Potential for Safety Improvement of Existing Roads

Montella, A.
Assistant Professor - University of Naples "Federico II" – Department of Transportation Engineering "Luigi Tocchetti"

SYNOPSIS

Safety reviews of existing roads aim to identify any features which may lead to future crashes, so that remedial treatments may be implemented before crashes happen. Safety reviews are complementary and not alternative to accident investigation studies. Accident investigation is a "reactive programme", it examines past accidents and aims to remove or change the features that contributed to those past crashes. Safety review is a "proactive programme", aimed at reducing road accidents before they occur. Accident investigation tend to concentrate on single locations, whereas safety reviews are more akin to mass action studies.

Safety reviews may be high cost-effective, but the subjective nature of the process may give rise to inconsistencies which limit their effectiveness. To address this issue, a technique to support road safety reviews in order to quantify the safety gains that could be achieved by addressing the problems identified in the review process is presented.

The approach is based on known accident relationships, and a systematic process has been described to determine which road features should be investigated and how each feature should be evaluated during the review. As a result of the process, a potential for safety improvement index (PFI) is calculated. PFI represents a measure of the accident increase due the identified safety items. That is, PFI is a measure of the safety gains which can be obtained by eliminating the safety issues.

The validity of the PFI has been evaluated by comparing the results of the PFI index, which has been assessed in 400 kms of rural two lane highways, with expected collision frequency. Collision frequency has been determined by applying a collision prediction model, calibrated in the study network, and has been refined by applying the Empirical Bayes technique. Correlation between EB safety estimates and PFI values is highly significant, with 93% of the variation in the estimated number of accidents explained by the PFI value. The level of agreement between the results of the EB estimates and the PFI has been evaluated also by the Spearman's rank-correlation coefficient. Sites were ranked according to both the EB estimate and PFI, with the results of the Spearman correlation indicating agreement at a 99.9% significance level.

Due to the validation and quantifiable nature of the PFI, the procedure can be used to support road safety reviews, accident investigation, and decision-making. High risk segments, where safety measures that can reduce accident frequency and/or severity do exist, and specific safety issues, which contribute to unsafety, can be identified. The procedure can be helpful also to support the safety reviews carried out on low volume roads, where often accurate accident data do not exist.

Potential for Safety Improvement of Existing Roads

INTRODUCTION

Road safety audit is a formal safety examination of a proposed change to an existing road, or a new highway scheme, made by an independent and qualified team (Austroads, 2002a). Road safety audits were first developed for checking the safety performance of new road designs and improvement schemes, and some of the principles have now been extended to apply to existing roads. When the audit process is applied to an existing road it is called a road safety review.

In service safety reviews aim to identify any features which may lead to future crashes, so that remedial treatments may be implemented before crashes happen. As a result of the review, a report listing safety issues and recommendations for improvement is written.

Safety reviews are complementary and not alternative to accident investigation studies. Accident investigation is a "reactive programme", it examines past accidents and aims to remove or change the features that contributed to those past crashes. Safety review is a "proactive programme", aimed at reducing road accidents before they occur. Accident investigation tend to concentrate on single locations, whereas safety reviews are more akin to mass action studies. Moreover, the accident records are far from complete, not only in coverage, but also in detail. In countries with poor accident statistics, the role of safety reviews as complement to accident investigation studies becomes more important.

Safety reviews may be high cost-effective. An Austroads research study (Austroads, 2002b) reports that the analysis of a range of existing roads reviews indicated benefit/cost ratios (BCRs) between 2.4:1 and 84:1, when considering the value of completing the proposed actions identified in response to the review findings. The BCRs of individual proposed actions within existing road reviews ranged between 0.003:1 and 460:1. Over 78% of all proposed actions had BCRs > 1.0.

Even if safety reviews may be cost-effective, the subjective nature of the process may give rise to inconsistencies which limit their effectiveness. The fact that the results of the review are a matter of judgement does not downgrade the value of the safety review. However, caution must be exercised if the results of one safety review are compared with another. There is no guarantee that two different review teams reviewing the same network will come up with exactly the same results. The matter is further compounded if different teams review different networks. To address this issue, in this paper a quantitative method of existing roads safety impact assessment is presented.

RISK ASSESSMENT IN SAFETY REVIEWS

When considering review recommendations, capital expenditure may be required to address the safety issues identified to reduce the collision risk, and the owner would need to prioritize the remedial actions. Risk assessment assists in determining the priority of safety issues identified by the safety reviews. Below, main existing roads safety impact assessment procedures are presented, and advantages and drawbacks in their application during the safety review process are empathized.

Road Risk Index

In British Columbia, a criterion for a driver-based evaluation of road safety risk has been developed (de Leur and Sayed, 2001). The process for the development of the road safety risk index is not a formal safety review. The process is based on well defined and quantifiable characteristics of road features that are studied and scored while completing a drive through review. These scores are combined to produce an overall safety index, formulated by combining three components of risk; namely the exposure of road users to road hazards, the probability of becoming involved in a collision and the resulting consequences should a collision occur. For each factor, the three aforementioned elements of risk are evaluated basing on defined threshold values. By combining the scores for the three components of risk, specific and combined risk index are assessed. The specific index defines the risk associated to each road feature while the combined risk defines overall risk.

The methodology can effectively support safety reviews results, and the risk score can be used to support road safety analysis and decision making. Nevertheless, it requires input data that in many instances are not available to the audit team.

Road Protection Score

In 2002 the AA Foundation for Road Safety Research launched the Euro Road Assessment Programme. Part of the programme is the development of a procedure for a drive through inspection of routes and the assessment of the Road Protection Score.
The Road Protection Score has been trialled by scoring a sample of roads in seven different countries and further development of the scoring system has been proposed (Lynam, et. al., 2004). A direct visual inspection of the road quality was used and the roads were assessed, using Road Protection Score to measure the extent to which roads offer protection from accidents and from injury when collisions do occur. Risk tables have been developed, based on speed limit and road design features, for the injury protection that the road provided in relation to three key accident types: head on collisions, single vehicles leaving the road and side impacts at intersections.
The Road Protection Score differs from normal road safety reviews because its aim is to assess the general standard of a route rather than identify individual sites of concern, but the methodology looks very promising.

