Safety Inspections as Supporting Tool for Safety Management of Low-Volume Roads

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Road safety inspections (RSIs) are becoming an accepted practice in many agencies around the world. A safety assessment procedure based on safety inspections that can be used as a supporting tool in the safety management of low-volume rural roads is presented. From the procedure, a safety index (SI) that quantitatively measures the relative safety performance of a road segment is calculated. The RSIs carried out according to the defined procedures showed that, for the majority of the safety issues, there was a statistically significant level of agreement on the ranking of the issues produced by different inspectors. Further, the SI was assessed in 30 segments of two-lane rural roads, and rankings performed according to the SI scores and according to the empirical Bayes (EB) safety estimates were compared. This comparison showed a good correlation between SI and EB estimates. The results from the Spearman's rank correlation analysis provide additional validation of the procedure, indicating that the rankings from the SI scores and the EB estimates agreed at the 99.9% level of significance. The SI can be assessed as part of the safety inspection process without relevant supplementary work. The low cost and applicability in road networks where geometric and crash data are not available make the procedure very attractive for low-volume roads.

An essential part of any road safety improvement program is network screening, that is, the identification of sites where the greatest cost-effectiveness of the safety measures is expected. Several alternative ranking criteria are used in screening (*1*). Although crash data analysis is essential, it is well recognized that crash data suffer from a number of shortcomings (*2, 3*) and that there are clues to hazardousness other than crash occurrence (*4*). On low-volume roads, where crash frequency is less than on high-volume roads, the role of procedures complementing crash investigation studies becomes substantially more important. Indeed, the fewer the crash data, the less the past crashes can give enough information on crashes to be prevented. As a result, it appears that network screening of low-volume rural roads can be better performed if joint use is made of all the important clues and not only of the crash history.

In the framework of the research project "Identification of Hazard Locations and Ranking of Measures to Improve Safety on Local Rural Roads" (Italian acronym IASP), funded by the European Commission (EC) Directorate General for Transport and Energy (DGTREN) and the Province of Catania, Italy, a methodological approach for the safety evaluation of two-lane rural highways that uses both analytical procedures referring to alignment design consistency models and the safety inspection process was defined (*5–10*). The IASP procedure uses theoretical experimental models for the evaluation of alignment design consistency. However, the resulting analyses, even if effective in addressing alignment inconsistencies, do not highlight all the potential crash contributory factors. Hence, the methodology integrates the results of the models with those deriving from the safety issue evaluation performed during the safety inspection process.

Road safety inspections (RSIs) are aimed at identifying potential hazards, which are assessed by measuring risk in relation to those road features that may lead to future crashes so that remedial treatments may be implemented before crashes happen. RSIs are recognized as an effective tool and are becoming an accepted practice in many agencies around the world. Recent research in the United States (*11*), British Columbia (*12*), Europe (*13, 14*), and Italy (*10, 15–17*) clearly shows the potential effectiveness of road safety evaluations based on RSIs.

After a thorough review of current international practices and policies, the discussion focuses on the use of RSIs as a systematic and replicable supporting tool in the safety management of low-volume roads.

RSIs IN ROAD SAFETY MANAGEMENT: INTERNATIONAL COMPARISON

Policies

In order to improve road safety, after July 1996, the Council of Ministers and the European Parliament authorized the EC to propose guidelines such that the Trans-European Road Network (TERN) should "guarantee users a high, uniform and continuous level of services, comfort and safety." This legal obligation brought the EC to propose Directive 2008/96/EC (*14, 18*), which introduces a comprehensive system of road infrastructure safety management. The directive proposes four procedures among which RSIs are defined as "an ordinary periodical verification of the characteristics and defects that require maintenance work for reasons of safety as a preventive tool." Recognizing that more than 50% of fatalities occur on rural or secondary roads, or on both, in the policy orientation on road safety 2011–2020 the EC states that ways should be found to gradually extend the relevant principles of safe management of infrastructure to the secondary road network (*19*).

In 2002, the European Community cofunded the European Union (EU) *Guidelines to Black Spot Management—Identification and Handling,* in which RSIs are indicated as crash-preventive measures (*20*). The main objectives of the RSI development are to reduce

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crash frequency and severity and to guarantee that all the roads have optimal safety conditions.

At the EU level, in the new ERA-NET ROAD—Coordination and Implementation of Road Research in Europe, a coordination action funded by the sixth framework program of the EC, RSIs are considered among the useful tools to identify locations with the potential for safety improvements and that allow consideration of local factors when assessed against solutions proven to be successful in other countries. In the RIPCORD-iSEREST EU project, 18 states were investigated with respect to application of the RSI procedure. Several differences in the way RSIs are carried out were detected (*13*).

