Vol 53 • *October 2009*

COST OF CRASHES RELATED TO ROAD CONDITIONS, UNITED STATES, 2006

Eduard Zaloshnja, Ph.D.
Ted R. Miller, Ph.D.
Pacific Institute for Research and Evaluation, Calverton, Maryland

ABSTRACT – This is the first study to estimate the cost of crashes related to road conditions in the U.S. To model the probability that road conditions contributed to the involvement of a vehicle in the crash, we used 2000-03 Large Truck Crash Causation Study (LTCCS) data, the only dataset that provides detailed information whether road conditions contributed to crash occurrence. We applied the logistic regression results to a costed national crash dataset in order to calculate the probability that road conditions contributed to the involvement of a vehicle in each crash. 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, we changed the calculated probability of being road-related to 1. We used the state distribution of costs of fatal crashes where road conditions contributed to crash occurrence or severity to estimate the respective state distribution of non-fatal crash costs. The estimated comprehensive cost of traffic crashes where road conditions contributed to crash occurrence or severity was $217.5 billion in 2006. This represented 43.6% of the total comprehensive crash cost. The large share of crash costs related to road design and conditions underlines the importance of these factors in highway safety. Road conditions are largely controllable. Road maintenance and upgrading can prevent crashes and reduce injury severity.

INTRODUCTION

This study analyzes the U.S. national and state-specific costs of crashes where road conditions contributed to crash frequency or severity and the portion of those costs paid by employers and government. It compares these costs with the costs of alcohol-related and speeding-related crashes and the costs of belt non-use.

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. A change in driver behavior, vehicle capabilities, or roadway characteristics and conditions might have averted a crash or reduced the severity of associated occupant injuries.

Poorly maintained or designed roads, or the congestion caused by insufficient road networks are road conditions that can contribute to both the frequency and severity of motor vehicle crashes. The famed Indiana Tri-Level Study (Treat, 1980) analyzed pre-crash factors involved in traffic crashes, but deliberately focused more on human errors rather than the environment. Viano and Ridella (1991) analyzed fatal crashes of lap-shoulder belted occupants and found that in 30% of such crashes, drivers could do nothing to avoid them. However, it did not identify crashes where road conditions contributed to the crash. Similarly, Lestina and Miller (1994) 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. Viner (1991) analyzed first and most harmful events in traffic crashes but did not investigate whether these events caused the crashes. Finally, the Federal Motor Carrier Safety Administration developed a data set on large truck crash causation in 2001-2003 (Federal Motor Carrier Safety Administration 2005). The study found that 20% of heavy truck crashes were caused in part by roadway conditions. However, these factors raised crash risk less than virtually any driver-related or vehicle-related factor (Craft 2007).

METHODS

Crash Costs

Computing 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 (i.e. KABCO). 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 crashes not captured by CDS, 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).

We also adjusted the sampling weights on fatal crashes in both CDS and non-CDS strata 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), we inflated weights in the hybrid CDS/NASS/GES/FARS file 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.

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.

We followed the methods described in Blincoe et al. (2002) to estimate comprehensive costs for fatalities and we adopted injury costs from Zaloshnja et al. (2004) for the rest. 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.

Blincoe et al. (2002) and Zaloshnja et al.'s (2004) medical cost estimates drew on data from 1992–1994 Civilian Health and Medical Program of the Uniformed Services (CHAMPUS) data for physician and emergency department fees, 1994–95 data on hospital costs in MD and NY (the only two states where costs were known), and 1987 National Medical Expenditure Survey (NMES) and 1979–1987 National Council on Compensation Insurance (NCCI) data on the percentage of costs that occur more than 6 months post injury.

Blincoe et al. (2002) and Zaloshnja et al. (2004) based short-term productivity loss on information from the CDS 1988–1991(for AIS85) and CDS 1993–1999 (for AIS90) about the probability an employed person would lose work for a specific injury and the 1993 Survey of Occupational Injury and Illness (SOII) of the U.S. Bureau of Labor Statistics on the days of work lost per person who lost work. Mean probabilities of work loss were estimated from just those CDS records that had the relevant information, which frequently was missing. Sample size considerations drove the decision to pool several years of CDS data. Long-term productivity loss by diagnosis was based on 1979–1987 NCCI Detailed Claims Information (DCI) data on the probability that injuries would cause permanent partial/total disability and 1997 DCI data on the percentage loss of earning power for partially disabled injury victims.

