Safety Reviews of Existing Roads

Quantitative Safety Assessment Methodology

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Safety reviews of existing roads are becoming an accepted practice in many agencies around the world. These reviews can be highly cost-effective, but the subjective nature of the process can give rise to inconsistencies that limit their effectiveness. To address this issue, a technique to support safety reviews 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. A systematic process to determine which road features should be investigated and how each feature should be evaluated during the review is described. The procedure addresses rural two-lane highways at nonintersections. From the process, a potential for a safety improvement index (PFI) was calculated. Validation of the procedure was carried out by a comparison of the PFI values with the expected collision frequency. PFI was assessed in 406 km of rural two-lane rolling highways in Italy. Collision frequency was determined by application of a collision prediction model, calibrated in the study network, and was refined by application of the empirical Bayes (EB) 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. Because of the validation and quantitative nature of the PFI, the procedure can be used to support safety reviews and decision making.

In-service safety reviews aim to identify potential hazards, which are assessed by measuring risk in relation to road features that may lead to future crashes, so that remedial treatments may be implemented before crashes happen. From the review, safety issues and recommendations for improvement are derived.

Safety reviews are complementary and not alternative to accident investigation studies. Accident investigation is a reactive program; it examines past accidents and aims to remove or change the features that contributed to those past crashes. Safety review is a proactive program, aimed at reducing road accidents before they occur. Accident investigations 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. Indeed, the fewer the accident data, the less the information accidents can give about accidents to be prevented.

Safety reviews may be highly cost-effective. An Austroads research study reports that the analysis of a range of existing roads reviews indicated benefit–cost ratios (BCRs) between 2.4:1 and 84:1 when one considers the value of completing the proposed actions identified in response to the review findings (*1*). More than 78% of all proposed actions had BCR > 1.0.

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

RISK ASSESSMENT IN SAFETY REVIEWS

When review recommendations are considered, capital expenditure may be needed to address the safety issues identified to reduce the collision risk, and the owner would need to prioritize the remedial actions. Risk assessment helps determine the priority of safety issues identified by the safety reviews. Main existing road safety impact assessment procedures are presented, and advantages and drawbacks in their application are emphasized. Existing studies show that risk assessment is a key point in the development of the review process, but further research is needed.

Road Risk Index

In British Columbia, a criterion for a driver-based evaluation of road safety risk was developed (*2*). The process is based on well-defined and quantifiable characteristics of road features that are studied and scored during a drive-through review. These scores are combined to produce a safety index, formulated by combining three components of risk: the exposure of road users to road hazards, the probability of becoming involved in a collision, and the resulting consequences should a collision occur. Specific and combined risk indices are assessed. The specific index defines the risk associated with each road feature, while the combined risk defines overall risk.

The methodology can effectively support safety review results. Nevertheless, it requires input data that in many instances are not available to the review team.

Road Protection Score

In 2002, the AA Foundation for Road Safety Research launched the Euro Road Assessment Programme. Part of the program 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 tested by scoring a sample of roads in seven countries, and further development of the scoring system has been proposed (*3*). A direct visual inspection of the road quality was used, and the roads were

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assessed by using the 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 on the basis of 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 to identify individual sites of concern, but the methodology looks promising.

New Zealand Road Infrastructure Safety Assessment

In New Zealand, safety reviews of existing roads have been extensively carried out in the last decade. A Transfund manual of safety audits of existing roads 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 (*4*). A matrix is provided on which one axis is the exposure to risk and the other axis is the severity of the expected crash. The cells of the matrix are filled with words such as "low," "medium," and "high" level of importance. 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 (*5*). 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 some of the assigned risk ratings were not accurate.

On the basis of these considerations, Transfund is developing a rating methodology to improve the systematic quantification of the safety impact associated with the items identified during safety reviews (*6*). The method, although not definitive, is very well suited as a support to the review process.

POTENTIAL FOR SAFETY IMPROVEMENT INDEX

General Aspects of Procedure

The main objective for developing a potential for a safety improvement index (PFI) was to produce a technique to support road safety reviews to quantify the safety gains that could be achieved by addressing the problems identified in the review process. The procedure looks at rural two-lane highways and does not take into account junctions. Key elements in developing the PFI procedure were as follows:

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

The PFI assessment is based on evaluation of safety items that have a known impact on road safety. For each safety item, the relative increase in accident number and severity has been estimated. Safety reviewers, after a site investigation, 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 into homogeneous segments. 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 for both 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 predictive model calibrated in the study network).

Formulation of PFI

Ten general safety issues have been identified: alignment, cross section, markings, longitudinal rumble strips, pedestrian crosswalks, delineation, signs, pavement, roadside, and accesses. General issues are divided into detailed issues (see Table 1). The safety issues have been selected by considering that they are common issues and that effective remedial measures do exist and have already proved their effectiveness. On the basis of existing literature (*6–23*), the safety effect of each detailed issue has been estimated. The safety effect is expressed by two indices (see Table 1): ΔA, which represents the estimated relative increase in injury accidents risk caused by the safety issue, and ΔS, which is the estimated relative increase in accident severity. Accident severity is the ratio between fatal accidents and all-injuries accidents. Estimated relative increase in accident severity is different from 0 only for roadside issues. Since some safety features do not affect all accident types, related accidents have been defined for each detailed issue (see Table 1). Length of road affected by each item is expressed by the parameter related effect (see Table 1).

