

Innovative Estimation of Crash Reduction Factors: Application to Horizontal Curves

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Abstract

The crash reduction factor (CRF) for road safety treatments is the expected percentage change in crash rate after a treatment is installed. An innovative method was used to estimate CRFs by incorporating literature reviews, quantifying the quality of the study and the quality of the statistics cited, and disaggregating CRFs in terms of treatment, speed and type of crash. For treatments involving horizontal curve alignment, high reliability literature (reliability score greater than 20) was difficult to find. Nevertheless, the findings indicated that for crash types other than “head-on”, the CRFs in current use appeared to be too high.

Background

The NSW Centre for Road Safety (CRS) uses an existing set of CRFs, determined some years ago, to calculate the expected percentage change in crash rate after a road treatment. A need was identified to establish revised CRFs based on the best available current evidence, in order to rigorously prioritise proposals for funding in Road Safety Infrastructure Programs.

There are many different methods to calculate CRF (Cairney et al., 2012) yet it is sometimes difficult to claim statistical reliability because the number of crashes is generally low. At the request of CRS, Safe System Solutions Pty Ltd examined CRF identification methods for five treatments related to horizontal curve re-alignment, as shown in the rows of Table 1.

Table 1. Horizontal curve re-alignment categories

Original radius range (metres)	Radius range after horizontal curve re-alignment (metres)
200–600	600–1000
200–600	>1000
<200	600–1000
<200	>1000
600–1000	>1000

Method

The innovative method, suggested by CRS, to devise CRFs was a literature-review based method, incorporating statistics, quantifying the quality of the study and the quality of the statistics cited. In addition, CRFs were disaggregated in terms of treatment, speed categories and crash types based on NSW RUM (Road User Movement) codes. Disaggregation was important because CRFs vary greatly by these variables.

Each item of literature was objectively assessed for the reliability of its findings (Austroads, 2010) by calculating two scores: the robustness of the result, depending on the quality of the research (study rating) and the statistical confidence levels (accuracy rating). These were combined to produce a reliability score for each CRF which impacted on the weighted-mean CRF. That is, studies with high reliability scores had greater weighting in the revised CRFs. There is ample evidence that the weighted mean is a more reliable way of combining information than, for example, a mean of means (Kendall and Comer, 2010: p.67) and this is widely used in climate

modelling wherein the results of an ensemble of models has been shown to be more reliable than the results of any single model (Flato et al., 2013: p.766).

Study Rating

A ‘study rating’ (SR) was assigned to each piece of literature for the robustness of the study according to Austroads Report AP-T151/10 (2010) as shown in Table 2. A rating of 1 indicated poor robustness of study methodology and 5 indicated a rigorous and appropriate study methodology. In cases where the matrix did not properly describe the study, expert judgement was applied.

Table 2. Methodology for Selecting Study Rating (Turner, et al., 2010)

Study type	Descriptive statistics only	Simple statistical analysis	Complex statistical analysis
Simple study – no controls; no traffic volume.	1	1	(Not likely)
Study without control group but traffic volume.	2	2	(Not likely)
Study using comparison group/all crashes etc. to control for general crash trends.	3	4	5
Study controlling for general crash trends and the regression-to-the-mean effect, generally using controls based on similar sites.	3	4	5
Study using matched comparison group, based on crash rates controlling for general trends and regression-to-the-mean.	3	4	5

Accuracy Rating

An ‘accuracy rating’ (AR) was also assigned to each finding within a study that reflects the range of confidence levels for the statistical analysis completed (Table 3). The accuracy rating attempts to quantify the confidence in the finding of the study. As will be discussed subsequently, a compromise needs to be made between the full statistical information that would be needed to produce an unambiguous accuracy rating, and the statistical information that is generally provided in a published research finding. The latter usually consists of one statistical measure of either significance, confidence or variance. Thus, as an interim measure, the methodology depicted in Table 3 considers these three factors

Table 3. Methodology for selecting accuracy rating

Accuracy rating	p-value	95% confidence limit	Standard deviation/error
1	> 0.2	>20%	>10%
2	0.11-0.2	<20%	<10%
3	0.051-0.1	<15%	<7.5%
4	0.01-0.05	<10%	<5%
5	<0.01	<5%	<2.5%

Reliability Score

A reliability score (RS) is generated from the literature's study rating and accuracy rating; a higher reliability score indicating greater applicability to CRFs in NSW. The reliability score is a multiplication of the study and accuracy ratings.