In the United States, FHWA started a road safety audit (RSA) pilot project in 1998 subsequent to which 13 states indicated that RSA reviews (RSARs) were part of their state's safety program (*21*). In particular, postconstruction RSAs result in useful evaluation of all roadway and roadside features, design elements, and local conditions (glare, night visibility, adjacent land uses, etc.) that would increase the likelihood and severity of a crash (*22*). The RSAR tool has been widely recognized as particularly beneficial to local governments in systematically addressing safety deficiencies on existing rural road networks. On local rural highways, the RSAR process has been developed to give specific recognition to the functionality of the road being evaluated for safety issues (*23*).

In Canada, initiatives undertaken in support of the plan Road Safety Vision 2001 (1996–2001) previewed a new Technical Assistance Center committee called the Road Safety Subcommittee, which deals with the integration of road safety considerations into road design and traffic operations and also with the implementation of RSAs of new and existing roads.

In Australia, regular audits of existing roads have been carried out since the beginning of 1990 in order to identify road safety hazards before they result in crashes (*24*). Austroads states that ideally a program of safety reviews that covers every road in the network should be developed. Individual states are incorporating RSAs at different rates throughout Australia. In New South Wales 20% of existing roadways within all regions are to be audited to identify deficiencies and priorities for action. In New Zealand, safety reviews of existing roads have been extensively carried out in the past 20 years.

Guidelines and Operative Manuals

Worldwide, in the past decade, a series of guidelines and operative manuals recognizing the usefulness of RSIs were published.

The Technical Committee on Road Safety of the Permanent International Association of Road Congresses–World Road Association (PIARC) published the outcome of committee research and the results of the Kuala Lumpur Congress on Road Safety Audits, focused on current practices and experiences in different countries. PIARC sought to address some current road safety issues in six technical publications soon to be available online, among which is "Road Safety Inspection Guideline," to be introduced as an investigative method in the *Road Safety Manual* (*3*). Recently, the same committee produced the *Catalogue of Design Safety Problems and Potential Countermeasures,* aimed at developing and emerging countries and countries in transition (*25*). The catalogue gives brief information, including pictorial representations, of well-known design errors in an easily understood way, suggests a range of methods to overcome these errors, and indicates the comparative countermeasure costs to facilitate prioritization of the work. The catalogue can be used both as a proactive safety tool to ensure that the design faults do not arise and as a reactive safety tool to assist in designing cost-effective countermeasures for problems that already exist on the road network (*25*).

In Canada, guidelines for RSIs were published in 2004 by the Transportation Association of Canada (*26*). The guidelines define inspection procedures and their interactions with the road safety management system and emphasize human factors review as a specific part of the procedure.

In Australasia, Austroads released a broad set of guidelines for a national RSA program in 1994, revised in 2001 and in 2009, which specifically address the safety review of existing roads (*24*). The Austroads procedure aims to ensure that the safety features of a road are comparable with the functional classification of the road and to identify any feature that may develop over time into a safety concern.

In Europe, the Research Council of Norway and RIPCORD-iSEREST WP5 formulated good practice guidelines for implementing RSIs in the European context as a complementary procedure for safety management of two-lane rural roads (*13, 27*). Specifically, in Norway, RSA and inspection guidelines reveal the use of a so-called Vidkon inspection (a preliminary examination of the site carried out by using video) to perform a field investigation more swiftly (*28*). A summary of the procedure was reported by Cardoso et al. together with practical experience and existing practices of RSIs in Austria, Germany, and Portugal (*29*). Since 1997, Denmark has applied RSAs on new road projects for systematic prevention of road accidents, according to procedures described in the Danish manual of RSAs, in which Stage 5 of monitoring corresponds to road inspections (*30*). In Italy, guidelines on RSAs were published in 2001 and are divided in two sections: RSAs of highway schemes and safety reviews of existing roads, that is, special emphasis on safety review is given (*31*). Their goal is road safety improvement by using a specific approach to integrate several aspects (technical, behavioral, and physiological).

RSI Tools

An improvement of the RIPCORD-iSEREST project is represented by the Secondary Roads Expert System (SEROES), a web-based tool, freely accessible and based on the *Handbook of Road Safety Measures* by Elvik and Vaa (*32*). In that context best practice information about road safety improvement, based on RSIs from the EU member states and a worldwide background, was collected, examined, and synthesized. The application is structured into various menus for users and an additional menu for administrators. SEROES is a tool with low data requirements. In a further step, SEROES has been demonstrated together with the decision support safety tool (*13*) in three countries: Turkey, Poland, and the Netherlands.

