A Methodological Approach for the Safety Evaluation of Two-Lane Rural Roads with Low-Medium Traffic Volume

Salvatore Cafiso
Grazia La Cava
Department of Civil and Environmental Engineering
University of Catania Viale Andrea Doria 6, I-95125 Catania, Italy
Phone + 39 095 738 2213 Fax +39 095 738 2247 E-mail dcafiso@dica.unict.it

Alfonso Montella
Department of Transportation Engineering "Luigi Tocchetti"
University of Naples "Federico II" E-mail alfonso.montella@unina.it

Mariano Pernetti
SUN – Second University of Naples E-mail peruetti@unina.it

ABSTRACT

A methodological approach for the safety evaluation of two lane rural roads which use both analytical procedures referring to alignment design consistency models and the "Safety review" process is suggested.
Alignment features and design consistency related to road safety conditions can be effectively evaluated using both Accident Prediction Models and "Safety Criteria" defining three different levels of judgment (good, fair, poor). The model of IHSDM was adapted to the Italian accident and road design characteristics. The Safety Criteria allow to evaluate three different levels of inconsistencies in the horizontal alignment.
It is useful to integrate the results of the analyses carried out from the theoretical-experimental models with those deriving from the judgments collected on inspected sites (the Safety Reviews). The low cost of the procedure and his capability in addressing the safety problems not identified in the previous steps highlight the effectiveness of the Safety Inspection method as part of the safety evaluation process on existing roads.
The methodological framework presented in the paper, consisting of safety inspections carried out as support of the analyses conducted through the theoretical-experimental models, will be applied in Italy as part of the "IASP" project financed by European Commission.

INTRODUCTION

In the contest of the EU program " Road Safety in EU: the 1997-2001 program", the "IASP" project, proposed by the Province of Catania in collaboration with the Department of Civil and Environmental Engineering of University of Catania, was approved and co-financied by European Commission (DG TREN).
The target of the proposed action is the development of a "pilot project" on two lane local rural roads with low-medium traffic volume, defining methodologies and procedures for the analysis of actual road safety conditions and the programming of safety improvements projects. The provincial local roads are characterized by low-medium traffic volume and short travel distance. The network is composed by two lane roads with design speed in the range 40 ÷ 80 km/h. In year 2000, in the province of Catania on 1350 km of provincial roads, 72 accidents took place giving rise to 5 fatalities and 137 injuries. As highlighted in the Italian National Plan Road Safety, for such roads there is a remarkable lack of reliable information referring both to the real state of the road and to the accident situation. This circumstance makes ineffective the usual methodologies of hazard locations

identification based on the accident data statistical analysis. In order to overcome this weakness, the proposed methodological approach uses procedures referring both to theoretical-experimental models for the analysis of safety conditions on road (Accident Prediction Model and Design Consistency) and to the "Safety Review" procedures.

1. THE CRASH PREDICTION MODEL

The prediction of the expected road safety performance is a fundamental part in the implementation of a road safety program. A valuable approach is given by the Crash Prediction Module (CPM) of the Interactive Highway Safety Design Model (IHSDM), a set of highway safety analysis software tools developed by the Federal Highway Administration (FHWA). This module combines the use of historical accident data (if available), regression analysis, before and after studies, and expert judgements to estimate the accident frequency of each geometric element in homogeneous road segments [1].
A regression model for predicting the value of the accident frequency of a road segment is used as the base model of CPM. The accident frequency is a dependent variable predicted as function of a set of indipendent variables descriptors of the traffic volumes, geometric design and traffic control features of the roadway segment.
The base model to calculate the predicted number of total roadway segment accidents per year for nominal or base conditions is expressed by the following formula:

$$N_{br} = EXPO \times e^{\sum_{i=1}^{6} \alpha_i x_i} \times \sum_{j=1}^{3} (w_k \times e^{\beta_j y_j}) \tag{1}$$

where:
N_{br} = predicted number of total roadway segment accidents per year for nominal or base conditions;
EXPO = exposure in million vehicle-miles of travel per year = (ADT)(365)(L)(10^{-6});
ADT = average daily traffic volume (veh/day) on roadway segment;
L = length of roadway segment (m);
α_i = constant;
x_i = roadway indipendent variables such as lane width, shoulder width and type, driveway density and roadside hazard rating
w_k = weight factor related to y_i;
β_i = constant;
y_i = roadway indipendent variables such as horizontal curve length and radius, presence of spiral transition, grade, to calculate the predicted number of total roadway segment accidents per year for nominal or base conditions (N_{br}).

