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Geographic Analysis of Traffic Injury in Wisconsin: Impact on Case Fatality of Distance to Level I/II Trauma Care

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ABSTRACT

Purpose: Traffic injuries are an important public health problem in Wisconsin. This paper examines geographic variations in the incidence and case fatality of traffic injuries, and evaluates proximity to Level I/II trauma care as a predictor of case fatality.

Methods: Data on all persons injured in motor vehicle crashes on Wisconsin roadways during a 10-year period (1992-2001) were obtained from the Wisconsin Crash Outcome Data Evaluation System. Injury rates per 100 million vehicle miles traveled (VMT) and case fatality were visually displayed by county. Multiple logistic regression models were used to evaluate distance between crash site and Level I/II trauma care as a risk factor for fatality, controlling for other factors.

Results: During the 10-year period, 50,300 people were severely injured in motor vehicle crashes and 7450 (15%) died. Injury rates per VMT were highest in the southeast counties. In contrast, case-fatality for all injuries and for severe injuries was highest in northern and western counties and significantly associated with distance from Level I/II trauma care after controlling for other predictors of case fatality.

Conclusions: Strategies are needed to reduce the disparity in traffic injury case fatality across the state and to improve outcomes for persons injured in counties distant from Level I/II trauma care.

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INTRODUCTION

Injuries resulting from motor vehicle crashes are the leading cause of death in young people and a major cause of morbidity and hospitalization in all age groups in Wisconsin.[1] In 2001, Wisconsin ranked 30th in the nation in its motor vehicle death rate, at 15.28 per 100,000 people.[2] Each year, approximately 700-800 people die, and more than 50,000 sustain nonfatal injuries, as a result of motor vehicle crashes on Wisconsin roadways.[3] To better characterize the risk of traffic injuries in Wisconsin and to identify opportunities for prevention, this paper examines county-level geographic variations in both the incidence of injuries per 100 million vehicle miles traveled (VMT) and the case fatality of severe traffic injuries (i.e., the percentage of severe injuries that are fatal). It also evaluates the extent to which variations in case fatality of severe traffic injuries are associated with the distance between the crash site and the nearest Level I or Level II trauma center within the state, after controlling for other predictors of case fatality such as age and type of crash.

METHODS

Data for the years 1992-2001 were obtained from the Wisconsin Crash Outcome Data Evaluation System (CODES) database, which includes anonymous data on all injuries caused by motor vehicle crashes on Wisconsin roadways.[4] The CODES linkage project is a multi-agency collaboration between the Wisconsin Department of Transportation, the Department of Health and Family Services, and the Center for Health Systems Research and Analysis of the University of Wisconsin-Madison. It includes data from police reports on all persons involved in motor vehicle crashes in Wisconsin. For persons hospitalized, it includes hospital discharge data matched to the crash data using a

probabilistic linking process.[4] For each person involved in a motor vehicle crash, the CODES database includes information on, among other factors: attributes of the person (age; sex; whether he/she was involved as a driver or passenger of car, light truck, motorcycle, moped or bicycle, as a pedestrian, or other; whether he/she was using safety equipment such as lap and shoulder belts, child restraint and booster seats, a helmet or goggles), whether the person was observed by the police officer to be injured from the crash, whether the person was hospitalized as a result of injuries from the crash, whether the person died as a result of the crash, and attributes of the crash (the county in which the crash occurred; the date of the crash; whether the roadway was a city street, county road, state highway, or federal highway; the posted speed limit; whether the driver was exceeding the speed limit; whether alcohol was a factor in the crash; and whether the collision was head-on and/or resulted from a vehicle crossing the center line).

Vehicle Miles Travel Data

The Traffic Forecasting Section of the Wisconsin Department of Transportation provided estimates of vehicle miles traveled (VMT) for each of the state's 72 counties from 1994 to 2001 and statewide VMT from 1992 to 2003. These estimates were derived from traffic counts and annual daily traffic estimates.[5] Using these estimates, we calculated 3-year moving averages of VMT for each county for the years 1994 to 2000. Interpolation using the beta coefficient from a regression model was used to estimate the VMT for 1992, 1993, and 2001.

