SAFETY RATING AND MANAGEMENT OF ROAD NETWORK BASED ON SAFETY INSPECTION

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ABSTRACT

Low/medium incoming countries experience a lack of data (i.e crash, traffic, road features) to carry out reliable identification of site with high accident concentration. Moreover, even if road sections with a high accident concentration are correctly identified and remedial measures have been taken, safety inspections as a preventive measure should assume a more important role *(*EU Directive 2008/96/EC”)

Based on these considerations, a Safety Risk Index (RI) was defined and tested in several years of research and practical application as surrogate measure of safety for ranking of high risk sites and identification of related safety issues.

RI is formulated by combining three components of risk: exposure of road users to road hazards, probability of a vehicle being involved in an accident and the resulting consequences should an accident occur.

Moreover, as the available budget is often not enough to undertake all the treatments that are necessary for addressing the safety deficiencies identified in the network screening, an optimization process is developed for selecting projects to be included in the budget for maximizing the safety benefits of the investments.

Low cost equipment and software tools have been developed for supporting the human task during on road inspections and in office reporting, as well.

For road agencies facing the problem of road safety data and budget constraints when selecting safety countermeasures, the proposed computed-aid procedure is very effective. It is able to cover the whole safety evaluation process from the identification of safety deficiencies, with a proactive approach, to the evaluation of the treatment alternatives providing the best benefit/cost ratio within the available budget.

The paper will present an overview of the whole process and examples of practical application in different countries highlighting the adaptability in different national contexts and standards.

KEYWORDS

Safer Roads, Safety Inspection, Network Management, Rating

INTRODUCTION

Safety Management of Road Network in operation can be based both on identification of sites with high crash concentration (network screening) and routine Safety Inspection.

Specifically, network safety screening is able to identify sites with higher crash concentration than expected. When such sites with potential for safety improvement are ranked, selection of sites and treatments can be carried out by means of a cost benefit analysis where benefit are identified by the expected reduction in crash frequency. A part of the appropriate application of the process (e.g. HSM, (1)), the quantitative nature of data (i.e. number of crashes) makes it possible the rating of the hazard and the estimation of the benefits.

That safety ranking has a high potential immediately after its implementation, but once road sections with a high accident concentration have been treated and remedial measures have been taken, safety inspections as a preventive measure should assume a more important role *(*EU Directive 2008/96/EC, (2)). Moreover, low/medium incoming countries experience a lack of quality data (i.e crash, traffic, road factors) to carry out reliable identification of site with high accident concentration.

In those circumstances, periodic safety inspections on existing roads remain the best option in order to identify the hazard road features and to prevent accidents. Safety inspections are recognized as an effective tool for identifying potential hazards and are becoming an accepted practice in many agencies around the world. SIs are considered part of the network safety management in the European Directive 2008/96/CE (2).

A safety inspection (SIs) is a formal examination of an existing road, in which inspectors report on the road’s crash potential and safety performance. The inspectors should be “independent”, i.e. not part of the team that designed or manage the road. They should have a very good road safety knowledge and in-depth understanding of potential countermeasures and what is required for their implementation.

There are four steps in the SI’s process:

Step 1 preparatory work in the office;

Step 2 on site field study;

Step 3 SIs report;

Step 4 remedial measures and follow up.

SI’s reports can be a source of information needed to identify treatments in road sections with potential hazards, but due to its qualitative nature, the identification of potential hazards is not enough for ranking several sites and for performing a benefit/cost analysis.

Such a possibility is introduced in a novel SI procedure defined in the framework of the European project “Identification of Hazard Locations and Ranking of Measures to Improve Safety on Local Rural Roads” (IASP), in conjunction with the development of a Risk Index (RI) (3) used to predict frequency and severity of accidents when using SIs. Despite the procedure was developed and validated in European countries, the scientific framework and the open and clear presentation of the algorithms make it possible adaptation to different national conditions and issues. In new emerging economies, like India, vast rural road network created recently has resulted in increased social and economic benefits. However, these benefits would reduce substantially due to poor maintenance. This topic is relevant for identifying strategies for rational uses of limited resources available for safety maintenance of rural network.

This paper presents a synthesis of previous publications and it was prepared for the IRF WRM 2017 in New Delhi, with the aim to provide an overview of a research project which is going on in last 10 years but with limited distribution outside the academic and research arena.

