A STUDY BY THE PACIFIC INSTITUTE FOR RESEARCH & EVALUATION

ON A CRASH COURSE:

THE DANGERS AND HEALTH COSTS OF DEFICIENT ROADWAYS

Dr. Ted R. Miller &
Dr. Eduard Zaloshnja

Commissioned by
The Transportation Construction Coalition
May 2009

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About the Pacific Institute for Research and Evaluation

This study was conducted by Drs. Ted R. Miller and Eduard Zaloshnja of the Pacific Institute for Research and Evaluation (PIRE), a non-profit public health research organization. For more than 30 years, PIRE staff have been involved in studies related to transportation safety, doing groundbreaking work on issues related to driver behavior, including studies of safety belt use, driver distraction, hazard perception, aggressive driving and fatigue. PIRE has also been an international leader and made seminal contributions in research to understand and prevent impaired driving and reduce harm consequent to it.

PIRE transportation safety research sponsors have included, among others:

- National Highway Traffic Safety Administration
- Federal Highway Administration
- Federal Motor Carrier Safety Administration
- Advocates for Highway & Auto Safety
- Insurance Institute for Highway Safety
- National Safety Council
- Mothers Against Drunk Driving
- American Automobile Association

About the Authors

Ted R. Miller, Ph.D, City Planning and Operations Research, Regional Science (Economics)
Principal Research Scientist

Dr. Miller is an internationally recognized safety economist, who has led more than 150 studies and authored over 200 scholarly publications. He is a leading expert on injury incidence, costs and consequences, as well as substance abuse costs. His cost estimates are used by the U.S. Department of Transportation, the U.S. Consumer Product Safety Commission, the Justice Department, and several foreign governments. He has estimated benefit-cost ratios for more than 100 health and safety measures. Dr. Miller founded the Children's Safety Network Economics and Data Resource Center, which has worked since 1992 to forge child safety partnerships between insurers and advocates. The Center received a Nationwide Insurance "On Your Side Highway Safety Award" in 1996. He is a fellow of the Association for the Advancement of Automotive Medicine and has received several national awards for his work.

Eduard Zaloshnja, Ph.D, Applied Economics
Research Scientist

Dr. Zaloshnja has a background in applied economics and econometrics, specializing in safety issues. At PIRE, he has estimated U.S. bus and truck crash costs and conducted benefit-cost analyses. He also has analyzed ambulance crash injuries, impaired driving, and occupant restraint. Recently, he estimated U.S. highway crash costs and costs of transport and other injuries to employers. Currently, Dr. Zaloshnja is analyzing how often catastrophic injury causes people to move onto Medicaid and public disability support for life. In related projects, he probed traumatic brain injury prevalence and costs in the United States.

About the Transportation Construction Coalition

The Transportation Construction Coalition (TCC), which commissioned this research, was founded in 1996 and includes 28 national organizations and labor unions with a collective interest in federal transportation policy and funding. It is co-chaired by the American Road & Transportation Builders Association and the Associated General Contractors of America. Its other members include:

American Coal Ash Association; American Concrete Pavement Association; American Concrete Pipe Association; American Council of Engineering Companies; American Society of Civil Engineers; American Subcontractors Association; American Traffic Safety Services Association; Asphalt Emulsion Manufacturers Association; Asphalt Recycling and Reclaiming Association; Associated Equipment Distributors; Association of Equipment Manufacturers; International Association of Bridge, Structural, Ornamental and Reinforcing Iron Workers; International Slurry Surfacing Association; International Union of Operating Engineers; Laborers' International Union of North America; Laborers-Employers Cooperation & Education Trust; National Asphalt Pavement Association; National Association of Surety Bond Producers; National Lime Association; National Ready Mixed Concrete Association; National Stone, Sand and Gravel Association; National Utility Contractors Association; Portland Cement Association; Precast/Prestressed Concrete Institute; The Road Information Program; United Brotherhood of Carpenters and Joiners of America.

Executive Summary

While considerable research has been conducted over the past 50 years quantifying the significant roles motor vehicle design, drunk and drugged driving, speeding and non-use of seatbelts play as factors in the number, severity and economic costs of motor vehicle crashes in the United States, this is the first national study in many years to examine the role and consequences of another major factor in these tragic incidences—the physical condition of U.S. roadways.

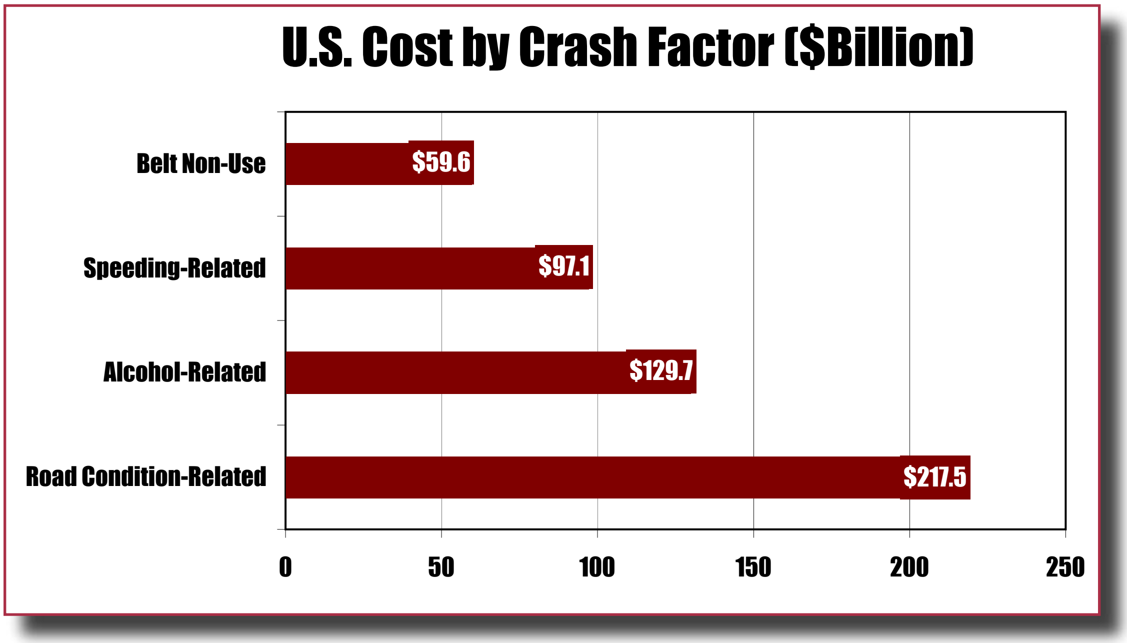
The study finds that the cost and severity of crashes where roadway conditions are a factor "greatly exceeds the cost and severity of crashes where alcohol or speeding was involved, or the cost of non-use of seatbelts."

Among the study's key findings:

- Roadway condition is a contributing factor in more than half—52.7 percent—of the nearly 42,000 American deaths resulting from motor vehicle crashes each year and 38 percent of the non-fatal injuries. In terms of crash outcome severity, it is the single most lethal contributing factor—greater than speeding, alcohol or non-use of seat belts.

- Motor vehicle crashes in which roadway condition is a contributing factor cost the U.S. economy more than $217 billion each year. That is more than three-and-one-half times the amount of money government at all levels is investing annually in roadway capital improvements—$59 billion, according to the Federal Highway Administration. This societal cost includes $20 billion in medical costs; $46 billion in productivity costs; $52 billion in property damage and other resource costs; and $99 billion in monetized quality of life costs.