Hospital Location Data

The 130 hospitals in Wisconsin were mapped based on address information provided by the Wisconsin Department of Administration. Of these hospitals, seven have Level I or Level II Trauma Center accreditation from the American College of Surgeons.[6]

Data Analysis

Computation of Incidence and Case Fatality— Annual incidence rates of traffic injuries were computed for the entire state by dividing the total number of injured persons each year by the estimated VMT in the state during the same year. The average annual incidence rate for each county was computed by dividing the number of persons injured in the county during the 10-year period by the estimated VMT in the county over the same period and dividing this quotient by 10. The case fatality of severe injuries was calculated by dividing the total number of fatal injuries by the total number of injuries resulting in hospitalization and/or death.

Mapping and Estimation of Distance Between County of Crash and Nearest Trauma Center and Other Hospital— Visual display of the injury incidence rates and case-fatality was performed using ArcGIS software.[7] Centroids of counties were calculated in ArcView software[8] using plain geometric mean of East-West and North-South ranges. ArcView software was used to calculate distances from county centroid point location to the nearest Level I/II trauma center and other hospital point location (measured in meters and converted to miles). The hospital point location map and county map were projected in the Wisconsin Universal Transverse Mercator system to allow minimal distortion of distances for these distance calculations.

Statistical Analysis— To evaluate and control for predictors of fatal outcome among severely injured persons, we performed cross-tabulations and multiple logistic regression analysis using SAS software.[9] Independent variables considered for inclusion in the logistic regression model were those found in univariate analyses to be associated with fatality, including role of the person in the crash, age, sex, use of safety equipment, posted speed limit, whether speeding was a factor in the crash, whether alcohol was a factor in the crash, whether the crash was a head-on collision and/or resulted from a vehicle crossing the center line, and the distance from the centroid of the county of crash to the nearest level I or II trauma center in Wisconsin.

RESULTS

During the 10-year study period, 1,365,642 motor vehicle crashes occurred on Wisconsin roadways and a total of 3,612,898 individuals were involved in the collisions. Of these persons, 654,920 (18.1%) were reported on police and/or hospital records as potentially injured (with injuries not observable to the police officer but reported by the individual affected and/or suspected by the officer), definitely injured and/or killed. No information regarding injury status was recorded for an additional 2312 (0.4%).

Of the 654,920 recorded as potentially or definitely injured, 604,620 (92.3%) survived and were not hospitalized (Table 1). The remaining 50,300 (7.8%) sustained injuries severe enough to result in hospitalization and/or death and make up the case group of severely injured persons in this study's analyses. A total of 7450 (1.1% of those recorded as injured or potentially injured and 14.8% of the severely injured) died from their injuries. The majority of persons who died (83.0%) were not hospitalized (Table 1).

Among the 50,300 severely injured, 76.9% were oc-

Table 1. Number (%) of Persons Injured in Motor Vehicle Crashes on Wisconsin Roadways, 1992-2001, by Role of Injured Person and Whether Injuries Resulted in Hospitalization and/or Death; Case Fatality of Severe Injuries*

