Estimating Crash Costs in the Updated Roadside Safety Analysis Program

Malcolm H. Ray
RoadSafe, LLC
Box 312
12 Main Street
Canton, Maine 04221
Phone: 207 514 5474, e-mail: mac@roadsafellc.com

Christine E. Carrigan
RoadSafe, LLC
Box 312
12 Main Street
Canton, Maine 04221
Phone: 413 626 1516, e-mail: christine@roadsafellc.com

Chuck Plaxico
RoadSafe, LLC
Box 312
12 Main Street
Canton, Maine 04221
Phone: 614 578 1942, e-mail: chuck@roadsafellc.com

Submitted
August 1, 2011

Word count

Text = 4,730
Figures&Tables: 11 @ 250 words each =2,750
Total number of words= 7,480

Paper prepared for consideration for presentation and publication at the
91th Annual Meeting of the Transportation Research Board, January 2012

Estimating Crash Costs in the Updated Roadside Safety Analysis Program

Malcolm H. Ray, Christine E. Carrigan and Chuck Plaxico

ABSTRACT

Roadside designer have used the Severity Index (SI) approach to model roadside hazard severity for some time. SI is a linear function of speed and the slope values for the SI curves were based primarily on engineering judgment. While this approach to determining crash severity has been widely used, it has never been validated or compared to real-world crash data because there were no crash databases available with reconstructed impact speeds that could be used to check the validity of the SI-speed relationship. This paper reviews the traditional SI approach results compared to collected crash data from the NCHRP 17-22 crash database and presents a new approach for estimating crash severity proposed for use in the updated version of RSAP.

The Effective Fatal Crash Cost Ratio (EFCCR) is proposed to replace the SI in the updated version of RSAP. The EFCCR uses the severity distribution of reported crashes for any hazard, adjusted for unreported crashes, then divides the average crash cost calculated for any particular year by the cost of a fatal crash in that same year creating a dimensionless measure of risk. This dimensionless value allows for direct comparison of hazard severity between roadside hazards.

INTRODUCTION

Roadside design benefit-cost programs like Roadside, BCAP, ABC and prior versions of RSAP used a Severity Index (SI), unique to each roadside hazard, to represent the severity of striking a roadside hazard. Once the probability of leaving the roadway and the probability of striking an object have been calculated, these programs must estimate the likely severity of the crash in order to appropriately apportion the crash costs. SI is a linear function of speed. For example, the slope of the SI-speed curve for a crash with a two inch diameter tree is 0.009 SI/mph while the SI for a crash with an eight inch tree is 0.0839 SI/mph. RSAP 2.0.3 would randomly generate an impact speed which was multiplied by the slope of the SI-speed curve and mapped to the generic distribution of crash severities shown in TABLE 1. When the resulting SI equaled 0.5, 100 percent of the crashes were categorized as "Property Damage Only" crashes. The slope values for the SI curves were based primarily on engineering judgment.

TABLE 1 NCHRP 492 Generic Severity Distributions

	None	O	C	B	A	K
1994 $	$0	$2,000	$19,000	$36,000	$180,000	$2,600,000
SI						
0	100.0%					
0.5		100.0%				
1		90.4%	7.3%	2.3%		
2		71.0%	22.0%	7.0%		
3		43.0%	34.0%	21.0%	1.0%	1.0%
4		30.0%	30.0%	32.0%	5.0%	3.0%
5		15.0%	22.0%	45.0%	10.0%	8.0%
6		7.0%	16.0%	39.0%	20.0%	18.0%
7		2.0%	10.0%	28.0%	30.0%	30.0%
8			4.0%	19.0%	27.0%	50.0%
9				7.0%	18.0%	75.0%
10						100.0%

This approach to determining crash severity has been widely used but never validated or compared to real-world crash data because there were no crash databases available with reconstructed impact speeds that could be used to check the validity of the SI-speed relationship. NCHRP Project 17-22 compiled 890 ran-off-road crash records from several sources and supplemented the data with additional field data collection. Thirty-three years of crashes were included in the review, ranging from 1970 to 2003. The database includes crash severities, vehicle information, departure angle, crash reconstruction information and general crash data for each crash record. One of the unique features of the 17-22 data is that each crash was reconstructed so both encroachment speed and the impact speed for each crash was estimated.

This paper reviews the traditional SI approach results compared to collected crash data and presents a new approach for estimating crash severity proposed for use in the updated version of RSAP. Previous research studies have also proposed replacing the SI method with methods which use the severity distribution of police-level reported crashes.*(1)*

COMPARISON OF THE SEVERITY INDEX METHOD AND CRASH DATA

Police reported crashes generally use the KABCO crash severity scale. The SI method uses numbers (i.e., the severity index) and then translates the numbers into a KABCO distribution which is then weighted by crash costs to determine the average crash cost of crashes at that impact speed. In the following discussion, the crash severity data and the SI data were both mapped to 2009 comprehensive crash costs to allow for a direct comparison. This comparison was conducted for longitudinal barriers and for trees. These two roadside hazards are believed to behave quite differently in crashes and, therefore, represent a good cross-section of crash types.

Longitudinal Barrier Comparison

Guardrails and all other longitudinal barriers have a Severity Index (SI) slope equal to 0.1944 SI/MPH. The SI is in turn related to the severity distribution using TABLE 1 as described above. This severity distribution is used for crashes with all types of longitudinal barriers (i.e., cable guardrail through concrete bridge rails). One of the weaknesses of the SI approach as implemented in prior versions of RSAP is that there is no distinction between, say, a flexible cable barrier and a rigid concrete barrier since all longitudinal barriers are presumed to result in the same severity distribution. TABLE 2 shows how the SI for longitudinal barriers is mapped from impact speed to the SI to the KABCO distribution than crash cost.