New Zealand RISA

In New Zealand safety reviews of existing roads have been extensively carried out in the last decade. Transfund safety audit of existing roads manual (Transfund, 1998) defines a risk assessment procedure that involves the prediction of the frequency and severity of potential accidents associated with each problem identified in the audit report. A matrix is provided on which one axis is exposure to risk and on the other axis is the severity of the expected crash. The cells of the matrix are filled with words like “Low”, “Medium”, “High” level of importance.
During the period 1995 to 2002 approximately 40 audits were completed and a database used to store the results. In part it was this database that started to show the inadequacies of the comparability of the data being collected. In order to assess the repeatability of the procedure, Transfund commissioned two independent Safety Audits of the same road network. The lack of common findings and the variation in assessing Risk Level Ratings raised concerns about a lack of repeatability (Transfund, 2001). Transfund also commissioned a study into the relationship between the issues raised by auditors and actual traffic crashes. This work produced widely varying results and showed that while some of the assigned risk ratings were accurate, others were less accurate. Of particular concern was the finding that some issues that can be shown to contribute to crashes were not being identified during audits.
Basing on the above considerations, Transfund (Transfund, 2003) is developing a rating methodology to improve the systematic quantification of the safety impacts associated with items identified during safety reviews named Road Infrastructure Safety Assessment.

POTENTIAL FOR SAFETY IMPROVEMENT INDEX

General Aspects of the Procedure

The main objective of developing a potential for safety improvement index (PFI) was to produce a technique to support road safety reviews in order to quantify the safety gains that could be made by addressing the problems identified in the review process. Key elements in developing the PFI procedure were as follows:

- Ensure that the PFI index can be assessed as part of the safety review process without relevant supplementary work;
- Ensure that the process is applicable to low volume roads;
- Construct the process such that the results can be used to prioritize locations for that hold promise for accident reduction;
- Ensure that the potential for safety improvement index is valid by comparing the results with collision history.

The procedure looks at rural two lane highways and does not take into account junctions. The PFI assessment is based on evaluation of safety items that have a known impact on road safety. For each safety issue, the relative increase in accident number and severity have been determined on the basis of existing literature. Safety auditors, after a preliminary inspection of the road, by examination of videos recorded during the inspection, identify the presence of individual features and measure the approximate exposure length of each feature, dividing the road in segments 200 m long. By combining the different safety issues, exposure length and relative increase in accident frequency and severity, the relative risk increase for injury and fatal accidents is computed. Potential for improvement is assessed both for injury and fatal accidents; it is equal to the product of the relative risk and traffic volume (raised to a power coefficient that depends on the accident prediction model calibrated in the study network, or in roads with similar characteristics in the same geographical area).

Formulation of the PFI index

Ten general safety issues have been identified: markings, longitudinal rumble strips, pedestrian crosswalks, delineation, signs, alignment, pavement, roadside, cross section, accesses. General issues are divided in detailed issues (see Table 1). The safety issues have been selected taking into account that they are common issues and that effective remedial measures do exist and have already proven their effectiveness.
In each section of the road segment (it is suggested to assume one section any 200 m), the audit team scores the detailed issues: 0 if the issue is not present, 1 if the issue is present (punctual items, such as not breakaway barrier terminals are scored by their number). Scores are multiplied for their relative effect (e.g., the relative effect of not breakaway terminals is 25 m, whereas the relative effect of edge lines missing is equal to the length of the segment) and summed; the ratio between the length of the safety item and the total length of the road (twice the length of the road for roadside safety items) represents the exposure of the safety item.
Relative Risk of the detailed issue j, which represents the global estimated increase in injury accidents risk due to the issue j, is computed by the formula:

$$RR_j = Expo_j \times \Delta A_j \times P_j \quad (1)$$

where:
RR_j = Relative Risk of detailed issue j;
$Expo_j$ = exposure of the safety item j;
ΔA_j = estimated relative increase in injury accidents risk (%) due to the issue j;
P_j = percentage of accident types affected by the issue j.

Fatal accidents Relative Risk of the detailed issue j is computed by the formula:

$$RR_{faj} = RR_j \times (1 + \Delta S_j) \quad (2)$$

where:
RR_{faj} = fatal accidents Relative Risk of detailed issue j;
ΔS_j = estimated relative increase in accident severity (fatal accidents/injury accidents) due to the issue j.

Relative Risk of the general issue i is computed by the formula (equal to the formula for fatal accidents):

$$RR_i = \sum_{j=1}^{n} RR_j \quad (3)$$

where:
RR_i = Relative Risk of general issue i;
RR_j = Relative Risk of the detailed issue j associated to the general issue i;
n = number of the detailed issues associated to the general issue i.

Relative Risk of the segment, which represents the global estimated increase in injury accidents risk due to identified issues, is computed by the formula (equal to the formula for fatal accidents):

$$RR = RR_1 + RR_2 \times (1 + RR_1) \times RR_3 \times (1 + RR_2) \times (1 + RR_1) + \ldots \quad (4)$$

where:
RR = Relative Risk of the segment;
$RR_{1, 2, 3, .., n}$ = Relative Risk of the general issues.

Potential for Safety Improvement (PFI) represents a measure of the accident increase due the identified safety items. That is, PFI is a measure of the safety gains which can be obtained by eliminating the safety issues. It depends both on the relative risk and the traffic volume, and is equal to:

$$PFI = RR \times (AADT)^b \qquad (5)$$

where:
AADT = average annual daily traffic [(veh./day)/1000];
b = exponent of AADT in the pertinent accident predictive model.

Potential for Improvement of fatal accident (PFI_{fa}) is equal to:

$$PFI_{fa} = RR_{fa} \times (AADT)^b \qquad (6)$$

Safety Issues

Many road features impact traffic safety, but not all factors can be considered in determining the PFI. It is important to point out that the safety effect of each item depends also on others road, traffic and environmental features which all together play a key role. However, in order to make the assessment more objective it has been decided to assign a relative increase in injury accidents risk and in fatal accidents risk for each factor (see table 1) independently from the interaction of the different road features. The audit team will decide if one item applies in relation to road contest (e.g. chevron missing has to be evaluated in relation to the road alignment and perception).
Much literature has investigated the effect of road marking on accidents, showing that road markings improvements are likely to be cost-effective. Detailed items considered are: edge lines missing or inadequate, center line missing or inadequate, and no overtaking line missing in sections where passing sight distance is not provided. Relative increase in injury accidents risk has been assumed equal to 8% for edge lines missing, and equal to 13% for center line missing (Transfund, 2003). Relative increase for no overtaking line missing has been assumed equal to 50 %; this factor applies only to head on accidents (Transfund, 2003).
A very effective safety measure, which has been applied recently by many road authorities, is the installation of shoulder rumble strips (or audible edge lines), that are warning devices intended to alert drivers that they are leaving the traveled way and that a steering correction is required, and center line rumble strips (or audible center line), that are intended to alert drivers that they have crossed the center of the road and are traveling in the opposing traffic lanes. The former have positive effect on run off the road accidents, the latter on head-on accidents. Basing on TAC guidelines suggestions (Bahar, et al., 2001), relative increase in accident risk due to rumble strips missing has been assumed equal to 40% for shoulders and equal to 11% for center line, although other literature sources suggest even greater values (e.g. Persaud, et. al., 2004, Huang, et al., 2002).
Missing or ineffective crosswalks in areas with pedestrian activity are one of the main contributory factors in pedestrian accidents. Relative increase in accident risk due to this safety issue has been assumed equal to 60% (Austroads, 2004, Proctor, et al., 2001). Length of road used as reference for exposure calculation is the total length of road in areas with pedestrian activity.
Delineation is an important safety factor in any condition. On severe curves, which can be defined as curves where operating speed difference between tangent and curve is greater than 20 km/h (Lamm, et al., 1999), chevron missing or ineffective can lead to an accident risk increase equal to 20% (Transfund, 2003). It has been assumed that this factor applies to a segment 200 m long. Guideposts or barrier reflectors damaged or missing on non severe curves and on tangents are also a safety deficiency; relative risk factor has been assumed equal to 8% (Transfund, 2003). Some studies report positive effects associated with the installation of permanent raised pavement markers (PRPMs), however recent comprehensive research tasks state that PRPMs have positive effect only under certain particular conditions (Bahar, et al., 2004) and it has been decided to do not include the PRPMs in the safety issues.
Road signs which have greatest effect on traffic safety are the warning signs. They call attention to unexpected conditions and to situations that might not be readily apparent to road users, giving suggestions about the safe behavior. For curve warning signs missing or ineffective on severe curves, the relative risk factor has been assumed equal to 10% (Transfund, 2003).
Road alignment is the road factor with greatest safety impact, even if upgrading road alignment is generally quite expensive. Circumstances where severe curve realignment is needed (e.g., horizontal radius less than 150 m following long tangents) give rise to an increase in the risk accident up to 100% applying accident modification factors reported in (Harwood, et al., 2000). Inadequate sight distance on horizontal and vertical curves is a common accident contributory factor. Relative increase in accident risk due to inadequate sight distance (<75% stopping sight distance) on horizontal curves caused by removable obstacle has been assumed equal to 5% (Kentucky Transportation Center, 2003); relative increase in accident risk due to inadequate sight distance (<50% stopping sight distance) on crest curves has been assumed equal to 50% (Hassan, et al., 1996).

Table 1 Safety items

General issues	Detailed issues	ΔA	ΔS	Related accidents	Related effect
Markings					
	Edge lines missing or inadequate	8%	0	All	Segment
	Center line missing or inadequate	13%	0	All	Segment
	No overtaking line missing	50%	0	Head-on	Segment
Longitudinal rumble strips					
	Audible edge lines missing		0	Run off the road	Segment
	Audible center line missing		0	Head-on	Segment
Pedestrian crosswalks					
	Missing or ineffective crosswalks in areas with pedestrian activity	60%	0	Hit pedestrian	Segment
Delineation					
	Chevron missing or ineffective on severe curve	20%	0	All	200 m
	Guideposts (or barrier reflectors) damaged or missing	8%	0	All	Segment
Signs					
	Curve warning missing or not visible on severe curve	10%	0	All	200 m
Alignment					
	Severe curve realignment needed	100%	0	All	200 m
	Inadequate sight distance on horizontal curves caused by removable obstacles (<0.75 SSD)	5%	0	All	200 m
	Inadequate sight distance on crest curves (<0.5 SSD)	50%	0	All	200 m
Pavement					
	Inadequate skid resistance	30%	0	Wet	Segment
Roadside					
	Unshielded embankment (3<h<6m and i>0.5)	80%	800%	Run off the road	Segment
	Unshielded embankment (h>6m and i>0.5)	100%	1400%	Run off the road	Segment
	Embankment shielded with very low containment (or ineffective) safety barrier (3<h<6m and i>0.5)	10%	70%	Run off the road	Segment
	Embankment shielded with very low containment (or ineffective) safety barrier (h>6m and i>0.5)	11%	100%	Run off the road	Segment
	Ditch	50%	150%	Run off the road	Segment
	Trees	90%	1000%	Run off the road	50 m
	Rigid utility poles	90%	1000%	Run off the road	50 m
	Rigid obstacles	90%	1000%	Run off the road	25 m
	Not breakaway barrier terminals	60%	300%	Run off the road	25 m
	Missing transition between barriers (or between barrier and wall)	60%	300%	Run off the road	25 m
	Inadequate bridge rails	6%	2000%	Run off the road	25 m
Cross section					
	Lane width				
	very narrow <2.75 m	5-50%$_{f(AADT)}$	0	Run off the road, Head-on, Sideswipe	Segment
	narrow <3.25 m	2-30% $_{f(AADT)}$	0		Segment
	Shoulder width				
	very narrow <0.3 m	9-40% $_{f(AADT)}$	0	Run off the road, Head-on, Sideswipe	Segment
	narrow <1.0 m	6-20% $_{f(AADT)}$	0		Segment
	Missing passing lane in section where there are not passing opportunities	33%	0	All	Segment
	Missing climbing lane where high speed difference between cars and trucks do exist in mountainous terrain	33%	0	All	Segment
Accesses					
	Excessive density of uncontrolled accesses (>10/km)	75%	0	All	Segment

The pavement factor which more has effect on road safety is friction. Relative risk increase when skid resistance is inadequate has been assessed equal to 30% (Transfund, 2003); it applies to wet road accidents. Experimental results show wet accident increase in poor friction condition equal to 60% (Shen, et al., 2004).

Roadside improvement measures may reduce either the accident frequency or severity. Accident frequency can be reduced removing or relocating roadside hazards so as to provide a clear zone along the roadside that provides errant vehicles an opportunity to recover and return to travel way or to come to a controlled and safe stop. Accident severity can be reduced making the hazards forgiving or shielding the hazards with road restraint systems. Injury accidents and fatal accidents risk increase, for different road features, have been calculated by using the AASHTO severity indices (AASHTO, 1996). In relation to design speed, severity

