective). However, our findings of independent predictors of driver death are consistent with previous studies—namely, non-use of seat belts,^{24–26} higher speeds/speed limits,^{24–27} alcohol use,^{26–28} bridges or tunnels,²⁶ bad weather,²⁶ intercity or non-urban roads,²¹²⁵²⁸²⁹ motorcycles,³⁰ low population density,²⁴ males,²⁵ older age²⁵ and specific days of the week³¹ are all associated with higher MVC deaths.

In conclusion, using the concept of weighted averages, we identified a few counties that contributed to the majority of Florida state driver fatalities. These counties are geographically clustered in central and south Florida. This method shows that a regionalised approach for certain risk factors to address statewide driver deaths may be possible for future interventions. However, future work will also have to address the death among Florida’s visiting drivers, better documentation of passenger deaths and other protective factors in preventing driver deaths such as arrival of EMS and vehicle safety devices. In addition, prospective interventional studies in these high-risk counties will be needed to determine whether a regionalised strategy for intervention can positively influence overall state driver deaths.

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What is already known on this subject

- ▶ High traffic states such as Florida have increased driver deaths.
- ▶ Risk factors such as alcohol, driving speed and road conditions are associated with driver deaths.
- ▶ Vehicle miles travelled has been used as a denominator for comparing the rate of driver deaths.
- ▶ Intervention for a state's driver death rate is limited by financial resources available.

What this study adds

- ▶ The use of weighted averages of driver death by VMT is a novel approach in identifying high-risk counties that contribute most to these deaths.
- ▶ A small number of counties make up half of the driver deaths after MVC in Florida.
- ▶ Road conditions, speed limit and highway type are county-specific risk factors amenable to intervention in preventing driver-related death after a crash.
- ▶ In the state of Florida, preventing driving under the influence should be the primary statewide initiative in decreasing overall driver deaths after MVC.

Figure 1.
Map of Florida counties sorted by vehicle miles travelled (VMT)-weighted death rate.

Table 1

Selection method for counties that contribute most to driver death

Step 1	Sort counties by driver death rates using county VMT as denominator
Step 2	Select counties with higher than state average death rate
Step 3	Calculate VMT-weighted average for each county (driver death multiplied by VMT proportion)
Step 4	Re-sort counties by weighted death average from highest to lowest
Step 5	Select the number of counties in descending order that contribute 50% to state driver deaths

VMT, vehicle miles travelled.

Table 2

Risk factors for driver death MVC within the top 12 VMT-weighted risk counties

Risk factors	Grouping of risk factors	Crude OR (95% CI) of fatal vs non-fatal driver MVC	Adjusted OR* (95% CI) of fatal vs non-fatal driver MVC
Alcohol/drugs	Yes	9.29 (9.14 to 9.44)	9.16 (9.00 to 9.32)
	No	Reference	Reference
Speed limit (mph)	25	0.44 (0.42 to 0.46)	0.43 (0.41 to 0.45)
	26–35	0.79 (0.77 to 0.80)	0.77 (0.75 to 0.79)
	36–45	Reference	Reference
	46–55	2.05 (2.01 to 2.09)	2.01 (1.97 to 2.05)
	56–65	2.23 (2.17 to 2.29)	2.17 (2.11 to 2.23)
	>65	3.89 (3.78 to 4.01)	3.73 (3.62 to 3.84)
Time of day	06.01–09.00	Reference	Reference
	09.01–12.00	0.90 (0.85 to 0.96)	0.84 (0.79 to 0.90)
	12.01–14.00	0.77 (0.72 to 0.83)	0.73 (0.68 to 0.78)
	14.01–16.00	0.77 (0.72 to 0.82)	0.73 (0.69 to 0.78)
	16.01–19.00	0.63 (0.59 to 0.67)	0.61 (0.58 to 0.65)
	19.01–23.00	1.30 (1.23 to 1.38)	1.23 (1.16 to 1.30)
	23.01–06.00	1.15 (1.10 to 1.20)	1.10 (1.05 to 1.15)
Day of the week	Monday–Thursday	0.59 (0.58 to 0.60)	0.61 (0.59 to 0.62)
	Friday	0.61 (0.59 to 0.62)	0.62 (0.60 to 0.64)
	Saturday	0.84 (0.82 to 0.86)	0.84 (0.82 to 0.86)
	Sunday	Reference	Reference
Rural/urban	Rural	2.43 (2.40 to 2.47)	2.43 (2.39 to 2.47)
	Urban	Reference	Reference
Weather at time of crash	Clear	Reference	Reference
	Cloudy	1.16 (1.14 to 1.19)	1.17 (1.15 to 1.20)
	Rain	0.72 (0.69 to 0.74)	0.73 (0.71 to 0.76)
	Fog	4.35 (4.08 to 4.63)	4.23 (3.97 to 4.51)
Road surface type	Slag/gravel/stone	0.51 (0.48 to 0.54)	0.50 (0.47 to 0.54)
	Blacktop	Reference	Reference
	Brick	0.66 (0.56 to 0.78)	0.66 (0.56 to 0.77)
	Concrete	0.51 (0.48 to 0.53)	0.51 (0.48 to 0.53)
	Dirt	1.46 (1.35 to 1.58)	1.38 (1.27 to 1.49)
Divided/undivided highway	Divided	Reference	Reference
	Undivided	1.03 (1.01 to 1.04)	1.04 (1.02 to 1.05)
Type of vehicle	Automobile	Reference	Reference
	Heavy truck	3.04 (2.89 to 3.19)	3.01 (2.87 to 3.16)
	Truck-tractor	4.16 (4.00 to 4.33)	4.04 (3.88 to 4.20)
	Bicycle	4.69 (4.51 to 4.88)	4.28 (4.10 to 4.46)
	Motorcycle	9.78 (9.51 to 10.06)	8.45 (8.19 to 8.71)
	All terrain vehicle	5.92 (5.28 to 6.62)	5.72 (5.10 to 6.40)