For the special case of longitudinal barriers, the SI relationship is based on the lateral component of velocity, $V \sin \theta$, rather than just the velocity. TABLE 2 shows that all longitudinal barrier crashes with a lateral component of impact speed of 55 mph or greater are assumed to result in a fatal crash while crashes with a lateral component of impact speed of less than 20 mph would result in B, C, or PDO crashes but no A or K injuries. Using the 2009 crash costs , the above KABCO severity distributions were converted to crash costs by impact speed and graphed. The NCHRP 17-22 crashes with all longitudinal barriers were reviewed and assigned a crash cost based on the most severe injury in each police report using 2009 dollars. A comparision of the predicted crash costs using the SI method and actual crash data is presented in FIGURE 1. The solid line represents the longitudinal barrier SI value at five mile per hour impact speed increments based on the linear SI equation. The point markers represent the crash cost based on the actual injuries observed in individual crashes in the NCHRP 17-22 data . Each marker style represents a different type of longitudinal barrier.

TABLE 2 NCHRP 492 Longitudinal Barrier Severity Distribution based on impact speed

V sin θ	SI	None	O	C	B	A	K	2009 Crash Cost ($)
0	0.0	100.0%						$0
5	1.0		90.4%	7.3%	2.3%			$9,283
10	1.9		90.4%	7.3%	2.3%			$9,283
15	2.9		71.0%	22.0%	7.0%			$18,738
20	3.9		43.0%	34.0%	21.0%	1.0%	1.0%	$98,492
25	4.9		30.0%	30.0%	32.0%	5.0%	3.0%	$241,892
30	5.8		15.0%	22.0%	45.0%	10.0%	8.0%	$569,262
35	6.8		7.0%	16.0%	39.0%	20.0%	18.0%	$1,202,815
40	7.8		2.0%	10.0%	28.0%	30.0%	30.0%	$1,952,354
45	8.7			4.0%	19.0%	27.0%	50.0%	$3,129,692
50	9.7				7.0%	18.0%	75.0%	$4,580,585
55	10.7						100.0%	$6,000,000

FIGURE 1 shows that fatal crashes (i.e., crashes with a crash cost of $6,000,000) occur at both low and high lateral impact speeds in the NCHRP 17-22 data. There were four fatal crashes with w-beam guardrails at relatively low speeds but none at high speeds and there were far more low severity crashes even at high speeds. The very high lateral impact speed longitudinal barrier crashes (i.e., over 40 mph) resulted in fatal crashes in only 1 of the 5 cases while all SI predicted crashes with a lateral impact speed over 30 mph were predicted to result in crash costs of at least $1 million. Clearly, predicting the severity of a longitudinal barrier crash is not as simple as the linear relationship between SI and speed that has been assumed in prior cost-benefit analysis programs.

Trees and Poles Comparison

A similar annalysis was conducted for trees and utility poles. Unlike longitudinal barriers, many SI values exist for different trees based on their diameter, however, the NCHRP 17-22 crash data only contains a single field for “tree” not indicating the size of the tree. For this comparision, crash data for trees, poles, and utility poles were compared to the eight inch SI value (i.e., 0.0839 SI/MPH) for trees and the results are shown in FIGURE 2.