- American businesses are paying an estimated $22 billion of the annual economic cost of motor vehicle crashes involving their employees in which roadway condition is a contributing factor. This includes almost $10 billion a year in health-related fringe benefit expenses for insurance ($6.0 billion) workers' compensation claims ($1.2 billion), sick leave ($1.7 billion) and Social Security ($920 million). These crashes cost government (taxpayers) at all levels $12.3 billion.



Drs. Ted R. Miller and Eduard Zaloshnja of the Pacific Institute for Research & Evaluation conclude: **"The large share of crash costs related to road conditions underlines the importance of these factors in highway safety. Road conditions are largely controllable. Road maintenance and upgrading, and the installation of traffic safety features can prevent crashes and reduce injury severity."** They add: "Although driver factors are involved in most crashes, avoiding those crashes through driver improvement requires reaching millions of individuals and getting them to sustain best safety practices. That is not fail-safe. It is far more practical to make the environment more forgiving and protective."

The authors suggest "numerous solutions—some simple, some complex" that could help make the roadway environment safer for users. They also estimate the economic cost of fatal or injury crashes by state.

Costs of Crashes Where Road Conditions Contributed to Crash Frequency or Severity by State, 2006, in Millions of Dollars Unless Otherwise Indicated

State	Medical Costs	Productivity Loss	Quality of Life Loss	Other Costs	Comprehensive Cost	Comprehensive Cost Per Million Vehicle-Miles (2006 Dollars)	Comprehensive Cost Per Mile of Road (2006 Dollars)
U.S.	*20,196*	*46,433*	*98,929*	*51,884*	*217,442*	*72,301*	*73,359*
Alabama	632	1,438	3,265	1,676	7,012	116,316	99,344
Alaska	29	36	98	32	196	39,592	19,934
Arizona	402	766	1,730	880	3,779	60,625	78,971
Arkansas	335	715	1,649	837	3,536	107,357	47,499
California	2,457	5,109	11,810	5,945	25,321	77,491	211,059
Colorado	271	653	1,211	679	2,814	57,978	42,390
Connecticut	206	519	956	551	2,232	70,476	143,038
Delaware	34	99	200	102	436	46,323	92,961
D.C.	14	51	107	55	227	62,865	198,743
Florida	1,159	2,615	5,576	2,923	12,272	60,367	124,513
Georgia	780	1,859	3,683	2,016	8,339	73,612	95,702
Hawaii	91	176	570	239	1,075	105,792	338,310
Idaho	151	295	702	348	1,496	98,639	44,301
Illinois	661	1,785	3,128	1,826	7,400	69,397	68,492
Indiana	428	991	2,031	1,076	4,525	63,682	66,622
Iowa	121	306	624	326	1,377	44,010	17,977
Kansas	200	469	926	520	2,114	70,128	20,908
Kentucky	449	1,016	2,266	1,169	4,900	102,867	84,726
Louisiana	453	992	2,389	1,164	4,999	110,301	106,496
Maine	118	226	563	285	1,192	79,421	77,625
Maryland	257	798	1,283	776	3,114	55,428	133,283
Massachusetts	349	810	1,723	896	3,779	68,688	143,988
Michigan	383	1,045	2,097	1,138	4,663	44,855	52,926
Minnesota	185	462	874	478	1,999	35,451	20,978
Mississippi	393	831	2,145	1,034	4,401	106,293	79,630

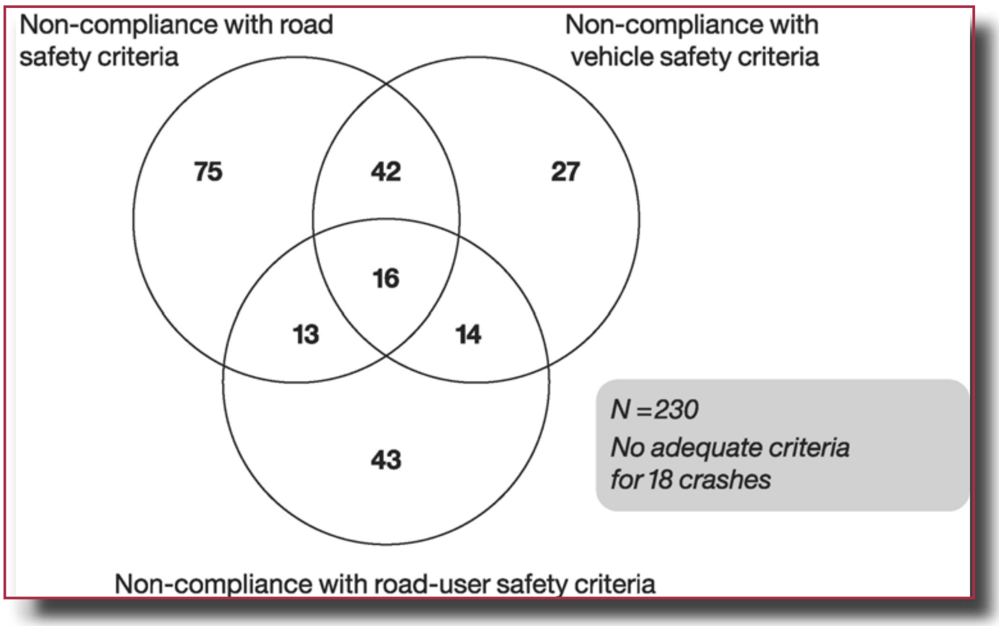
State	Medical Costs	Productivity Loss	Quality of Life Loss	Other Costs	Comprehensive Cost	Comprehensive Cost Per Million Vehicle-Miles (2006 Dollars)	Comprehensive Cost Per Mile of Road (2006 Dollars)
Missouri	545	1,294	2,601	1,395	5,834	84,947	61,041
Montana	93	174	425	232	925	82,259	17,528
Nebraska	81	210	414	211	917	47,314	13,370
Nevada	176	379	801	426	1,781	81,806	68,616
New Hampshire	64	209	396	221	891	65,584	75,904
New Jersey	418	1,018	2,047	1,112	4,594	61,093	154,347
New Mexico	174	322	838	387	1,721	66,905	33,292
New York	938	2,094	5,068	2,505	10,605	75,197	127,674
North Carolina	807	1,823	3,912	2,033	8,575	84,656	108,203
North Dakota	24	65	138	71	297	37,715	4,176
Ohio	635	1,361	3,191	1,590	6,776	61,048	71,780
Oklahoma	408	924	2,042	1,068	4,442	91,439	54,136
Oregon	261	496	1,167	570	2,494	70,429	59,424
Pennsylvania	874	2,324	4,671	2,545	10,415	96,402	111,869
Rhode Island	46	100	254	130	530	63,947	104,459
South Carolina	522	1,130	2,675	1,318	5,645	112,704	119,374
South Dakota	64	153	332	168	717	78,406	11,689
Tennessee	700	1,650	3,295	1,805	7,449	105,753	109,761
Texas	1,281	2,953	5,769	3,166	13,169	55,394	59,083
Utah	57	134	320	139	649	25,066	19,470
Vermont	68	133	316	176	693	88,650	66,352
Virginia	472	1,345	2,400	1,363	5,581	68,972	104,983
Washington	327	724	1,428	773	3,252	57,665	53,438
West Virginia	206	431	1,017	519	2,174	104,320	83,428
Wisconsin	317	741	1,453	777	3,288	55,484	38,268
Wyoming	77	187	353	213	829	88,246	61,028

The Study

While considerable research over the past 50 years has quantified the significant roles motor vehicle design, drunk and drugged driving, speeding and non-use of seatbelts play as factors in the number, severity and economic costs of motor vehicle crashes in the United States, this is the first national study in many years to examine the role and consequences of another major factor in these tragic incidents—the physical condition of U.S. roadways.