Blincoe et al. (2002) and Zaloshnja et al. (2004) included a variety of other direct costs. Among them were emergency services, property damage, travel delay, insurance claims administration, legal and court costs, and workplace disruption costs. These estimates used insurance data, recent data on travel delay that crashes cause motorists whose vehicles did not crash, and data from prior NHTSA studies.

Blincoe et al. (2002) and Zaloshnja et al. (2004) based quality of life loss on physicians' estimates of the functional capacity lost over time by injury diagnosis and a systematic review of the survey literature on the loss in value of life that results from different functional losses. These losses were costed based on meta-analyses (Miller 1990; Miller 2000; and Viscusi and Aldy, 2003) examining what people pay for small changes in fatality risk and surveys on what they state they are willing to pay.[*]

National cost of crashes where road conditions contributed to crash frequency or severity

The CDS, NASS, GES and FARS files provide some information on road conditions (like presence/absence of traffic controls, poor road condition, surface conditions etc). However, they do not indicate if the presence of such factors contributed to the crash. The only recent database that identifies crash contributors is the 2001-03 Large Truck Crash Causation Study (LTCCS). Therefore, we used LTCCS data to model the probability that road conditions contributed to the involvement of a vehicle in the crash. The model we used was a logistic regression model, where the crash was considered related to road conditions (the dependent variable) if one of the following factors contributed to the crash: 1 - traffic control device not functioning, 2 - congestion, 3 - traffic density, 4 – insufficient crown, 5 - excessive crown, 6 - insufficient super-elevation, 7 - excessive super-elevation, 8 – excessive curvature, 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.

To control for road, crash, and driver type, we included the following explanatory variables 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). Given that this model was intended for predictive rather than explanatory purposes, we kept all the hypothesized explanatory variables regardless of their statistical insignificance.

We applied the logistic regression results 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 1 compares crash profiles in CDS/NASS/GES/FARS and LTCCS. Large truck crashes are similar to all crashes – although large truck drivers are less likely to strike parked cars, pedestrians, and pedalcyclists or to incur serious damage when crashing into an animal. The regression variables for type of road, relation to juncture, and type of collision assure that the differences observed do not skew attribution of causation for all crashes from large truck crashes.

Table 1 - Crash Profiles in CDS/NASS/GES/FARS and LTCCS Files

Crash type	CDS/NASS/ GES/FARS (%)	LTCCS (%)
Angle	27.3	35.1
Rear-end	30.4	30.4
Sideswipe	8.2	8.2
Head-on	2.4	6.6
Fixed object	15.5	14.6
Parked motor vehicle	5.5	0.6
Animal	4.8	2.6
Pedestrian/Pedalcyclist	1.8	0.5
Non-collision	3.3	0.8
Other/Unknown	0.7	0.6
Total	100.0	100.0

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-

---

[*] 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. We used NHTSA's value (Blincoe et al. 2002). To roughly incorporate the updated value of life into our quality of life loss estimates, multiply them by a factor of 4.69/2.82.

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, we changed the calculated probability of being road-related to 1. Our rationale 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. We 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 2 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.

We did not reclassify all crashes into bridges 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, we only treated the crash as road-related if the regression predicted that it was. The adjusted probability of road-relatedness for each case, multiplied by the case's weight, served as its weight when computing the incidence of crashes where road conditions contributed to crash frequency or severity.

Table 2 - Percentage of Vehicles in Towaway Crashes That First Contacted a Bridge or Harmfully Contacted a Large Tree or Medium or Large Non-Breakaway Pole and Relative Risk of Injury in the Vehicle by MAIS 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-6

The same weights were used when calculating crash costs - i.e., a $1,000 crash that had a 50% probability of being related to road conditions would add $500 to the road-related costs.