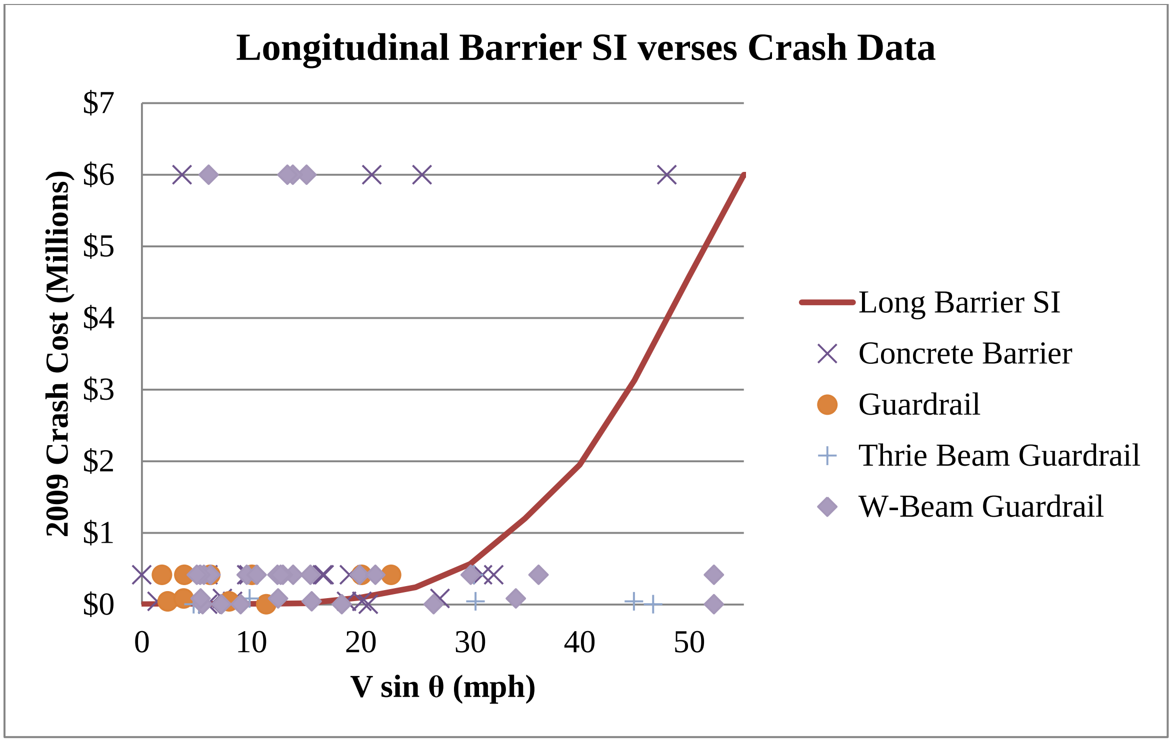


FIGURE 1 Predicted v. Actual Crash Severities Converted to Crash Costs for Longitudinal Barriers.

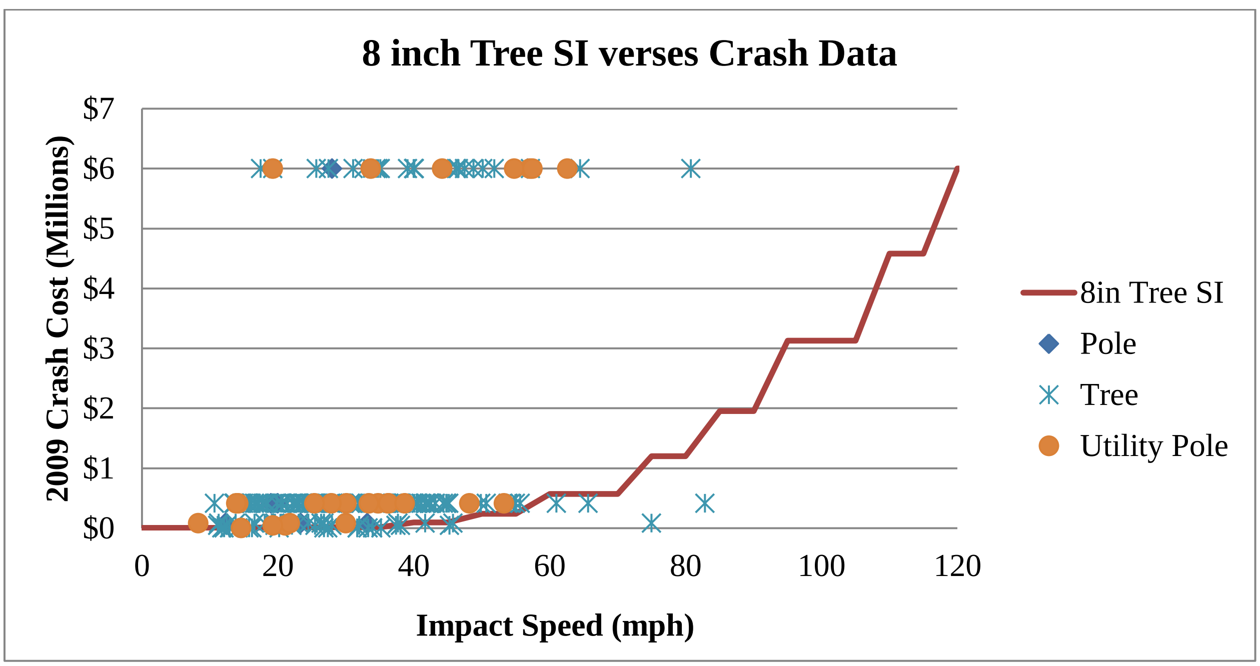


FIGURE 2 Predicted v. Actual Crash Severities Converted to Crash Costs for Trees and Poles.

The data summarized in FIGURE 1 and FIGURE 2 show that the traditional formulation of the SI does not do a very good job of predicting crash costs. This suggests that the relationship between crash cost and impact speed is not a simple linear mapping. In general, the traditional SI method tends to over predict the crash costs.

Sicking in NCHRP Report 638 found much the same when investigating guardrail crashes. He compared RSAP 2.0.3 analysis runs with the results of an examination of the Kansas guardrail, median barrier and bridge rail data and found that the average crash costs from RSAP 2.0.3. were a little over twice as large as the Kansas longitudinal barrier data indicating that RSAP 2.0.3 was over predicting the severity and, hence the crash cost. *(2)* Sicking resolved this by adjusting the RSAP severity indices downard until the average crash costs from RSAP 2.0.3 agreed with the Kansas data. One of the important reasons for this over-prediction identified by Sicking is that RSAP 2.0.3 and the traditional severity model ignore unreported crashes which are generally low-cost property damage only crashes. Improving the accuracy of RSAP will require a different approach to modeling crash severity that is more closely tied to observable crash data.

PROBABILITY OF INJURY METHOD

The probability of injury method is a technique for estimating crash severity for RSAP that is based on observed police reported crashes which are then adjusted for any unreported crashes and scaled to account for speed affects. The process for developing the POI look-up tables (LUT) will be presented below using an example.

POI Development Process

The general process for developing a POI lookup table for a particular hazard involves three steps as outlined below. Each of the three steps will be discussed more completely in the following sections.