Road crashes result from a combination of driver, vehicle, and roadway factors. Often two or more of these factors are simultaneously involved in a crash. Changes in any of driver behavior, law enforcement, vehicle capabilities, or roadway characteristics and conditions might have averted a crash or reduced the severity of associated occupant injuries. In Sweden, Stigson et al. (2008) investigated 248 fatal crashes and estimated that at least 59% were road-related (Figure 1).

Figure 1. Contributing Factors in 248 Fatal Crashes in Sweden



Source: Stigson et al. (2008).

Poorly maintained roads or the congestion caused by insufficient road networks can contribute to both the frequency and severity of motor vehicle crashes. However, except for analyses of specific crash types that might be reduced by intelligent vehicle-highway systems, the traffic safety literature rarely emphasizes the importance of road-related factors. For example, a 1991 study analyzed fatal crashes of lap-shoulder belted occupants and found that in 30% of such crashes, drivers could do nothing to avoid them (Viano and Ridella, 1991). However, it did not identify crashes where road conditions contributed to the crash. Similarly, a 1994 study analyzed the causes of crashes involving drivers under age 25, but counted crashes involving skidding as driver-related without considering whether a different road environment might have prevented the skid and averted the crash (Lestina and Miller, 1994). The Federal Motor Carrier Safety Administration (FMCSA) developed a data set on large truck crash causation in 2001-2003 (FCMSA 2005). Craft (2007) used those data to estimate that 20% of heavy truck crashes were caused in part by roadway conditions.

Crashes Related to Road Conditions Pose a Heavy Burden to Society

As Table 1 shows, in 5.32 million crashes, or in 31.4% of all traffic crashes nationally in 2006, road conditions contributed to crash occurrence or severity. Road-relatedness rose with crash severity. Road-related crashes accounted for 38.2% of non-fatal injuries (2.2 million cases) and 52.7% of fatalities (22,455 deaths).

Table 1. 2006 U.S. Traffic Crash Incidence

	No. of Crashes	%	No. of Non-Fatally Injured People	%	No. of Killed People	%
All Crashes	16,954,351	100%	5,746,231	100%	42,642	100%
Crashes Where Road Conditions Contributed to Crash Frequency or Severity	5,317,316	31.4%	2,194,829	38.2%	22,455	52.7%

The estimated comprehensive cost of traffic crashes where road conditions contributed to crash frequency or severity was $217.5 billion in 2006 (Table 2). This represented 43.6% of the total comprehensive crash cost of $498.8 billion. Unlike other previous federal reports, the $498.8 billion represents both actual and quality of life costs.

The $217.5 billion figure is more than three-and-one-half times the amount of money government at all levels is investing annually in roadway capital improvements—$59 billion, according to the Federal Highway Administration. This societal cost includes $20.2 billion in medical costs; $46.5 billion in productivity costs; $51.9 billion in property damage and other resource costs; and $98.9 billion in monetized quality of life costs.

Road-related crash incidence and costs were similar in 2000 (Tables A-3 and A-4, page 29).

As the Annex details, this study relied on the crash costs and crash incidence data sets that the U.S. Department of Transportation uses in its regulatory analyses. Given the lack of detailed information on the contribution of road conditions in the national crash data, large truck crash data were used to model the probability of a crash relating to road conditions. This choice assumes that truck crashes have reasonably similar causes to other crashes in the U.S. To the extent they do not, the study over-estimates or under-estimates the cost of road-related crashes. Three events—first impact with a bridge or any harmful impact with a large tree or a medium/large non-breakaway pole—were considered road-related factors whose presence increased the severity of moderate injury to fatal crashes. More than 40% of serious to fatal crashes and 30% of moderate injury crashes involved one of these events. Conservatively, the estimates do not account for the greater risk of injury associated with a wider range of harmful events involving the roadway and roadside. The large share of crash costs related to road conditions underlines the importance of these factors in highway safety. Road conditions are largely controllable. Road maintenance and upgrading, and the installation of traffic safety features can prevent crashes and reduce injury severity.

Table 2. 2006 U.S. Traffic Crash Costs (in Billions of 2006 Dollars)

Cost Category	Crashes Where Road Conditions Contributed to Crash Frequency or Severity	% of All Crashes	All Crashes
Medical Costs	20.2	40.5%	49.9
Emergency Services	0.7	41.5%	1.8
Market Productivity	35.0	45.1%	77.5
Household Productivity	11.5	44.7%	25.7
Workplace Costs	2.7	45.8%	5.8
Insurance Administration	7.0	42.6%	16.5
Legal Costs	5.8	41.4%	13.9
Travel Delay	11.0	40.5%	27.2
Property Damage	24.7	34.9%	70.7
Economic Cost	*118.5*	*41.0%*	*289.1*
Quality of Life Loss	98.9	47.2%	209.8
Comprehensive Cost	*217.5*	*43.6%*	*498.8*

The large share of crash costs related to road conditions underlines the importance of these factors in highway safety. A focus on road improvement is consistent with the philosophy of Vision Zero (Tingvall and Haworth 1999). Although driver factors are involved in most crashes, avoiding those crashes through driver improvement requires reaching millions of individuals and getting them to sustain best safety practices. That is not fail-safe. It is far more practical to make the environment more forgiving and protective.

Numerous solutions—some simple, some complex—could help make the roadway environment safer for users. These improvements include structural changes such as adding or widening shoulders, improving roadway alignment, replacing or widening narrow bridges, reducing pavement edges or drop offs, and providing more clear space in the area adjacent to roadways (Mahoney et al, 2006). Cost-effective, immediate solutions include using brighter, more durable pavement markings, installing better signage with easier-to-read legends, adding rumble strips, and using more guardrail or barrier where appropriate (Mattox et al, 2007).

Road-related crashes represented more than 40% of governments' and employers' traffic crash bills in 2006. Government paid an estimated $12.3 billion and employers paid $22.3 billion for these crashes (Tables 3 and 4, page 14).

Figures 2 (page 15) and 3 (page 16) show the ranking of states by road-related crash costs per vehicle mile of travel and per mile of road. Since this report is concerned with relative road safety, not differences between states in medical prices and wages, the ranking was done before adjusting costs from national averages to state-specific prices. Table 5 presents costs by state. Those costs use state-specific prices.

Mahoney, Kevin M; Julian, Frank; Taylor, Harry W., Jr. 2006, "Good Practices: Incorporating Safety into Resurfacing and Restoration Projects" Report No. FHWA-SA-07-001: U.S. Federal Highway Administration.

Mattox, James H; Sarasua, Wayne A; Ogle, Jennifer H; Eckenrode, Ryan T; Dunning, Anne 2007 "Maintenance Operations: Work Zones, Pavement Markings and Weather" Journal of the Transportation Research Board, No. 2015.