State costs of crashes where road conditions contributed to crash frequency or severity

The CDS, NASS, and GES are national samples and cannot be used for state specific analysis. On the other hand, FARS, being a census of fatal crashes, is the only source of uniformly measured crash data at the state level. Therefore, we used it to estimate the distribution of all crash costs by state. 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 medical care, general price, 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 employees' 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. We used the ratios from the estimates of these two studies 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. We used factors developed by Blincoe et al. (2002) to estimate what portion of the traffic crash costs were paid by government.

US 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. We used those factors to adjust the GES and CDS weights of cases that were reported by police as alcohol-involved. Then, using these adjusted weights, we estimated the incidence and costs of alcohol-involved crashes for 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, we used the methods in Blincoe et al. (2002) to estimate speeding incidence and costs by speed involvement. That report compared rates of speed involvement in 1985-86 for each severity level of non-fatal crashes from NASS to the rate for fatalities from FARS to determine a relative speed involvement factor for each severity level of non-fatal crashes. These factors were applied to the current speed involvement rate for fatalities to determine the rate of involvement for each nonfatal severity category in 2006.

US costs of belt non-use

Following methods in Zaloshnja and Miller (2006), we estimated the cost of belt non-use 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 whom restraint use was unknown. Property damage was kept constant because it is not affected by restraint use.

RESULTS

Table 3 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 were concordant, 22.2% discordant, and 0.6% tied.

As Table 4 shows, in 5.32 million crashes, or in 31.4% of all traffic crashes nationally in 2006, road conditions contributed to crash frequency 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).

The estimated comprehensive cost of traffic crashes where road conditions contributed to crash frequency or severity was $217.5 billion in 2006 (Table 5). This represented 43.6% of the total comprehensive crash cost. The medical cost of those crashes was an estimated $20.2 billion; productivity losses were $46.5 billion; monetized quality of life losses were $98.9 billion; and property damage and other resource costs totaled $51.9 billion.

In 2006, government and employers paid respectively an estimated $12.3billion and $22.3 billion for crashes where road conditions contributed to crash frequency or severity (Tables 6 and 7). The cost of such crashes to government and employers represented, respectively, 42.9% and 40.3% of the total paid by them for traffic crashes in 2006.

Figures 1 and 2 show the ranking of states by road-related crash costs per vehicle mile of travel and per mile of road. Since our interest is in 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 8 presents costs by state. Those costs use state-specific prices.

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 Midwestern. 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 3 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 Annex Tables A-1 through A-3 for details.)

Figure 1 - Ranking of States by Road -Related Crash Costs per Vehicle Mile of Travel

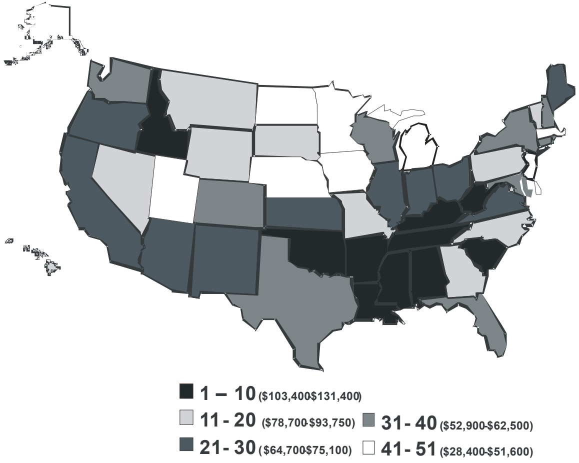
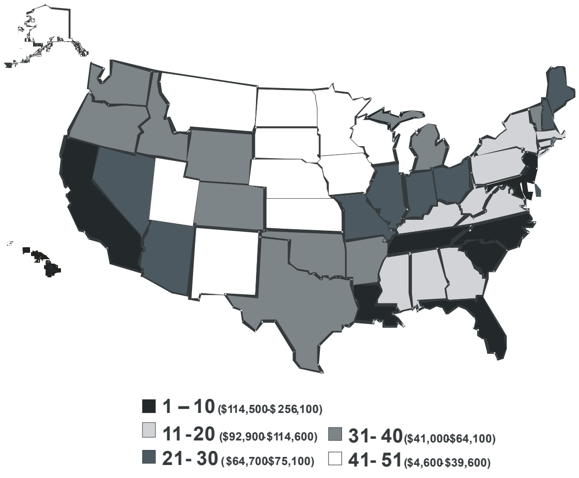
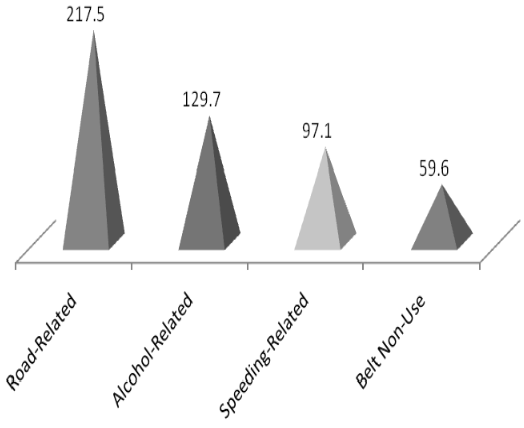