1. Calculate the equivalent fatal crash cost ratio (EFCCR),
2. Adjust for speed affects by determining the baseline equivalent fatal crash cost ratio for a baseline impact speed of 50 mi/hr (i.e., $EFCCR_{50}$) for a particular hazard,
3. Develop the POI lookup table.

POI Application Process

The updated RSAP uses the POI LUT the following way:

1. Determine the baseline equivalent fatal crash cost ratio for a baseline impact speed of 50 mi/hr (i.e., $EFCCR_{50}$) from the POI LUT for a particular hazard,
2. From the collision module of RSAP determine the velocity at impact for a particular trajectory,
3. Scale the $EFCCR_{50}$ to the actual impact speed of the vehicle in the trajectory to determine the EFCCR,
4. Determine the crash cost by multiplying the EFCCR by the value of statistical life (VSL),
5. For multiple event crashes (e.g., a vehicle strikes a barrier, penetrates it then strikes a tree and rolls over), chose the event with the highest EFCCR and use that value to calculate the crash cost and

Sum the crash cost of each crash on a particular hazard.

Severity Distribution

As an example, the Washington State crash data for the years 2000 through 2008 were examined to identify the crash performance of low-tension cable median barriers. The data was collected statewide over eight years so it represents a census of low-tension cable median barrier crashes for crashes were the vehicle was contained and/or redirected.

TABLE 3 Police-Reported Low-Tension Cable Median Barrier Crash Severity

Severity	Contain/Redirected	
	No.	%
K	2	0.37
A	4	0.75
B	25	4.68
C	62	11.61
PDO	441	82.59
Total	534	100.00

Unreported Crashes

It has long been recognized that police-reported crash data underreport lower severity crashes. These low-severity crashes represent roadside safety and roadside design successes since the vehicle was able to encroach onto the roadside or median without causing an injury. The EFCCR approach uses police-reported crash data and, therefore, is subject to this same underreporting of lower severity crashes. Before using a crash severity distribution in RSAP an appropriate adjustment to account for underreported lower severity crashes must be made. For example, a driver would likely not file a report if he hit a guardrail and was successfully redirected onto the roadway without injury or serious damage to the vehicle; the driver would simply drive away without reporting the crash. This crash may have caused minor damage to the guardrail and the vehicle, but the vehicle was still operable and the driver was uninjured. This type of crash represents a “successful” guardrail crash and to ignore it would bias the results toward high-cost higher-severity crashes. RSAP predicts the total number of encroachments – those that produce reportable crashes as well as those that result in unreported or no crashes. These successes must be accounted for in the EFCCR approach by adjusting for the unreported crashes. Properly adjusting for underreported crashes will allow for more correct crash cost estimates, otherwise, RSAP would overestimate crash costs by calculating these successes as more severe crashes.

Several research studies have estimated the size of the unreported crash problem including NCHRP Report 490, the FHWA Pole Study and NCHRP Report 638 to name several. (3,4,2) Blincoe estimated for all types of highway crashes that nearly half (i.e., 48 percent) of all PDO crashes and a little over 20 percent (i.e., 21.42 percent) of injury crashes go unreported.(*5*) For the example of low-tension cable median barrier discussed in the last section, a review of the WSDOT maintenance records in two particular maintenance districts for cable barriers was undertaken to determine the number of unreported cable barrier crashes. TABLE 4 provides a summary of the crashes for each category (i.e., “reported,” “unreported,” or “too soon?”) and the percentage of the total crashes during the study period for the low-tension cable median barrier, the high tension cable median barrier and for both. In this database, “To soon” refers to crashes that may eventually be reported but were not yet in the crash reporting system when the data was compiled. They are added to the unreported crashes in this analysis although one could argue that one reason they may not be in the data yet is that they are higher severity cases where the police investigation takes longer; in any case there are relatively few of them. “Unreported” crashes in the WS DOT data are crash locations which were repaired by maintenance crews but could not be associated with a particular police crash report. Even this estimate is probably on the low side since it is possible to strike a cable median barrier and cause essentially no repairable damage. Nevertheless, using maintenance reports is one straightforward way of getting an estimate on the size of the unreported crash problem.

TABLE 4 Reported and Unreported Low-Tension Cable Median Barrier Crashes in in Two Maintenance Districts in Washington State (*6*)

Type	No.	%
Reported	322	66.5
Unreported	152	31.4
Too Soon?	10	2.1
Total	484	100.0

Almost 35 percent of the 484 low-tension cable median barrier crashes in these two maintenance districts were unreported (i.e., unreported or “too soon”). As mentioned above, several different researchers have attempted to estimate the percentage of unreported crashes for different types of roadside features. A recent study of guardrail collisions in Kansas found that approximately 26 percent of collisions with all types of longitudinal barriers are unreported.*(2)* Ray and Weir performed an in-service performance evaluation for control sections in Iowa, North Carolina and Connecticut where specific guardrail installations were inspected for damage including scratches, rubs and minor dents. They found that 50 percent of guardrail crashes were unreported although some of the damage they recorded may have been caused by snow plowing and grass mowing equipment.(*7*)Fitzpatrick *et al.* performed a similar control section damage survey using a video logging truck and found that 77 percent of concrete barrier crashes were unreported on a major interstate in Hartford, CT. (*8*)

There is a wide difference between these longitudinal barrier unreported crash percentages which may be due in part to regional maintenance practices and/or the type of barrier involved. For example, the 88 percent unreported rate shown for North Carolina by Ray was largely due to the fact that at the time guardrail repair was contracted out periodically rather than after each crash so police reports were often not associated with a specific location where in Iowa, the local DOT maintenance crews made the repairs soon after the crash and associated each crash with a repair in order to collect the repair cost from the driver.