Table 3. 2006 Government Traffic Crash Costs (in Millions of 2006 Dollars)

Cost category	Crashes Where Road Conditions Contributed to Crash Frequency or Severity	%	All Crashes
Total Government Cost	*12,279*	*42.9%*	*28,600*
Medical Costs	4,881	40.5%	12,060
Emergency Services	585	41.5%	1,409
Market Productivity	6,733	45.1%	14,936
Legal Costs	81	41.4%	195

Table 4. 2006 Employer Traffic Crash Costs (in Millions of 2006 Dollars)

Cost category	Crashes Where Road Conditions Contributed to Crash Frequency or Severity	%	All Crashes
Total Employer Cost	*22,324*	*40.3%*	*55,336*
Health Fringe Benefit Costs	*9,973*	*39.9%*	*24,993*
Workers' Compensation	1,267	40.1%	3,157
-Medical	333	39.6%	843
-Disability	950	41.1%	2,314
Health Insurance	4,373	39.7%	11,018
Disability Insurance	477	38.9%	1,226
Life Insurance	367	39.2%	935
Insurance Administration	601	40.0%	1,502
Insurance Overhead	215	40.1%	536
Social Security	920	40.3%	2,283
Sick Leave	1,754	40.4%	4,337
Non-Fringe Costs	*12,351*	*40.7%*	*30,343*

States with the worst road-related crash problems primarily are in the Southeastern United States. Louisiana, South Carolina, and Tennessee rank in the highest cost quintile in terms of both costs per vehicle mile of travel and per mile of road. Alabama, Georgia, Kentucky, Mississippi, North Carolina, Pennsylvania, and West Virginia also have above-average road-related crash costs. The states with the most favorable road-related crash experience are largely Mid-western. They include Colorado, Iowa, Michigan, Minnesota, Nebraska, North Dakota, Texas, Utah, Washington, and Wisconsin. Idaho, Wyoming, Montana, and South Dakota also have low costs per road mile, but that ranking results from the sparse traffic on these roadways. Per vehicle mile traveled, these states rank poorly. Conversely, Hawaii, California, and the eastern seaboard from Virginia to Massachusetts rank poorly in terms of cost per mile of road, but that poor ranking largely results from traffic density. When the exposure measure is vehicle miles traveled instead of miles of roads, they rank much better.

Figure 2: Ranking of States By Road-Related Crash Costs Per Million Vehicle Miles of Travel (With All Costing Done Using U.S. Prices)

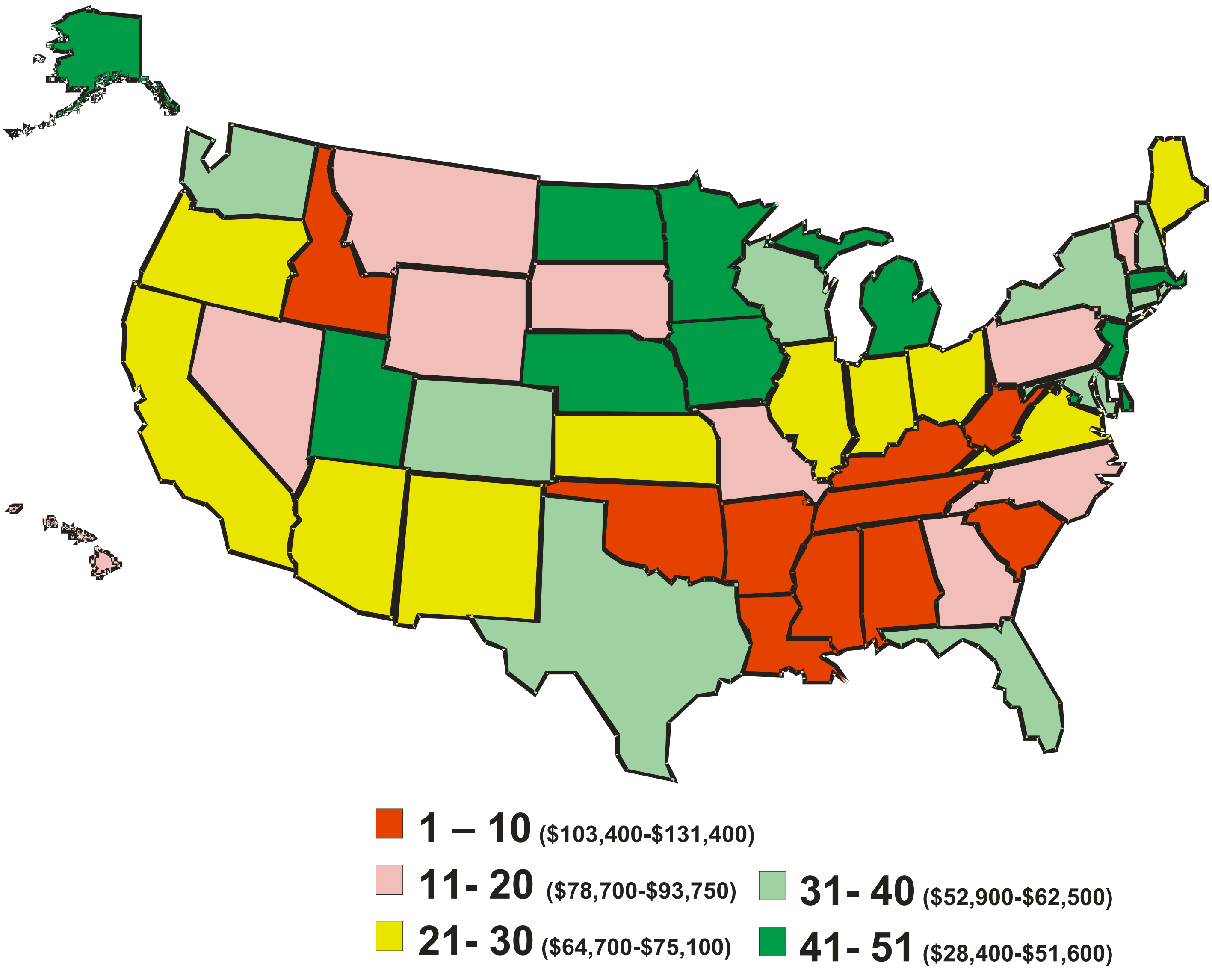


Figure 3: Ranking of States By Road-Related Crash Costs Per Mile of Roadway (With All Costing Done Using U.S. Prices)