indices for each roadside feature define the probability of injuries and fatalities, given a collision. By comparing the injuries and fatalities probability of roadside obstacles with those of safety barriers, or of breakaway terminals, the risk increase factors reported in table 1 have been obtained. Length of road affected by risk increase has been calculated by using the impact angle distribution reported in (Mak, et al., 1986). Risk increase for safety barriers with low containment level and inadequate bridge rails has been calculated taking into account analytical relationships between barrier's containment capacity and impact conditions that allow to evaluate the number of vehicles successfully redirected in relation to safety barriers containment level (Montella, 2001).
Lane and shoulder width affect single vehicle run-off-the-road and multiple vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents (Harwood, et al., 2000). The greater the lane and shoulder widths, the lesser the accidents. The effect of lane and shoulder widths depends on traffic volumes. Considering the task of the audit team, which does not measure in continuum the lane and shoulder widths, two classes of lanes and shoulders have been selected. Lanes are classified very narrow if width is less than 2.75 m, narrow if width is between 2.75 and 3.25 m. Shoulders are classified very narrow if width is less than 0.30 m, narrow if width is between 0.30 and 1.00 m. If AADT is more than 2000 veh/day, relative increase in accident risk is 50% for very narrow lanes, 30% for narrow lanes, 40% for very narrow shoulders and 20% for narrow shoulders. If AADT is lesser than 400 veh/day, the coefficients are 5% for very narrow lanes, 2% for narrow lanes, 9% for very narrow shoulders and 6% for narrow shoulders. For intermediate values of AADT, the coefficients vary linearly (Harwood, et al. 2000). Missing passing lane, in sections where there are not passing opportunities, and missing climbing lane, where high speed difference between cars and trucks do exist in mountainous terrain, give rise to an increase in accident risk, which has been quantified equal to 33% (Harwood, et al., 2000).
Direct access to high-speed road can significantly increase accidents. Accidents modification factors (AMFs) that take into account driveway density have been developed (Harwood, et al., 2000). AMFs show that a roadway segment with 10 driveways per km can experience 75% accidents more than a segment with 4 driveways per km.

VALIDATION OF THE PROCEDURE

In order to evaluate the validity of the procedure, a pilot study has been carried out. For each section, the PFI index has been calculated. Then, the PFI index has been compared with the expected collision frequency, which has been determined by applying a collision prediction model and has been refined by applying the Empirical Bayes technique.

Pilot Study

A pilot study has been carried out as part of a safety review of a rural road network in Italy. Network is composed by 406 kms of two lane rural highways located in Province of Avellino (Region Campania), that are national roads transferred to the Province in the year 2001 (see table 2). Safety reviews have been carried out by two experienced auditors according to the procedures defined in the Italian RSA guidelines (Ministero LL.PP., 2001) and the PFI index has been evaluated as a research task. Traffic data are based on traffic simulations (Palamara, 2003) and ANAS traffic counts (year 2000).
The accident data analysis has been carried out elaborating ISTAT (Italian National Institute of Statistics) electronic data of Region Campania for the period 1995-2002; intersection accidents have been excluded. Most common accident types (see table 3) are right angle/turning (32.2%), head-on (18.3%) and run off the road (17.3%). Accidents on wet pavement account for 28.7% of the total.
For each segment, Relative Risk (RR) and Potential for Improvement (PFI) have been assessed (see table 4 and figure 1). Relative Risk ranges from 44% to 131%; that is, significant accident reductions may be obtained if road safety improvements are carried out. Ranking of safety issues in each segment show different patterns, even if alignment, cross section, delineation and markings are generally the safety issues with greater Relative Risk.

Table 2 Study network

Segments	Segment length (km)	Segment AADT (veh/day)	Injury accidents (intersection excluded)
Ex SS 7 dir/c "Appia" (from km 12.6 to km 24.2)	11.6	6023	4
Ex SS 88_a "Dei due Principati" (from km 15.6 to km 32.0)	16.4	9561	7
Ex SS 88_b "Dei due Principati" (from km 36.0 to km 56.4)	20.4	11958	34
Ex SS 91_a "Della Valle del Sele" (from km 0 to km 31.2)	31.2	3539	13
Ex SS 91_b "Della Valle del Sele" (from km 31.2 to km 44.4)	13.2	2545	0
Ex SS 91_c "Della Valle del Sele" (from km 44.4 to km 58)	13.6	1270	1
Ex SS 91 bis "Irpinia"	8.2	1985	3
Ex SS 164_a "Delle Croci di Acerno" (from km 34.2 to km 53.4)	19.2	2314	2
Ex SS 164_b "Delle Croci di Acerno" (from km 53.4 to km 76.2)	22.8	1800	8
Ex SS 165 "Di Materdomini"	14.8	576	1
Ex SS 303_a "Del Formicoso" (from km 20.2 to km 41.0)	20.8	5600	12
Ex SS 303_b "Del Formicoso" (from km 41.0 to km 59.0)	18.0	1560	7
Ex SS 368 "Del Lago Laceno"	19.2	3565	1
Ex SS 371 "Della Valle del Sabato"	10.8	4532	7
Ex SS 374 "Di Summonte" (from km 0 to km 20.0)	20.0	4020	18
Ex SS 374 dir "Di Montevergine"	11.0	650	0
Ex SS 399 "Di Calitri"	19.8	5204	8
Ex SS 400 "Di Catelvetere"	29.4	7000	31
Ex SS 400 dir "Di Catelvetere"	3.4	12425	6
Ex SS 403 "Della Valle di Lauro" (from km 3.0 to km 9.8)	6.8	7492	9
Ex SS 414 "Di Montecalvo Irpino"	18.6	3191	15
Ex SS 428 "Di Villa Maina"	15.0	2100	7
Ex SS 574 "Del Monte Terminio"	38.4	2430	8
Ex SS 574 dir "Del Monte Terminio"	3.6	1200	0
Total	406.2		202

Table 3 Aggregate accident data

	Injury accidents		Fatalities		Injuries		Fatalities/ Injury accidents
	N	%	N	%	N	%	
Head on	37	18,32%	3	23,08%	85	22,79%	8,11%
Right angle/turning	65	32,18%	2	15,38%	124	33,24%	3,08%
Side swipe	17	8,42%	0	0,00%	33	8,85%	0,00%
Rear end	21	10,40%	0	0,00%	41	10,99%	0,00%
Hit pedestrian	12	5,94%	2	15,38%	14	3,75%	16,67%
Hit stopped vehicle	5	2,48%	1	7,69%	6	1,61%	20,00%
Hit parked vehicle	1	0,50%	0	0,00%	3	0,80%	0,00%
Hit obstacle in carriageway	6	2,97%	2	15,38%	8	2,14%	33,33%
Collision with train	0	0,00%	0	0,00%	0	0,00%	-
Run off the road	35	17,33%	3	23,08%	51	13,67%	8,57%
Sudden braking	1	0,50%	0	0,00%	5	1,34%	0,00%
Falling from a vehicle	2	0,99%	0	0,00%	3	0,80%	0,00%
Total	**202**	**100,00%**	**13**	**100,00%**	**373**	**100,00%**	**6,44%**
Wet	58	28,71%	1	7,69%	125	33,51%	1,72%
Other	144	71,29%	12	92,31%	248	66,49%	8,33%
Total	**202**	**100,00%**	**13**	**100,00%**	**373**	**100,00%**	**6,44%**