Role of Person Injured or Potentially Injured	Number of Persons with Non-Fatal Injuries: Non-Hospitalized, Reported Injured or Potentially Injured	Number of Persons with Non-Fatal Injuries: Hospitalized	Number of Persons with Fatal Injuries: Hospitalized	Number of Persons with Fatal Injuries: Non-Hospitalized	Total Persons Injured or Potentially Injured, Number (%)	Severe Injuries Number (%)*	Case Fatality of Severe Injuries %†
Motor Vehicle Occupant							
Total	556,380	36,946	1046	5482	599,854 (91.6)	43,474 (86.4)	15.0
Car, driver	309,035	19,262	545	2874	331,716 (50.6)	22,681 (45.1)	15.1
Car, passenger	164,218	8543	253	1290	174,304 (26.6)	10,086 (20.1)	15.3
Light truck, driver	47,931	3738	95	697	52,461 (8.0)	4530 (9.0)	17.5
Light truck, passenger	18,983	1170	33	160	20,346 (3.1)	1363 (2.7)	14.2
Motorcycle, driver	13,827	3771	97	403	18,098 (2.8)	4271 (8.5)	11.7
Motorcycle, passenger	2386	462	23	58	2929 (0.4)	543 (1.1)	14.9
Moped	835	159	1	5	1000 (0.2)	165 (0.3)	3.6
Bicycle	14,242	1141	34	81	15,498 (2.4)	1256 (2.5)	9.2
Pedestrian	17,161	3405	150	387	21,103 (3.2)	3942 (7.8)	13.6
Other	14,030	862	21	187	15,100 (2.3)	1,070 (2.1)	19.4
Unspecified	1972	337	14	42	2365 (0.4)	393 (0.8)	14.2
Total	**604,620**	**42,850**	**1266**	**6184**	**654,920 (100)**	**50,300 (100)**	**14.8**

* Injuries resulting in hospitalization and/or death
† Percent of severely injured who died

cupants of cars or light trucks, 9.6% were occupants of motorcycles, 2.5% were bicyclists, and 7.8% were pedestrians (Table 1). The case fatality of severe injuries varied somewhat by the role of the person injured, from a high of 19.4% for "other" (uncategorized) to a low of 3.6% for persons on mopeds (Table 1).

Geographic analysis shows considerable variation across the 72 counties in both the incidence of severe injuries (ranging from 3 to 15 per 100 million VMT, Figure 1) and in the case fatality of these injuries (ranging from 7.5% in Milwaukee County to 57.1% in Douglas County, Figure 2). The counties with the highest rates of all traffic injuries per 100 million VMT are generally located in the southeastern section of the state, which also includes the counties with the highest population density and highest VMT (data not shown). The counties with the highest rates of severe injuries are somewhat dispersed throughout the center of the state (Figure 1). In contrast, the counties with the highest case fatalities for severe injuries are located in northern and western regions (Figure 2). The counties with the highest case fatalities also tend to be more distant from the state's 7 Level I/II trauma centers than is true for the low case fatality counties (Figure 2). Injuries from crashes occurring in counties with a Level I/II trauma center less than 30 miles from the county centroids had an overall case fatality for severe injury of 12.2% (n=23 counties), whereas the mean case fatality for injuries occurring in the 49 more distant counties was 19.1% (relative risk 1.57, 95% confidence interval 1.50, 1.63, $P<0.001$, Table 2).

In univariate analyses, a number of factors, in addition to distance from Level I/II trauma center care, were significantly associated with a fatal outcome among persons sustaining severe injuries (Table 2). Multivariate analysis identified a significant interaction ($P=0.018$) between use of safety equipment among non-pedestrians and distance between crash site and nearest Level I/II trauma care. There were also significant interactions between pedestrian vs non-pedestrian injury and other independent variables. In light of these interactions, we excluded pedestrian injuries from the multivariate analysis and stratified this analysis by whether or not safety equipment was used by the person injured. Variables retained in the multivariate analysis presented in Table 3 are those for which data were available for at least 85% of cases and that remained as significant predictors of fatality among persons sustaining severe injuries after adjusting for other variables in the model. The effects of age (>1 year vs 1-74 years), posted speed limit (65 or greater vs 45 or less), and distance between crash site and nearest Level I/II trauma center (<30 miles vs >30 miles) on risk of fatality are significant whether safety equipment is used or not, but are substantially increased in the absence of indicated safety equipment (Table 3). For example, distance from Level I/II trauma care <30 miles vs >30 miles increases the risk of fatality by 29% (adjusted odds ratio 1.29, 95% confidence interval 1.20,

1.39) when safety equipment is used, and by 51% (adjusted odds ratio 1.51, 95% confidence interval 1.39, 1.65) when the injured person was not using indicated safety equipment (Table 3).

