

ATTACHMENT F

CRASH COSTS AND ADJUSTMENTS CLOSED-PROFILE CONCRETE BRIDGE RAILING

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**Recommended Guidelines for the Selection of
Test Levels 2 through 5 Bridge Railings**



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INTRODUCTION

Police-reported crash data is collected by every State and various roadside features are included in these standard crash reports. Severity distributions of crashes can be developed based on these police-level crash reports; this has been widely done by many researchers for many years in studying highway crashes. State crash reports invariably represent predominantly passenger cars because passenger cars dominate the vehicle population and the vehicle miles travelled.

Crash costs have also been developed in many other studies and these costs generally represent “all crashes.” Since the majority of crashes involve passenger vehicles such crash costs are heavily weighted toward passenger cars as well although there have been a few studies of the cost of crashes for vehicle subgroups like heavy truck or single vehicle crashes. [Zaloshnja06; Council11] In deciding how to account for crash costs in this research it is important to understand the crash cost differences across the vehicle fleet. For example, are heavy truck crashes on average more costly than a motorcycle crashes or passenger vehicle crashes. If crash costs are different for different types of vehicles an adjustment factor which corrects for the crash cost of heavy vehicles and motorcycles is needed.

This report summarizes some previous studies, the data used and the methods implemented to develop these crash cost adjustment factors. These factors could be used in combination with Probability of Injury (POI) tables discussed in previous reports.

BACKGROUND

Truck and Bus Crashes

The Federal Motor Carrier Safety Administration (FMCSA) was established on January 1, 2000 within the US DOT. Its primary mission “is to prevent commercial motor vehicle-related fatalities and injuries.” The FMCSA activities include the collection and dissemination of data on motor carrier safety. [FMCSA11] In December 2010, the FMCSA published a compilation of “Commercial Motor Vehicle Facts.” [FMCSA10] This pamphlet contains a number of tables comparing large truck and motor coach crashes to all other crashes. This data was compiled from several sources, including National Highway Traffic Safety Administration (NHTSA), Fatality Analysis Reporting System (FARS) and General Estimates System (GES). Table 1 is a summary of 2009 police-reported crashes compiled by the FMCSA using the sources listed above. Table 1 shows the distribution of crash severity for trucks, buses, and all vehicles (i.e., mostly passenger vehicles).

Table 2, in contrast, provides the number of people injured in each crash by vehicle type. The distinction becomes increasingly significant when a vehicle has the potential to carry many passengers (i.e., busses). For example, Table 1 shows that there were 9,221 fatal and injury crashes involving busses in 2009, however,

Table 2 shows that 20,254 people were killed or injured in bus crashes in 2009; it would appear that on average a little over two people are killed or injured in each bus crash. In contrast, there were 1,547,797 fatal and injury crashes involving all vehicle types and 2,250,808 people were killed or injured in these crashes; the average number of people killed or injured in crashes with all types of vehicles is 1.45. On average, then, a bus crash will result in 50 percent more injuries and deaths than a crash involving a passenger car.

Table 1. 2009 Police-Reported Motor Vehicle Traffic Crashes [FMCSA10]

Crash Severity	Large Trucks	Buses	Large Trucks & Buses	All Vehicles
Fatal	2,987	221	3,197	30,797
Injury	51,000	9,000	60,000	1,517,000
PDO	232,000	47,000	278,000	3,957,000
Total	286,000	56,000	341,000	5,505,000

Table 2. 2009 Traffic Crash Victims

Number of Victims	In Large Truck Crashes	In Bus Crashes	In Large Truck and Bus Crashes	In All Vehicle Crashes
Killed	3,380	254	3,619	33,808
Injured	74,000	20,000	93,000	2,217,000

Motorcycle Crashes

A federal organization of motorcycles similar to the FMCSA for heavy vehicles does not exist, however, the same sources can be used to obtain the data and several researchers are conducting research on motorcycle safety and performance in crashes.