The paper is divided into 3 main sections presenting:

IASP procedure for road safety inspection;

Hardware and Software tools;

Validation

IASP PROCEDURE

Safety Inspection of Two Lane Rural Roads

The IASP procedure (3) was developed in the framework of a European project. As part of the project, safety inspections procedures, which address rural two-lane highways, have been defined. Albeit many safety inspection procedures already exist, the IASP procedures present some innovative elements and, above all, they are very operational in nature. At least three operators are needed: the driver, the inspector in front seat and the inspector in back seat. Recommended equipment are GPS receiver, digital video camera and checklists. The road is ran in both directions at very low speed (about 30 km/h). Checklists are aimed at ensuring that important safety problems are not overlooked. Checklists are a prompt and not a substitute for knowledge and experience, that is, checklists should aid using safety engineering experience and judgment. IASP checklists (Figure 1 and Figure 2) are very synthetic, since they relate only to the main safety features which usually are present along two lane rural roads. Moreover, only features which are easily detectable during inspections have been inserted. Checklists must be filled in both directions. Front seat and back seat inspectors, which have different views of the road, compile separate checklists filling the fields with a step of 200 m (24 s at 30 km/h). Basing on experience, one team is able to inspect in one day about 50 km of road in both directions.

Safety issues are ranked as: high score problem, low score problem and no problem.

Experience pointed out that including in the checklist a limited number of items and a three level scores improve effectiveness without reducing the reliability of results.

		0,2		0,4		0,6		0,8		1,0	
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											
Accesses											
	Dangerous accesses	▨		▨		▨		▨		▨	
	Presence of accesses	▨		▨		▨		▨		▨	

FIGURE 1 Checklist for General Inspection: Module for Front Seat Inspector

		0,2		0,4		0,6		0,8		1,0	
PART A											
Cross section											
	Lane width	▨		▨		▨		▨		▨	
	Shoulder width	▨		▨		▨		▨		▨	
Pavement											
	Friction	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Unevenness	▨		▨		▨		▨		▨	
Delineation											
	Chevrons	▨		▨		▨		▨		▨	
	Guideposts and barrier reflectors	▨		▨		▨		▨		▨	
PART B											
Signs											
	Warning signs, regulation signs	▨		▨		▨		▨		▨	
Markings											
	Edge lines	▨		▨		▨		▨		▨	
	Center line	▨		▨		▨		▨		▨	

FIGURE 2 Checklist for General Inspection: Module for Back Seat Inspector

After the preliminary inspection, in the office, the team analyses videos and (if wasn’t done on site) complete part of the checklists. By brainstorming among the team members’ checklist results are reviewed and the final version is edited. As final result of the meeting, a preliminary report describing general problems and recommendations is edited. Moreover, some sites requiring specific inspection (site visits) might be identified.

Risk Index

The Risk Index (RI) is a surrogate safety measure, which was defined to supplement crash investigation studies in the safety evaluation of two-lane rural highways by using data from Sis (3). In road network safety management, RI is a quantitative measure which fills the gap in the use of Safety Inspection that are qualitative in their nature.

Cafiso et al. (3) formulated the RI by combining the risk main components related to: exposure of road users to road hazards (EF); probability of a vehicle being involved in a collision (AFF); resulting consequences should a crash occur (ASF):

$$RI = EF \times AFF \times ASF \qquad (1)$$

In the following the theoretical background and the analytical formulation of RI will be synthetically reported. The detailed explanation of the model is out the topic of the present paper, but the reader interested in a more details will be able to find all the information in the referenced papers (3, 4).

Exposure Factor (EF)

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

$$EF = L \times AADT \qquad (2)$$

where:

- L is the length of each unit (in kilometers)
- AADT is average annual daily traffic (in 1,000 vehicles per day).

Accident Frequency Factor (AFF)

The accident frequency factor depends on the safety features of the segment, which are assessed by road Safety Inspection

The accident frequency factor is obtained by:

$$AFF = SI\ AF \qquad (3)$$

where:

- SI AF quantify the presence of safety issues which can be assessed on the basis of road safety inspections. SIs relate to the main safety issues that can be effectively detected in two lane rural roads by means of inspections (Accesses, Cross sections, Delineation, Markings, Signs, Pavement, Roadside, Sight distance, Alignment).