In each section of the road (it is suggested to assume that any one section is 200 m), the review team scores the detailed issues: 0 if the issue is not present, 1 if the issue is present (point items, such as not breakaway barrier terminals, are scored by their number). Scores are multiplied for the related effect and summed over all the sections; the ratio between the length of road affected by the safety item and the total length of the road (twice the length of the road for roadside 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

$$\mathrm{RR}_j = \mathrm{expo}_j \times \Delta A_j \times P_j \tag{1}$$

where

RR_j = relative risk of the detailed issue *j;*
expo_j = exposure of the issue *j*, that is, the proportion of road affected by the issue *j;*
ΔA_j = estimated relative increase in injury accidents risk due to the issue *j;* and
P_j = proportion of accidents affected by the issue *j.*

Fatal accident RR_j is computed by the formula

$$\mathrm{RR}_{\mathrm{fa}j} = \mathrm{RR}_j \times \left(1 + \Delta S_j\right) \tag{2}$$

where $\mathrm{RR}_{\mathrm{fa}j}$ is the fatal accidents relative risk of the detailed issue *j* and ΔS_j is the estimated relative increase in accident severity (fatal and 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)

$$\mathrm{RR}_i = \sum_{j=1}^{n} \mathrm{RR}_j \tag{3}$$

TABLE 1 Safety Items

General Issues	Detailed Issues	ΔA (%)	ΔS (%)	Related Accidents	Related Effect
Alignment					
	Very severe curve realignment needed	100	0	All	200 m
	Inadequate sight distance on horizontal curves caused by removable obstacles (stopping sight distance, <0.75)	5	0	All	200 m
	Inadequate sight distance on crest curves (stopping sight distance, <0.5)	50	0	All	200 m
Cross section					
	Lane width				
	Very narrow <2.75 m	5–50$_{\text{f(AADT)}}$	0	Run off the road	Segment
	Narrow <3.25 m	2–30$_{\text{f(AADT)}}$	0	Head-on Sideswipe	Segment
	Shoulder width				
	Very narrow <0.3 m	9–40$_{\text{f(AADT)}}$	0	Run off the road	Segment
	Narrow <1.0 m	6–20$_{\text{f(AADT)}}$	0	Head-on Sideswipe	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
Markings					
	Edgelines missing or inadequate	8	0	All	Segment
	Centerline missing or inadequate	13	0	All	Segment
	No-overtaking line missing	50	0	Head-on	Segment
Longitudinal rumble strips					
	Audible edgelines missing	40	0	Run off the road	Segment
	Audible centerline missing	11	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
Pavement					
	Inadequate skid resistance	30	0	Wet	Segment

(continued)

TABLE 1 *(continued)* **Safety Items**

General Issues	Detailed Issues	Δ*A* (%)	Δ*S* (%)	Related Accidents	Related Effect
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	1,400	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	1,000	Run off the road	50 m
	Rigid utility poles	90	1,000	Run off the road	50 m
	Rigid obstacles	90	1,000	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	2,000	Run off the road	25 m
Accesses					
	Excessive density of uncontrolled accesses (>10/km)	75	0	All	Segment

h = height; *i* = longitudinal grade.

where

RR_i = relative risk of the general issue i,
RR_j = relative risk of the detailed issue j associated with the general issue i, and
n = number of detailed issues associated with the general issue i.

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

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

where RR is the relative risk of the segment and $RR_{1, 2, 3, \ldots, n}$ is the relative risk of the general issues.

PFI represents a measure of the accident increase due to the identified safety items. That is, PFI is a measure of the safety gains that can be obtained by eliminating the safety issues. It depends both on the relative risk and the traffic volume and is equal to

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

where AADT is the average annual daily traffic [(vehicles per day)/1,000] and b is the exponent of AADT in the pertinent accident predictive model.

Formula 5 is used also for calculating PFI_i of each safety item, by inserting in the formula the relative risk of the item. PFI_{fa} of fatal accidents is calculated by inserting into Formula 5 fatal accidents relative risk.

An example real-world application of the procedure is presented in Table 2.

Safety Issues

Many road features affect 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 other road, traffic, and environmental features that all together play a key role. However, to make the assessment more objective, it has been decided to assign a relative increase in accident risk for each factor independent from the interaction of the different road features. The review team will decide if one item applies in relation to the road contest (e.g., chevron missing has to be evaluated in relation to the road alignment and perception).

Road alignment is the road factor with the greatest safety impact, even if its upgrading is generally quite expensive. Circumstances in which 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 by Harwood et al. (*7*). In the literature, severe curves are defined as curves where operating speed difference with preceding tangent is greater than 20 km/h (*8*); in the PFI procedure, curves with estimated operating speed differential greater than 30 km/h are classified as severe. Inadequate sight distance on horizontal and vertical curves