Daniello and Gabler examined motorcycle fatal crash risk with roadside objects in a recent paper. [Daniello11] Because motorcycle crashes with roadside objects often involve a collision with the ground and then another object, the object was to determine if the ground or the subsequently hit roadside object (i.e., concrete barrier, guardrail, trees, poles, signs, etc.) pose a greater risk to motorcyclists in a crash. They found that the fatality risk for hitting a tree is 0.050; guardrail is 0.183; concrete barrier, sign, pole, post, or support is 0.104; and a rollover is 0.011. Notably, the study concluded that collisions with roadside barriers are less severe than with other roadside objects. [Daniello11]

A review of the NHTSA 2009 Traffic Safety Facts yields the fatal and injury crashes for motorcycles during 2008 and 2009.[NHTSA09] These values are shown in Table 3.

Table 3. 2008 and 2009 Fatal and Injury Crashes for Motorcycles. [NHTSA09]

Year & Injury	Motor-cyclist
2008 Fatal	5,312
2009 Fatal	4,462
2008 Injured	96,000
2009 Injured	90,000

Vehicle Miles Traveled

Federal Highway Administration 2008 Highway Statistics Data can be used to compile a table of vehicle miles traveled by vehicle type. Table 4 provides a summary of this data.

Table 4. 2008 Million Vehicle Miles Traveled.

Vehicle Type	Million Vehicle Miles Traveled
All Vehicles	2,973,509
Large Trucks	227,458
Buses	7,114
Motorcycles	14,484

Accurate registration and travel data for motorcycles has been the source of much discussion for the last decade between the NTSB and the FHWA. Motorcycle fatalities and the related fatality rate have been increasing significantly over this same period. Motorcyclist fatalities have increased over 110 percent in 10 years, however, motorcycle registrations have increased only 61 percent. The reported Vehicle Miles of Travel (VMT) for motorcycles increased only 8.6 percent. The result is a 94 percent increase in the motorcycle fatality rate.[FHWA07] FHWA has made Federal funding available for the specific collection of these data to improve the data.

The FHWA has several obstacles to overcome in order to improve data collection and capture an accurate picture of the VMTs by motorcycles. The NTSB issued safety recommendation H-07-34 to FHWA in October 2007 which directed FHWA to develop guidelines for the collection of accurate registration and VMT data on motorcycles by the States.[NTSB07] Within this recommendation, the NTSB acknowledges the obstacles to the data collection, including:

- The Motorcycle Industry Council notes that “not all motorcyclists register their bikes.”
- Some states do not collect motorcycle data and the data is included as “zero” in FHWA summaries.
- There are problems with using automatic traffic recorders to count motorcycles (i.e., motorcycles that travel side by side or close behind each other, distinguishing larger motorcycles from passenger vehicles, counters not sensing motorcycles travel close enough to the sensor.).
- Classification counts are frequently conducted during the week and may do not capture weekend motorcycle traffic numbers which are presumably higher.

The Motorcycle Industry Council estimated that motorcycles traveled 20,669 million miles in 2003 [NTSB07] while FHWA estimated motorcycles traveled 9,577 million miles in the same period; an order of magnitude difference. The FHWA estimate for 2008 motorcycle vehicles miles traveled is 14,484. [RITA11] This 2008 FHWA data has been included in Table 4 because it is considered the most reliable of the information available. As these data issues are remedied, this issue may need revisiting.

Crash Costs

The FHWA uses the so-called willingness-to-pay concept (i.e., comprehensive costs), which has been documented by economists who observed that people “express how much well-being they get out of something by demonstrating *willingness-to-pay* for it.”[AASHTO03] Willingness-to-pay, however, is a misnomer and the figures actually represent how much a person actually pays. When considering crash costs, this concept would translate to “how much people actually pay to reduce safety risks.”[FHWA09]

Miller *et al.* conducted a study in 1988 which determined the comprehensive costs of crashes mapped to the KABCO scale commonly used by police officers to describe the severity of a crash.[Miller88] Each letter of the scale equals a different severity (e.g., K for a fatal injury and O for a property damage only crash) and results in a different comprehensive crash cost. Miller noted that “these costs should be updated annually using the GDP implicit price deflator.”[Miller88] FHWA then updated this study to 1994 dollars.[FHWA94]