Risk factors	Grouping of risk factors	Crude OR (95% CI) of fatal vs non-fatal driver MVC	Adjusted OR* (95% CI) of fatal vs non-fatal driver MVC
First vehicle defect	No defects	Reference	Reference
	Defective brakes	1.28 (1.14 to 1.44)	1.26 (1.12 to 1.41)
	Worn/smooth tyres	5.56 (5.21 to 5.92)	5.36 (5.03 to 5.71)
Location on roadway	On road	Reference	Reference
	Not on road	1.30 (1.27 to 1.33)	1.28 (1.25 to 1.31)
	Shoulder	5.48 (5.36 to 5.60)	5.38 (5.26 to 5.50)
	Median	5.25 (5.05 to 5.46)	5.25 (5.05 to 5.46)

* Adjusted by age, gender, insurance.

Reference is the comparison cohort for the regression analysis.

MVC, motor vehicle collision; VMT, vehicle miles travelled.

Table 3

Descriptive analysis of fatal and non-fatal driver crashes in the 12 highest risk counties

Risk factors	Grouping	Fatal (N=6513)	Non-fatal (N=1 594 102)	p Value
Gender	Male	76.3%	60.2%	<0.0001
	Female	23.7%	39.8%	<0.0001
Age	16–25	24.8%	24.8%	0.86
	26–35	18.6%	22.5%	<0.0001
	36–45	17.9%	22.2%	<0.0001
	46–55	15.6%	15.5%	0.85
	>55	23.1%	15.0%	<0.0001
Alcohol/drugs	Yes	32.3%	4.9%	<0.0001
	No	67.8%	95.1%	<0.0001
Speed limit (mph)	25	4.2%	11.0%	<0.0001
	26–35	17.5%	25.9%	<0.0001
	36–45	35.8%	41.6%	<0.0001
	46–55	23.2%	13.2%	<0.0001
	56–65	10.9%	5.7%	<0.0001
	>65	8.5%	2.5%	<0.0001
Time of day	06.01–09.00	2.9%	3.2%	0.26
	09.01–12.00	2.9%	3.4%	0.01
	12.01–14.00	2.3%	3.2%	<0.0001
	14.01–16.00	2.8%	3.9%	<0.0001
	16.01–19.00	3.6%	6.2%	<0.0001
	19.01–23.00	5.2%	4.4%	0.001
	23.01–06.00	80.4%	75.8%	<0.0001
Day of the week	Monday–Thursday	50.2%	57.3%	<0.0001
	Friday	15.4%	17.2%	<0.0001
	Saturday	17.7%	14.3%	<0.0001
	Sunday	16.8%	11.3%	<0.0001
Rural/urban	Rural	62.2%	40.3%	<0.0001
	Urban	37.8%	59.7%	<0.0001
Weather at time of crash	Clear	71.4%	72.7%	0.14
	Cloudy	20.9%	18.3%	<0.0001
	Rain	6.1%	8.7%	<0.0001
	Fog	1.5%	0.4%	<0.0001
Road surface type	Slag/gravel/stone	1.4%	2.7%	<0.0001
	Blacktop	95.2%	92.2%	<0.0001
	Brick	0.2%	0.3%	0.14
	Concrete	2.2%	4.1%	<0.0001
	Dirt	1.0%	0.6%	0.008
Divided/undivided highway	Divided	54.9%	54.2%	0.003
	Undivided	45.1%	45.8%	0.003

Risk factors	Grouping	Fatal (N=6513)	Non-fatal (N=1 594 102)	p Value
Type of vehicle	Automobile	47.2%	65.7%	<0.0001
	Heavy truck	2.7%	1.3%	<0.0001
	Truck-tractor	4.3%	1.4%	<0.0001
	Bicycle	4.2%	1.3%	<0.0001
	Motorcycle	9.1%	1.3%	<0.0001
	All terrain vehicle	0.5%	0.1%	<0.0001
First vehicle defect	No defects	96.0%	98.6%	0.03
	Defective brakes	0.5%	0.4%	0.25
	Worn/smooth tyres	1.6%	0.3%	<0.0001
Location on roadway	On road	69.3%	83.8%	<0.0001
	Not on road	11.3%	10.5%	0.04
	Shoulder	14.6%	3.2%	<0.0001
	Median	4.3%	1.0%	<0.0001