Figure 2 - Ranking of States by Road - Related Crash Costs per Mile of Roadway



Independently of the probability assigned by the statistical model used, it was assumed that crashes were 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 where 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. Crashes where road-related factors were assumed to raise injury severity but did not contribute to the crash cost an additional $79.3 billion.

Figure 3 - 2006 U.S. Cost of Crashes where Selected Factors Might Have Contributed to Crash Frequency or Severity (in billion 2006 dollars).



Note: In some crashes, more than one of the factors may have contributed to crash frequency or severity. The overlapping costs cannot be apportioned accurately between categories due to the probabilistic nature of our estimation procedures. These estimates should not be added together in order to account for the portion of costs that represent the combined factors.

DISCUSSION

Given the lack of detailed information on the contribution of road conditions in the national crash data, we relied on LTCCS data to model the probability of road condition relatedness. This was based on the imperfect assumption that the sample of truck crashes in LTCCS is representative of all road-related crashes in the U.S. Heavy truck drivers typically sit at a much higher level than passenger vehicle drivers, resulting in sight distance differences. Also, heavy vehicles require a much longer braking distance and off-track to a much greater degree when negotiating horizontal curves (back wheel path can deviate significantly from front wheel path). Heavy vehicles are also typically operated by more skilled drivers and operate primarily on higher classification roadways; since CDS/GES does not provide information on road classification, we could not control for it while applying regression results. The inherent differences between truck and passenger vehicle crashes are also present in the dependent variables used to indicate a crash was influenced by road design/conditions. For example, "excessive superelevation" would be more likely to be an issue for heavy vehicles due to lower velocities around a horizontal curve than for passenger vehicles traversing the same curve. To the extent that the sample of truck crashes in LTCCS is not representative of all road-related crashes in the U.S., we have over- or under-estimated the cost of road-related crashes.

We selected four harmful events as road-related factors which increased crash severity, but we did not build a statistical model that estimated the relative risk of injury associated with a wider range of harmful events involving the roadway and roadside. More research is needed on the factors that contribute to injury severity. Similarly, the distribution of non-fatal crash costs by state was based on the distribution of fatal crash costs. To the extent these two distributions do not match each other our results for individual states would be biased.

The large share of crash costs related to road design and conditions underlines the importance of these factors in highway safety. Road conditions are largely controllable. Road maintenance and upgrading can prevent crashes and reduce injury severity. 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.

CONCLUSION

Road-related crashes are a major problem in the United States. More than 31% of all crash costs result from crashes where road conditions were a contributing factor. In some cases, road conditions were one cause of the crash. In others, they probably increased crash severity. Overall, road-related crashes cost $217.5 billion in 2006. Many of these crashes also involved alcohol or excessive speed.

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).