TABLE 2 Example Real-World Application of Procedure for Road Ex SS 400 dir

General Issue	Detailed Issue	Expo$_j$ (%)	ΔA_{ij} (%)	P_j(%)	RR$_i$ (%) (see Eq.1)	ΔS_{ij} (%)	RR$_{fa}$ (%) (see Eq.2)
Alignment					2.19		2.19
	Very severe curve	0.0	100.0	100.0	0.0	0.0	0.00
	Inadequate sight distance on horizontal curves caused by removable obstacles (<0.75 SSD)	43.75	5.0	100.0	2.19	0.0	2.19
	Inadequate sight distance on crest curves (<0.5 SSD)	0.0	50.0	100.0	0.0	0.0	0.0
Cross section					35.57		35.57
	Lane width				17.92		17.92
	Very narrow <2.75	81.25	50.0	44.12	17.92	0.0	17.92
	Narrow <3.25	0.0	30.0	44.12	0.0	0.0	0.00
	Shoulder width				17.65		17.65
	Very narrow <0.3	100.0	40.0	44.12	17.65	0.0	17.65
	Narrow <1.0	0.0	20.0	44.12	0.0	0.0	0.0
	Missing passing lane and passing opportunities	0.0	33.0	100.0	0.0	0.0	0.0
	Missing climbing lane where high speed differentials between cars and trucks do exist because of longitudinal grade	0.0	33.0	100.0	0.0	0.0	0.0
Markings					17.06		17.06
	Edgelines missing or poor	81.25	8.0	100.0	6.5	0.0	6.5
	Centerline missing or poor	81.25	13.0	100.0	10.56	0.0	10.56
	No-overtaking line missing	0.0	50.0	18.14	0.0	0.0	0.0
Longitudinal rumble strips					7.20		7.20
	Audible edgeline missing	81.25	40.0	17.16	5.58	0.0	5.58
	Audible centerline missing	81.25	11.0	18.14	1.62	0.0	1.62
Pedestrian crosswalks					0.96		0.96
	Missing or ineffective crosswalks in areas with pedestrian activity	27.27	60.0	5.88	0.96	0.0	0.96
Delineation					12.50		12.50
	Chevron missing or ineffective on severe curve	50.0	20.0	100.0	10.0	0.0	10.0
	Guideposts (or barrier reflectors) damaged or missing	31.25	8.00	100.0	2.5	0.0	2.5
Signs					1.25		1.25
	Curve warning missing or not visible on severe curve	12.50	10.0	100.0	1.25	0.0	1.25
Pavement					8.53		8.53
	Smoothing surface pavement	100.0	30.0	28.43	8.53	0.0	8.53
Roadside					3.95		41.45
	Unshielded embankment (3<h<6m and *i*>0.5)	0.0	80.0	17.16	0.0	800	0.0
	Unshielded embankment (h>6m and *i*>0.5)	12.5	100.0	17.16	2.15	1,400	32.18
	Embankment shielded with very low containment (or ineffective) safety barrier (3<h<6m and *i*>0.5)	0.0	10.0	17.16	0.0	70	0.0
	Embankment shielded with very low containment (or ineffective) safety barrier (h>6m and *i*>0.5)	12.5	11.0	17.16	0.24	100	0.47
	Ditch	0.0	50.0	17.16	0.0	150	0.0
	Trees	0.0	90.0	17.16	0.0	1,000	0.0
	Rigid utility poles	0.0	90.0	17.16	0.0	1,000	0.0
	Rigid obstacles	2.34	90.0	17.16	0.36	1,000	3.98
	Not breakaway barrier terminals	11.72	60.0	17.16	1.21	300	4.83
	Missing transition between barriers (or between barrier and wall)	0.0	60.0	17.16	0.0	300	0.0
	Inadequate bridge rails	0.0	6.4	17.16	0.0	2,000	0.0
Accesses					0.0		0.0
	Excessive density of uncontrolled accesses (>10/km)	0.0	75.0	100.0	0.0	0.0	0.0

$\mathrm{RR} = \mathrm{RR}_1 + \mathrm{RR}_2 \times (1+\mathrm{RR}_1) + \mathrm{RR}_3 \times (1+\mathrm{RR}_2) \times (1+\mathrm{RR}_1) + \ldots$	125.55%
AADT [(veh/day)/1000]	12.425
b (exponent of AADT in the accident predictive model)	0.9722
$\mathrm{PFI} = \mathrm{RR} \times \mathrm{AADT}^b$	14.54
$\mathrm{RR}_{fa} = \mathrm{RR}_{1fa} + \mathrm{RR}_{2fa} \times (1+\mathrm{RR}_{1fa}) + \mathrm{RR}_{3fa} \times (1+\mathrm{RR}_{2fa}) \times (1+\mathrm{RR}_{1fa}) + \ldots$	206.93%
$\mathrm{PFI}_{fa} = \mathrm{RR}_{fa} \times \mathrm{AADT}^b$	23.97

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 obstacles has been assumed equal to 5% (*9*); relative increase in accident risk due to inadequate sight distance (<50% stopping sight distance) on crest curves has been assumed equal to 50% (*10*).

Lane and shoulder widths affect single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe and same-direction sideswipe accidents (*7*). The greater the lane and shoulder widths, the fewer the accidents. The effect of lane and shoulder widths depends on traffic volumes. Considering the task of the review team, which does not measure in continuum the pavement width, two classes of lanes and shoulders have been selected. Lanes are classified as very narrow if the width is less than 2.75 m and are narrow if the width is between 2.75 and 3.25 m. Shoulders are classified as very narrow if the width is less than 0.30 m and as narrow if the width is between 0.30 and 1.00 m. If AADT is more than 2,000, the 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 less than 400, 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 (*7*). Missing passing lane, in sections where there are not passing opportunities, and missing climbing lane, where high speed differences between cars and trucks exist in mountainous terrain, give rise to an increase in accident risk, which has been quantified equal to 33% (*7*).