Table 4 Relative Risk and Potential for Improvement

Segments	Segment AADT (veh/day)	RR	PFI
Ex SS 7 dir/c "Appia" (from km 12.6 to km 24.2)	6023	55.51%	3.18
Ex SS 88_a "Dei due Principati" (from km 15.6 to km 32.0)	9561	60.34%	5.42
Ex SS 88_b "Dei due Principati" (from km 36.0 to km 56.4)	11958	116.54%	13.01
Ex SS 91_a "Della Valle del Sele" (from km 0 to km 31.2)	3539	81.51%	2.78
Ex SS 91_b "Della Valle del Sele" (from km 31.2 to km 44.4)	2545	44.00%	1.09
Ex SS 91_c "Della Valle del Sele" (from km 44.4 to km 58)	1270	65.92%	0.83
Ex SS 91 bis "Irpinia"	1985	129.34%	2.52
Ex SS 164_a "Delle Croci di Acerno" (from km 34.2 to km 53.4)	2314	97.50%	2.20
Ex SS 164_b "Delle Croci di Acerno" (from km 53.4 to km 76.2)	1800	104.12%	1.84
Ex SS 165 "Di Materdomini"	576	51.48%	0.30
Ex SS 303_a "Del Formicoso" (from km 20.2 to km 41.0)	5600	87.77%	4.69
Ex SS 303_b "Del Formicoso" (from km 41.0 to km 59.0)	1560	87.09%	1.34
Ex SS 368 "Del Lago Laceno"	3565	82.07%	2.82
Ex SS 371 "Della Valle del Sabato"	4532	95.18%	4.14
Ex SS 374 "Di Summonte" (from km 0 to km 20.0)	4020	92.67%	3.58
Ex SS 374 dir "Di Montevergine"	650	117.02%	0.77
Ex SS 399 "Di Calitri"	5204	68.46%	3.40
Ex SS 400 "Di Catelvetere"	7000	107.72%	7.14
Ex SS 400 dir "Di Catelvetere"	12425	125.55%	14.54
Ex SS 403 "Della Valle di Lauro" (from km 3.0 to km 9.8)	7492	99.11%	7.02
Ex SS 414 "Di Montecalvo Irpino"	3191	130.67%	4.04
Ex SS 428 "Di Villa Maina"	2100	103.07%	2.12
Ex SS 574 "Del Monte Terminio"	2430	77.35%	1.83
Ex SS 574 dir "Del Monte Terminio"	1200	79.86%	0.95

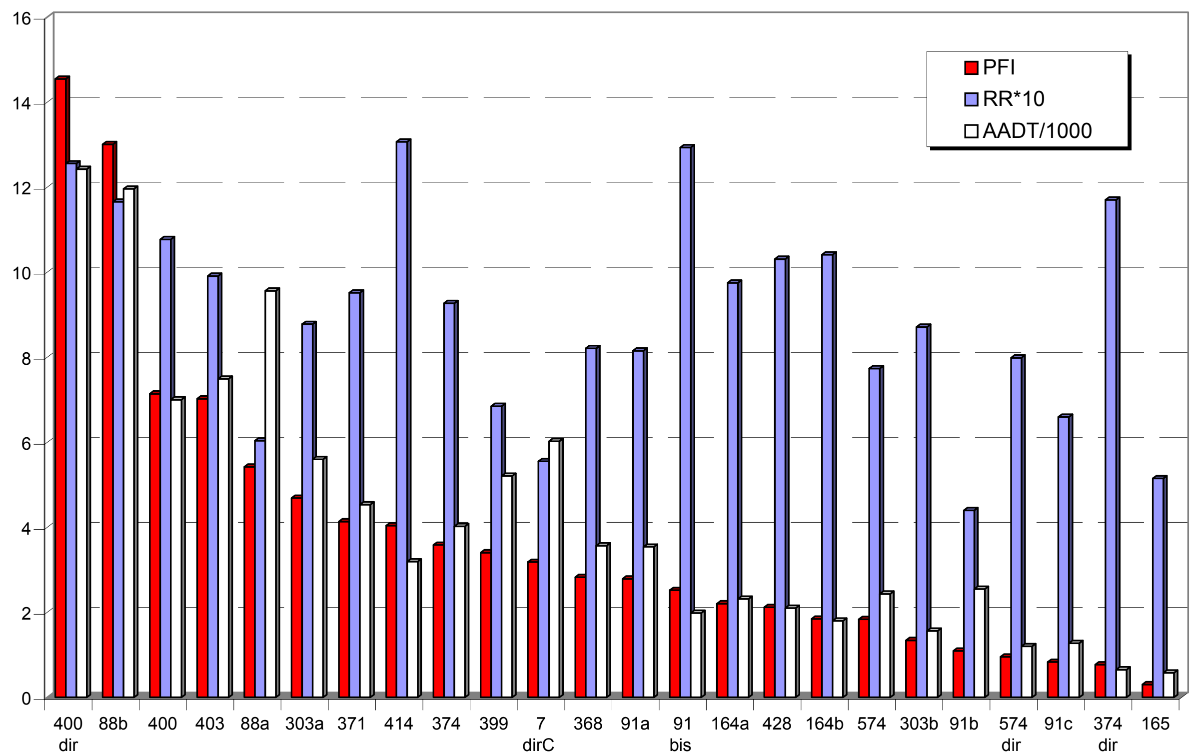

Figure 1 Segments ranked for descending order of PFI

Accident History

The number of accidents expected to occur on the study segments has been estimated by the Empirical Bayes technique, which corrects for regression-to-mean bias (Hauer, 1997). The estimate of the expected accidents depends on the accident count and the estimate of the expected number of accidents based on a collision prediction model.
Using data reported in table 2, a model that predicts the non intersection collision frequency, basing on the segment length and the average annual daily traffic volume, has been developed. Generalized linear modeling techniques (GLM) have been used to fit the model, and a negative binomial distribution error structure has been assumed. Several researchers have demonstrated the inappropriateness of conventional linear regression for modeling discrete, non-negative, and rare events such as traffic collisions. GLM has the advantage of overcoming these shortcomings associated with conventional linear regression (de Leur and Sayed, 2001). The regression analyses were performed by use of the GENMOD procedure in SAS.
The model form is as follows:

$$\hat{E}(Y) = e^{a_0} \times L^{a_1} \times AADT^{a_2} \tag{7}$$

where:

- $\hat{E}$ (Y) = predicted accident frequency (in the period 1995-2002);
- L = segment length (km);
- AADT = average annual daily traffic [(veh./day)/1000];
- a_0, a_1, a_2 = model parameters.