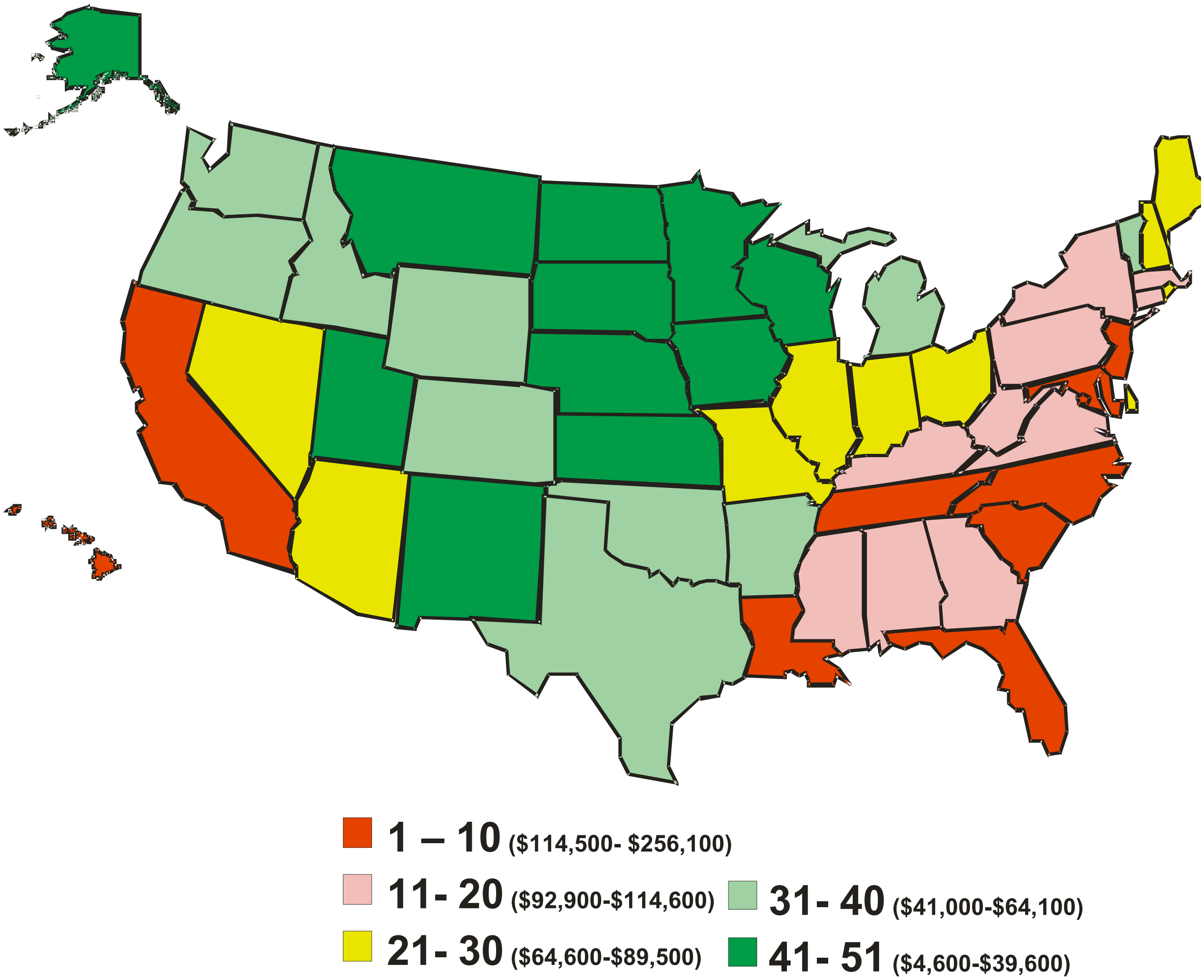


Table 5. Costs of Crashes Where Road Conditions Contributed to Crash Frequency or Severity by State, 2006, in Millions of Dollars Unless Otherwise Indicated

State	Medical Costs	Productivity Loss	Quality of Life Loss	Other Costs	Comprehensive Cost	Comprehensive Cost Per Million Vehicle-Miles (2006 Dollars)	Comprehensive Cost Per Mile of Road (2006 Dollars)
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(Continued on page 18)

Table 5. Costs of Crashes Where Road Conditions Contributed to Crash Frequency or Severity by State, 2006, in Millions of Dollars Unless Otherwise Indicated

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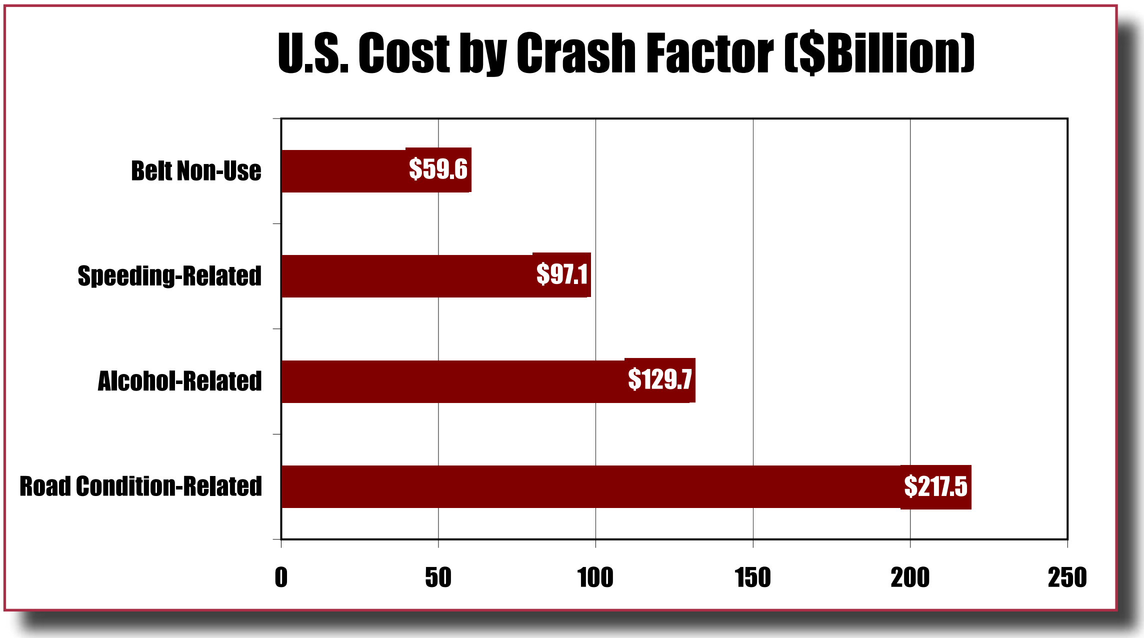
North Carolina	807	1,823	3,912	2,033	8,575	84,656	108,203
North Dakota	24	65	138	71	297	37,715	4,176
Ohio	635	1,361	3,191	1,590	6,776	61,048	71,780
Oklahoma	408	924	2,042	1,068	4,442	91,439	54,136
Oregon	261	496	1,167	570	2,494	70,429	59,424
Pennsylvania	874	2.324	4,671	2,545	10,415	96,402	111,869
Rhode Island	46	100	254	130	530	63,947	104,459
South Carolina	522	1,130	2,675	1,318	5,645	112,704	119,374
South Dakota	64	153	332	168	717	78,406	11,689
Tennessee	700	1,650	3,295	1,805	7,449	105,753	109,761
Texas	1,281	2,953	5,769	3,166	13,169	55,394	59,083
Utah	57	134	320	139	649	25,066	19,470
Vermont	68	133	316	176	693	88,650	66,352
Virginia	472	1,345	2,400	1,363	5,581	68,972	104,983
Washington	327	724	1,428	773	3,252	57,665	53,438
West Virginia	206	431	1,017	519	2,174	104,320	83,428
Wisconsin	317	741	1,453	777	3,288	55,484	38,268
Wyoming	77	187	353	213	829	88,246	61,028

* Comparisons between states are discouraged. Prices vary between states. For example, medical care costs more in New York than in Wyoming. Furthermore, the state estimates are based on fatality patterns. Thus, rather than resulting from differing safety levels, differences between states may result from differences in prices or in the proportion of crashes that are fatal.

Figure 4 compares crash costs for selected factors that might have contributed to crash frequency or severity in 2006. The cost of crashes where road conditions were a factor greatly exceeds the costs of crashes where alcohol or speeding was involved, or the cost of belt non-use. (See Tables A-5 through A-10, pages 30-32 for details.) The relative magnitudes of these costs were stable between 2000 and 2006.



Note: In some crashes, more than one of the factors contributed to crash frequency or severity. The costs of these crashes were counted in both categories. The estimates in this figure cannot be summed. In aggregate they exceed the portion of costs that represent the combined factors.