For each safety issue j the related SI AF_j is computed as follows:

$$SI\ AF_j = 1 + WS_j \times \Delta AF_j \times P_j \qquad (4)$$

where:

- WS_j is the score assigned to each issue during the Safety Inspection;
- ΔAF_j is the estimated relative increase in accident risk due to issue j;
- P_j is the proportion of accident typologies affected by issue j.

On the basis of existing literature, the relative increase in accident risk ΔAF due to each issue was defined (3)

Accident Severity Factor (ASF)

The accident severity factor (ASF) is a measure of severity of crashes basing on roadside hazards, identified by Safety Inspection (SIs), and speed value as the ratio between the 85th percentile of free flow speed (V_{85}) and the posted/design speed (V_{base}).

$$ASF = \left(\frac{V_{85}}{V_{base}}\right) \times SI\ AS_{roadside} \tag{5}$$

where:

- V_{85} is the average 85th percentile of speed along segment (weighted to element length);
- V_{base} is the base operating speed for two-lane local rural highways (may be assumed equal to legal speed limit);
- $SI\ AS_{roadside}$ is the roadside accident severity factor of segment equal to

$$\mathrm{SI\ AS_{roadside}} = 1 + \mathrm{WS_{roadside}} \times \mathrm{P_{roadside}} \times \Delta\mathrm{AS_{roadside}} \tag{6}$$

where:

- $WS_{roadside}$ is the score of roadside safety issue assigned during the SIs;
- $P_{roadside}$ is the proportion of accidents related to roadside issue, equal to proportion of run-off-the-road accidents;
- $\Delta AS_{roadside}$ is the estimated relative increase in accident severity due to the roadside $hazard_j$ (embankments, bridges, dangerous barrier terminals and transitions, trees, utility poles, rigid obstacles and ditches).

The assessment of RI has two main applications. High-risk segments can be identified and ranked by the RI score. Specific safety issues that contribute more to lack of safety are pointed out by the accident frequency factor and the accident severity factor in order to give indications regarding more appropriate mass-action programs.

Finally, the availability of RIs, as surrogate safety measure, may be an effective tool for local road agencies in the development of suitable maintenance programs. As the available budget is usually not adequate to apply all the safety countermeasures that correspond to the safety deficiencies identified during SIs of the road network, the necessary steps of the management process after the risk assessment, are the identification of 1) sites to be treated (where), 2) countermeasures to be applied (what), 3) the associated cost (how much) and a 4) multi-year work program (when) with a priority ranking able to maximize benefits within the available budget. If the budget is not enough to solve all the problems applying always the best maintenance program, prioritization and optimization criteria have to be applied to set up a maintenance program to get the maximum benefit within the available budget.

Figure 3 (4) shows the flow chart of the proposed safety management process using Safety Inspection as source of information for risk assessment.