The accident frequency estimate calculated with the base model is adjusted with the accident modification factors (AMFs), that represent the safety effect of individual geometric design and traffic elements, and is calibrated with the calibration factor (C_r) according to formula:

$$N_{rs} = N_{br} \times C_r \times (AMF_{1r} \times AMF_{2r} \times \ldots\ldots\ldots \times .AMF_{nr}) \tag{2}$$

where:
N_{rs} = predicted number of total roadway segment accidents per year after application of accident modification factors;
C_r = Calibration factor for roadway segments developed for use by a particular highway agency;
$AMFi_r$ =Accident Modification Factor for roadway segment.

Each Agency should develop and input their own calibration factor C_r, in order to adjust model estimates to be more suitable to their crash experience. A study has been performed in order to calibrate the CPM proposed in IHSDM to the Italian situation. The first step was the comparison of accident types in Italy and in U.S.A., which showed the lack in Italian official statistics of property damage accidents. For the type of road investigated the Italian distribution were introduced. In this way the output of CPM will give only injuries and/or fatalities accidents. In particular, for Italian situation and for two lane rural roads C_r has the value 0.3 [2].
The AMFs adjust the base model estimates for individual geometric design element dimensions and for traffic control features. Specifically AMF_1 and AMF_2 are related to lane and shoulder width. Lane and shoulder width affect single vehicle run-off-the-road and multiple vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents. On Italian two-lane rural roads these accident types account for 43% of non intersection related accidents.

Moreover the calibration of superelevation AMF_4 was conducted through a comparison of design diagram for superelevation adopted in the AASHTO Green Book [3] (used as reference in IHSDM) and in the Italian guidelines [4]. The results are showed in Figure 1, which allows to consider acceptable for Italy the AASHTO design criterion with maximum superelevation rate (e) of 6%.
The other AMF values were determinate using the default formula, referring to the investigated road elements characteristics.

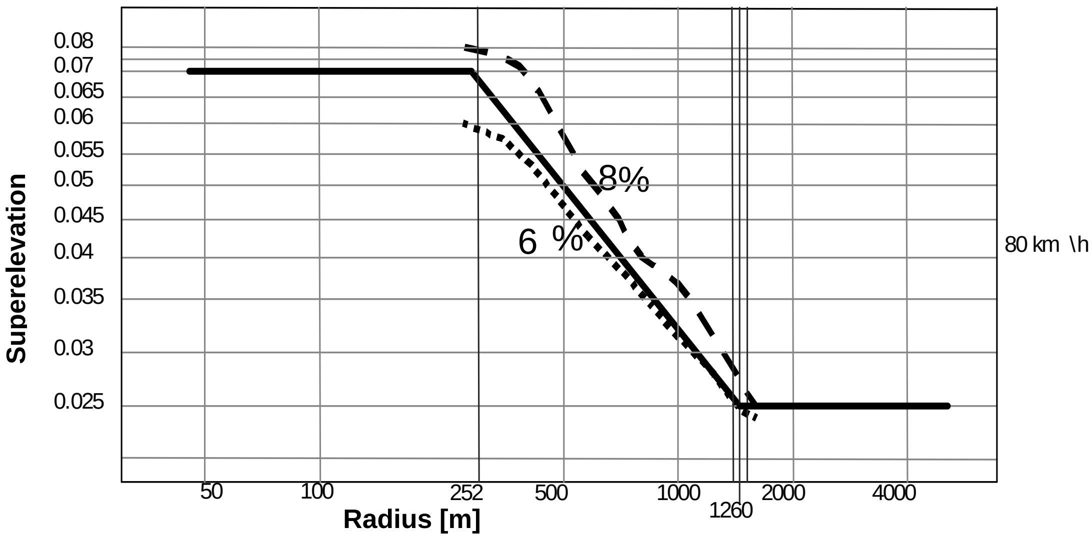

FIGURE 1 Comparison of superelevation rate values in AASHTO Green Book (dash and dot lines) and Italian Guidelines (solid line) for road construction.