Based on improved understanding of literature, FHWA issued a memorandum in 2008 which suggested that the GDP implicit price deflator should no longer be used to update the comprehensive costs of crashes but rather the value of statistical life (VSL) should be used instead. The memorandum notes “the relative values of injuries of varying severity were set as a percentage of the economic value of a life.” These values are still being reviewed by FHWA and the relative values may be modified in the future. In 2008, a VSL of \$5.8million was established. In 2009 the VSL was changed to \$6.0million. [FHWA08,FHWA09]

FHWA plans to periodically issue updates to the VSL rather than having users update the comprehensive costs through updates to the GDP, as suggested previously. Additional updates

to the VSL have not been issued since 2009. Using the relative values of injuries and the 2008 and 2009 VSLs provided by FHWA, Table 5 reflects recent and current comprehensive costs of crashes.

Table 5. Recent Comprehensive Crash Costs.

Crash Severity	Cost per Crash		
	1994	2008	2009
K	\$2,600,000	\$5,800,000	\$6,000,000
A	\$180,000	\$401,538	\$415,385
B	\$36,000	\$80,308	\$83,077
C	\$19,000	\$42,385	\$43,846
PDO	\$2,000	\$4,462	\$4,615

Motorcycle Crash Costs

In 2005, FHWA sponsored a study to review the comprehensive and economic costs of crashes.[Council11] The economic costs of crashes are used to estimate the effect of crashes after the crash has occurred where the comprehensive costs are used in cost/benefit analyses to estimate the benefit to society of the reduced risk of having a crash. Comprehensive costs are higher than economic costs because the comprehensive costs equal the economic crash cost plus what society is willing to pay for the reduced risk. Council *et al.* determined the crash costs in 2001 dollars for a variety of crash types, by two different speed categories and by various groupings of the KABCO scale. Particularly interesting to this research are the single vehicle crash costs. Table 6 provides a summary of the comprehensive crash cost findings for single vehicle crashes from this study compared with the all crashes comprehensive cost for the same study, in 2001 dollars.

Table 6. Comprehensive Cost per Single Vehicle Crash and All Crashes in 2001 Dollars.

Maximum Injury Severity	Single Vehicle		All Crashes
	Object	Rollover	
K	\$3,943,720	\$4,092,803	\$4,008,885
A	\$247,690	\$280,609	\$216,059
B or C	\$63,329	\$67,357	\$79,777
U*	\$22,662	\$342,922	\$82,642
Unknown	\$21,799	\$21,032	\$24,248
No injury	\$5,618	\$13,331	\$7,428

U*-Injury, unknown severity
Unknown-unknown severity

Unfortunately, literature similar to this is not available for motorcycle crashes. These single vehicle crash costs, however, may most closely represent motorcycle crash costs as motorcycle crashes typically involve only the motorcycle or the crash is considerably more severe for the motorcyclist.

Heavy Vehicle Crash Costs

Zaloshnja and Miller recently determined the comprehensive cost of various truck crashes by truck size. [Zaloshnja06] These costs were reported by total crash cost by most severe injury and by cost of injury per victim. The findings are based mainly on the “injury severity profile from the 2001-03 period” and updated to 2005 dollars. These costs include the following categories: “(1) medically related, (2) emergency services, (3) lost productivity (wage and household work), and (4) the monetized value of pain, suffering, and lost quality of life.” A summary of the findings are presented in Table 7, which shows the 2005 cost per victim and cost per crash of all medium/heavy truck crashes.

The FMCSA updated these costs to reflect the updated FHWA VSL to 2008 dollars. These updated 2008 costs are also shown in Table 7. The cost of a fatal truck crash in 2005 was approximately \$3.6M, while the 2008 estimate jumped to \$7.2M which is a reflection of the increase in the statistical value of life.[FMCSA08]

Table 7. 2005&2008 Cost of All Truck Crashes by Injury Severity and per Victim.