Much research has investigated the effect of road marking on accidents, showing that road marking improvements are likely to be cost-effective. Detailed items considered are edge lines missing or inadequate, centerline 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 centerline missing (*6*). Relative increase for no-overtaking line missing has been assumed equal to 50%; this factor applies only to head-on accidents (*6*).

An effective safety measure, which has been applied recently by many road authorities, is the installation of shoulder rumble strips (or audible edge lines), which are warning devices intended to alert drivers that they are leaving the traveled way and that a steering correction is required, and centerline rumble strips (or audible center line), which 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 a positive effect on run-off-the-road accidents, the latter on head-on accidents. On the basis of Transportation Association of Canada (*11*) and NCHRP (*12–14*) suggestions, relative increase in accident risk due to rumble strips missing has been assumed equal to 40% for shoulders and equal to 11% for centerline, although other literature sources suggest even greater values (*15, 16*).

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% (*17, 18*).

Delineation is an important safety factor in any condition. On severe curves, missing or ineffective chevrons can lead to an accident risk increase equal to 20% (*6*). It has been assumed that this factor applies to a segment 200 m long. Damaged or missing guideposts or barrier reflectors on nonsevere curves and on tangents are also a safety deficiency; relative risk factor has been assumed equal to 8% (*6*). Some studies report positive effects associated with the installation of permanent raised pavement markers (PRPMs); however, recent comprehensive research tasks state that PRPMs have a positive effect only under certain particular conditions (*19*), and it has been decided not to include PRPMs in the safety issues.

Road signs that have the greatest effect on traffic safety are warning signs. They call attention to unexpected conditions and to situations that might not be readily apparent to road users, giving suggestions for safe behavior. For missing or ineffective curve warning signs on severe curves, the relative risk factor has been assumed equal to 10% (*6*).

The pavement factor that has more effect on road safety is friction. Relative risk increase when skid resistance is inadequate has been assessed equal to 30% (*6*); this applies to wet road accidents. Experimental results show even greater wet accident increase in poor friction conditions (*20*).

Roadside improvement measures may reduce either accident frequency or accident severity. Accident frequency can be reduced by removing or relocating roadside hazards to provide a clear zone along the roadside that provides errant vehicles an opportunity to recover and return to the travel way or to come to a controlled and safe stop. Accident severity can be reduced by making the hazards forgiving or shielding the hazards with road restraint systems. Injury accidents and fatal accidents risk increase, for different road features, has been calculated with the AASHTO severity indices (*21*). 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 to those of safety barriers, or of breakaway terminals, the risk increase factors reported in Table 1 were obtained. Length of road affected by risk increase was calculated by using the impact angle distribution reported by Mak et al. (*22*). Risk increase for safety barriers with low containment level and inadequate bridge rails was calculated by taking into account analytical relationships between a barrier's containment capacity and impact conditions that allow evaluating the number of vehicles successfully redirected in relation to the safety barriers containment level (*23*).

Direct access to roads can significantly increase accidents. Accident modification factors (AMFs) that take into account driveway density have been developed (*7*). AMFs show that a roadway segment with 10 driveways per kilometer can experience 75% more accidents than a segment with four driveways per kilometer.

VALIDATION OF PROCEDURE

A pilot study was done to evaluate the validity of the procedure. Values of the PFI index and expected collision frequency were compared.

Pilot Study

A pilot study was carried out as part of a safety review of a rural road network in Italy. The network is composed by 406 km of rural two-lane rolling highways with at-grade junctions and direct access from properties, located in the province of Avellino (Region Campania) and divided into 24 segments (see Table 3). Safety reviews were carried out by two experienced reviewers according to the procedures defined in the Italian road safety audit guidelines (*24*), and the PFI index was evaluated as a research task. Traffic data are based on traffic simulations (*25*) and ANAS (Italian National Roads Institute) traffic counts (for year 2000).

The accident data analysis was carried out by elaborating ISTAT (Italian National Institute of Statistics) electronic data of Region Campania for the period 1995–2002. Intersection accidents were excluded.