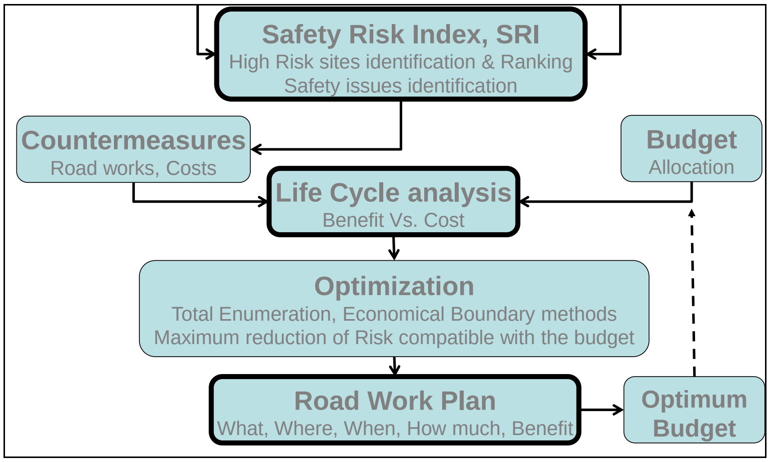

FIGURE 3 Safety Management of road network using surrogate safety measures

The optimization process (4) is carried out by means of a total enumeration algorithm, evaluating the number of years in the analysis period, the budgetary periods (that is, the time duration of allocated budget), the budgetary resource constraints (that is, the budgetary limits defined according to the spending period), the annual values of ΔRI (change in RI due to the treatment works in the year) and associated construction costs. Budget permitting, the best combination of work strategies is sought for each spending period to obtain the greatest RI reduction (ΔRImax). When the best combination exceeds the spending limits, an optimization process, based on economic boundary theory, is applied to identify the most efficient strategies to submit to further budget checks (4). The result obtained is a combination of strategies (each to be applied to a specific road section in a specific year) that makes it possible to obtain the maximum RI reduction compatible with the spending limits established for each period. By reference to the optimal solution, an intervention program can be drawn up, which made it possible to identify, year by year, the works to be carried out on each single homogeneous section of the network and their relative costs.

Figure 4 (4) shows results that can be drawn with the proposed procedure in terms of investment costs for treatments (Present Net Value, PV) and corresponding benefits associated to the expected reduction in crash frequency due to ΔRIs values.

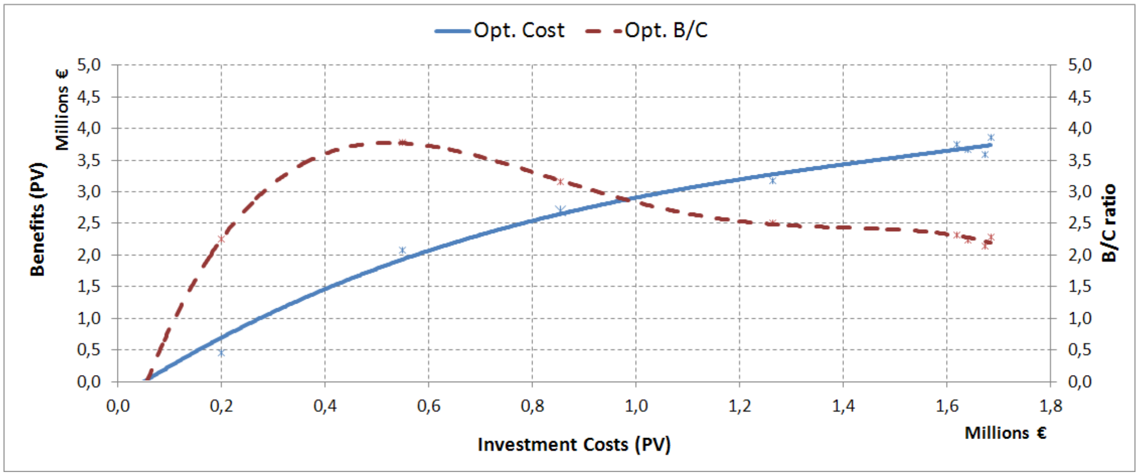

FIGURE 4 Program Level - PV of Road network Investments vs. Benefits and Benefit/Cost

Ratio

Figure 4 shows as Present Net Value (PV) of benefits (blue line) and benefit/cost ratio (dashed red line) change increasing the PV of the investments costs in the cycle life of 10 years considered in the case study. This example is useful to point out which results can be achieved by using the proposed procedure. Ascertained that, even if each budget allocation gives the maximum benefits (i.e. reduction of crashes) as result of the optimization process, increasing investment costs will produce increased benefits.

At program level, if the goal of the road agency is the maximum reduction in the number of crashes, it is possible to estimate budget allocation to reach the maximum benefit (e.g. PV=1.7 M€ in the example of Figure 4). This budget is appropriate to solve, in the analysis period of 10 years, every relevant safety issue and maintenance needs, beyond this investment more works do not result in substantial further safety improvements.

If the point of view is the benefit/cost ratio, the maximum value could be reached with a reduced investment in 10 years (e.g. PV=0.5 million € in the example of Figure 4). If compared with the maximum benefit solution, this investment gives less benefits but leaves budget (i.e. 1.1 M €) available for actions in other parts of the road network.

To balance the maximum benefit with the maximum benefit/cost ratio (B/C), the minimum B/C value can be set and the budget to achieve the maximum benefits is estimated from Figure 4, as well. In the example fixing the minimum value of B/C at 3.0 a budget of 0.95 M€ is estimated. Using this budget, the total RI after 10 years is computed equal to 151.0 that predicts a reduction of 37% in crash numbers.