The Australian RSA toolkit (www.rsatoolkit.com.au) is an online tool that assists practitioners in carrying out RSAs. It steps users through the Austroads RSA process (feasibility stage, preliminary design stage, detailed design stage, pre-opening stage, roadwork traffic scheme, and existing roads), provides Australasian- and jurisdiction-specific references, and allows auditors to generate road safety reports.

In the past decade, the Asian Development Bank (ADB) has become increasingly concerned about the growing road safety problems affecting its developing member countries (DMCs) and has developed manuals and toolkits on RSAs and RSIs. The DMCs, sharing their expertise and commitment, assist ADB in its efforts to spread the use of effective RSAs throughout the Asia and Pacific region. Checklists were set up for five stages (planning and feasibility, preliminary draft design, detailed design, construction, and audit of existing roads), each one containing at its beginning plans, documents, and information required for that stage (*33*).

In the United States, the FHWA toolkit's sections include RSA videos, guidelines, case studies, program contacts, sample reports, and program web links as well as information about both RSA training and the RSA peer-to-peer program.

Worldwide, the International Road Assessment Programme (iRAP) works in partnership with government and nongovernmental organizations to

- Inspect high-risk roads and develop star ratings and safer roads investment plans;
- Provide training, technology, and support that will build and sustain national, regional, and local capability; and
- Track road safety performance so that funding agencies can assess the benefits of their investments.

iRAP is the umbrella organization for EuroRAP, AusRAP, usRAP, KiwiRAP, and sgRAP. The iRAP protocol rates roads by assigning one to five stars based on approximately 20 key roadway features related to safety. The roads with the most safety design features are assigned five stars, whereas those that generally lack such features are assigned one star. The star-rating concept has been used extensively in Europe and Australia and is being considered by usRAP for implementation in the United States. The star ratings for roads are analogous to the star ratings assigned to cars based on their crashworthiness.

In addition to the potential value of star ratings as a public communication tool, iRAP has developed a web-based safety analysis software tool that uses the roadway inventory data on which the star ratings are based to identify cost-effective safety improvement programs for the road networks covered by the ratings. The software considers the data used to develop the star ratings, approximately 20 additional roadway features, and nearly 70 candidate crash countermeasures for each location on the road network and selects those with the highest benefit–cost ratio for potential implementation. Recent research carried out in the United States (*11*) has developed star ratings using iRAP protocols for over 3,000 mi of roads in Iowa and Washington and compared those star ratings with observed crash frequencies and rates for the same roads. The study demonstrated the validity of the star-rating concept and the applicability of the iRAP analysis software to U.S. roads. These results indicate that RSIs and star ratings can serve as valid tools for use in safety management.

IASP SAFETY INSPECTION PROCEDURE

General Aspects

Even though many safety inspection procedures already exist, the IASP procedure presents some innovative elements: (*a*) definition of the inspector and client roles; (*b*) definition of the site inspection phases (preliminary inspection, general inspection, detailed inspection, nighttime inspection); and (*c*) definition of the inspection procedures (objectives of the inspection, needed equipment, inspection methodology, criteria for identifying and ranking safety issues, roles of each team member).

Road Safety Inspectors

The safety inspection team should never be a one-person team. The team must comprise three or more people because (*a*) road inspections, because of operative reasons, require at least three inspectors and (*b*) diverse backgrounds and different approaches by individuals create cross-fertilization of ideas and are beneficial in problem identification and analysis.

Main requisites of the team are independence and qualification. Independence from the design, maintenance, and operation of the road network to be inspected is needed since the team has to look only at safety problems and apply fresh eyes to the task. Qualification is vital for the process to be effective, given that addressing the safety problems and providing recommendations to eliminate or mitigate them does not give any real benefit in terms of crash reduction if the task is not based on sound road safety engineering experience and practice. Qualification requires both detailed knowledge of road safety principles and familiarization with IASP procedures.

RSIs

Different phases of inspections are required:

1. Preliminary inspections, in daytime, aimed at understanding the general road safety conditions and the relationships of the road segments with surrounding land use, terrain, and road network;
2. General inspections, in daytime, aimed at examining the general safety concerns along the road segments;
3. Detailed inspections, in daytime, aimed at examining in detail safety concerns of specific sites; and
4. Nighttime inspections, aimed at analyzing road perception without natural lighting.

Particular attention is due to the general inspections. The road is driven in both directions at very low speed (about 30 km/h), and video recording is performed; the driver calls the traveled distance every 100 m, and inspectors in the front and back seats compile the checklists (Figures 1 and 2). The checklists are very synthetic, since they relate only to the main safety features usually present along two-lane rural highways.