Truck Type	Max Severity in Crash	Annual Number of Crashes	2005 Cost per crash	2005 Cost per Victim	2008 Cost per Crash
All medium/ heavy trucks	K	4,278	\$3,604,518	\$3,055,232	\$7,200,310
	A	16,035	\$525,189	\$325,557	\$1,049,107
	B	23,955	\$180,323	\$134,579	\$360,209
	C	40,774	\$78,215	\$62,702	\$156,241
	O	326,121	\$15,114	\$5,869	\$30,191
	U*	1,024	\$38,661	\$33,759	\$77,228
	Unknown	21,685	\$23,479	\$20,540	\$46,901

U*-Injury, unknown severity
Unknown-unknown severity

In summary, crash costs can be estimated using different indexes and for different types of crashes and for different years which results in different dollar estimates for crash costs. Each index has an appropriate use. When considering benefits to society, it is accepted that the willingness-to-pay concept (i.e., comprehensive costs) is most appropriate and should be used in combination with an appropriate crash modeling technique which can capture crash severity. The variations in crash costs between different vehicle classes result in unique costs which have

not been captured in previous roadside cost/benefit programs. The following section proposes a method to capture these different costs.

HEAVY VEHICLE AND MOTOR CYCLE ADJUSTMENTS

The data is not available to understand the crash severity of each vehicle classification for all possible roadside objects. There are many possible ways to adjust for heavy vehicle and motorcycle involvement in crashes from an “all crash” base. One could adjust for the relative crash costs, the relative exposure, relative severity of these crashes, or some combination thereof.

Exposure Adjustment

Using the data presented in Table 4, which represents the exposure of large trucks, buses, and motorcycles to potential hazards versus the entire vehicle fleet exposure to potential hazards and the data in Table 1, Table 2, and Table 3 which provides the fatal and injury crashes for the same types of vehicles, the relative crash risk for each type of vehicle can be determined. The rate of fatal and injury crashes and fatal and injury victims for these various classifications of vehicles is shown in Table 8.

Table 8. Fatal and Injury Crash Rate for Various Vehicle Types.

	Crashes				Victims			
	Large Trucks	Buses	Motor-cycles	All Vehicles	Large Trucks	Buses	Motor-cycles	All Vehicles
Fatality Rate	0.013	0.031	0.367	0.010	0.015	0.036	0.367	0.011
Injury Rate	0.224	1.265	6.628	0.510	0.325	2.811	6.628	0.746

Data was not available on the specific number of victims for motorcycle crashes, however given the nature of motorcycles, it is assumed that each crash had approximately one victim, therefore the crash rate equals the victim rate. Recall that the vehicle miles travel data for motorcycles has been called into question and is considered very low, therefore the high crash rates for motorcycles may be exaggerated by poor data.

Table 3 does show that while buses represent a relatively small portion of the vehicle miles traveled on the nation’s highways, buses are significantly more likely to be involved in a crash and when involved in a crash, many more people are likely to be injured. Large trucks are about half as likely as the general vehicle fleet to be involved in an injury crash, however, large trucks are equally as likely to be involved in a fatal crash.

Understanding this relative risk establishes that not all vehicles have the same risk and all vehicles should not be treated equally.

Crash Cost Adjustment

A review of the crash costs presented above for both heavy vehicles and for single vehicle crashes was conducted to determine the relative crash costs for these types of crashes when compared to an “all crashes” base scenario. The heavy vehicle and single vehicle crash cost data were from different years, therefore the all crashes base data was adjusted to 2008 to match the heavy vehicle data (Table 5). The single vehicle crash data was from 2001, therefore the crash costs data for all crashes was used from the same study for comparison. The relative crash costs are presented in Table 9. Recall that single vehicle crash costs are being used in place of motorcycle crash costs.

Table 9. Relative Crash Costs for Heavy Vehicles and Motorcycles.

SEVERITY	1994 All Crashes	2009 All Crashes	Truck ADJ	Motor-cycle ADJ
K	\$2,600,000	\$6,000,000	1.24	0.98
A	\$180,000	\$415,385	2.61	1.15
B	\$36,000	\$83,077	4.49	0.79
C	\$19,000	\$43,846	3.69	0.79
PDO	\$2,000	\$4,615	6.77	0.76

These ten relative adjustments appear reasonable. For example, a fatal heavy vehicle crash is approximately 24 percent more costly than other types of fatal crashes, while the PDO crash is over 600 percent more costly. Since many heavy vehicles are carrying cargo and these costs must be reflected in addition to the costs normally considered, these numbers are reasonable. The relative costs of motorcycle crashes, however, are slightly less in all categories except “A,” incapacitating injuries.