The model parameters and the indicators for the model significance are listed in table 5. The reported indicators are the t-ratio for the model parameters, the κ value (the negative binomial parameter), the scaled deviance (SD) and the Pearson χ^2 statistic. For a well-fitted model, both the scaled deviance and the Pearson χ^2 should be significant compared with the value obtained from the χ^2 table for the given degrees of freedom. The scaled deviance is the likelihood ratio test statistic measuring twice the difference between the maximized log-likelihood's of the studied model and the full or saturated model. The formulation of SD (for a negative binomial distribution) and of the Pearson χ^2 statistic are shown in equations 8 and 9.

$$SD = 2\sum_{i=1}^{n}\left[yi\ln\left(\frac{yi}{\hat{E}(yi)}\right) - (yi+k)\ln\left(\frac{yi+k}{\hat{E}(yi)+k}\right)\right] \tag{8}$$

where:

- SD = scaled deviance;
- y_i = observed number of accidents in the segment i;
- $\hat{E}$ (y_i) = predicted number of accidents in the segment i;
- κ = the negative binomial parameter.

$$Pearson\ \chi^2 = \sum_{i=1}^{n}\frac{\left[yi - \hat{E}(yi)\right]^2}{Var(yi)} \tag{9}$$

where:

Var(y_i) = Variance of the observed accidents.

Table 5 Model parameters

DoF	Parameter	Estimate	t-ratio	$t_{0.05, 21}$	κ	SD	*Pearson* χ^2	$\chi^2_{0.05,21}$
21	a_0	-8.694	-4.77	2.08	4.06	28.01	20.45	32.67
	a_1	0.9648	3.93					
	a_2	0.9722	5.09					

These measures indicate that the prediction model has a relatively good fit and the values that are calculated for the t-ratios for all independent variables are significant.
The collision estimates were then subjected to an Empirical Bayes (EB) refinement technique to obtain a better estimate of the existing safety performance (see table 6), produced as follows:

$$EB = (\frac{\hat{E}(Y)}{k + \hat{E}(Y)}) \times (k + count) \quad (10)$$

where:
EB = Empirical Bayes estimate of the collision frequency;
count = observed collision frequency.

Table 6 EB safety estimates

Segments	Segment length (km)	Segment AADT (veh/day)	Observed injury accidents	Model predicted accidents	EB estimate
Ex SS 7 dir/c "Appia" (from km 12.6 to km 24.2)	11.6	6023	4	8.43	5.44
Ex SS 88_a "Dei due Principati" (from km 15.6 to km 32.0)	16.4	9561	7	18.46	9.07
Ex SS 88_b "Dei due Principati" (from km 36.0 to km 56.4)	20.4	11958	34	28.32	33.29
Ex SS 91_a "Della Valle del Sele" (from km 0 to km 31.2)	31.2	3539	13	13.06	13.01
Ex SS 91_b "Della Valle del Sele" (from km 31.2 to km 44.4)	13.2	2545	0	4.13	2.05
Ex SS 91_c "Della Valle del Sele" (from km 44.4 to km 58)	13.6	1270	1	2.16	1.76
Ex SS 91 bis "Irpinia"	8.2	1985	3	2.05	2.37
Ex SS 164_a "Delle Croci di Acerno" (from km 34.2 to km 53.4)	19.2	2314	2	5.41	3.46
Ex SS 164_b "Delle Croci di Acerno" (from km 53.4 to km 76.2)	22.8	1800	8	5.00	6.66
Ex SS 165 "Di Materdomini"	14.8	576	1	1.09	1.07
Ex SS 303_a "Del Formicoso" (from km 20.2 to km 41.0)	20.8	5600	12	13.80	12.41
Ex SS 303_b "Del Formicoso" (from km 41.0 to km 59.0)	18.0	1560	7	3.46	5.09
Ex SS 368 "Del Lago Laceno"	19.2	3565	1	8.24	3.39
Ex SS 371 "Della Valle del Sabato"	10.8	4532	7	5.97	6.58
Ex SS 374 "Di Summonte" (from km 0 to km 20.0)	20.0	4020	18	9.63	15.52
Ex SS 374 dir "Di Montevergine"	11.0	650	0	0.92	0.75
Ex SS 399 "Di Calitri"	19.8	5204	8	12.25	9.06
Ex SS 400 "Di Catelvetere"	29.4	7000	31	23.94	29.98
Ex SS 400 dir "Di Catelvetere"	3.4	12425	6	5.22	5.66
Ex SS 403 "Della Valle di Lauro" (from km 3.0 to km 9.8)	6.8	7492	9	6.23	7.91
Ex SS 414 "Di Montecalvo Irpino"	18.6	3191	15	7.17	12.17
Ex SS 428 "Di Villa Maina"	15.0	2100	7	3.88	5.40
Ex SS 574 "Del Monte Terminio"	38.4	2430	8	11.07	8.82
Ex SS 574 dir "Del Monte Terminio"	3.6	1200	0	0.57	0.50

Comparison Between PFI and Accident History

To test the procedure, comparisons between the PFI scores and EB safety estimates have been carried out (see table 7 and figure 2). Since PFI index is assessed per unit of length, it can be compared to the number of accidents per year and per km. EB estimates have been divided for the road segment lengths and the number of years.
The correlation between EB safety estimates and PFI values is highly significant (t = 17.39, p-value < 0.001), with 93% of the variation in the estimated number of accidents explained by the PFI value. This means that the relationship between EB estimates and PFI scores had less than 0.1% chance of occurring by accident.

Table 7 Comparison of PFI and EB ranks

Segments	PFI	PFI rank	EB estimate [acc./(km×year)]	EB rank	Rank difference
Ex SS 7 dir/c “Appia” (from km 12.6 to km 24.2)	3.18	11	0.59	10	1
Ex SS 88_a “Dei due Principati” (from km 15.6 to km 32.0)	5.42	5	0.69	9	-4
Ex SS 88_b “Dei due Principati” (from km 36.0 to km 56.4)	13.01	2	2.04	2	0
Ex SS 91_a “Della Valle del Sele” (from km 0 to km 31.2)	2.78	13	0.52	12	1
Ex SS 91_b “Della Valle del Sele” (from km 31.2 to km 44.4)	1.09	20	0.19	20	0
Ex SS 91_c “Della Valle del Sele” (from km 44.4 to km 58)	0.83	22	0.16	22	0
Ex SS 91 bis “Irpinia”	2.52	14	0.36	15	-1
Ex SS 164_a “Delle Croci di Acerno” (from km 34.2 to km 53.4)	2.20	15	0.23	18	-3
Ex SS 164_b “Delle Croci di Acerno” (from km 53.4 to km 76.2)	1.84	17	0.36	14	3
Ex SS 165 “Di Materdomini”	0.30	24	0.09	23	1
Ex SS 303_a “Del Formicoso” (from km 20.2 to km 41.0)	4.69	6	0.75	8	-2
Ex SS 303_b “Del Formicoso” (from km 41.0 to km 59.0)	1.34	19	0.35	16	3
Ex SS 368 “Del Lago Laceno”	2.82	12	0.22	19	-7
Ex SS 371 “Della Valle del Sabato”	4.14	7	0.76	7	0
Ex SS 374 “Di Summonte” (from km 0 to km 20.0)	3.58	9	0.97	5	4
Ex SS 374 dir “Di Montevergine”	0.77	23	0.09	24	-1
Ex SS 399 “Di Calitri”	3.40	10	0.57	11	-1
Ex SS 400 “Di Catelvetere”	7.14	3	1.27	4	-1
Ex SS 400 dir “Di Catelvetere”	14.54	1	2.08	1	0
Ex SS 403 “Della Valle di Lauro” (from km 3.0 to km 9.8)	7.02	4	1.45	3	1
Ex SS 414 “Di Montecalvo Irpino”	4.04	8	0.82	6	2
Ex SS 428 “Di Villa Maina”	2.12	16	0.45	13	3
Ex SS 574 “Del Monte Terminio”	1.83	18	0.29	17	1
Ex SS 574 dir “Del Monte Terminio”	0.95	21	0.17	21	0