The following safety issues are assessed: access, cross section, delineation, markings, pavement, roadside, sight distance, and signs. To improve safety issue evaluation, each item is divided into more detailed concerns. Features that concern horizontal and vertical alignment are not considered because alignment evaluation is performed as a separate quantitative procedure under the IASP project.

Checklists are filled out in both directions with a step of 0.2 km. In order to simplify the inspectors' task, each checklist is split into two parts: Part A has to be compiled on site, and Part B can be compiled both on site and during the video examination performed in the office.

Front seat and back seat inspectors, who have different views of the road, compile different checklists, filling the boxes with a step of 0.2 km (24 s at 30 km/h). This interval is a compromise between the possibility of easily expressing a unique evaluation of the safety issues to be assessed, which requires observation periods of limited length, and of having a sufficient amount of time available to compile the checklist, which requires periods that are not too short.

Safety issues are ranked as high-level problems (H: score equal to 1), low-level problems (L: score equal to 0.5), or no problem

	Station									
	Kilometer 0.2		Kilometer 0.4		Kilometer 0.6		Kilometer 0.8		Kilometer 1.0	
	H	L	H	L	H	L	H	L	H	L
Part A										
Roadside										
Embankments										
Bridges										
Dangerous terminals and transitions										
Trees, utility poles, and rigid obstacles										
Ditches										
Sight distance										
Inadequate sight distance on horizontal curve										
Inadequate sight distance on vertical curve										
Part B										
Access										
Dangerousness of access										
Presence of access										

FIGURE 1 Checklist for general inspection: module for front seat inspector.

(score equal to 0). Since a good friction evaluation requires instrumented measures, the friction problems are ranked with only two levels of judgment: problem (H and L) and no problem. To improve the reliability and repeatability of the process, criteria for identifying and ranking safety issues have been defined (see Table 1).

Quantitative Safety Evaluation

From the RSI process, a safety index (SI) is assessed. The SI measures the relative safety performance of a road segment. It does not take junctions into account.

The SI is formulated by combining three components of risk: the exposure of road users to road hazards (exposure factor), the probability of a vehicle's being involved in an accident (accident frequency factor), and the resulting consequences should an accident occur (accident severity factor). The general formulation of the SI is

$$\text{SI} = \text{exposure factor} \times \text{accident frequency factor} \times \text{accident severity factor} \quad (1)$$

Considering the evaluation of only one safety issue (see Table 3), the SI of each safety issue is also computed.

The exposure factor measures the exposure of road users to road hazards and is assessed as follows:

$$\text{exposure factor} = L \times \text{AADT} \quad (2)$$

where L is the length of the segment under consideration (in kilometers) and AADT is annual average daily traffic (in 1,000 vehicles per day).

	Station									
	Kilometer 0.2		Kilometer 0.4		Kilometer 0.6		Kilometer 0.8		Kilometer 1.0	
	H	L	H	L	H	L	H	L	H	L
Part A										
Cross section										
Lane width										
Shoulder width										
Pavement										
Friction										
Unevenness										
Delineation										
Chevrons										
Guideposts and barrier reflectors										
Part B										
Signs										
Warning signs and regulation signs										
Markings										
Edge lines										
Center line										

FIGURE 2 Checklist for general inspection: module for back seat inspector.

TABLE 1 Safety Issues of RSIs

Safety Issue	Detailed Safety Issue	Main Criteria for Identifying High-Level Problems	Main Criteria for Identifying Low-Level Problems
Access	Dangerous access	Location on horizontal curves, on crests, on sites with poor visibility, close to intersections	Unpaved access, narrow access
	Density of access	Three or more access points in one 200-m long stretch	One or two access points in one 200-m long stretch
Cross section	Lane width	$L < 2.75$ m; $L > 4.50$ m	$2.75 \leq L < 3.25$ m; $3.75 < L \leq 4.50$ m
	Shoulder width	Width < 0.30 m	0.30 ≤ width < 1.00 m
Delineation	Chevrons	Missing chevrons on severe curves Chevron placement or visibility inadequate to give correct perception of curve	Missing chevrons on moderate curves Partially obscured chevrons Low reflective chevrons
	Guideposts and barrier reflectors	Missing guideposts Missing reflectors on guideposts, on roadside safety barriers, or on roadside walls	Variable height of reflectors along road Low reflective guideposts Local discontinuity of guideposts
Markings	Edge lines	Missing edge lines Very faded edge lines	Slightly faded edge lines Edge lines partially obscured by vegetation
	Center line	Missing center line Very faded center line	Slightly faded center line
Pavement	Friction	Polished aggregate, bleeding, raveling, low macro-texture	Not defined, friction is ranked as high-level problem or no problem
	Unevenness	Potholes, rutting, patches, shoving on curves or close to intersections	Little shoving, shallow potholes, rutting, patches on tangents
Roadside	Embankments	Unshielded embankments with great slope ($h > 3$ m, $i \geq 2/3$)	Unshielded embankments with medium slope ($h > 3$ m, $1/3 \leq i < 2/3$)
	Bridges	Ineffective barriers	Medium containment barriers if the bridge overpasses roads or railways
	Dangerous terminals and transitions	No breakaway terminals (fish tails, buried in the ground, etc.)	Inadequate transition between steel barriers
	Trees, utility poles, and rigid obstacles	High diameter trees or rigid obstacles located less than 3 m from carriageway	High-diameter trees or rigid obstacles located between 3 and 8 m from carriageway
	Ditches	Rectangular or trapezoidal ditches located less than 3 m from carriageway	Rectangular or trapezoidal ditches located between 3 and 5 m from carriageway
Sight distance	Inadequate sight distance on horizontal curve	Available sight distance less than 50 m caused by continuous obstructions to visibility inside curve	Available sight distance greater than 50 m but less than SSD or inadequate to give correct road perception
	Inadequate sight distance on vertical curve	Available sight distance less than 50 m	Available sight distance greater than 50 m but less than SSD or inadequate to give correct road perception
Signs	Warning signs, regulation signs	Missing curve or crest warning sign	Curve or crest warning sign faded or with low visibility