It makes sense that the unreported rate would be different for different types of barriers. For example, 77 percent of concrete barrier crashes were unreported (*8*) while 34 percent of low tension cable barrier crashes were unreported. This seems reasonable because the concrete barrier is rarely damaged and is located in an area where it is not safe to stop (i.e., the study site was a high-volume urban freeway) so the only reason to report the crash would be if there were injuries involved or the vehicle was disabled. Concrete median barriers are generally close to the edge of the road, especially in this particular urban situation, so there are numerous minor collisions that result in little harm. On the other end of the spectrum are cable barriers. Even a minor collision will detach the cables and possibly bend a few posts. The vehicle, however, may not be disabled so maintenance workers must repair the damage even though the crash was not reported to the police. Likewise, a slightly damaged w-beam guardrail is still at least partly functional even though the rail is bent and the posts are displaced in the soil. Such damage may or may not trigger a repair event. If possible an engineer developing the EFCCR should attempt to obtain the maintenance records for the same geographical area used to develop the severity distribution in order to estimate the percentage of the unreported crashes. In the absence of maintenance data between 25 and 75 percent of all longitudinal barrier collisions will go unreported as a function of the barrier type.

Returning to the Washington State low-tension cable median barrier example, TABLE 4 showed that about 33.5 percent of the actual crashes were not reported to the police. The severity distribution shown earlier in TABLE 3 must, therefore, be adjusted to account for these unreported crashes. It is assumed that all unreported crashes resulted in Property Damage Only (PDO) crashes. The total number of estimated crashes of a particular outcome is the number of reported crashes divided by one minus the assumed percentage of unreported crashes. Further, it is assumed that virtually all crashes involving rollovers and penetrations are reported since these vehicles would almost certainly be disabled. There were 484 reported crashes where the vehicle was contained or redirected and the percent of unreported crashes was conservatively, based on TABLE 4, assumed to be 30 percent so the total number of crashes was 763. The number of unreported crashes was therefore 763-534=229. The unreported adjusted severity distribution is shown in TABLE 5.

TABLE 5 Low-Tension Cable Median Barrier Severity Distributions including Unreported Crashes

Severity	Contain/Redirected	
	No	%
K	2	0.26
A	4	0.52
B	25	3.28
C	62	8.13
PDO	441	57.80
Unreported	229	30.01
Total	763	100.00

Crash Costs

There are several methods for estimating crash costs. The AASHTO “Red Book” measures accidents costs as those that directly impact the user, including:

- “Injury, morbidity, and mortality of the user;
- Injury, morbidity and mortality of those other than the user who must be compensated;
- Damage to the property of the user;
- Damage to the property of others.” (*9*)

FHWA uses the willingness-to-pay approach or comprehensive costs approach 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." (*9*) Miller *et al*. conducted a study in 1988 which determined the comprehensive costs of crashes related to the KABCO scale and Blincoe did a similar study relating comprehensive costs to the MAIS scale. (*10*,*11*) Each letter of the KABCO scale equals a different severity (e.g., K for a fatal injury and O for a property damage only crash) and corresponds to a different comprehensive cost. The authors noted that "these costs should be updated annually using the GDP implicit price deflator."(*10*) FHWA subsequently updated this study to 1994. (*11*) These comprehensive cost values can be used to calculate the average expected crash cost given a severity distribution like the one shown for low-tension cable median barriers in TABLE 5.

Returning to the low-tension cable median barrier example, the crash severity distribution for collisions where containment or redirection was the outcome including the presumed unreported crashes shown earlier in TABLE 5 can be transformed into an average expected crash cost for a cable median barrier collision as shown in TABLE 6. The average crash cost for a collision with a cable median barrier that results in redirection or containment is, therefore $11,878 in 1994 dollars.

TABLE 6 Average Crash Cost of Low-Tension Cable Median Barrier Crahes

Severity	No.	%	$	Weighted Cost
K	2	0.26	2,600,000	$6,760
A	4	0.52	180,000	$936
B	25	3.28	36,000	$1,181
C	62	8.13	19,000	$1,545
PDO	441	57.80	2,000	$1,156
UNR	229	30.01	1,000	$ 300
Total	763	100.00	Avg. Cost =	$11,878

Equivalent Fatal Crash Cost Ratio

The EFCCR uses the severity distribution of reported crashes for any hazard, adjusted for unreported crashes, then divides the average crash cost calculated for any particular year by the cost of a fatal crash in that same year creating a dimensionless value. This dimensionless value allows for direct comparison of hazard severity between roadside hazards.

Crash costs, like any economic indicator, change continuously so it is desirable to represent crash severity in a non-dimensional way. Similarly, it is also useful to represent average crash severity as a single number rather than a distribution of five values (i.e., KABCO). A single, dimensionless value allows for direct comparison of hazard severity between roadside hazards. The equivalent fatal crash cost ratio (EFCCR) accomplishes this by dividing the average crash cost calculated in any particular year by the cost of a fatal crash in that same year. For example, the average crash cost of low-tension cable median barrier crashes in the State of Washington using the 1994 FHWA comprehensive crash cost was found to be $11,878 as shown in TABLE 6. The cost of a fatal crash in 1994 was estimated to be $2,600,000 so if the average crash cost is divided by the fatal crash cost an EFCCR of 11,878/2,600,000 = 0.0047 is obtained. The average low-tension cable median barrier crash that results in redirection or containment on a divided highway is expected to cost 0.47 percent of the cost of a fatal crash. For example, in 2009 the FHWA recommended a fatal crash cost of $6,000,000 so the average contained/redirected cable median barrier crash cost in 2009 would be 6,000,000 · 0.0047=$28,200.