HARDWARE AND SOFTWARE TOOLS

New software tools and low cost equipment are proposed to support the Safety Inspection activities that are the main time consuming part of the process and to compute easily the RI for a large road network.

In addition, the optimization procedure requires a considerable number of calculations, so the SAFOPT (SAFety OPTimization) software has been developed.

Tools for Safety Inspection

As reported before, in IASP procedure the inspectors observe and evaluate road conditions, filling two different checklists. The most important part of the infield inspection is assessment of the safety issues and filling of the checklist for each road section of fixed length composing the road segment under investigation. This task requires relevant expertise and skill of the inspectors. The innovative system developed by the University of Catania (Cafiso et al. 2014) and presented in this paper frees the operator from the concern to link the position in the road segment to the checklist to be filled. The inspectors fill the checklists touching the screen of the tablet connected to the GPS via Bluetooth. In this way data are easily collected, stored and linked to the road segment stretch where they are taken and synchronized with the video records. The system has the objective to simplify the operator's work without user’s concern:

allows easy data insertion to the user;

links inspection data with an unique road section travelling the route in both directions;

stores all information to allow the post-inspection review.

By means of an easy-to-use interface the application allows the user to insert inspection data for each section of the road using his/her own tablet.

To improve accuracy in vehicle positioning, an external GPS receiver can be connected with Android application running on the tablet. Finally, to associate also images of the road space, frames recorded by a video-camera installed on the vehicle can be geo-referenced and linked to the inspection data through a system of synchronization based on the GPS UTC time used as a metronome for all devices. The architecture and organization of the system is shown in Figure 5. If the GPS module is the “heart” of the system, the Data Acquisition Module is the “brain”. This module uses data from GPS to support the inspector task via the Graphic User Interface (GUI). For each inspection two check-list-form are available: one for the operator in the front seat and one for the operator in the rear one. The checklist-form may be modified before the inspection because it is saved in the form of XML file which can be edited at any time. If the inspection is carried out for a two-lane road, after the forward path inspection, the operator must begin a return path inspection in the opposite direction and the system helps to find the starting point of the return path. Once the acquisition procedure is concluded in both directions, the application merges data obtained in the forward path to those obtained in the return path.

At the end of the infield inspection, the Data Acquisition Module exports all data in the form of text files that can be read and processed by the Data Analysis Module.

The Data Analysis Module concludes in the office the last part of the inspection process. Once infield data acquisition phase is completed, in the office the Data Analysis Module allows the inspection team to review the checklists and, supported by the video, to fill missed information or to correct errors before finish the inspection report. In this step, the Module puts together data recorded by the front seat operator and the rear seat operator. The user can investigate every single step of the inspection by moving from sheet to sheet and from time to time with the opportunity of reviewing the corresponding video sequence and, if necessary, modify the values of each checklist.