The CPM can be used both when crash history of the site is available and when not. In the former case the Empirical Bayesian (EB) procedure provides a methodology to combine the accident frequencies predicted by the accident prediction model (Np) with the accident frequency from the site specific accident history data (O), using a weighted average of Np and O.
The expected accident frequency considering both the predicted and the observed accident frequencies is given by the following formula:

$$Ep = w \times (Np) + (1-w) \times O \qquad (3)$$

where:
Ep = expected accident frequency based on a weighted average of Np and O;
Np = number of accidents predicted by the accident prediction algorithm during a specified period of time
w = weight to be placed on the accident frequency predicted by the accident prediction algorithm;
O = number of accidents observed during a specified period of time.

The weight placed on the predicted accident frequency is determined in the EB procedure by the formula:

$$w = \frac{1}{1 + k(N_p)} \qquad (4)$$

where:
k = overdispersion parameter of the relevant base model of the accident prediction algorithm

A comparative analysis of the application of CPM with (EB estimate) and without crash history (Model prediction) was carried out on an Italian two lane rural road (SS 417 in Sicily), composed by 153 geometric elements [2]. This case study highlights that the availability of the site accident crash history, which increases the accuracy of the predicted accident frequency, can produce an accident prediction that substantially differs from the one coming out from CPM without crash history (Figure 2).

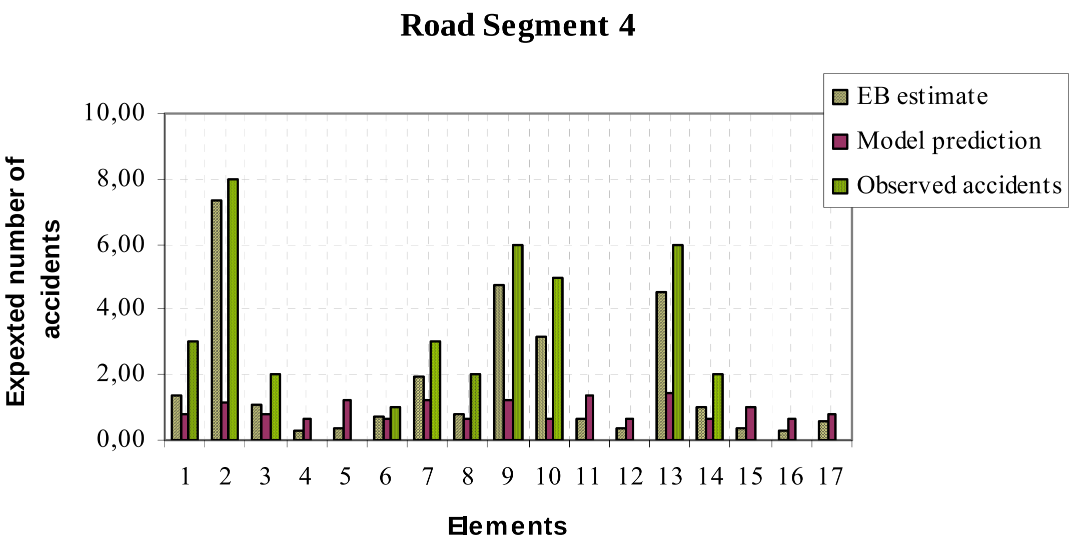

FIGURE 2 Comparative analysis of CPM application for a road segment (SS 417).

Using the results from CPM application, the procedure to identify blackspots based on statistical control of quality was carried out. The control limit is defined on the hypothesis of the Poisson statistical distribution of accidents that better describes the phenomenon, on the basis of which the control limits for a level of confidence (δ) can be defined. Such values describe the casual variation of AR around the expected value into which the phenomenon should occur with a probability of (1-δ).
The upper control limit (UCL) was calculated with the equation:

$$UCL = AR_R + k_\delta \sqrt{\frac{AR_R}{\ell_i \cdot 365 \cdot \sum_t AADT_{it}}} + \frac{1}{2 \cdot \ell_i \cdot 365 \cdot \sum_t AADT_{it}} \tag{5}$$

where:
AR_R = average accident rate;
k_δ = value of the standard normal variable for a level of confidence δ;
ℓ_i = length of the i-th stretch (km);
$AADT_{it}$ = average annual daily traffic on the i-th section in the t-th year (millions of vehicles);
t = number of years of the investigated period.