For example, if a CRF that was examined in the literature was determined using 'before and after' data, considered changes in traffic volume but was not examined against a control group and used simple statistical analysis; the study would be given a study rating of 2. The CRF was reported as being 70%, with a 95% confidence interval (55%, 85%) and a confidence limit of 15%. The AR of this study is 2.

The overall RS of this study would be 4, from multiplying the study and accuracy ratings. Table 4 reflects the confidence level applied to literature based on its reliability score.

Table 4. Ranges of reliability score and level of confidence

Reliability Score	Level of confidence
0-5	Very low (VL)
6-15	Low (L)
16-20	Medium (M)
21-25	High (H)

Studies that produced a reliability score of 15 or less are not considered reliable and should only be considered for a CRF if other higher reliability literature could not be identified. For the purpose of this paper, and to illustrate all the material that has been gathered, lower reliability studies have been retained in the spreadsheets though we maintain anonymity of these authors.

Studies that consist of technical guidelines or reviews, rather than original research, pose a difficulty in this regard. The United States prefers to use a crash modification factor (CMF) rather than a crash reduction factor (CRF) where the CMF is a multiplication factor that is applied to existing crash rates to determine the new crash rate following road treatments. An on-line CMF clearinghouse has been established at <http://www.cmfclearinghouse.org/index.cfm>

The CMF clearinghouse uses a star system of ratings with five stars as the highest. For CMF values with stars we have used a reliability score of 5 for each star. Thus, for example, a CMF three star rating is assigned a reliability score of 15.

Un-starred CMF values pose a dilemma because “The Clearinghouse uses the adjusted standard error to provide a surrogate star quality rating for all CMFs that were imported from the Highway Safety Manual (HSM), so without this value, a star rating is not possible. In the HSM, there is a notation for these CMFs that ‘the standard error of the CMF is unknown’. This is generally because the CMF was developed either through an expert panel or was obtained from an older study for which the standard error was unknown.” (CMF Clearinghouse, 2017). A similar issue applies in relation to CRF values based on Austroads documents. In such situations, expert judgement has been used.

Disaggregation

CRS sub-divides the CRFs for the five horizontal alignment treatment categories listed in Table 1 into ten crash categories on the basis of Road User Movement (RUM) codes as follows:

- Head-on (RUM 20 and 50)
- Off Left on Right-Hand Bend (RUM 80)
- Off Left on Right-Hand Bend Hit Object (RUM 81)
- Off Right on Right-Hand Bend (RUM 82)
- Off Right on Right-Hand Bend Hit Object (RUM 83)
- Off Right on Left-Hand Bend (RUM 84)
- Off Right on Left-Hand Bend Hit Object (RUM 85)
- Off Left on Left-Hand Bend (RUM 86)
- Off Left on Left-Hand Bend Hit Object (RUM 87)
- Out of Control on Bend (RUM 88).

In addition, each of these crash categories is further subdivided into three speed categories:

- 60 km/h or less
- 70 km/h or 80 km/h
- 90 km/h or greater.

In the ideal case there would be 3 studies for each of these subdivisions making $150 \times 3 = 450$ pieces of data. We note that such a level of disaggregation has not been achieved for any past CRF studies, including those by the CMF Clearinghouse. Thus in many cases the CRF has to be calculated on the basis of studies that do not differentiate on the basis of RUM and speed.

Results

Figure 1 depicts, as an example, the results for treatment of the horizontal alignment from radius <200m to >1000m for the requisite RUM categories. CRFs reported in the literature for crashes other than ‘head-on’ were noticeably lower than the existing CRFs used by CRS, indicating that this treatment is less effective at reducing high speed crashes than is presently assumed. For this treatment the existing CRF approximates the literature-weighted mean for head-on crashes but overestimates for all other crash types. This study highlighted that though there is extensive literature that can be used to sub-divide CRFs, literature of high reliability, with reliability score greater than 20, for horizontal curve re-alignment remains difficult to find.