TABLE 3 Relative Risk and Potential for Improvement

Segment	Observed Injury Accidents	Segment Length (km)	Segment AADT (veh/day)	RR (%)	PFI
Ex SS 7 dir/c “Appia”$_{\text{(from km 12.6 to km 24.2)}}$	4	11.6	6,023	55.51	3.18
Ex SS 88$_a$ “Dei due Principati”$_{\text{(from km 15.6 to km 32.0)}}$	7	16.4	9,561	60.34	5.42
Ex SS 88$_b$ “Dei due Principati”$_{\text{(from km 36.0 to km 56.4)}}$	34	20.4	11,958	116.54	13.01
Ex SS 91$_a$ “Della Valle del Sele”$_{\text{(from km 0 to km 31.2)}}$	13	31.2	3,539	81.51	2.78
Ex SS 91$_b$ “Della Valle del Sele”$_{\text{(from km 31.2 to km 44.4)}}$	0	13.2	2,545	44.00	1.09
Ex SS 91$_c$ “Della Valle del Sele”$_{\text{(from km 44.4 to km 58)}}$	1	13.6	1,270	65.92	0.83
Ex SS 91 bis “Irpinia”	3	8.2	1,985	129.34	2.52
Ex SS 164$_a$ “Delle Croci di Acerno”$_{\text{(from km 34.2 to km 53.4)}}$	2	19.2	2,314	97.50	2.20
Ex SS 164$_b$ “Delle Croci di Acerno”$_{\text{(from km 53.4 to km 76.2)}}$	8	22.8	1,800	104.12	1.84
Ex SS 165 “Di Materdomini”	1	14.8	576	51.48	0.30
Ex SS 303$_a$ “Del Formicoso”$_{\text{(from km 20.2 to km 41.0)}}$	12	20.8	5,600	87.77	4.69
Ex SS 303$_b$ “Del Formicoso”$_{\text{(from km 41.0 to km 59.0)}}$	7	18.0	1,560	87.09	1.34
Ex SS 368 “Del Lago Laceno”	1	19.2	3,565	82.07	2.82
Ex SS 371 “Della Valle del Sabato”	7	10.8	4,532	95.18	4.14
Ex SS 374 “Di Summonte”$_{\text{(from km 0 to km 20.0)}}$	18	20.0	4,020	92.67	3.58
Ex SS 374 dir “Di Montevergine”	0	11.0	650	117.02	0.77
Ex SS 399 “Di Calitri”	8	19.8	5,204	68.46	3.40
Ex SS 400 “Di Catelvetere”	31	29.4	7,000	107.72	7.14
Ex SS 400 dir “Di Catelvetere”	6	3.4	12,425	125.55	14.54
Ex SS 403 “Della Valle di Lauro”$_{\text{(from km 3.0 to km 9.8)}}$	9	6.8	7,492	99.11	7.02
Ex SS 414 “Di Montecalvo Irpino”	15	18.6	3,191	130.67	4.04
Ex SS 428 “Di Villa Maina”	7	15.0	2,100	103.07	2.12
Ex SS 574 “Del Monte Terminio”	8	38.4	2,430	77.35	1.83
Ex SS 574 dir “Del Monte Terminio”	0	3.6	1,200	79.86	0.95
Total	202	406.2			

Ex SS indicates a regional road that was a national road.

The database includes injury and fatal accidents only. Most common accident types (see Table 4) are right-angle/turning (32.2%), head-on (18.3%), and run-off-the-road (17.3%). Right-angle accidents occur in proximity to accesses and are classified by ISTAT as nonintersection accidents. Accidents on wet pavement account for 28.7% of the total.

For each segment, relative risk and PFI were assessed (see Table 3). 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 shows that cross section, markings, and delineation generally are the safety issues with greater relative risk.

Accident History

The number of accidents expected to occur on the study segments was estimated by using the EB technique, which corrects for regression-to-mean bias (*26*). The estimate of the expected accidents depends on the accident count and the number of accidents predicted by a model.

A model that predicts the nonintersection collision frequency, as based on the segment length and the AADT volume, was developed with data reported in Table 3. Generalized linear modeling techniques (GLM) were used to fit the model, and a negative binomial distribution error structure was assumed. Several researchers have demonstrated the inappropriateness of conventional linear regression for modeling discrete, nonnegative, and rare events such as traffic collisions. GLM has the advantage of overcoming these shortcomings associated with conventional linear regression (*2*). The regression analyses were performed by using the GENMOD procedure in SAS.

The model form is as follows:

$$\hat{E}(Y) = e^{a_0} \times L^{a_1} \times \text{AADT}^{a_2} \tag{6}$$

where

$\hat{E}(Y)$ = predicted accident frequency (1995–2002),
L = segment length (km), and
a_0, a_1, a_2 = model parameters.

The model parameters and the indicators for the model significance are given in Table 5. The reported indicators are the *t*-ratio for the model parameters, the κ-value (the negative binomial parameter), the scaled deviance, and the Pearson χ^2 statistic. The formulations of the scaled deviance (for a negative binomial distribution) and of the Pearson χ^2 statistic are shown in Equations 7 and 8. 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. 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.

$$\text{SD} = 2\sum_{i=1}^{n}\left\{y_i \ln\left[\frac{y_i}{\hat{E}(y_i)}\right] - (y_i + \kappa)\ln\left[\frac{y_i + \kappa}{\hat{E}(y_i) + \kappa}\right]\right\} \tag{7}$$

TABLE 4 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%
Sideswipe	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%
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%

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*, and
κ = negative binomial parameter.

$$\text{Pearson } \chi^2 = \sum_{i=1}^{n} \frac{\left[y_i - \hat{E}(y_i)\right]^2}{\mathrm{Var}(y_i)} \tag{8}$$

where $\mathrm{Var}(y_i)$ is the variance of the observed accidents.

The collision estimates were then subjected to an EB refinement technique to obtain a better estimate of the existing safety performance (see Table 6), produced as follows:

$$\mathrm{EB} = \left[\frac{\hat{E}(Y)}{\kappa + \hat{E}(Y)}\right] \times (\kappa + \text{count}) \tag{9}$$

where count is the observed collision frequency.

Comparison of PFI and Accident History

To test the procedure, comparisons of the PFI scores and the EB safety estimates were carried out (see Table 7 and Figure 1). Since PFI is assessed per unit of length, it can be compared to the number of accidents per year and per kilometer. 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.