Therefore, stretches showing an accident rate (ARi), deriving from Model prediction or from EB estimate of CPM, higher than their respectively UCL, are defined as Blackspots.
Also in this case, the application to the case study, using k_{90}=1.282, evidences the weakness of CPM without the introduction of crash history. Indeed, Figures 3 and 4 show that in the case of CPM model prediction (see Figure 3), only the road element 4 is identified as black spot in comparison with the case of the EB estimate which identified also the elements 8, 11 and 12 (see Figure 4).
If accident data are not available the results form CPM are not accurate. In this case, CPM is helpful above all in comparing the safety performance of different design alternative. Instead, on low volume roads, where also black spot sites are characterized by few accidents, using CPM with EB estimate improves the accuracy of the analysis.

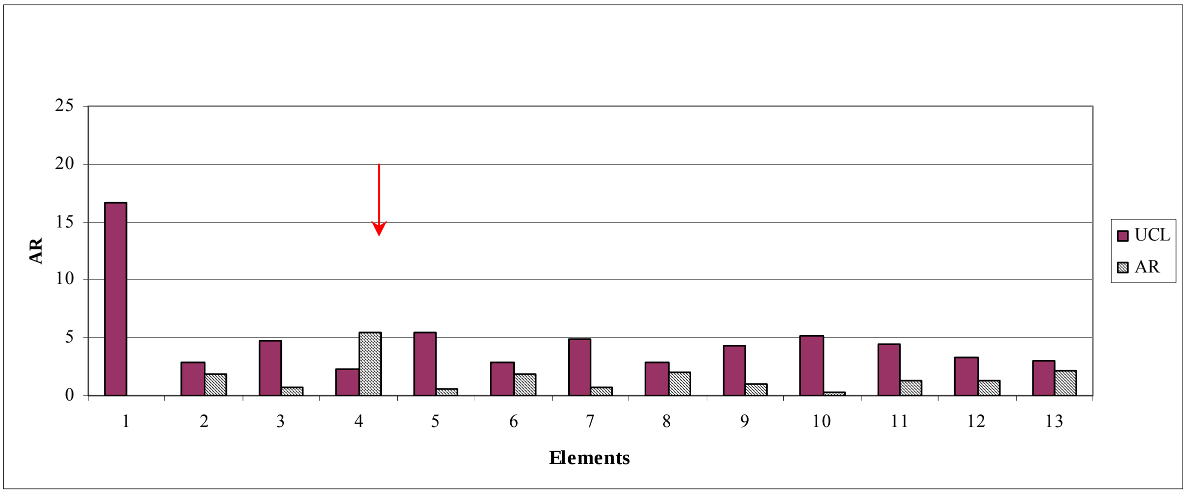

FIGURE 3 Black spots identification using CPM model prediction for a road segment (SS 417).

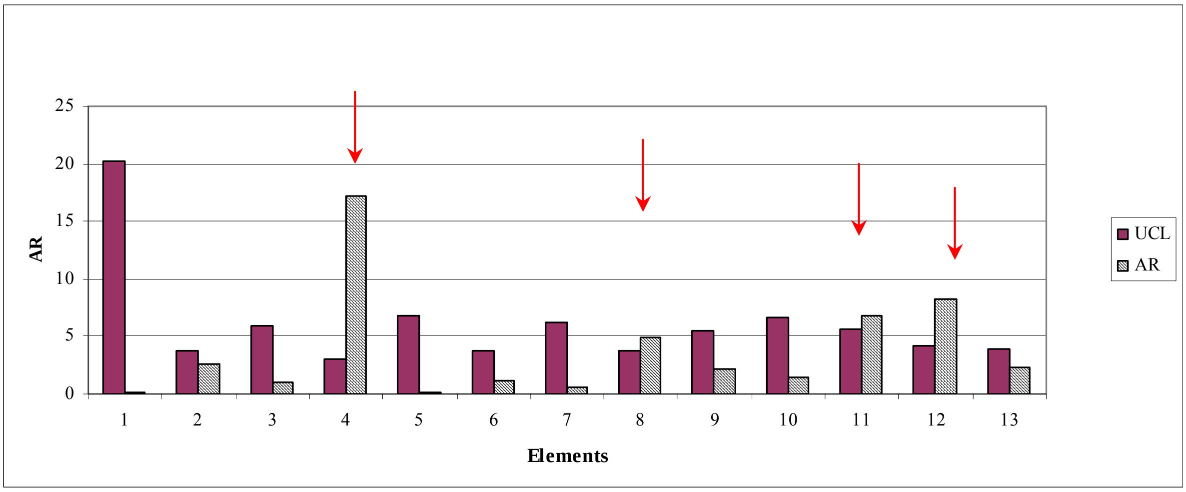

FIGURE 4 Black spots identification using EB estimate for a road segment (SS 417).