NOTE: L = lane width; h = embankment height; i = embankment slope; SSD = stopping sight distance.

The accident frequency factor depends on the safety features of the segment, which are assessed by two analysis methodologies: RSIs and design consistency evaluations and design standards check. The accident frequency factor is obtained by using the formula

$$\text{accident frequency factor} = \text{RSI AF} \times \text{GD AF} \quad (3)$$

where RSI AF is the RSI accident frequency factor and GD AF is the geometric design accident frequency factor.

Accident severity is intended as a measure of the ratio between the number of severe accidents (injury or fatal) and the total number of accidents. Two factors were considered significant: operating speed and roadside hazard.

The accident severity factor for the segment is computed with the following formula:

$$\text{accident severity factor} = \left(\frac{V_{85}}{V_{\text{base}}}\right) \times \text{RSI AS}_{\text{roadside}} \quad (4)$$

where

V_{85} = average 85th percentile of speed along the segment (weighted to element length);

V_{base} = base operating speed for two-lane, local rural highways (assumed equal to legal speed limit of 90 km/h); and

$\text{RSI AS}_{\text{roadside}}$ = roadside accident severity factor of segment.

More specific and operative details for the assessment of the SI can be found elsewhere (*8, 10*).

VALIDATION OF PROCEDURE

To effectively use safety inspections as a supporting tool for road safety management, the procedure must satisfy the following objectives: (*a*) it must be reliable, (*b*) it must produce a safety evaluation correlated with crash history, (*c*) it must rank safety problems; and (*d*) rankings must be consistent.

To validate the procedure, an in-field experiment was conducted. SI was assessed in road segments by a group of three experienced road safety inspectors having the road safety background described earlier.

Reliability of Procedure

To test the reliability of the methodology, the agreement of the results of the general safety issue rankings produced by different inspectors for road segments was addressed. Specifically, to check the consistency of the risk assignment between different inspectors, the statistic kappa has been used. The kappa coefficient (k) provides a measure of agreement among a set of inspectors who rated a set of N objects using a nominal scale with M different category judgments, correcting for expected chance of agreement:

$$k = \frac{P - P_e}{1 - P_e} \tag{5}$$

where P is the proportion of times that the inspectors agree (0.00–1.00), and P_e is the proportion of times that agreement by chance is expected (0.00–1.00).

If there is total agreement, k is equal to 1. If there is no agreement other than that which would be expected by chance, k is equal to 0. A negative kappa value indicates disagreement between inspectors. Moreover, it is possible to test whether the level of agreement is statistically significant. Under a test hypothesis of no agreement beyond chance, the level of significance α of the agreement can be determined by evaluating the probability of $k/\sqrt{\text{var}(k)}$ for a standard normal distribution. An α of 10% can be used as the level of significance.

The k-statistics were computed with reference to different combinations of inspectors and different category judgments. First, the checklists filled out by two teams of experienced safety specialists were compared. The checklists were compiled with respect to three different two-lane rural roads with a total length of 40 km (200 segments). Each team was composed of the driver and two inspectors, one in the front seat and the other in the back seat. Safety issues were ranked with three categories of judgment: high-level problem, low-level problem, and no problem. Results showed that there was a significant level of agreement for the majority of the safety issues identified by different teams of inspectors. For some issues (terminals and transitions, presence of access, unevenness, chevrons and markings), the level of agreement was very satisfactory ($\alpha \leq 0.1\%$). For bridges, ditches, sight distance on vertical curves, delineation guideposts, and friction, the collected data were not significant for the test because the judgment expressed by both groups assumed an almost constant value along the entire road. Safety issues for which there was no statistically significant level of agreement were embankments, roadside obstacles, and dangerous access points.