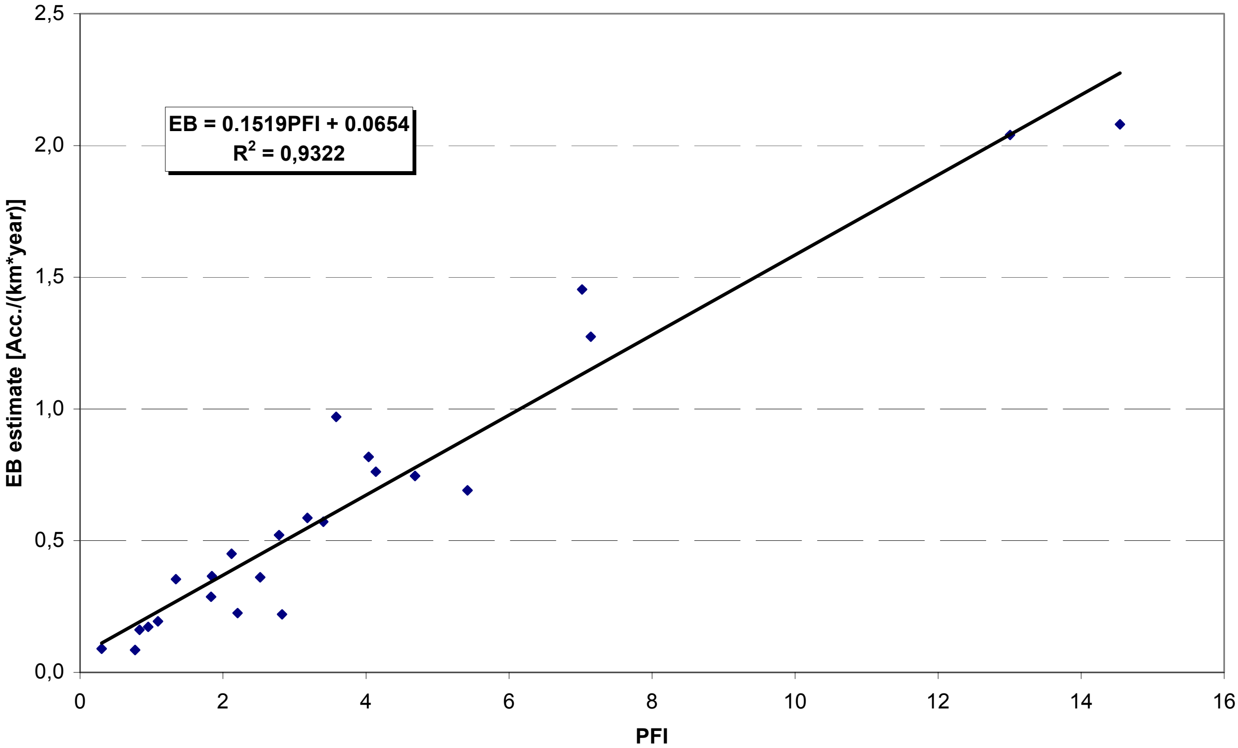

Figure 2 Correlation between EB accidents estimate and PFI

In order to determine the level of agreement between the sorting of segments based on EB estimates and PFI values, each of the 24 segments have been ranked in descending order according the two criteria (see table 7) and the Spearman’s rank-correlation coefficient has been calculated by the formula shown in equation 11.

$$\rho_s = 1 - \frac{6 \times \sum_{i=1}^{n} d_i^{\,2}}{n \times (n^2 - 1)} \tag{11}$$

where:
ρ_s = Spearman's rank-correlation coefficient;
d_i = differences between ranks;
n = number of paired sets.

Under a null hypothesis of no correlation, the ordered data pairs are randomly matched and thus the sampling distribution of ρ_s has a mean of zero. Since this sampling distribution can be approximated with a normal distribution even for relatively small values of n, it is possible to test the null hypothesis on the statistic given in equation 12.

$$z = \rho_s \times \sqrt{(n-1)} \tag{12}$$

The results from the correlation analysis (ρ_s = 0.94, z = 4.52) indicate that the ranking from the subjective PFI and the objective EB estimate do agree at the 99.9% level of significance. These results provide further validation for the PFI.
The ranking from the subjective PFI index has been compared also with the ranking from an analytical PFI index, which is calculated as the difference between the number of accidents at the investigated site, that is the EB estimate, and the number of expected accidents at similar sites with the same traffic, that is the model prediction (Persaud, 2001). The results from the correlation analysis (ρ_s = 0.30, z = 1.46) indicate that the ranking from the subjective PFI and the analytical PFI do agree at the 92.7% level of significance. The correlation, albeit significant, is not as strong as the correlation between PFI and EB estimate. This is due to two main reasons:

- The accident prediction model used for estimates does not take into account road features explanatory variables other than segment length. Therefore subjective PFI assesses potential for improvement, due to road features detrimental to safety, in segments where the analytical index is negative;
- Segments with very low traffic volume have analytical PFI index greater than segments with high traffic volume which experienced less accidents than predicted. However, these segments with high traffic volume may have high potential for improvement due to factors not included in the accident predictive model.

The focus of the PFI is to obtain an index which is related to the accident frequency and quantifies the potential for improvement. Any how, as part of the process, a relative risk increase is assessed and it is expected that this is correlated with the accident rate. The hypothesis of correlation has been tested by assessing Spearman's rank-correlation coefficient for the two criteria: descending order of accident rate (EB estimate of accident frequency/10^8veh×km) and descending order of relative risk. The ranking from the accident rate and the relative risk do agree at the 99.9% level of significance (ρ_s = 0.63, z = 3.02).