2. ALIGNMENT FEATURES AND DESIGN CONSISTENCY

The theoretical-experimental models proposed in IASP, based on safety factors related to horizontal and vertical alignment, supply a good degree of efficiency and objectivity with special emphasis to the alignment defects and design consistency. Such problems often exist on Italian provincial roads which were realized thirty-forty years ago using obsolete design criteria. Therefore, the first basic analysis is the comparison of the horizontal and vertical alignment characteristics with the new Italian design standard [4]. The restoration of existing roads in conformity with modern design criteria can improve road safety and produces homogeneity in the network features, too. Although, experience shows considerable difficulties encountered in strictly applying the new standards to existing roads. On the other hand, a simple comparison between site characteristics and road design standard, can highlight the existing defects, but not always this type of comparison is adequate in order to completely characterize the dangerousness of geometric elements.
From this point of view it is useful the application of the "Safety Criteria" proposed by prof. Lamm of the University of Karlsruhe [5, 6, 7] that define three different levels of judgment (good, fair, poor) for different degree of safety respect to horizontal alignment consistency (tangents, circular curves and transition curves). Such judgments are expressed on the basis of three criteria related to:

- ✓ Design consistency considering the difference between the maximum operating speeds previewed for drivers (V85) and the design speed (Criterion I);

- ✓ Operating speed consistency, referring to the change in the operating speed between two consecutive elements (Criterion II);
- ✓ Driving dynamic consistency related to the difference between the side friction factor demanded in curve and the assumed side friction factor (Criterion III).

Furthermore, for an overall safety evaluation procedure, the above mentioned three safety criteria are combined in an overall Safety Module. The reason for this is that each of the safety criteria represents a separate safety aspect in highway geometric design. In order to evaluate Safety Module, good design is classified by the weighting factor of "+1.0", fair (tolerable) design is described by the factor "0.0" and for poor design the factor "-1.0" becomes relevant. Summing up the weighting factors for each safety criterion, the calculated average value represents an evaluation scheme for the safety module [8].

The classification classes deriving from safety module applied on all 153 elements of the case study were compared with accident rate values carried out from the CPM with crash history. The results give a mean accident rates equal to 4.03 for POOR elements, 1.91 for FAIR ones and 1.13 for GOOD elements. T-test results for accident rates confirm that differences in accident rates between the three different classes are statistically significant at 85% level of confidence. The analysis of the results shows that elements classified as POOR are characterized by highest accident rates.

3. AN INSPECTION METHODOLOGY FOR SAFETY EVALUATION OF TWO-LANE RURAL ROADS

The analyses carried out from the theoretical-experimental models, although effective in addressing the alignment inconsistencies, do not highlight all the potential accident contributory factors. Hence, it is useful to integrate the results of models with those deriving from the judgments collected on inspected sites during the Safety Review process. Furthermore, it's helpful to repeat the process every five years in order to monitor the effectiveness of the implemented safety measures and to identify new problems.

3.1 Background

Safety reviews of existing roads are becoming an accepted practice in many agencies around the world, but only a few guidelines define the operational procedures for safety reviews of existing roads by a complete distinction between audit of design and audit of existing road infrastructures [9-12]. Since the project has been carried out in Italy, Italian road safety audit guidelines [13] have been used as main reference, but a specific procedure has been defined. Other EU safety review procedures [10, 11, 14] are not in contrast with the new one. Main differences between the IASP inspection methodology and the existing methodologies relate to the role of the client and to the definition of a detailed framework and a precise activities chain for the whole process. A safety review of a rural two lane roads network has been carried out to check the proposed procedure.

Main steps of the process are:selection of the review team, daytime site inspections, brainstorming in the office, night time site inspections, writing review report.

3.2 Selection of the review team

Road Authority selects the review team. Main requisites of the team are independence and qualification. Independence from the design, maintenance and operation of the road to be reviewed is needed since the team has to look only at safety problems applying "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 doesn't give any real benefit in terms of accident reduction if the task is not based on sound road safety engineering experience and practice.