Speed Affects

Census police reported crash severity data likely includes subtle biases. For example, if collisions with trees on urban roads and streets are collected, there is an unstated bias toward lower speed crashes since that would be the likely impact speed condition on such roads. If one were to take the severity distribution collected on low-speed roads and use it unchanged for high-speed highways, the results may be erroneous. Another example is the low-tension cable median barrier discussed earlier. Nearly all such barriers are used on high-speed divided highways. If a designer wanted to use the severity distributions derived from data collected on high-speed facilities to analyze, say, using a cable median barrier in a narrow low-speed situation, the results might over predict the crash severity.

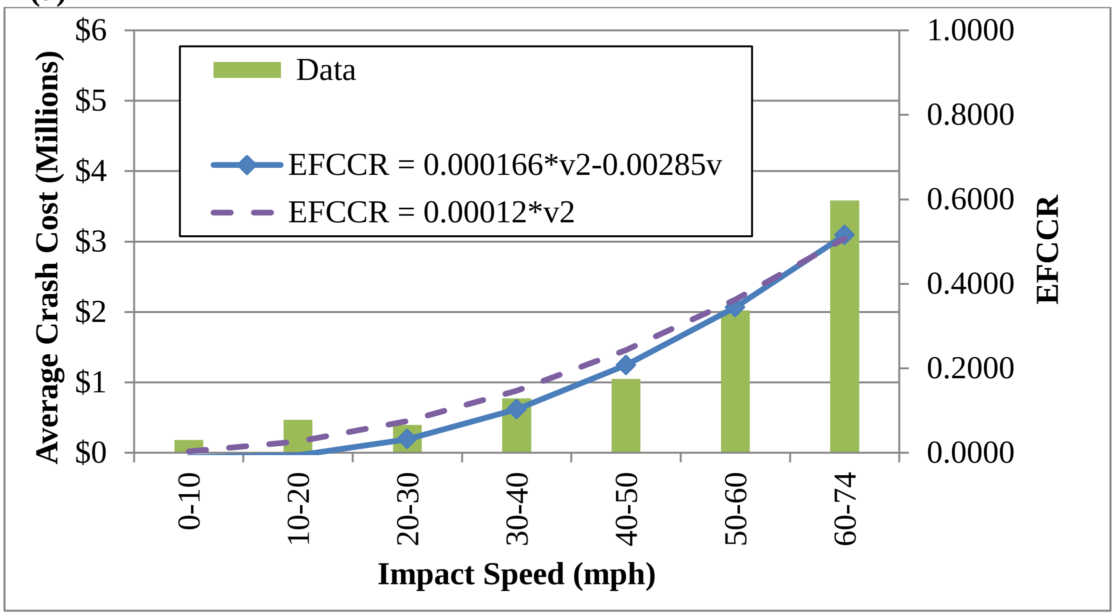
Terrain-related rollovers are a serious type of roadside crash that was not explicitly addressed in prior versions of RSAP. Fortunately, the NCHRP 17-22 data includes numerous terrain rollover cases allowing for an examination of the impact speed affect for this important type of crash scenario. FIGURE 3 shows a plot of average crash cost and EFCCR versus impact speed where the green bars represent the NCHRP 17-22 data and the blue curve is a regression equation calculated by regressing the impact speed to the EFCCR (R^2 = 0.94). The square of the velocity in the regression equation implies a physical relationship with energy which is also a function of speed squared but the linear term makes no particular physical sense. The regression equation was modified to eliminate the linear term in the equation and recalculate the coefficient as shown in the following equation, which resulted in a reasonable fit to the data at all impact speed ranges (i.e., R^2 = 0.93). Note that the EFCCR (and thus injury severity) increases as a function of the impact speed squared, which indicates that injury severity is a function of kinetic energy.

$$EFCCR_{rollover} = \frac{12}{100{,}000}V^2$$

The relationship is linear with respect to velocity squared and increases at a rate of 12/100,000, which basically confirms that risk and crash severity are a function of the energy available to do harm.

The same procedure was performed for crashes involving narrow fixed objects in the NCHRP 17-22 data and the results are shown in FIGURE 3. The red curve is an approximate fit (R^2 = 0.84) of the data as a function of velocity squared similar to what was done for terrain rollovers. Just as for terrain rollovers, the EFCCR, and thus crash severity, increases linearly with respect to impact speed squared.