To check whether the lack of agreement could be reduced by considering a simpler identification of the safety issues, the checklists were compiled by using a nominal scale of two categories of judgment: problem (which includes low-level and high-level problems) and no problem. A general improvement in the agreement was observed, but it appeared that the advantage arising from the greater level of detail reached with the three-level judgment overcomes the reduced level of agreement in comparison with the two-level judgment procedure.

Correlation of Safety Evaluations with Crash History

A sample of about 100 km of two-lane, low-volume rural highways located in the province of Catania, Italy, was used. A segmentation into homogeneous sections was carried out on the basis of the geometric alignment characteristics and traffic flow volumes. Thirty homogeneous segments were obtained. From crash data collected for a 5-year period, a model that predicts road segment crash frequency using the segment length and the AADT volume as explanatory variables was developed (*8, 10*). Generalized linear modeling techniques were used to fit the model, and a negative binomial distribution error structure was assumed. The crash estimates were then subjected to an empirical Bayes (EB) refinement technique to correct for regression-to-mean bias and to obtain a better estimate of the expected accident frequency.

To test the procedure, comparisons were carried out between SI scores and EB safety estimates. The correlation between SI values and EB safety estimates was highly significant ($t = 9.64$, p-value $< .001$), with 77% ($R^2 = 0.77$) of the variation in the estimated number of crashes explained by the SI value. This finding means that the relationship between EB estimates and SI scores had less than 0.1% chance of occurring by accident. Comparisons between SI/L scores and EB/L safety estimates gave similar results. The correlation between EB/L safety estimates and SI/L values was highly significant ($t = 9.05$, p-value $< .001$), with 75% of the variation in the estimated number of crashes per kilometer explained by the SI/L value (see Figure 3).

Correlation of Procedure Rankings with Crash-Based Rankings

The main object of the procedure is to define management priorities with respect to road safety. Thus, a comparison was made of the rankings obtained by the SI and by the EB method. Indeed, recent research has shown that the EB method is the most consistent and reliable crash-based method for identifying and priority-ranking investigation locations (*34–36*).

Spearman's rank correlation was used to determine the level of agreement between the rankings obtained using the two techniques. The Spearman's rank correlation coefficient is a measure of association between the rankings of two variables measured on N individuals. To calculate the Spearman's rank correlation coefficient, it is necessary to segment the data sets and then rank the paired data sets in ascending or descending order. The Spearman's rank correlation coefficient is often used as a nonparametric alternative to a traditional coefficient of correlation and can be applied under general conditions. The correlation coefficient is calculated from the two vectors of ranks for the samples: let $\{Xi;\ i = 1 \ldots n\}$ and $\{Yi;\ i = 1 \ldots n\}$ be the vectors of ranks for Sample 1 and Sample 2, respectively; then

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

where

ρ_s = Spearman's rank correlation coefficient,
d_i = differences between rankings, and
n = number of paired sets.