Independently of the probability assigned by the statistical model used, crashes were assumed to be road-related if an occupant was moderately to fatally injured in a vehicle that harmfully impacted a large tree or medium or large non-breakaway pole, or if the first harmful event was collision with a bridge. In these crashes, road-related factors often worsened crash severity but may not have contributed to crash causation. Dropping this reclassification would yield a comprehensive cost of $138.2 billion for crashes where road conditions were a contributing factor in 2006 (Tables A11-A12, page 33). Crashes where road-related factors were assumed to raise injury severity but did not contribute to the crash cost an additional $79.3 billion.

Although this study did not break costs out by class of roads, interstate highways are built to higher safety standards than other roads. Prior studies showed that rural collectors, urban arterials, and local streets had the highest crash costs per vehicle mile of travel while interstate highways had the lowest (Miller et al., 1991). Moreover, rural crashes were more severe and costly than urban ones.

Police crash reports differ between states and jurisdictions and often do not include check boxes for road-related factors contributing to the crash. Increased standardization and enriched infrastructure coding would provide more robust data for use in judging crash causation.

Annex

Annex

METHODS

Crash Costs

Modeling crash costs requires estimates of the number of people involved in a crash, the medical details of each person's injuries (ideally, body part injured, nature of the injury, and injury severity, e.g,, skull fracture not resulting in loss of consciousness), and the costs of those injuries and associated vehicle damage and travel delay. No data system that contains a nationally representative sample of recent U.S. non-fatal crash injuries records both crash type and medical descriptions of the injuries. The National Highway Traffic Safety Administration (NHTSA) last collected data containing medical descriptions of injuries for a representative sample of all police-reported U.S. motor vehicle injury victims in 1984–1986.

In 1988, NHTSA's National Accident Sampling System (NASS) was replaced by two ongoing sampling systems. The Crashworthiness Data System (CDS) collects data similar to NASS, but focuses on crashes involving automobiles and automobile derivatives, light trucks and vans with gross vehicle weight less than 10 000 pounds (4 537 kg) that are towed due to damage, and excludes pedestrian and non-motorist records. The General Estimates System (GES) collects data on a representative sample of all police-reported crashes, but the only injury description it gives is the severity that a police officer assigns in the police accident report. GES, like the police reports, uses the KABCO severity scale (National Safety Council, 1990) to classify crash victims as K-killed, A-disabling injury, B-evident injury, C-possible injury, or O-no apparent injury. The codes are selected by police officers without medical training, typically without benefit of a hands-on examination, and is not accurate or reproducible (Zaloshnja et al., 2006).

This study uses NHTSA's standard procedures (see, e.g., Blincoe et al. 2002) to derive a nationally representative crash data set from the NASS, CDS, and GES data. Specifically, we rely on 2006 CDS and for non-CDS strata, on 1984-1986 NASS data reweighted using 2006 GES data to account for current belt use and alcohol involvement. This procedure assumes that particular crash types generate typical profiles of injury outcomes that are stable over time, an assumption that Australian research supports (Andreassen, 1986).

The weights on fatal crashes in both CDS and non-CDS strata also were adjusted so that the weighted counts by strata, police reported alcohol involvement, and belt use matched the fatal crash victim counts (a 100% census) in NHTSA's Fatality Analysis Reporting System (FARS). Finally, following Blincoe et al. (2002), the weights in the hybrid CDS/NASS/GES/FARS file were inflated with inflators by Abbreviated Injury Score (AIS). These inflators account for unreported crashes and the under-sampling of injuries. The adjusted file became our study's incidence file.

The methods described in Blincoe et al. (2002) were followed to estimate comprehensive costs for fatalities. Injury costs from Zaloshnja et al. (2004) were adopted for the rest.[1] The latter reports comprehensive costs per victim in 2000 dollars by body part, whether or not a fracture was involved, and AIS (for both AIS85 and AIS90). We updated the costs to 2006 dollars and merged them onto the hybrid CDS/NASS/GES/FARS file. Comprehensive costs represent the present value, computed at a 4% discount rate, of all costs that result from a crash over the victim's expected life span. We chose this discount rate for consistency with NHTSA's crash costs. We included the following major categories of costs: medically related, emergency services, property damage, lost productivity (market and household work), travel delays, and the monetized value of pain, suffering, and lost quality of life. Together, the literature calls these comprehensive costs. Economic costs exclude the last item.

National Cost of Crashes Where Road Conditions Contributed to Crash Frequency or Severity

The CDS, NASS, GES and FARS files do not provide detailed information whether road conditions contributed to the crash. Only the 2001-03 Large Truck Crash Causation Study (LTCCS) provides such detailed information. Therefore, LTCCS data were used to model the probability that road conditions contributed to the involvement of a vehicle in the crash. The model used was a logistic regression model, where the crash was considered related to road conditions if one of the following factors was present: 1 - traffic control device not functioning, 2 - congestion, 3 - traffic density, 4 - insufficient crown (the final layer of asphalt or concrete on a road surface that raises low spots, promotes good drainage of water off the road, and improves the smoothness of ride quality), 5 - excessive crown (making it possible to fall off the edge of the road), 6 - insufficient super-elevation (the extra height on the outside edge of a lane on a curve that counters the vehicle's centrifugal force and helps the vehicle to stay on the road), 7 - excessive super-elevation, 8 - excessive curvature (the tightness of a spiral that changes the direction of a road), 9 - surface defect, 10 - signs missing, 11 - object obscured, 12 - vehicle obscured, 13 - bad road geometry, 14 - insufficient sight, 15 - bad lane marking, 16 - narrow shoulders, 17 - narrow road, 18 - ramp speed, 19 - poor road condition, 20 - icy conditions, 21 - road under water, 22 - road washed out.

The following explanatory variables were included in the model: 1- maximum injury severity in the vehicle (fatal, AIS-4-5, AIS3, AIS2, AIS-1 vs. no injury), 2 - reported driver alcohol use, 3 - driver gender, 4 - driver age (under 21 years old vs. older driver), 5 - time of crash (night, dawn/dusk, vs. day), 6 - reported speeding (5-10 MPH over the limit, 10-20, more than 20, speeding unknown amount, vs. no speeding), 7 - speed limit (up to 44 MPH vs. 45 MPH and over), 8 - type of road (divided highway with no barrier, divided highway with barrier, one-way road vs. other), 9 - relation to juncture (intersection, interchange, other juncture, driveway vs. no juncture), 10 - type of collision (rear-end, head-on, angle, sideswipe same direction, sideswipe opposite direction, collision with shrubbery/embankment, small tree/breakaway pole/ditch/culvert/fire hydrant, fence/wall/building, traffic barrier, curb vs. other). The logistic regression results were applied to the costed CDS/NASS/GES/FARS file in order to calculate the probability that road conditions contributed to the involvement of a vehicle in each crash.

Table A-1 (page 23) presents the parameters of the LTCCS logistic regression equation we used to estimate the probability that road conditions contributed to the involvement of a vehicle in the crash. Testing the association of predicted probabilities and observed responses showed that 77.2% of compared pairs of predicted probabilities and actual outcomes for any full percentage point cut-off level were concordant, 22.2% discordant, and 0.6% tied.

[1]On February 5, 2008, Office of the Secretary of Transportation (OST) recommended an estimate of the economic value of preventing a human fatality at $5.8 million, in 2007 dollars. NHTSA's latest crash costs, however, were based on OST's previously recommended, much lower value of life. In this study the NHTSA's value (Blincoe et al. 2002) was used. To roughly incorporate the updated value of life into quality of life loss estimates used here, multiply them by a factor of 4.69/2.82.