Table 3 - 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
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/ fire hydrant	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
No. of observations: 2,258; Likelihood Ratio: 166.8 , Pr > ChiSq <.0001; Score: 158.4, Pr > ChiSq <.0001; Wald: 144.2, Pr > ChiSq <.0001				

Table 4 - 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%

Table 5 - 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 crash costs**	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***

Table 6 - 2006 Government Traffic Crash Costs
(in millions of 2006 dollars)

Cost category	Crashes where road conditions contributed to crash frequency or severity	**% of all crash costs**	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 7 - 2006 Employer Traffic Crash Costs (in millions of 2006 dollars)

Cost category	Crashes where road conditions contributed to crash frequency or severity	**% of all crash costs**	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***

Table 8 - Costs of crashes where road conditions contributed to crash frequency or severity by State, 2006
(millions of 2006 dollars)

State	**Medical costs**	**Productivity loss**	**Quality of life loss**	**Other costs**	***Comprehensive cost per million vehicle-miles (2006 dollars)***	***Comprehensive cost per mile of road (2006 dollars)***
US	***20,196***	***46,433***	***98,929***	***51,884***	***72,301***	***73,359***
Alabama	632	1,438	3,265	1,676	116,316	99,344
Alaska	29	36	98	32	39,592	19,934
Arizona	402	766	1,730	880	60,625	78,971
Arkansas	335	715	1,649	837	107,357	47,499
California	2,457	5,109	11,810	5,945	77,491	211,059
Colorado	271	653	1,211	679	57,978	42,390
Connecticut	206	519	956	551	70,476	143,038
Delaware	34	99	200	102	46,323	92,961
Dist of Columbia	14	51	107	55	62,865	198,743
Florida	1,159	2,615	5,576	2,923	60,367	124,513
Georgia	780	1,859	3,683	2,016	73,612	95,702
Hawaii	91	176	570	239	105,792	338,310
Idaho	151	295	702	348	98,639	44,301
Illinois	661	1,785	3,128	1,826	69,397	68,492
Indiana	428	991	2,031	1,076	63,682	66,622
Iowa	121	306	624	326	44,010	17,977
Kansas	200	469	926	520	70,128	20,908
Kentucky	449	1,016	2,266	1,169	102,867	84,726
Louisiana	453	992	2,389	1,164	110,301	106,496
Maine	118	226	563	285	79,421	77,625
Maryland	257	798	1,283	776	55,428	133,283
Massachusetts	349	810	1,723	896	68,688	143,988
Michigan	383	1,045	2,097	1,138	44,855	52,926
Minnesota	185	462	874	478	35,451	20,978
Mississippi	393	831	2,145	1,034	106,293	79,630
Missouri	545	1,294	2,601	1,395	84,947	61,041
Montana	93	174	425	232	82,259	17,528
Nebraska	81	210	414	211	47,314	13,370
Nevada	176	379	801	426	81,806	68,616
New Hampshire	64	209	396	221	65,584	75,904
New Jersey	418	1,018	2,047	1,112	61,093	154,347
New Mexico	174	322	838	387	66,905	33,292
New York	938	2,094	5,068	2,505	75,197	127,674
North Carolina	807	1,823	3,912	2,033	84,656	108,203
North Dakota	24	65	138	71	37,715	4,176
Ohio	635	1,361	3,191	1,590	61,048	71,780
Oklahoma	408	924	2,042	1,068	91,439	54,136
Oregon	261	496	1,167	570	70,429	59,424
Pennsylvania	874	2,324	4,671	2,545	96,402	111,869
Rhode Island	46	100	254	130	63,947	104,459
South Carolina	522	1,130	2,675	1,318	112,704	119,374
South Dakota	64	153	332	168	78,406	11,689
Tennessee	700	1,650	3,295	1,805	105,753	109,761
Texas	1,281	2,953	5,769	3,166	55,394	59,083
Utah	57	134	320	139	25,066	19,470
Vermont	68	133	316	176	88,650	66,352
Virginia	472	1,345	2,400	1,363	68,972	104,983
Washington	327	724	1,428	773	57,665	53,438
West Virginia	206	431	1,017	519	104,320	83,428
Wisconsin	317	741	1,453	777	55,484	38,268
Wyoming	77	187	353	213	88,246	61,028

ACKNOWLEDGMENTS

This study was funded by The Transportation Construction Coalition.

REFERENCES

Andreassen, D. (1986). Some further observations on accident severity and casualty class, *Proceedings of the 13th ARRB Conference* (Vol. 13:9, pp. 12-16). Victoria, Australia: ARRB Melbourne.