To determine the level of agreement between the sorting of segments based on EB estimates and PFI values, each of the 24 segments was ranked in descending order according the two criteria, and the Spearman's rank-correlation coefficient was calculated by the formula (see Table 7)

$$\rho_s = 1 - \frac{6 \times \sum_{i=1}^{n} d_i^2}{n \times \left(n^2 - 1\right)} \tag{10}$$

where

ρ_s = Spearman's rank-correlation coefficient,
d_i = differences between ranks, and
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 by

$$z = \rho_s \times \sqrt{(n-1)} \tag{11}$$

TABLE 5 Model Parameters

df	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					

TABLE 6 EB Safety Estimates

Segment	Model Predicted Accidents	Observed Injury Accidents	EB Estimate
Ex SS 7 dir/c "Appia"$_{\text{(from km 12.6 to km 24.2)}}$	8.43	4	5.44
Ex SS 88$_a$ "Dei due Principati"$_{\text{(from km 15.6 to km 32.0)}}$	18.46	7	9.07
Ex SS 88$_b$ "Dei due Principati"$_{\text{(from km 36.0 to km 56.4)}}$	28.32	34	33.29
Ex SS 91$_a$ "Della Valle del Sele"$_{\text{(from km 0 to km 31.2)}}$	13.06	13	13.01
Ex SS 91$_b$ "Della Valle del Sele"$_{\text{(from km 31.2 to km 44.4)}}$	4.13	0	2.05
Ex SS 91$_c$ "Della Valle del Sele"$_{\text{(from km 44.4 to km 58)}}$	2.16	1	1.76
Ex SS 91 bis "Irpinia"	2.05	3	2.37
Ex SS 164$_a$ "Delle Croci di Acerno"$_{\text{(from km 34.2 to km 53.4)}}$	5.41	2	3.46
Ex SS 164$_b$ "Delle Croci di Acerno"$_{\text{(from km 53.4 to km 76.2)}}$	5.00	8	6.66
Ex SS 165 "Di Materdomini"	1.09	1	1.07
Ex SS 303$_a$ "Del Formicoso"$_{\text{(from km 20.2 to km 41.0)}}$	13.80	12	12.41
Ex SS 303$_b$ "Del Formicoso"$_{\text{(from km 41.0 to km 59.0)}}$	3.46	7	5.09
Ex SS 368 "Del Lago Laceno"	8.24	1	3.39
Ex SS 371 "Della Valle del Sabato"	5.97	7	6.58
Ex SS 374 "Di Summonte"$_{\text{(from km 0 to km 20.0)}}$	9.63	18	15.52
Ex SS 374 dir "Di Montevergine"	0.92	0	0.75
Ex SS 399 "Di Calitri"	12.25	8	9.06
Ex SS 400 "Di Catelvetere"	23.94	31	29.98
Ex SS 400 dir "Di Catelvetere"	5.22	6	5.66
Ex SS 403 "Della Valle di Lauro"$_{\text{(from km 3.0 to km 9.8)}}$	6.23	9	7.91
Ex SS 414 "Di Montecalvo Irpino"	7.17	15	12.17
Ex SS 428 "Di Villa Maina"	3.88	7	5.40
Ex SS 574 "Del Monte Terminio"	11.07	8	8.82
Ex SS 574 dir "Del Monte Terminio"	0.57	0	0.50

Ex SS indicates a regional road that was a national road.

The results from the correlation analysis ($\rho_s = 0.94$, $z = 4.52$) 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 a valuable validation for the PFI. Indeed, studies on methodologies aimed at identifying the sites with promise (*27*), which are the sites where the greatest cost-effectiveness of the safety measures is expected, found that ranking criteria based on accident frequency gives the best results.

The ranking from the subjective PFI was compared with the ranking from the analytical PFI, which is calculated as the difference between the accident EB estimate and the model prediction (*28*). The results from the correlation analysis ($\rho_s = 0.30$, $z = 1.46$) indicate that the ranking from the subjective PFI and the analytical PFI agree at the 92.7% level of significance. The correlation, albeit significant, is not as strong as the correlation between the subjective PFI and EB the estimate. This has two main reasons:

- The accident prediction model used for estimates does not take into account road feature explanatory variables other than segment length.
- Segments with low traffic volume have analytical PFI greater than segments with high traffic volume that experienced fewer accidents than predicted. However, these high-traffic-volume segments may have high potential for improvement because of factors not included in the accident predictive model.

Both PFI and accident frequency are dependent on traffic volume, but this is not the main explanation of their correlation. The relative risk, which depends only on the identified safety issues, is robustly correlated with the accident rate. The hypothesis of correlation was tested by assessing Spearman's rank-correlation coefficient for two criteria: descending order of accident rate (EB estimate of accident frequency/10^8 veh × km) and descending order of relative risk. The rankings from the two criteria agree at the 99.9% level of significance ($\rho_s = 0.63$, $z = 3.02$).

CONCLUSIONS

A systematic process to determine which road features should be investigated and how each feature should be evaluated during the safety review was proposed. The approach is based on known accident relationships, and as a final result a PFI was computed. PFI quantifies the safety gains that could be achieved by addressing the problems identified in the review process.