RUM Code groups	Total crashes				Head-On 20; 50				80			
	Crash Description				Head-On				Off Left on R/H Bend			
	Speed zone				Head-On				Off Left on R/H Bend			
	60k or less	70k or 80k	90k or greater	Reliability	60k or less	70k or 80k	90k or greater	Reliability	60k or less	70k or 80k	90k or greater	Reliability
Existing default CRF used by CRS						20	40			65	95	
US Author 1 (speeds up to 45 mph only)	41.5			4								
Australian Web Site			80.5	1								
Australian Author 1										61.1		8
Australian Author 2			74.4	16								
Australian Author 3			100	2								
US Report 1	16.2	42.1	67.9	16								
Turner, Singh and Nates, 2012					23	23	23	20	16.9	16.9	16.9	20
Ona et al., 2013			25.4	20								
Montella, 2009							68.5	20			89	20
Othman, Thomson, Lanner, 2009									60.4			21
US Web Site Study 1			69.5	15								
US Web Site Study 2									66			15
Average Reliability	10.0	16.0	11.7		20.0	20.0	20.0		20.0	18.7	16.0	
Literature-based weighted-mean	21.3	42.1	58.7		23.0	23.0	45.8		16.9	46.4	54.3	
Confidence (based on the average reliability)	L	M	L		M	M	M		M	M	M	

81				82				83				84				85				86				87				88			
Off Left on R/H Bend Hit Object				Off Right on R/H Bend				Off Right on R/H Bend Hit Object				Off Right on L/H Bend				Off Right on L/H Bend Hit Object				Off Left on L/H Bend				Off Left on L/H Bend Hit Object				Out of Control on Bend			
60k or less	70k or 80k	90k or greater	Reliability	60k or less	70k or 80k	90k or greater	Reliability	60k or less	70k or 80k	90k or greater	Reliability	60k or less	70k or 80k	90k or greater	Reliability	60k or less	70k or 80k	90k or greater	Reliability	60k or less	70k or 80k	90k or greater	Reliability	60k or less	70k or 80k	90k or greater	Reliability	60k or less	70k or 80k	90k or greater	Reliability
	65		95		65		95		65		95		65		95		65		95		65		95		65		95		65		95
		61.1	8			61.1	8			61.1	8			61.1	8			61.1	8			61.1	8			61.1	8			61.1	8
15.7	15.7	15.7	20	15.7	15.7	15.7	20	15.7	15.7	15.7	20	15.7	15.7	15.7	20	15.7	15.7	15.7	20	15.7	15.7	15.7	20	15.7	15.7	15.7	20	15.7	15.7	15.7	20
		88.4	20			88.4	20			88.4	20			88.4	20			88.4	20			88.4	20			88.4	20			88.4	20
		65.9	21			65.9	21			65.9	21	52.7			21	52.7			21	52.7			21	52.7			21	52.7			21
		66	15			66	15			66	15	66			15	66			15	66			15	66			15	66			15
20.0	18.7	16.0		20.0	18.7	16.0		20.0	18.7	16.0		20.0	18.7	16.0		20.0	18.7	16.0		20.0	18.7	16.0		20.0	18.7	16.0		20.0	17.5	15.8	
15.7	48.0	53.6		15.7	48.0	53.6		15.7	48.0	53.6		15.7	43.0	53.6		15.7	43.0	53.6		15.7	43.0	53.6		15.7	43.0	53.6		15.7	37.3	46.2	
M	M	M		M	M	M		M	M	M		M	M	M		M	M	M		M	M	M		M	M	M		M	M	L	

Figure 1. Results showing CRF values for horizontal alignment treatment from radius < 200 m to > 1000m disaggregated by speed class and RUM code group. Reliability scores 15 to 20 are medium (M) reliability. Studies with reliability scores <20 are kept anonymous.

Discussion

Undertaking this study has demonstrated the complexity associated with the derivation of crash reduction factors. This complexity is methodologic, philosophic and analytic.