CATASTROPHIC EVENT ADJUSTMENT

It will also be necessary to determine an adjustment for catastrophic crashes. For example, the majority of crashes will not penetrate or rollover a bridge railing so that average US DOT cost figures would be adequate for estimating the societal cost of such a crash. If the vehicle does leave the bridge and falls into a sensitive area below (e.g., an active railroad line, another highway or heavily urbanized area) the costs would be much higher. It will be necessary to develop a cost adjustment factor that captures the additional cost and risk of this type of catastrophic crash.

Using the information Zaloshnja and Miller reported [Zaloshnja06], an approximate comprehensive cost catastrophic crashes can be determined. Crashes investigated by NTSB or reported in the media are used in this analysis. These crashes were discussed earlier in the literature review.

These costs are presented to show the possible range of crash costs for these catastrophic crashes. This comprehensive cost data is appropriate for cost/benefit analysis when evaluating the cost of crashes that might happen against the cost of safety improvements, however, the crash cost values published by the National Safety Council (NSC) are best suited for calculating the cost of crashes which have already happened. The NSC values can be used to measure the economic loss (i.e., economic impact) of crashes. The NSC values do not include what people are willing to pay for improved safety.[NSC11] The NSC values are therefore lower than the comprehensive cost values. The NSC crash costs per victim values are shown in Table 10. Using these values and the comprehensive crash cost values, the costs of each NTSB investigated or media reported crash was determined and is shown in Table 11.

Table 10. NSC Economic Impact Crash Costs.[NSC11]

Severity	2009 Cost /Victim
Death	\$1,290,000
Nonfatal Disabling Injury	\$68,100
Property Damage Crash (including non-disabling injuries)	\$8,200

Table 11. Summary of the Cost of a Selection of Bridge Rail Crashes.

Crash	2005 Comprehensive Crash Costs	NSC 2009 Crash Cost	Additional Known Costs
Glenmont, New York, 2007	\$33,759	\$8,200	
Wiehlthal Bridge, Germany, 2004	\$67,518	\$16,400	\$400 Million in Repairs to Structure, \$42 million in Temp. traffic control
Boston, Massachusetts, 2007	\$269,158	\$16,400	
San Francisco, California, 2009	\$3,055,232	\$1,290,000	
Saint Petersburg, FL	\$3,140,357	\$1,510,700	
Fort Sumner, New Mexico, 1972	\$58,555,793	\$24,633,000	
Nashville, Tennessee, 1973	\$303,831	\$73,800	
Martinez, California, 1976	\$12,761,072	\$5,291,200	New bridge constructed
Houston, Texas 1976	\$24,340,494	\$9,199,600	Destroyed 94 feet of bridge railing, damaged bridge deck, and column supporting overpass was sheared off.
Elkridge, Maryland, 2004	\$12,254,687	\$5,168,200	
Huntsville, Alabama, 2006	\$20,043,240	\$6,457,100	
Sherman, Texas, 2008	\$56,032,713	\$22,227,700	

The costs of repairs to bridges are considerably higher than any other given section of highway and generally not considered in general crash cost figures. In addition to these calculated crash cost values, for example, the bridge rail crash in Wiehlthal Germany [Wiehlthal04] ultimately required that the entire bridge be reconstructed. The temporary traffic control and bridge repair costs totaled approximately \$442 million. The bridge rail crash in Martinez, California [Marinez76] required that a new bridge be constructed in addition to the approximately \$5.3 to \$12.7 million in calculated crash costs.

These catastrophic events are rare, however costly. The variables which can lead to such an event will be considered in the development of the guidelines on an individual basis.

CONCLUSIONS

Severity distributions of crashes can be developed from police-level crash records, however these distributions represent predominantly passenger cars, therefore it becomes difficult to distinguish between different crash costs in areas dominated by different types of vehicles or in scenarios where a particular vehicle-type is of greater concern (e.g., possibly installing a higher test level barrier).

Crash costs are different for different types of vehicles, as demonstrated above, therefore an adjustment factor is appropriate to account for these differences. The adjustment factors derived above will be applied to the crash severity distributions of the various barriers studied in this research to account for the effects of these crashes.

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