Validation of the procedure was carried out by comparing the PFI values with the expected collision frequency. PFI was assessed in 406 km of rural two-lane rolling highways in Italy. Collision frequency was estimated by applying a collision prediction model, calibrated in the study network, and was refined by applying the EB 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 was evaluated also by the Spearman's rank-correlation coefficient. Sites were ranked according to both the EB estimate and the PFI, with the results of

TABLE 7 Comparison of PFI and EB Ranks

Segment	PFI	PFI Rank	EB Estimate [acc./(km×year)]	EB Rank	Rank Difference
Ex SS 7 dir/c “Appia”$_{\text{(from km 12.6 to km 24.2)}}$	3.18	11	0.59	10	1
Ex SS 88_a “Dei due Principati”$_{\text{(from km 15.6 to km 32.0)}}$	5.42	5	0.69	9	–4
Ex SS 88_b “Dei due Principati”$_{\text{(from km 36.0 to km 56.4)}}$	13.01	2	2.04	2	0
Ex SS 91_a “Della Valle del Sele”$_{\text{(from km 0 to km 31.2)}}$	2.78	13	0.52	12	1
Ex SS 91_b “Della Valle del Sele”$_{\text{(from km 31.2 to km 44.4)}}$	1.09	20	0.19	20	0
Ex SS 91_c “Della Valle del Sele”$_{\text{(from km 44.4 to km 58)}}$	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”$_{\text{(from km 34.2 to km 53.4)}}$	2.20	15	0.23	18	–3
Ex SS 164_b “Delle Croci di Acerno”$_{\text{(from km 53.4 to km 76.2)}}$	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”$_{\text{(from km 20.2 to km 41.0)}}$	4.69	6	0.75	8	–2
Ex SS 303_b “Del Formicoso”$_{\text{(from km 41.0 to km 59.0)}}$	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”$_{\text{(from km 0 to km 20.0)}}$	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”$_{\text{(from km 3.0 to km 9.8)}}$	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

Ex SS indicates a regional road that was a national road.
$\rho_s = 0.94$; $z = 4.52$.

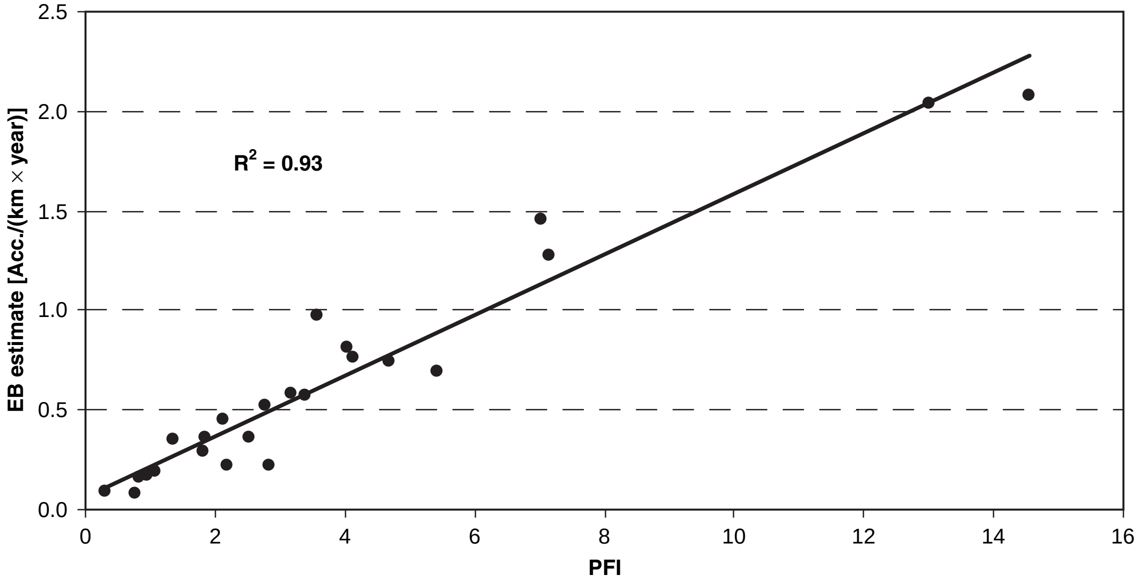

FIGURE 1 Correlation between EB accidents estimate and PFI.

the Spearman correlation indicating agreement at a 99.9% significance level. This means that ranking of segments that hold promise for accident reduction gives comparable results in terms of PFI or accident history.

PFI can be assessed whether accident data are available or not. If accident data are available and their quality is good, PFI can be effectively used in conjunction with accident frequency as ranking criteria, improving the ranking made by using accident frequencies alone. Indeed, segments with similar accident frequency may give rise to different potential benefits of the safety measures. The PFI index quantitatively assesses these potential benefits. If accident data are not available or are poor, PFI can be used as a proxy of accident data and becomes the only ranking criteria.

The PFI has two main practical applications. High-risk segments, where safety measures that can reduce accident frequency and/or severity do exist, can be identified and ranked by the global PFI. Specific safety issues that contribute the most to safety problems are pointed out to give guidance about more appropriate mass action programs. Relative risk ranks different types of safety measures in each segment, whereas PFI of single safety issues ranks the segments in relation to a specific safety improvement program.

PFI can be assessed as part of the safety review process without relevant supplementary work. Safety reviews represent a low-cost process for the periodic evaluation of the network safety performance, and the PFI assessment is an effective tool for the development of safety strategies incorporating the reviews in a more comprehensive road safety program. The low cost and applicability in road networks where geometric and accident data are lacking make the procedure very attractive for low-volume roads.