In terms of methodology, the favoured way to calculate a crash reduction factor is to use a ‘before-after’ approach in which the crash rate for a curve is measured before re-alignment, and then measured after re-alignment, and the two values are compared (Koorey, 2009; Montella, 2009). It is hard, if not logically impossible, for such studies to produce valid statistics (Shen and Gan, 2014). To obtain valid statistics requires a database with a large number of crashes. It is very unusual for a single curve to have had sufficient numbers of crashes both before and after to produce valid statistics. A very long time, both before and after, is usually needed to obtain suitable crash statistics and it is rare for such statistics to be available. In addition, the aim of the treatment is

to reduce crash numbers, whereas statistical validity seeks to have a large number of replicates. If there continue to be a large number of crashes after treatment, then serious questions would be asked as to the appropriateness of the treatment. There are, of course, appropriate statistical tests, such as the chi-squared, to examine the before-after difference that can be used when the difference is large even when the ‘after’ crash rate is small.

These statistical issues are important because the effectiveness of a treatment cannot be judged solely by the statistical significance, confidence or variance of the underlying data. A study could, for example, be statistically significant but be based on so few data points that the statistical power is low. Studies with low statistical power are likely incorrectly to ascribe crash reductions to a treatment that does not actually reduce the crash rate. Thus even though we acknowledge that an estimate of statistical power should be included in Table 3, we are not aware of any published study that reports the statistical power associated with the findings.

During major roadworks, multiple curves are usually aligned as part of the project, as for example in the Koorey (2009) study in New Zealand, so that the application of a CRF to an individual curve is less clear. In addition, uncertainties will remain over whether the before and after segment lengths are the same; and whether vehicle numbers have changed so that analysis of raw crash statistics, without correcting for vehicle numbers, may not be appropriate.

It is therefore more usual to use a cross-sectional approach in which categorised crash numbers and vehicle counts are obtained from roads in different locations and a CRF deduced from crashes on, for example, all curves in NSW compared to all straight sections in NSW. This approach is much used and has great merit but for this study we found that the categories that have been used are broad and not sufficiently fine-grained to permit examination of the differences between curve radius, speed limit, road treatment and RUM groups.

It should, in theory, be possible to undertake such a study on crash statistics and vehicle numbers by a detailed examination of individual crashes in NSW but it is not clear whether fine-graining the data to this level would produce valid statistics.

This also raises the philosophic issue of whether curve radius and speed limit are the correct variables to study. There is no doubt that crash rates on curves are greater than crash rates on straight sections (Anderson et al., 1999). There is also no doubt that there are more crashes when vehicles travel at a greater speed – all other factors being equal (Edquist et al., 2009). The queries relate to whether these are sufficient in themselves to categorise crashes, and how they should be measured (Hauer, 1999). Some studies deal with radius of curvature. However few, if any, curves are purely radial and some studies attempt to account for the spiral transitions. Other studies use angle of deflection rather than radius of curvature. In terms of speed, there is a consensus that vehicle speed is a more accurate determinant of crashes than posted speed limit, but there is uncertainty as to whether it is the curve entry speed, the minimum vehicle speed on the curve, or the difference between the two that is most relevant.

In terms of analytics, if we have decided that the vehicle speed is relevant, then which variable is the most relevant when examining a population (in the statistical sense) of vehicles: mean entry speed, maximum entry speed, or as commonly assumed, 85th percentile speed?

Most cross-sectional studies extend the analysis of the statistics and incorporate the results into a crash prediction model (CPM). This has advantages in that such a model can be used to extrapolate the existing statistics to other curves and other speeds. Most of these CPMs are based on regression analyses in which, unfortunately, the correlation coefficients are low – indicating the complexity of the problem. Even if the CPM is based on a high correlation coefficient, the validity of extending the CRF outside of the range of the measured data is unknown, as is the validity of extending a CPM determined in one geographic region to another region.

Despite these complexities the idea of a crash reduction factor, or a crash modification factor, remains a useful tool for the road engineer and practitioner.

Conclusions

The study appraised the available published literature and utilized it in a robust approach to estimating crash reduction factors that was developed by CRS. This enabled better quantification of the effect that horizontal curve re-alignment treatment has on reducing crashes. The findings demonstrate that for crash types other than “head-on”, the existing CRFs used by CRS appear to be too high.

Though the value assigned to the study reliability is objective, being based on documented criteria, there is a subjective element in deciding whether to incorporate low reliability studies or to exclude them. This abstract has included all studies in order to illustrate the method. Present CRS policy is to exclude low reliability studies.

The same approach has also been used internally by CRS to establish revised CRFs for all road safety treatments used in the NSW Safer Roads Program.

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