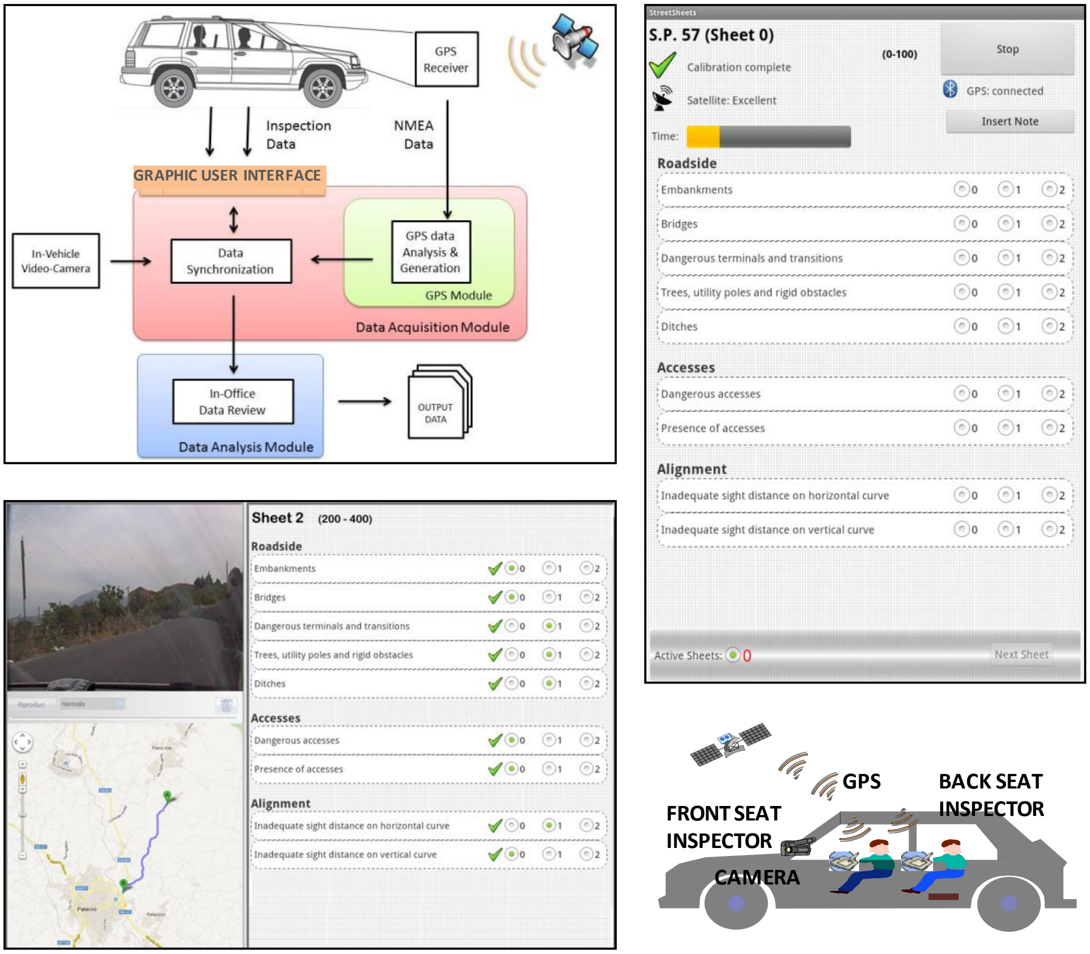

FIGURE 5 Architecture and organization of the system

VALIDATION

The risk index (RI) carried out by the safety inspection data represents the main innovation in the process, making possible to rank sections and to perform a quantitative benefit estimation.

Those applications can be expected reliable only if RI is a surrogate measure of safety, i.e. a parameter that is not directly a measure of crash frequency, but it is correlated to crash occurrence.

Therefore, to validate the procedure, comparisons were made between RI values and the expected frequency of severe (fatal and injury) crashes.

Initially, a sample of about 100 km of two-lane local rural highways, located in Italy in Province of Catania, was used in order to apply and validate the procedure. A latter validation was carried out in Poland on a sample of 184 km of two lane rural roads in the Krakow region.

Risk Index is calculated on a 200 m base, but unfortunately, such short segments do not allow a perfect correlation with observed crashes that are taken from Police reports and can contain some possible localization issues. Therefore, longer homogeneous sections were defined by aggregation of contiguous segments with similar values of RI. An iterative segmentation procedure (MINSSE) was applied which combine segments with statistically equal average value of RI. An example of the aggregation process is reported in figure 6.