Blincoe, L. J., Seay, A., Zaloshnja, E., Miller, T. R., Romano, E. O., Luchter, S., & Spicer, R. S. (2002, May). *The economic impact of motor vehicle crashes, 2000* (DOT HS 809 446). Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Craft, R. (2007). *Large truck crash causation study summary* [Analysis Brief]. Federal Motor Carrier Safety Administration Office of Research and Analysis Publication. Accessed December 12, 2008, from the World Wide Web: http://www.fmcsa.dot.gov/facts-research/research-technology/analysis/FMCSA-RRA-07-017.htm

Federal Highway Administration. (2007). *Highway Statistics 2006*. Federal Highway Administration. Accessed December 10, 2008, from the World Wide Web: http://www.fhwa.dot.gov/policy/ohim/hs06/index.htm

Federal Motor Carrier Safety Administration. (2005, March 2006). *Report to Congress on the Large Truck Crash Causation Study* (MC-R/MC-RRA). Washington, DC: US Department of Transportation.

Lestina, D., & Miller, T. R. (1994). Characteristics of crash-involved younger drivers, *38th Proceedings of the Association for the Advancement of Automotive Medicine* (pp. 425-437). Des Plaines, IL: Association for the Advancement of Automotive Medicine.

Mahoney, K. M., Julian, F., & Taylor Jr., H. W. (2006). *Good Practices: Incorporating Safety into Resurfacing and Restoration Projects* (FHW-SA-07-001): U.S. Federal Highway Administration.

Mattox, J. H., Sarasua, W. A., Ogle, J. H., Eckenrode, R. T., & Dunning, A. (2007). Maintenence operations: Work zones, pavement markings, and weather. *Journal of the Transporation Research Board, 2015.*

Miller, T. R. (1990). The plausible range for the value of life: Red herrings among the mackerels. Journal of Forensic Economics, 3(3), 17–39.

Miller, T. R. (2000). Valuing non-fatal quality of life losses with quality-adjusted life years: The health economist's meow. Journal of Forensic Economics, 13(2), 145–168.

Miller, T. R., Galbraith, M. S., Lestina, D., Schlax, T., Mabery, P., & Deering, R. (1997). United States passenger-vehicle crashes by crash geometry: Direct costs and other losses. *Accident Analysis and Prevention, 29*(3), 343-352.

Tingvall, C., & Haworth, N. (1999). *"Vision Zero" - An Ethical Approach to Safety and Mobility.* Paper presented at the 6th ITE International Conference in Road Safety and Traffic Enforcement: Beyond 2000, Melbourne, Australia.

Treat, J. R. (1980). A study of precrash factors involed in traffic accidents. *HSRI Research Review, 10*(6), 1-35.

Viano, D. C., & Ridella, S. A. (1991). *Crash Causation: A Case Study of Fatal Accident Circumstances and Configurations.* Paper presented at the 35th Annual Proceedings of Association for the Advancement of Automotive Medicine, AAAM, Toronto, Canada.

Viner, J. G. (1991). *Harmful events in crashes.* Paper presented at the 35th Annual Proceedings of Association for the Advancement of Automotive Medicine, AAAM, Toronto, Canada.

Viscusi, W. K., & Aldy, J. E. (2003). The value of statistical life: A critical review of market estimates throughout the world. Journal of Risk and Uncertainty, 27(1), 5–76.

Zaloshnja, E., Miller, T. R., Romano, E. O., & Spicer, R. S. (2004). Crash costs by body part injured, fracture involvement, and threat to life severity, United States, 2000. *Accident Analysis and Prevention, 36*(3), 415-427.

Zaloshnja, E., & Miller, T. R. (2006). The employer costs of motor vehicle crashes. *Injury Control & Safety Promotion, 13*(3), 145-150.

Zaloshnja, E., Miller, T., Council, F., & Persaud, B. (2006). Crash costs in the United States by crash geometry. *Accident Analysis and Prevention, 38*(4), 644-651.

APPENDIX

Table A-1 - 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-2 - 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-3 - 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%***