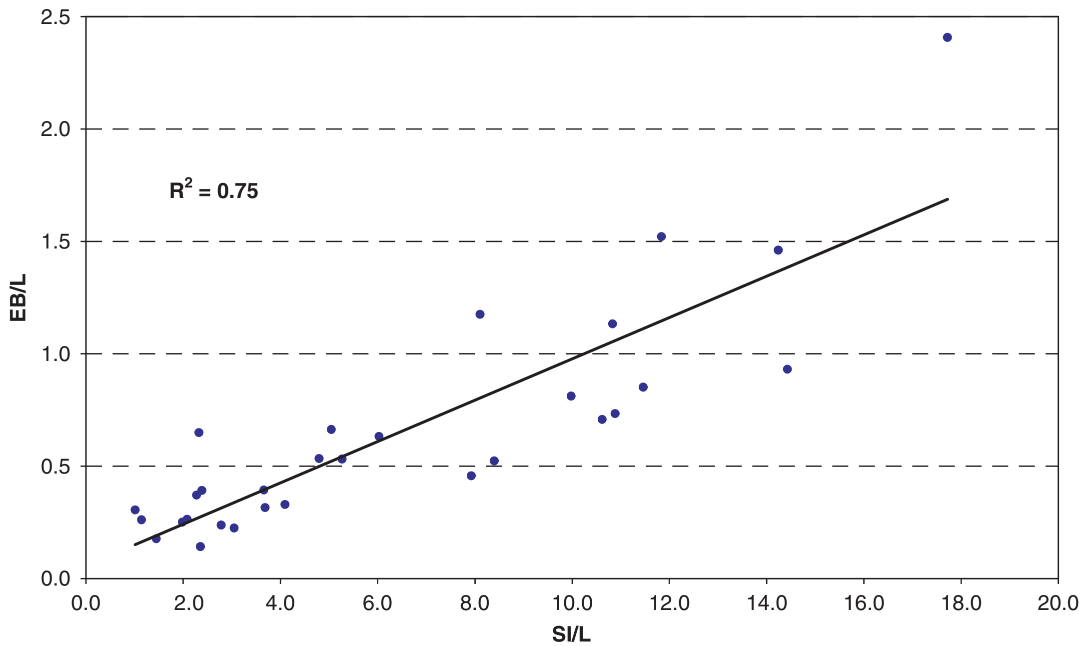

FIGURE 3 Correlation between SI/*L* scores and EB/*L* safety estimates.

A score of 1.0 represents perfect correlation and a score of zero indicates no correlation. The *t*-approximation for this statistic, *T*, is valid for samples of eight and up and is calculated by

$$T = \rho_s \times \sqrt{\frac{n-2}{1-\rho_s^2}} \qquad (7)$$

The *t* has approximately a *t*-distribution with $n - 2$ degrees of freedom and can be used for a test of the null hypothesis of independence between samples.

The results from the Spearman's rank correlation analysis (see Table 2) provide further validation for the SI, indicating that the rankings from the SI and the EB estimates agree at the 99.9% level of significance with a correlation coefficient of .87. The same level of agreement is obtained if rankings from SI/*L* and from EB/*L* are compared.

Selection of Countermeasures

On the basis of the inspection results, the team should write recommendations, which are engineering solutions to the reported problems. For example, at the sites where skid resistance deficiencies are identified, resurfacing could be recommended as a potential countermeasure. In Table 3, examples of recommendations for the general problems are reported. The problems and the recommendations are separated to underline the specificity of the individual infrastructure elements, but safety improvements must be undertaken with an integrated strategy that coordinates the various works.

The procedure has two main applications. High-risk segments where safety measures that can reduce crash frequency or severity already exist can be identified and ranked by the SI score. Specific safety issues that contribute more to the lack of safety are pointed out by their SI in order to indicate more appropriate mass-action programs. If a specific improvement program is planned, sites can be ranked according to the SI of the related safety issue. Moreover, changes in SI due to improvement of such safety issues can be evaluated to define the more effective safety improvements based on available budget.

CONCLUSIONS

The international comparison of current practices and policies on RSIs highlights the role of these procedures as a complement to traditional road safety assessment methods. The discussion focused on the feasibility of RSIs as a systematic and replicable supporting tool in the safety management of low-volume rural roads. A detailed safety inspection process was defined. From the procedure, a quantitative safety index (SI) is assessed, which integrates two different approaches, one based on design consistency evaluation and the other on safety inspections, and makes it possible to effectively address a wide variety of safety issues.

The RSIs carried out according to the defined procedures showed that there is a statistically significant level of agreement of the safety issue rankings produced by different inspectors for the majority of safety issues. As a result, the reliability of the procedure is satisfactory. Further, the SI was assessed in 30 segments of low-volume roads in Italy and rankings performed according to the SI scores and according to the EB safety estimates were compared. Spearman's rank correlation was used to determine the level of agreement between the rankings obtained using the two techniques. The results from the Spearman's rank correlation analysis provide additional validation of the procedure, indicating that the rankings from the SI scores and the EB estimates agree at the 99.9% level of significance with a correlation coefficient of .87.

The SI has two main practical applications. High-risk segments can be identified and ranked by the SI score. Specific safety issues that contribute more to lack of safety are pointed out in the RSI procedure in order to indicate more appropriate mass-action programs.