REFERENCES

1. *Evaluation of the Proposed Actions Emanating from Road Safety Audits.* Austroads, Sydney, New South Wales, Australia, 2002.
2. de Leur, P., and T. Sayed. Development of a Road Safety Risk Index. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1784,* Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 33–42.
3. Lynam, D., T. Hummel, J. Barker, and S. D. Lawson. European Road Assessment Programme. 2003. www.eurorap.org. Accessed May 7, 2004.
4. *Safety Audit Procedures for Existing Roads.* Transfund, Wellington, New Zealand, 1998.
5. *A Review of Two Independent Safety Audits of Existing Road Network in Manawatu District.* Transfund, Wellington, New Zealand, 2001.
6. *Safety Audits of Existing Roads: Developing a Less Subjective Assessment.* Transfund, Wellington, New Zealand, 2003.
7. Harwood, D. H., F. M. Council, E. Hauer, W. E. Hughes, and A. Vogt. *Prediction of the Expected Safety Performances of Rural Two-Lane Highways.* FHWA-RD-99-207. FHWA, U.S. Department of Transportation, 2000.
8. Lamm, R., B. Psarianos, T. Mailaender, E. M. Choueiri, R. Heger, and R. Steyer. *Highway Design and Traffic Safety Engineering Handbook.* McGraw-Hill, New York, 1999.
9. *Development of Procedures for Identifying High-Crash Locations and Prioritizing Safety Improvements.* Kentucky Transportation Center, Lexington, 2003.
10. Hassan, Y., S. M. Easa, and A. O. Abd El Halim. Analytical Model for Sight Distance Analysis on Three-Dimensional Highway Alignments. In *Transportation Research Record 1523,* TRB, National Research Council, Washington, D.C., 1996, pp. 1–10.
11. Bahar, G., J. Wales, and L. Longtin-Nobel. *Best Practices for the Implementation of Shoulder and Centreline Rumble Strips.* Transportation Association of Canada, Ottawa, Canada, 2001.
12. Neuman, T. R., R. Pfefer, K. L. Slack, K. K. Hardy, F. Council, H. McGee, L. Prothe, and K. Eccles. *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan. Volume 6: A Guide for Addressing Run-off-Road Collisions.* Transportation Research Board of the National Academies, Washington, D.C., 2003.
13. Neuman, T. R., R. Pfefer, K. L. Slack, K. K. Hardy, H. McGee, L. Prothe, K. Eccles, and F. Council. *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan. Volume 4: A Guide for Addressing Head-On Collisions.* Transportation Research Board of the National Academies, Washington, D.C., 2003.
14. Torbic, D. J., D. W. Harwood, D. K. Gilmore, R. Pfefer, T. R. Neuman, K. L. Slack, and K. K. Hardy. *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan. Volume 7: A Guide for Reducing Collisions on Horizontal Curves.* Transportation Research Board of the National Academies, Washington, D.C., 2004.
15. Persaud, B. N., R. A. Rettings, and C. A. Lyon. Crash Reduction Following Installation of Centerline Rumble Strips on Rural Two-Lane Roads. Presented at 83rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2004.
16. Huang, H. F., R. J. Schneider, C. V. Zegeer, A. J. Khattak, and J. K Lacy. Analysis of Serious Crashes and Potential Countermeasures on North Carolina Highways. Presented at 81st Annual Meeting of the Transportation Research Board, Washington, D.C., 2002.
17. *Guide to Traffic Engineering Practice Series Part 4: Treatment of Crash Locations.* Austroads, Sydney, New South Wales, Australia, 2004.
18. Proctor, S., M. Belcher, and P. Cook. *Practical Road Safety Auditing.* Thomas Telford, London, 2001.
19. Bahar, G., C. Mollett, B. N. Persaud, C. Lyon, A. Smiley, T. Smahel, and H. McGee. *NCHRP Report 518: Safety Evaluation of Permanent Raised Pavement Markers.* Transportation Research Board of the National Academies, Washington, D.C., 2004.
20. Shen, J., A. Rodriguez, and A. Gan. Development and Application of Crash Reduction Factors: State-of-the-Practice Review of State Departments of Transportation. Presented at 83rd Annual Meeting of the Transportation Research Board, Washington, D.C., 2004.
21. *Roadside Design Guide.* AASHTO, Washington, D.C., 1996.
22. Mak, K. K., D. L. Sicking, and H. E. Ross, Jr. Real-World Impact Conditions for Ran-off-the-Road Accidents. In *Transportation Research Record 1065,* TRB, National Research Council, Washington, D.C., 1986, pp. 45–55.
23. Montella, A. Selection of Roadside Safety Barrier Containment Level According to European Union Standards. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1743,* TRB, National Research Council, Washington, D.C., 2001, pp. 104–110.
24. *Guidelines for Road Safety Audit.* Public Works Ministry, Rome, Italy, 2001 (in Italian).
25. Palamara, D. *Traffic Flows Prediction by Analysis of Time Series.* Ph.D. thesis. University of Rome “La Sapienza,” Italy, 2004 (in Italian).
26. Hauer, E. *Observational Before-After Studies in Road Safety.* Pergamon Press, Oxford, England, 1997.
27. Hauer, E., B. K. Allery, J. Kononov, and M. S. Griffith. How Best to Rank Sites with Promise. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1897,* Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 48–54.
28. Persaud, B., C. Lyon, and T. Nguyen. Empirical Bayes Procedure for Ranking Sites for Safety Investigation by Potential for Safety Improvement. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1665,* TRB, National Research Council, Washington, D.C., 2001, pp. 7–12.

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