Table A-1. Logistic Regression Results from the LTCCS

Parameter	Estimate	Standard Error	Chi-Square Statistic	P-Value
Intercept	-0.90	0.25	13.42	0.000
Fatal Injury in Vehicle	-0.19	0.19	0.97	0.324
AIS 4-5 Injury in Vehicle	-0.40	0.34	1.39	0.239
AIS 3 Injury in Vehicle	-0.32	0.25	1.69	0.194
AIS 2 Injury in Vehicle	-0.05	0.20	0.06	0.805
AIS 1 Injury in Vehicle	-0.01	0.12	0.00	0.957
Reported Alcohol Use by Driver	-0.55	0.32	2.92	0.088
Male Driver	-0.14	0.13	1.05	0.305
Driver's Age Under 21	-0.12	0.22	0.29	0.591
Night	0.10	0.13	0.66	0.416
Dawn/Dusk	0.79	0.22	12.75	0.000
Speeding 5-10 MPH	0.59	0.37	2.51	0.113
Speeding 11-20 MPH	-0.26	0.53	0.24	0.624
Speeding Over 20 MPH	-0.59	0.59	0.99	0.321
Speeding Unknown	0.17	0.11	2.49	0.115
Speed Limit Over 44 MPH	-0.13	0.13	0.96	0.327
Divided Highway, No Barrier	-0.02	0.16	0.01	0.921
Divided Highway with Barrier	0.43	0.15	8.49	0.004
One-Way Street	0.44	0.24	3.30	0.070
Intersection	-0.73	0.17	18.56	<.0001
Interchange	-0.07	0.19	0.12	0.726
Other Juncture	0.53	0.17	9.34	0.002

(Continued on page 24)

Table A-1. Logistic Regression Results from the LTCCS

Driveway	-0.50	0.32	2.40	0.122
Rear-End Collision	0.15	0.15	1.03	0.309
Head-On Collision	0.09	0.23	0.16	0.686
Angle Collision	-0.28	0.15	3.66	0.056
Sideswipe Same Direction	0.05	0.24	0.04	0.832
Sideswipe Opposite Direction	-1.29	0.64	4.11	0.043
Collision with Shrubbery/Embankment	-0.52	0.52	1.02	0.313
Collision with Small Tree/ Breakaway Pole/Ditch/ Culvert/Firehydrant	0.08	0.29	0.07	0.785
Collision with Fence/Wall/Building	-0.23	0.35	0.41	0.522
Collision with Traffic Barrier	0.10	0.15	0.43	0.512
Collision with Curb	-1.65	0.77	4.59	0.032

Sometimes road conditions make crash injuries more severe even if they do not cause the crash. Those crashes are road-related. Therefore, in crashes where someone was moderately to seriously injured (AIS-2-6) in a vehicle that harmfully impacted a large tree or medium or large non-breakaway pole, or if the first harmful event was collision with a bridge, the calculated probability of being road-related was changed to 1. The rationale for this was that on an ideal road, all medium/large poles should be breakaway or behind railings that keep drivers from impacting them and trees should be cleared from the roadside or guarded by railings.

Even if these events do not cause the crash, their involvement greatly elevates the chance that the crash will result in moderate to fatal injury. It was also assumed that if the first harmful event was collision with a bridge, a wider or better-designed bridge might have prevented the crash.

As Table A-2 (page 25) shows, the relative risk that an occupant of a vehicle involved in a towaway crash will be moderately to fatally injured is high if the crash involves the targeted scenarios (The relative risk is calculated by dividing the percentage for each AIS level by the percentage for AIS-0). Indeed, more than 40% of vehicles with severely to fatally injured occupants experience these harmful events.

Table A-2. Percentage of Vehicles in Towaway Crashes that Made Contact with a Bridge as a First Harmful Event or Made Harmful Contact with a Large Tree or a Medium or Large Non-Breakaway Pole and Relative Risk of Injury of the Specified Severity in the Vehicle if Such Contact Occurred, 2006

MAIS	% Involved	Relative Risk
0: No Injuries	10.62	1.00
1: Minor	18.95	1.78
2: Moderate	31.24	2.94
3: Serious	40.53	3.82
4: Severe	40.23	3.79
5: Critical	36.40	3.43
6: Fatal*	46.58	4.39

**All fatalities were recoded to MAIS*

Not all crashes into bridges were reclassified as road-related because any crash on a bridge is likely to cause a vehicle to strike the bridge, even if lanes are of adequate width and the bridge structure is built to attenuate the impact while preventing the vehicle from going over the edge. Similarly, when vehicles struck an impact attenuator or median barrier, the crash was only treated as road-related if the regression predicted that it was. In the remaining cases, that roadside furniture is designed to be struck and safely absorb crash severity; it reduces severity.

The adjusted probability of road-relatedness for each case, multiplied by the case's weight, served as its weight when computing the incidence and costs of crashes where road conditions contributed to crash frequency or severity. The same procedures were used to estimate the incidence and costs of crashes where road conditions contributed to crash frequency or severity in year 2000, in order to provide a comparison with year 2006.

State Costs of Crashes Where Road Conditions Contributed to Crash Frequency or Severity

The CDS, NASS, and GES, being national samples, cannot be used for state specific analysis. On the other hand, FARS is a census of fatal crashes. Therefore, after applying the regression to compute the probability that each fatal crash was road-related, we estimated the cost distribution by state and cost category of fatal crashes where road conditions contributed to crash frequency or severity. We then applied the state proportions for fatalities to all crashes. To cost the FARS file, we calculated in the costed CDS/NASS/GES/FARS file the costs per person in fatal crashes by KABCO, reported belt use and alcohol use, and merged them onto FARS. All costs were adjusted to state-specific prices using ACCRA price adjusters and per capita income adjusters drawn from the United States Statistical Abstract.

For each state, we estimated the comprehensive costs per million vehicle-miles and per mile of road with information from "Highway Statistics 2006" (Federal Highway Administration, 2007).

Crash Costs Paid by Employers and Government

Employers pay for injuries that employees suffer on and off the job, as well as off-the-job injuries to their benefit-eligible dependents. They also pay for harm caused to non-employees involved in commercial motor vehicle crashes (crashes involving a vehicle on employer business). Zaloshnja and Miller (2006) estimated employer costs of traffic crashes for year 2000; Blincoe et al. (2002) estimated the overall economic costs of traffic crashes for the same year. The ratios from the estimates of these two studies were used to calculate what portion of the 2006 traffic crash costs was paid by employers.

Federal, state, and local governments, also pay a portion of traffic crash costs such as medical costs, emergency services, market productivity, and legal costs. Factors developed by Blincoe et al. (2002) to estimate what portion of the traffic crash costs were paid by government were used in this study.

U.S. Costs of Alcohol-Related and Speeding-Related Crashes

Blincoe et al. (2002) found that police reports correctly identify only 74 percent of all alcohol involved cases where BAC levels equal or exceed 0.10, and 46 percent of all cases where BAC levels are positive, but less than 0.10. It provides adjusting factors by MAIS, to account for police underreporting. Those factors were used to adjust the GES and CDS weights of cases that were reported by police as alcohol-involved. Then, using these adjusted weights, the incidence and costs of alcohol-involved crashes were estimated for years 2000 and 2006.