The SI can be assessed as part of the safety inspection process without relevant supplementary work. RSIs represent a low-cost process

TABLE 2 Comparison Between Ranking Criteria

Section	Exposure Factor	Accident Frequency Factor	Accident Severity Factor	SI	EB Estimate	SI Rank	EB Rank	SI/*L*	EB/*L*	SI/*L* Rank	EB/*L* Rank
1	14.20	2.68	0.98	37.50	3.92	2	2	10.83	1.13	7	5
2	11.41	2.89	0.97	31.89	2.37	6	6	11.46	0.85	5	7
3	2.62	4.92	0.88	11.32	1.54	19	13	17.72	2.41	1	1
4	14.25	3.33	0.82	39.02	4.00	1	1	14.24	1.46	3	3
5	8.11	4.63	0.61	22.73	2.99	8	4	5.05	0.66	15	11
6	2.52	4.66	0.57	6.71	0.75	25	25	4.79	0.53	16	14
7	16.96	1.67	1.19	33.57	2.26	4	7	10.88	0.73	6	9
8	11.57	2.10	1.39	33.86	3.41	3	3	5.27	0.53	14	15
9	5.61	2.50	1.34	18.78	1.97	12	9	6.03	0.63	13	13
10	3.20	2.02	1.20	7.71	0.94	24	22	1.45	0.18	28	29
11	0.62	3.55	0.47	1.05	0.32	30	30	1.01	0.30	30	23
12	0.87	2.15	0.89	1.66	0.38	29	29	1.14	0.26	29	25
13	5.07	3.84	0.60	11.71	1.49	18	14	2.08	0.26	26	24
14	6.87	3.70	0.71	17.99	1.09	13	19	2.36	0.14	23	30
15	1.63	5.27	0.50	4.33	0.71	27	27	2.39	0.39	22	19
16	2.69	4.62	0.67	8.32	0.71	23	28	2.78	0.24	21	27
17	8.22	1.85	1.37	20.89	1.54	10	12	3.05	0.22	20	28
18	2.89	2.25	1.36	8.88	0.76	22	24	3.68	0.32	18	22
19	2.66	2.42	1.41	9.09	0.73	21	26	4.10	0.33	17	21
20	8.33	1.86	1.47	22.78	1.31	7	17	7.93	0.46	12	17
21	6.07	2.43	1.15	16.98	2.46	14	5	8.11	1.18	11	4
22	13.60	5.02	0.48	32.65	2.04	5	8	8.40	0.52	10	16
23	5.29	2.73	0.97	13.91	1.79	16	10	11.84	1.52	4	2
24	7.26	2.89	0.92	19.27	1.28	11	18	10.62	0.71	8	10
25	8.66	1.94	1.29	21.61	1.76	9	11	9.98	0.81	9	8
26	4.58	4.45	0.81	16.53	1.07	15	20	14.43	0.93	2	6
27	1.39	3.18	0.67	2.93	0.82	28	23	2.33	0.65	24	12
28	3.68	3.68	0.90	12.25	1.32	17	16	3.66	0.39	19	18
29	2.84	3.97	0.52	5.87	0.96	26	21	2.27	0.37	25	20
30	5.80	3.21	0.56	10.46	1.32	20	15	1.98	0.25	27	26
							$\rho_s = .87$				$\rho_s = .87$
							$T = 9.54$				$T = 9.15$
							p-value < .001				p-value < .001

TABLE 3 Typical Recommendations for General Problems

General Problem	Recommendations
Delineation	Install continuous roadside delineation system using normal guideposts, reflectors on safety barriers, and chevrons.
Road signs	Draw up road sign plan and adapt existing signs according to provisions of plan. Install signs with high intensity reflective sheeting. Periodically check efficiency and reflectivity of signs. Remove obstacles that limit visibility of signs. Remove advertising material that does not respect regulations.
Access	Move access from dangerous locations. Remove obstacles to visibility. Pave point where roads join. Install access delineators. Use high-performance road markings and signs. Adapt alignment to guarantee suitable width and roundabouts where access points join main road.
Alignment	Remove obstacles that limit sight distance on horizontal curves so as to guarantee SSD at 85th percentile speed. Adjust design of vertical curves where SSD is not guaranteed. As a further measure, take steps to reduce speed and warn drivers of danger.
Cross section	Adapt cross section and install paved shoulders of suitable dimensions.
Road markings	Renew markings in those places where a low- or high-level problem was identified. Install highly reflective markings using highly durable materials. Carry out periodic checks as to condition of road markings.
Pavement	If there is friction problem, recover worn area. If there is unevenness, carry out repair works on bitumen conglomerate layers. Periodically check situation as regards friction and unevenness. If there are further problems, it is advisable to combine visual inspection with instrumental measurements to obtain exact evaluation of situation.
Roadsides	Embankments and bridges: install safety barriers with suitable containment capacity. Dangerous terminals and transitions: install breakaway terminals and transitions that guarantee graded performance variation. Other obstacles: move or protect obstacles. Ditches: protect ditches with metal grates or safety barriers, or replace existing ditches with different type.

for the periodic evaluation of network safety performance, and the SI assessment is an effective tool for the development of safety strategies incorporating the inspections in a more comprehensive road safety program. The low cost and applicability in road networks where geometric and crash data are not available make the procedure very attractive for low-volume rural roads.

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