CONCLUSION

The approach is based on known accident relationships, and a systematic process has been described to determine which road features should be investigated and how each feature should be evaluated during the review.
The validity of the PFI has been evaluated by comparing the results of the PFI index, which has been assessed in 400 kms of rural two lane highways, with expected collision frequency. Collision frequency has been determined by applying a collision prediction model, calibrated in the study network, and has been refined by applying the Empirical Bayes technique. Correlation between EB safety estimates and PFI values is highly significant, with 93% of the variation in the estimated number of accidents explained by the PFI value. The level of agreement between the results of the EB estimates and the PFI has been evaluated also by the Spearman's rank-correlation coefficient. Sites were ranked according to both the EB estimate and PFI, with the results of the Spearman correlation indicating agreement at a 99.9% significance level.
Due to the validation and quantitative nature of the PFI, the procedure can be used to support road safety reviews, accident investigation, and decision-making. High risk segments, where safety measures that can reduce accident frequency and/or severity do exist, can be identified also if accident data are not available. Specific safety issues, that give more contribution to unsafety, are pointed out in order to give indication about more appropriate mass action programs. These features make the procedure very useful also for low

volume roads, where usually very accurate geometric and accident data are not available. Moreover on these roads low investment and high effectiveness safety measures are strongly needed and the procedure represents a practical tool aimed at identifying, both at network and at route level, type of measures that hold promise for greater accident reduction.

REFERENCES

AASHTO, (1996); Roadside Design Guide; Washington, D.C., U.S.A..

Austroads, (2002a); *Road Safety Audit (2nd Edition)*; Austroads Publication AP-G30/02, Sydney, New South Wales, Australia.

Austroads, (2002b); *Evaluation of the Proposed Actions Emanating from Road Safety Audits;* Austroads Publication AP-R209/02, Sydney, New South Wales, Australia.

Austroads, (2004); *Guide to Traffic Engineering Practice series PART 4: Treatment of crash locations;* Austroads Publication AP-G11.4/04, Sydney, New South Wales, Australia.

Bahar, G., Wales, J., Longtin-Nobel, L., (2001); *Best Practices for the Implementation of Shoulder and Centreline Rumble Strips*; TAC Synthesis of Practice n.8, Ottawa, Canada.

Bahar, G., Mollett, C., Persaud, B.N., Lyon, C., Smiley, A., Smahel, T., McGee, H., (2004); *Safety Evaluation of Permanent Raised Pavement Markers*; NCHRP Report 518, Washington, D.C., U.S.A..

De Leur, P., Sayed, T., (2002); *Development of a Road Safety Risk Index*; Transportation Research Record: Journal of the Transportation Research Board 1784, pp. 33-42, TRB, National Research Council, Washington, D.C., U.S.A..

Harwood, D.H., Council, F.M., Hauer, E., Hughes, W.E., Vogt, A., (2000); *Prediction of the Expected Safety Performances of the Rural Two-Lane Highways*; Report FHWA-RD-99-207, Washington, D.C., U.S.A..

Hassan, Y., Easa, S.M., Abd El Halim, A,O., (1996); *Analytical Model for Sight Distance Analysis on Three-Dimensional Highway Alignments*; Transportation Research Record 1523, pp. 1-10, TRB, National Research Council, Washington, D.C., U.S.A..

Hauer, E., (1997); *Observational Before-After Studies in Road Safety*; Pergamon, Oxford, UK.

Huang, H. F., Schneider, R. J., Zegeer, C. V., Khattak. A. J., Lacy, J. K., (2002); *Analysis of Serious Crashes and Potential Countermeasures on North Carolina Highways*; 81th TRB Annual Meeting, Washington, D.C., U.S.A..

Kentucky Transportation Center, (2003); *Developing of Methodologies for Identifying High Crash Locations and Prioritizing Safety Improvements*; Lexington, Kentucky, U.S.A..

Lamm, R., B. Psarianos, T. Mailaender, E.M. Choueiri, R. Heger, and R. Steyer, (1999); *Highway Design andTraffic Safety Engineering Handbook*; McGraw-Hill, New York, N.Y., U.S.A..

Lynam, D., Hummel, T., Barker, J., Lawson, S.D., (2004); *European Road Assessment Programm. Eurorap I (2003) Technical Report*; www.eurorap.org.

Mak, K. K., Sicking, D. L., Ross, H. E. Jr., (1986); *Real World Impact Conditions for Ran-off-the-Road Accidents*; Transportation Research Record 1065, Transportation Research Board, Washington, D. C., U.S.A..

Ministero dei Lavori Pubblici, (2001); *Circolare n.3669 8 giugno 2001: Linee guida per le analisi di sicurezza delle strade*; Rome, Italy.

Montella, A., (2001); *Selection of Roadside Safety Barriers Containment Level According to EU Standards*; Transportation Research Record: Journal of the Transportation Research Board 1743, pp. 104-110, TRB, National Research Council, Washington, D.C., U.S.A..

Palamara, D., (2004); *La previsione dei flussi di traffico stradale mediante analisi di serie storiche*; PhD Thesis in Transportation Engineering, University of Rome “La Sapienza”, Rome.

Persaud, B., Lyon, C., Nguyen, T., (2001); *Empirical Bayes Procedure for Ranking Sites for Safety Investigation by Potential for Safety Improvement*; Transportation Research Record: Journal of the Transportation Research Board 1665, pp. 7-12, Transportation Research Board, National Research Council, Washington, D.C., U.S.A..

Persaud, B.N., Rettings, R.A., Lyon, C., (2004); *Crash Reduction Following Installation of Centerline Rumble Strips on Rural Two-Lane Roads*; 83th TRB Annual Meeting, Washington, D.C., U.S.A..

Proctor, S., Belcher, M., Cook, P, (2001); *Practical Road Safety Auditing*; Thomas Telford, London, UK.

Shen, J., Rodriguez, A., Gan, A., (2004); *Development and Application of Crash Reduction Factors: State-of-the-Practice Review of State Departments of Transportation*; 83th TRB Annual Meeting, Washington, DC, U.S.A..

Transfund New Zealand, 1998; *Safety Audit Procedures for Existing Roads*; Transfund Report RA97/623S, Wellington, New Zealand.

Transfund New Zealand, 2001; *A Review of Two Indipendent Safety Audits of Existing Road Network in Manawatu District*; Transfund Report OG/0901/4S, Wellington, New Zealand.

Transfund New Zealand, 2003; *Safety Audits of Existing Roads: Developing a Less Subjective Assessment*; Transfund Report OG/0306/24S, Wellington, New Zealand.