(a)



(b)

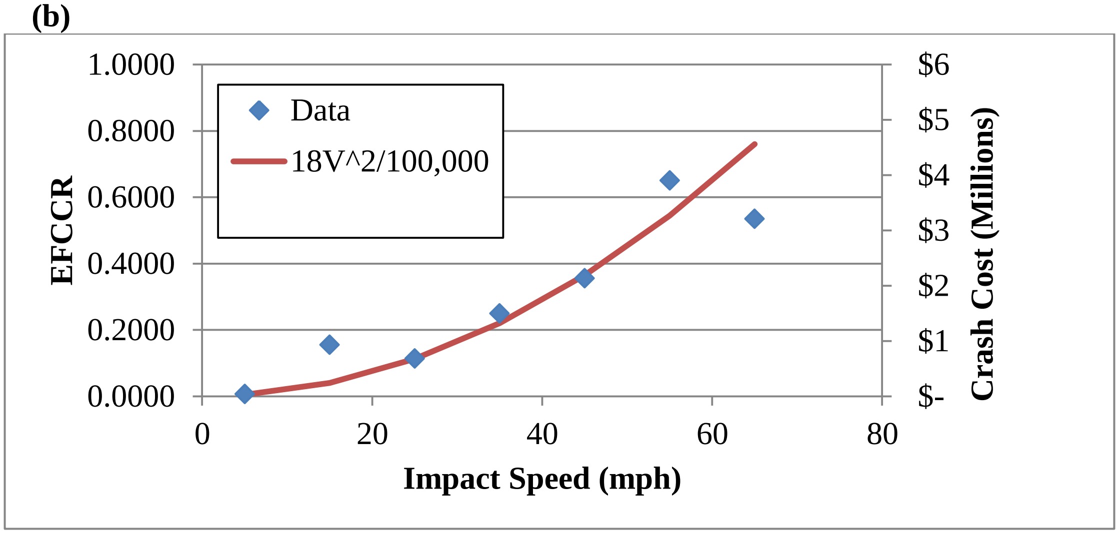


FIGURE 3 EFCCR and Average Crash Cost v. Impact Speed Range for (a) Terrain-Related Rollovers and (b) for Narrow Fixed Objects in the NCHRP 17-22 data.

A similar procedure was applied to guardrails using data from the 17-22 database. As was done for the terrain rollovers and narrow-fixed objects, the database was filtered to include only single-impact crashes. Multiple impact event crashes were excluded from the analysis, because it was not possible to discern which injuries were caused by which hazard. Also, only those cases where the impact occurred on the length-of-need section of the guardrail were considered for the analysis. As a result, only 20 crash cases remained, which was not enough data to determine injury severity for guardrails with any statistical certainty. Interestingly, however, for this small sample set the injury severity was correlated to impact speed in much the same way as was shown for rollovers and narrow fixed objects, as shown in FIGURE 3. An approximate relationship between injury severity and impact speed was developed and is defined by this equation:

$$EFCCR = \frac{2}{100{,}000}V^2$$

The previous three examples have shown that the EFCCR scales according to the square of the impact speed for many types of objects. The coefficient in the these equations can be viewed as a hazard severity index (HSI) that represents how the EFCCR for a particular hazard is scaled according to the velocity squared term. The HSI for a narrow fixed hazard based on the NCHRP 17-22 data was 18, the HSI for a terrain related rollover was 12 and generic longitudinal barrier was 2.

Knowing the HSI for a particular type of hazard allows for the estimation of the expected average crash cost for that hazard at a given impact speed. Unfortunately, impact speed is not available in police-reported crash records so a method is necessary to estimate the affect of speed on EFCCR based on the observed police-reported data. TABLE 7 shows the characteristics of impact speed with respect to posted speed limit for the 890 reconstructed crash cases in the NCHRP 17-22 data. While there are some speed limit ranges that do not have many cases, the trend appears to be that the impact speed is often about 75 percent of the posted speed limit. Thus, if crash severity data were collected on roadways with a posted speed limit of 65 mph, the base condition in RSAP, the average impact speed across all types of impacts would be around 50 mph.

Since it would be impossible to calculate HSI directly except in special cases where the impact speed is available as in the NCHRP 17-22 data, a method for adjusting the observed EFCCR to a common baseline is needed. Instead of tabulating HSI the EFCCR at a presumed impact speed of 50 mi/hr could be calculated as follows where PSL is the posted speed limit in mi/hr:

$$EFCCR = \frac{HSI}{100{,}000}V^2$$

$$EFCCR_{50} = \frac{HSI}{100{,}000}50^2$$

Solving these two equations for HSI and setting them equal and rearranging results in the following equation assuming V = 0.75 PSL:

$$EFCCR = EFCCR_{50}\left[\frac{0.75^2}{2{,}500}\right]PSL^2 = \left[\frac{EFCCR_{50}}{4{,}444}\right]PSL^2$$

TABLE 7 Relationship between Posted and Impact Speed in the NCHRP 17-22 Data

Impact Speed Characteristics	Posted Speed (mph)						
	45	50	55	60	65	70	75
No. of Cases	179	65	353	2	73	110	58
Average Impact Speed	36.3	38.2	38.7	46.9	47.1	42.6	48.4
Percent of Posted Speed	81%	76%	70%	78%	73%	61%	65%

Returning to the low-tension cable median barrier cases from Washington discussed above, the crash data shown was collected on roadways with PSL=60 mi/hr so the average impact speeds are estimated to be about 45 mi/hr, just a little lower than the baseline of 50 mi/hr. Using the equation above and solving for $EFCCR_{50}$ yields $EFCCR_{50\ \text{low-tension cable}} = (0.0047 \cdot 4{,}444)/60^2 = 0.0058$. So, the baseline $EFCCR_{50}$ value saved in the POI lookup table would be 0.0058 and this value would be adjusted for the specific impact speeds determined from the collision module.

In summary, the $EFCCR_{50}$ is a single, dimensionless value at a base speed. This adjustment to a base speed removes any unintentional speed bias in data collection. This value allows for direct comparison of hazard severity between roadside hazards and the use of data gathered for a specific hazard at one speed to be used to evaluate the same hazard for situations were data is not available.