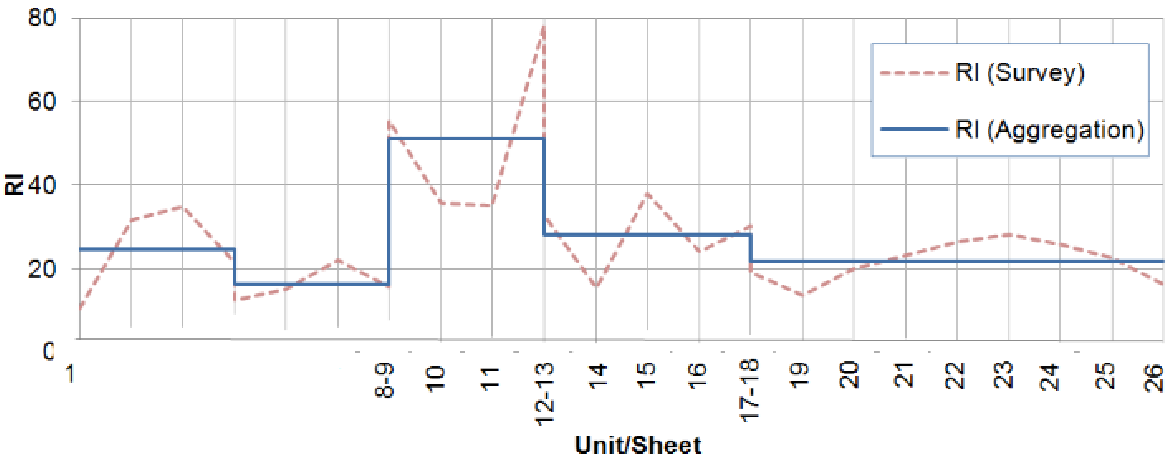

FIGURE 6 Example of aggregation using MINNSE

As result, 30 and 73 homogeneous sections were identified for the Italian and Polish samples respectively (3, 6).

Many studies have demonstrated the inappropriateness of conventional linear regression in modeling discrete, non-negative and rare events such as traffic accident occurrence. Therefore, to take into account the stochastic variability of crash counts in a limited number of years and to avoid regression to the mean effects, Safety Performance Functions (SPF) were calibrated to predict the crash frequency for each of the segments composing the two dataset and an empirical Bayes correction was applied to the observed crash count:

$$EB = w_i \text{ x } E[Y] + (1- w_i) \text{ x } Obs \qquad (7)$$

where:

- EB: expected number of crashes by Empirical Bayes correction;
- E[Y]: number of crashes predicted by SPF;
- Wi: weighting factor;
- Obs: observed number of crashes.

The predicted number of crashes E[Y] is estimated by SPF regression models:

$$E(Y) = e^{\alpha} \times L \times AADT^{\gamma} \qquad (8)$$

where:

- E (Y): predicted crash frequency (fatal plus injury) of random variable Y;
- L: length of road segment [m];
- AADT: average annual daily traffic [veh/day];
- α and γ are regression terms.

Consistent with the state of the art in road crash modeling a Negative Binomial error distribution was considered for estimation of regression coefficients α and γ.

The results are shown in Figures 7 and 8. As it is clear there is a high correlation between RI/L and crashes per km with R^2 always close to 0.8.