DISCUSSION

This study has demonstrated considerable variability across Wisconsin counties in both the injury rates per 100 million VMT and the case fatality of traffic injuries. The use of geographic information system (GIS) technology allowed us both to portray this variability in maps and to compute distance between county of crash and Level I/II trauma care for consideration as an independent predictor of case fatality. The apparent protective effect in terms of case fatality of proximity to Level I/II trauma care (Figure 2) is supported by the logistic regression analysis, which showed the risk of death after sustaining a severe traffic injury to be significantly associated with distance from the county of crash to the nearest Level I/II trauma center, after controlling for other relevant and measured factors.

Outcome after sustaining traffic injuries has been shown to be related to injury severity, host factors such as age, quality of trauma care, and time between the crash event and trauma care.[10] In addition, treatment in hospitals with Level I/II trauma accreditation has been shown to be associated with lower case fatality[11-17] despite an overall increased injury risk in that patient population. Although our database did not include measures of injury severity or time to receipt of trauma care, the findings are generally consistent with previous studies if distance from centroid of the county of crash to the nearest Level I/II trauma center is considered a proxy for time to treatment and access to Level I/II trauma care. The observation that this distance is an independent predictor of case fatality suggests that the disparities in case fatality for traffic injuries across Wisconsin's counties might be reduced by improving emergency medical services' (EMS) response times and access to Level I/II trauma care in the northern and western counties of the state. These findings are generally consistent with national data showing rural residents to be nearly twice as likely to die as a result of trauma than their urban counterparts.[18]

The results of this study also point to important factors associated with traffic injury case fatality other than distance from trauma care. These include the use of safety equipment, alcohol as a factor in the crash, high traffic speeds, and age (with infants and the elderly at greatest risk). The interaction between use of safety equipment and the other independent predictors of case

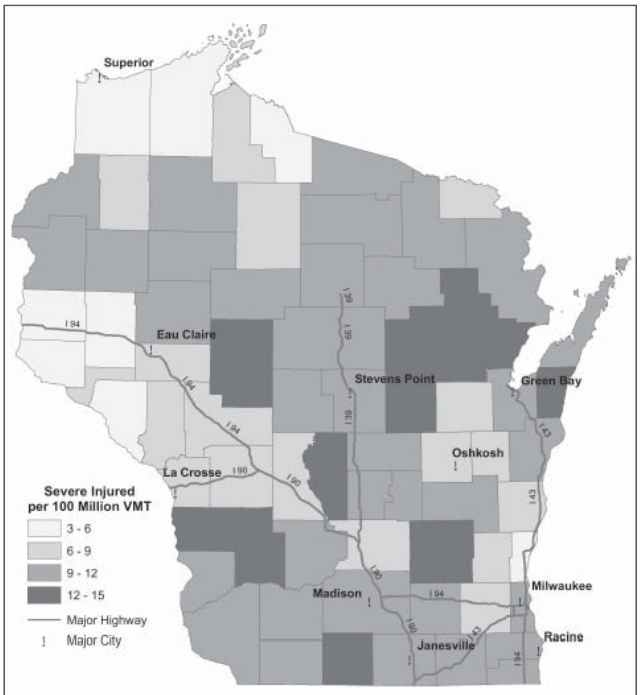

Figure 1. Incidence of severe traffic injuries per 100 million vehicle miles traveled (VMT), by county, 1992-2001.