POI Lookup Tables

With the foregoing analyses a POI lookup table can now be assembled. The POI table has three parts based on the possible outcomes of the crash. The $EFCCR_{50}$ for cases where redirection/contact/containment occur is estimated to be 0.0058 as shown in TABLE 8. The percent of vehicles that cross the barrier line by penetrating, breaking away or vaulting over it is 11.37 percent and the 6.61 percent of cases result in a rollover after redirection. $EFCCR_{50}$ are not needed for the penetration/breakaway/vaults and rollovers because there are separate POI tables for these outcomes. Rollovers, for example, have a separate POI table regardless of the cause of the rollover (i.e., terrain or barrier) and the severity of a crash after a penetration has occurred is determined by the next event. For example, if the vehicle penetrates, it may go on to strike another object and the $EFCCR_{50}$ of that object will be used for that event in the collision. The EFCCR for the total collision including all its events is simply the largest EFCCR for any event during the trajectory.

TABLE 8 POI LUT for Low-tension Cable Median Barriers

State/Ref	Contain/Redirect/In-Contact	Penetration/Breakaway/Vault	Rollover
	$\mathbf{EFCCR_{50}}$	%	%
WS	0.0058	11.37	6.61

While simple, the POI lookup table format is quite flexible for modeling different types of hazards. For example, if a census of breakaway sign crashes where only the sign was struck were collected the $EFCCR_{50}$ for that particular sign support could be calculated. Presumably some high percentage of vehicles break the sign away so the second column of the POI table would be a number approaching 100. Similarly, a small percentage of vehicles may rollover after striking the sign and this would be entered in the 3rd column. For a rollover hazard, the $EFCCR_{50}$ would represent the severity of rollover crashes, by definition 100 percent would be rollovers (i.e., 3rd column) and none would be penetrations/breakaway/vaults. Crossing into opposing lanes of traffic can also be modeled. The $EFCCR_{50}$ would represent the average severity of vehicles that entered the opposing lanes, the percent of "penetrations" would be 100 percent since the edge of the opposing lanes is an imaginary line. The percent of rollovers due to crossing the imaginary line would be zero.

CONCLUSIONS

The EFCCR approach uses police level reported crashes and adjusted for unreported crashes. This data is available to designers and policy makers alike, allowing for the removal of arbitrary judgments about severity of various roadside hazards and the compilation of a database of EFCCRs which describe roadside hazard crash severity based on crash data which are currently collected. The EFCCR is a dimensionless value which allows for direct comparison of hazard severity between roadside hazards. The pending updated version of RSAP proposes to incorporate the EFCCR approach to replace the SI approach to predicting crash severity.

ACKNOWLEDGEMENTS

This paper was based on work performed as part of National Cooperative Highway Research Program (NCHRP) Project 22-27, "Roadside Safety Analysis Program (RSAP) Update." The authors would like to thank the NCHRP for its support and the NCHRP project staff and the project panel for their comments, suggestions and direction. The authors are also indebted to Mr. Dave Olsen of Washington State DOT for providing the Washington State crash database.

REFERENCES

1 Mak, K. K., Sicking, D. L, and Zimmerman, K., "Roadside Safety Analysis Program: A Cost-Effectiveness Analysis Procedure," Transportation Research Record 1647, Transportation Research Board, Washington, D. C., 1998.

2 D. L. Sicking, K. A. Lechtenberg, S. Peterson, "Guidelines for Guardrail Implementation," NCHRP Report 639, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C., 2009.

3 Ray, M.H., J.Weir, and J. Hopp. In-Service Performance of Traffic Barriers. NCHRP Report 490. National Cooperative Highway Research Program, Transportation Research Board, 2003.

4 Mak, K.K., Mason, R.L, *Accident Analysis – Breakaway and Nonbreakaway Poles Including Sign and Light Standards Along Highways, Volume1:Executive Summary*, U.S. Department of Transportation, National Highway Traffic Safety Administration, Federal highway Administration, Washington, D.C., August 1980.

5 L. BLincoe, A. Seay, E. Zaloshnja, T. Miller, E. Romano, S. Luchter and R. Spicer, "The Economic Impact of Motor Vehicle Crashes, 2000," National Highway Traffic Safety Administration, Report No. DOT HS 809 446, Washington, D.C., 2002.

6 P. Hammond and J. R. Batiste, "Cable Median Barrier: Reassessment and Recommendations Update," Washington State Department of Transportation, October 2009.

7 Ray, M.H., and J.Weir. Unreported Collisions with Post-and-Beam Guardrails in Connecticut, Iowa, and North Carolina. Transportation Research Record 1743, Transportation Research Board, 2001, p.111-119.

8 M. S. Fitzpatrick, K. L. Hancock and M. H. Ray, "Videolog Assessment of the Vehicle Collision Frequency with Concrete Median Barriers on an Urban Highway in Connecticut," In Roadside Safety and Other General Design Issues, Transportation Research Record No. 1690, Transportation Research Board, Washington, D.C., 1999.

9 American Association of State Highway and Transportation Officials, "User Benefit Analysis for Highways Manual," Washington, D.C., 2003.

10 Miller, Ted R., C. Philip Brinkman, and Stephen Luchter; "Crash Costs and Safety Investment;" Proceedings of the 32nd Annual Conference, Association for the Advancement of Automotive Medicine, Des Plaines, IL, 1988

11 Motor Vehicle Accident Costs, Federal Highway Administration, http://safety.fhwa.dot.gov/facts_stats/t75702.cfm, accessed August 23, 2009.