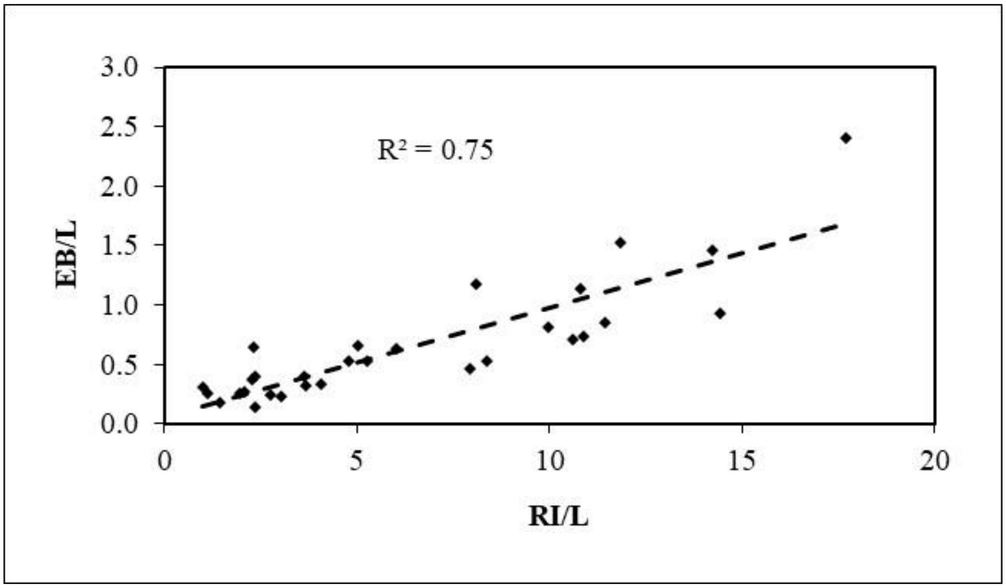

FIGURE 7. Validation in Italy. Dots represents homogeneous sections

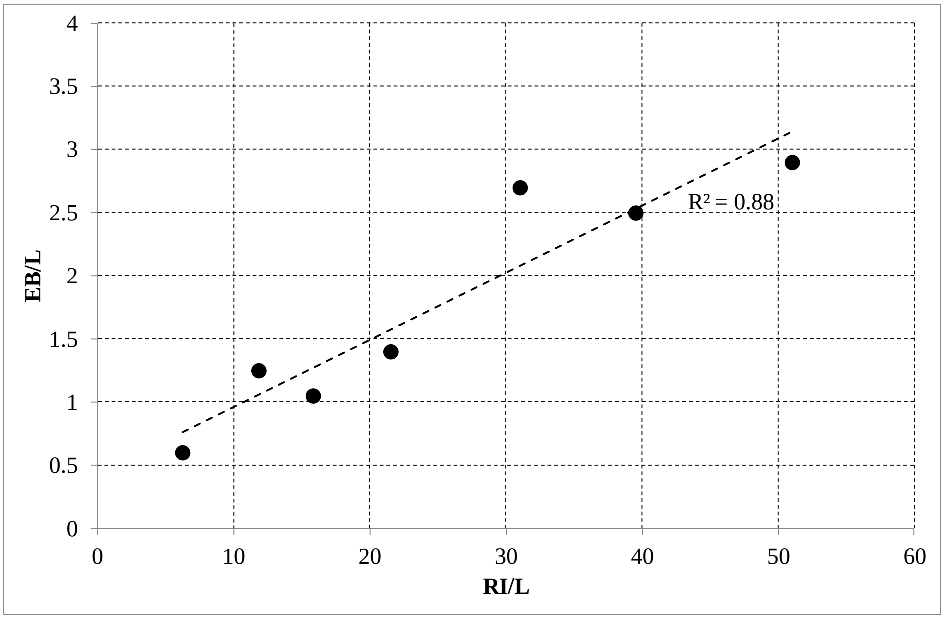

FIGURE 8. Validation in Poland. Dots represents clusters of homogeneous sections

CONCLUSIONS

Besides, there is great emphasis in developing road Safety Inspections (SIs) as an effective tool for safety management of existing roads, relevant issues remain in the use of SIs as source of information to prioritize sections and treatments with the highest safety benefit-cost ratio.

Beside, SI procedures and tools exist and are regularly applied in different countries, they are often limited to the traditional approach which is finalized to draw the inspection report of recommended countermeasures as output.

To advance the quality and efficiency of the periodic inspections in two lane rural road network, a system of software tools supported by low cost equipment have been developed and presented in the paper. The proposed hardware and software system allows easy insertion of data to the user, solves the association problem between data and location in both directions and after in-field inspection allows an efficient post-inspection review in the office. Moreover, data collected are suitable to carry out a new safety Risk Index (RI) as surrogate measure of safety. If accident data are not available or are unreliable, RI can be used as a proxy for accident data.

The importance of the availability and quality of crash data is strongly acknowledged since it informs the decision making process especially in the common environment of limited budgets. However, the road crash recording and database system in low and mid-incoming countries often does not qualify to be the reliable source of information for various uses. If accident data are not available or are unreliable, RI can be used as a proxy for accident data.

This quantitative measure, instead of the qualitative SI report, makes it possible to perform a cost benefit analysis to prioritize countermeasure and sections to be treated. For Road Agencies facing the problem of budget constraints and legal liability when selecting rehabilitation and maintenance projects, the proposed procedure is very effective because it is able to cover the whole process from the identification of safety deficiencies, with a proactive approach, to the selection of the intervention alternatives providing the highest benefits within the available budget.

In terms of international applicability, the validation tests carried out in Italy and Poland are promising for the international transferability of the Safety Inspections procedures and tools. For practical applications, each Road Agency can modify the list of roadworks and strategies to take into account local materials and technologies, costs and maintenance needs.

IASP procedure is one of the twenty-one models or approaches to road safety management reviewed and assessed by TRL in the Project Report PPR770 (7). IASP was chosen as one of the six most promising models that should be tested in UK, with iRAP Star Rating, NetRisk, SURE, iRAP Risk Mapping, North Yorkshire Route Assessment Tool. The six models were chosen based on the scores they obtained from the review process and also the impression of how cost-effective they might be.

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