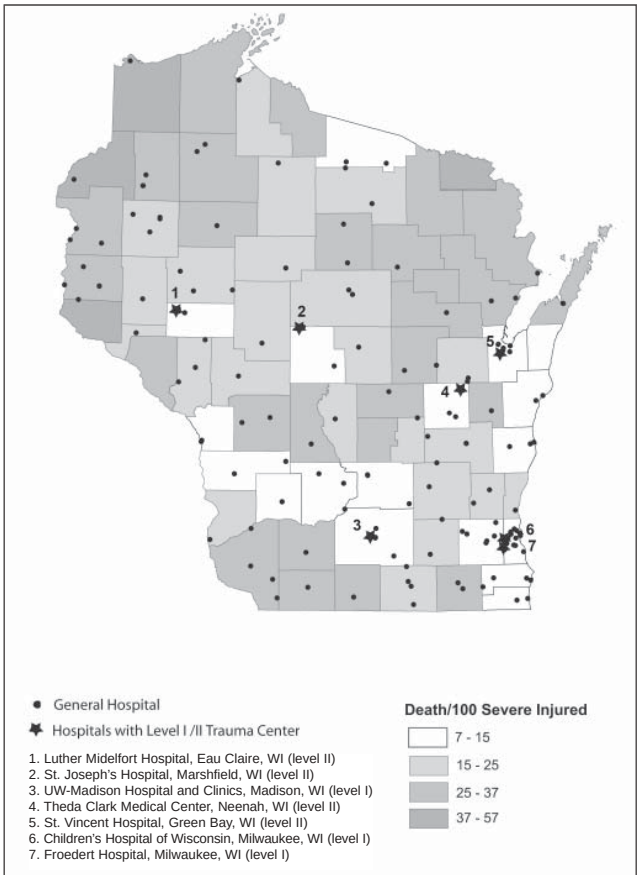

Figure 2. Severe traffic injury case ratality (% fatal among injuries resulting in hospitalization and/or death), by county, 1992-2001.

Table 2. Variables Associated with Case Fatality* in Univariate Analyses

	Number Injured (% Fatal)		Relative Risk (95% Confidence Interval)	
Age Group				
(missing data n=9)				
<1 year	228	(23.2)	1.60	(1.27, 2.03)
1-74 years†	45,590	(14.5)	1.00	
75-79 years	3440	(18.2)	1.26	(1.17, 1.35)
80+ years	1032	(24.1)	1.67	(1.49, 1.86)
Gender				
(missing data n=4)				
Female†	19,803	(13.0)	1.00	
Male	30,493	(16.3)	1.26	(1.21, 1.32)
Safety Equipment				
Yes, as indicated†	33,015	(12.6)	1.00	
No	14,190	(21.2)	1.68	(1.61, 1.75)
Missing data (6.2%)	3095	(11.5)		
Posted Speed Limit				
<= 45 miles/hour†	19,076	(9.1)	1.00	
50-60 miles/hour	23,114	(19.8)	2.16	(2.05, 2.23)
>= 65 miles/hour	2111	(21.6)	2.36	(2.15, 2.59)
Missing data (11.9%)	5999	(12.9)	1.41	(1.30, 1.53)
Excessive Speed				
No†	35,504	(13.7)	1.00	
Yes	3474	(20.8)	1.43	(1.33, 1.53)
Missing data (22.5%)	11,322	(17.3)		
Head-on Collision				
No†	35,144	(13.5)	1.00	
Yes	4,672	(22.2)	1.56	(1.47, 1.65)
Missing data (20.8%)	10,484	(17.0)		
Alcohol-Related Crash	9255	(22.4)	1.69	(1.61, 1.76)
Distance Between Crash Site and Level I/II Trauma Center				
<10 miles†	16,810	(9.4)	1.00	
11-79 miles	31,750	(17.5)	1.87	(1.77, 1.97)
80+ miles	1740	(24.3)	2.60	(2.36, 2.86)
<30 miles†	30,046	(12.2)	1.00	
>= 30 miles	20,254	(19.1)	1.57	(1.50, 1.63)

* Risk of fatal outcome among persons with severe traffic injuries
† Reference category

fatality suggests that a substantial proportion of the excess risk associated with age, traffic speeds, and distance from Level I/II trauma care can be mitigated by the use of safety equipment such as seat belts, child restraints, and helmets.