The 1986 NASS file is the latest crash file that contains adequate speed information stratified by MAIS level for all crash types. In the 2006 CDS, 61% of cases have missing values for reported travel speed. Therefore, the methods in Blincoe et al. (2002) were used to estimate speeding incidence and costs. That report compared rates of speed involvement for 1985 and 1986 for each severity level (from NASS) to rate for fatalities (from FARS) to determine a relative speed involvement factor for each severity level. These factors were adjusted based on the speed involvement rate for fatalities currently versus in 1985-1986 to determine the rate of involvement for each nonfatal severity category.

U.S. Costs of Belt Non-Use

Following methods in Zaloshnja and Miller (2006), the cost of belt non-use was estimated as a difference between the actual cost and the hypothetical cost of crashes in the case that all vehicle occupants were restrained. These hypothetical costs were calculated by applying mean costs of restrained occupants by age group and gender to unrestrained occupants and to occupants for which restraint use was unknown. Property damage was kept constant because it is not affected by restraint use.

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Supplemental Tables

Supplemental Tables

Table A-3. 2000 Traffic Crash Incidence

	No. of Crashes	%	No. of Non-Fatally Injured People	%	No. of Killed People	%
All Crashes	16,352,041	100%	5,309,288	100%	41,821	100%
Crashes Where Road Conditions Contributed to Crash Frequency or Severity	5,101,222	31.2%	2,001,284	37.7%	21,856	52.3%

Table A-4. 2000 Traffic Crash Costs (in Billions of 2006 Dollars)

Cost Categories	Crashes Where Road Conditions Contributed to Crash Frequency or Severity	%	All Crashes
Medical Costs	19.1	40.1%	47.5
Emergency Services	0.7	41.1%	1.7
Market Productivity	33.7	44.7%	75.3
Household Productivity	11.0	44.2%	24.9
Workplace Costs	2.5	45.5%	5.5
Insurance Administration	6.3	40.7%	15.6
Legal Costs	5.3	41.0%	13.0
Travel Delay	10.5	40.0%	26.2
Property Damage	23.7	34.2%	69.1
Economic Cost	*112.8*	*40.4%*	*278.8*
Quality of Life Loss	94.9	46.8%	202.9
Comprehensive Cost	*207.6*	*43.1%*	*481.7*

Table A-5. 2006 Cost of Alcohol-Related Crashes (in Billions of 2006 dollars)

Cost Category	Alcohol-Related	%
Medical Costs	11.7	23.4%
Emergency Services	0.2	12.0%
Market Productivity	26.6	34.3%
Household Productivity	8.3	32.3%
Workplace Costs	0.9	16.1%
Insurance Administration	4.0	24.2%
Legal Costs	4.4	31.7%
Travel Delay	3.1	11.4%
Property Damage	7.2	10.2%
Economic Cost	*66.4*	*23.0%*
Quality of Life Loss	63.3	30.2%
Comprehensive Cost	*129.7*	*26.0%*

Table A-6. 2000 Cost of Alcohol-Related Crashes (in Billions of 2006 Dollars)

Cost Category	Alcohol-Related	%
Medical Costs	10.6	22.4%
Emergency Services	0.2	11.3%
Market Productivity	24.8	32.9%
Household Productivity	7.9	31.8%
Workplace Costs	0.9	15.7%
Insurance Administration	3.6	23.0%
Legal Costs	4.1	31.2%
Travel Delay	3.1	12.0%
Property Damage	6.8	9.8%
Economic Cost	*61.9*	*22.2%*
Quality of Life Loss	60.4	29.8%
Comprehensive Cost	*122.3*	*25.4%*

Table A-7. 2006 Cost of Speeding-Related Crashes (in Billions of 2006 Dollars)

Cost Category	Speeding-Related	%
Medical Costs	8.0	16.0%
Emergency Services	0.2	12.7%
Market Productivity	17.9	23.1%
Household Productivity	5.5	21.3%
Workplace Costs	0.8	13.8%
Insurance Administration	2.9	17.4%
Legal Costs	3.1	22.4%
Travel Delay	3.3	12.1%
Property Damage	11.6	16.5%
Economic Cost	*53.3*	*18.4%*
Quality of Life Loss	43.7	20.9%
Comprehensive Cost	*97.1*	*19.5%*

Table A-8. 2000 Cost of Speeding-Related Crashes (in Billions of 2006 Dollars)

Cost Category	Speeding-Related	%
Medical Costs	7.5	15.8%
Emergency Services	0.2	12.1%
Market Productivity	16.3	21.7%
Household Productivity	5.1	20.6%
Workplace Costs	0.6	10.3%
Insurance Administration	2.7	17.6%
Legal Costs	2.7	20.7%
Travel Delay	2.7	10.2%
Property Damage	10.9	15.7%
Economic Cost	*48.7*	*17.5%*
Quality of Life Loss	40.2	19.8%
Comprehensive Cost	*88.9*	*18.5%*

Table A-9. 2006 Cost of Belt Non-Use (in Billions of 2006 Dollars)

Cost Category	Cost of Belt Non-Use	%
Medical Costs	6.6	13.3%
Emergency Services	0.2	11.9%
Market Productivity	11.7	15.1%
Household Productivity	3.8	14.8%
Workplace Costs	0.7	11.9%
Insurance Administration	1.9	11.7%
Legal Costs	1.9	13.3%
Travel Delay	3.2	11.8%
Property Damage	-	0.0%
Economic Cost	*30.1*	*10.4%*
Quality of Life Loss	29.5	14.0%
Comprehensive Cost	*59.6*	*11.9%*

Table A-10. 2000 Cost of Belt Non-Use (in Billions of 2006 Dollars)

Cost Category	Cost of Belt Non-Use	%
Medical Costs	6.9	14.5%
Emergency Services	0.2	12.8%
Market Productivity	12.2	16.2%
Household Productivity	3.9	15.9%
Workplace Costs	0.7	13.0%
Insurance Administration	2.0	12.9%
Legal Costs	1.9	14.8%
Travel Delay	3.4	12.8%
Property Damage	-	0.0%
Economic Cost	*31.3*	*11.2%*
Quality of Life Loss	30.6	15.1%
Comprehensive Cost	*61.9*	*12.9%*

Table A-11. 2006 Road-Related Crash Incidence—No Adjustment for Tree, Pole, or Bridge Involvement

	No. of Crashes	%	No. of Non-Fatally Injured People	%	No. of Killed People	%
All Crashes	16,954,351	100%	5,746,231	100%	42,642	100%
Crashes Where Road Conditions Contributed to Crash Frequency or Severity	4,612,134	27.2%	1,921,134	33.4%	8,144	19.1%

Table A-12. 2006 Traffic Crash Costs (in Billions of 2006 Dollars)—No Adjustment for Tree, Pole, or Bridge Involvement

Cost Category	Crashes in Which Road Conditions Contributed to Crash Frequency or Severity	%
Medical Costs	14.6	29.3%
Emergncy Services	0.5	30.9%
Market Productivity	24.3	31.3%
Household Productivity	7.9	30.8%
Workplace Costs	1.7	29.2%
Insurance Administration	5.0	30.4%
Legal Costs	4.0	28.5%
Travel Delay	7.9	29.0%
Property Damage	20.5	28.9%
Economic Cost	*86.4*	*29.9%*
Quality of Life Loss	51.8	24.7%
Societal Cost	*138.2*	*27.7%*

Index of Charts, Figures & Tables


ROAD CLOSED
TO
THRU TRAFFIC
DETOUR