Although the case fatality of severe injuries increases with distance from Level I/II trauma centers, we found the number and rate of all traffic injuries to be higher in the more urbanized counties of the state, which are also the counties most proximal to the Level I/II trauma centers. This raises the question of how many fatalities might be prevented if the case fatality for severe injuries occurring in distant counties could be lowered to the 12.2% case fatality observed for injuries occurring in the 23 counties located within 30 miles of Level I/II trauma care. After accounting for the number of deaths that would be expected if the case fatality of traffic injuries was reduced from 19.1% to the 12.2% observed for the other 23 counties, a total of 1409 excess traffic deaths occurred in the counties located more than 30 miles from Level I/II trauma care during the 10-year study period. Thus, an average of 141 traffic deaths might be prevented in Wisconsin each year if the excess case fatality in counties more distant from Level I/II trauma care could be eliminated. The multivariate analysis suggests that multiple factors associated with case fatality, in addition to distance from trauma care, would need to be addressed to eliminate the observed geographic disparity. These factors might best be addressed through a coordinated, statewide trauma system, as advocated by the National Highway Traffic Safety Administration.[19] Wisconsin is currently 1 of only 8 states in the country without such a trauma system.

The results of this study should be interpreted in light of a number of limitations. County level VMT was estimated and may not accurately reflect the actual traffic volume in the county. However, using VMT is more robust than adjustment for population density, as many people in urban areas do not drive and much of the traffic in any given county and the state as a whole involves residents of other counties or states. Another limitation is our lack of geographic point data indicating the locations of crash sites within counties. The availability of such point data would enhance precision and allow estimation of actual response times from the crash occurrence to receipt of trauma care. Another limitation is the lack of data on crash severity, injury severity, and other known and potential predictors of case fatality that may have confounded the associations reported in this study. To the extent that crash and injury severity are associated with measures we were able to control

for, such as speed, crash type, use of safety equipment, alcohol involvement, and age, the potentially confounding effects of these variables will have been controlled for in this study. The potential for selection bias due to geographic variability in ascertainment of crashes and crash-related injuries cannot be ruled out, though we have no evidence that reporting of these events is differential across the state's counties. Additionally, the benefits of preventive strategies to reduce infant and child fatalities may be underestimated due to the categorical reporting (yes/no) within CODES of the use of child safety seats. A child may be severely injured and not properly restrained; the CODES data would record the use of a child safety seat if one were found at the crash site whether or not it was used appropriately. Improved reporting on the effectiveness of restraint systems could result from forensic crash analysts receiving required training in child passenger safety.

Despite these limitations, the geographic variation in traffic injury case fatality demonstrated in this study points to the need for improved use of preventive strategies and availability of trauma care in the northern and western Wisconsin counties. This study also serves to raise awareness of the magnitude of traffic injuries and fatalities as a public health problem in Wisconsin and of the need to reduce the risk factors for these injuries and the fatalities they may cause.

Table 3. Results of Multivariate Logistic Regression Analysis: Adjusted Odds Ratios for Variables Associated with Case Fatality,* Stratified by Whether the Person Injured Was Using Indicated Safety Equipment†

	Adjusted Odds Ratio (95% Confidence Interval)	
	Using Indicated Safety Equipment (n=33,015)	**Not Using Indicated Safety Equipment (n=14,190)**
Age Group		
<1 year	1.86 (1.20, 2.90)	3.65 (1.87, 7.09)
1-74 years‡	1.00	1.00
75-79 years	1.50 (1.33, 1.69)	2.24 (1.86, 2.71)
80+ years	2.45 (2.02, 2.97)	2.33 (1.70, 3.19)
Posted Speed Limit		
<= 45 miles/hour‡	1.00	1.00
50-60 miles/hour	2.34 (2.22, 2.54)	2.08 (1.88, 2.29)
>= 65 miles/hour	2.44 (2.08, 2.86)	3.27 (2.74, 3.92)
Missing data	1.48 (1.24, 1.76)	1.7 (1.62, 1.94)
Alcohol-Related Crash	1.77 (1.62, 1.94)	1.77 (1.62, 1.94)
Distance Between Crash Site and Level I/II Trauma Center		
<30 miles‡	1.00	1.00
30+ miles	1.29 (1.20, 1.39)	1.51 (1.39, 1.65)

* Risk of fatal outcome among persons with severe traffic injuries
† Persons injured as pedestrians excluded
‡ Reference category

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