Generally, in order to achieve the independence requisite the client does not take part to the process. However, the Italian practice has showed that if the client is not actively involved in the process the procedure is not effective. This is because in countries where safety culture is not consolidated the review may be perceived as a formal process whose benefits are not completely understood. Hence, the IASP review team was composed by safety specialists of the Universities of Catania and Naples supported by personal of the Province of Catania (the client), with the role of observers.

The client was represented by three people: two engineers and one technician. In order to make the contribution of the client more effective, a one-day introductory training course has been carried out by the review team leader. The external team was composed by six safety specialists with academicals background: the IASP project coordinator, which is an expert in road design and human factors, the review team leader, which is an experienced safety reviewer, a specialist in accident analysis, a specialist in pavement design and maintenance and two specialists in junction design and operation.
Recommendations about the composition of the review team arising from the project are as follows.
The client participation to the process is a very positive aspect, but the review report should be written without the client and should be signed only from the review team. The client has a constructive feedback by making site inspections and a preliminary discussion about problems and recommendations with the review team. The team has advantage from discussion with the client since obtains in depth information about site history, and maintenance and rehabilitation procedures and practices. Nevertheless, it is better that the client does not assist in writing review report for two reasons: 1) independence might be compromised; 2) participation of many people in this phase is counterproductive.
The external review team should never be a "one man review team", since diverse backgrounds and different approaches of different people are beneficial. The cross-fertilization of ideas that can result from discussions is helpful. On the other hand, if the team is composed by more than three people it is more effective to have clear distinction in roles and responsibilities. The review team leader should participate in all the steps of the process. Site inspections and preliminary discussion should be carried out from the whole team. The review report should be written by two or three people. Some members might participate in writing only some paragraphs (e.g. intersection problems). All the members should read the draft report before the final report is edited and signed.

3.3 Daytime site inspections

The site inspections are a key task that the review team must undertake, and it is vital that the main information be acquired. All the guidelines agree that the inspections have to be performed both in daytime and in night time. In different light conditions, indeed, the road is differently perceived and some safety problems not identified in daylight conditions may be clear in night time. IASP experience confirms the need to carry out night time inspections and points out the best timescale for inspections. When reviewing a road network, more inspections have to be carried out.
The whole review team and the supporting personal of the client should participate to this phase of the review.
First, a preliminary survey of the whole network is needed. The review team should run the road in both direction at normal speed. If road is travelled in only one direction some problems may be overlooked (e.g. sight distance, alignment legibility). During the preliminary inspection, videos of the road and comments of the auditors should be recorded. Videos and comments may be helpful in the subsequent stages of the review. Main objective of the preliminary inspection is to understand the general nature of the network in relation to the terrain, the topography and the surrounding land use. Inconsistencies between the different stretches of the network may be not clear if only separated inspections of the roads are performed.
Secondly, a specific inspection of each road has to be performed. Site inspections should not be limited to the road itself. They should extend to the adjacent network with the aim of identification of the context of the road. In the IASP project, a one day inspection covered about 20 km of roads.
During the site inspections, the review team ran the road in both direction at normal speed. Main objective of this drive trough is trying to investigate how the road environment is perceived, and ultimately utilised by different road users. The analysis has to look not only the road, but also the environment which can interact with the road and the road users.
In a second drive through at low speed, detailed inspections of the sites which showed the main safety concerns have been performed by stopping the car and looking in detail at the safety concerns of the site. Each site has been located on a digital map by recording the position with a GPS receiver. Depending on the site characteristics, some dimensions (e.g. pavement width and roadside safety barriers height) have been measured. Digital photos of the safety issues are useful both for further in office investigation and for supplementing the review report. Detailed inspections differ if they relate to road segments or intersections. Since intersections will be addressed in a subsequent stage of the

IASP project, the paper does not specifically make reference to intersection aspects. It is stressed that inspections are aimed not only at looking at road deficiencies or standard non compliance but also at looking at road user behaviour in different traffic and environmental conditions. As an example, Braking marks or damages in roadside barriers are good indications of potential safety problems. IASP experience has highlighted that filling in inspection modules during the detailed inspections of the specific sites assists in writing the review report and in focusing the identified problems. Indeed, troubles may occur in not loosing the many personal impressions arising from the site visit.

TABLE 1 Inspection module for sections.

Road name	
Progressive number of problem	
GPS location	
ID number of first and last photo	
Pavement width	
Other measures	
Visibility obstructions	
Presence of accesses	
Markings, delineation and signs conditions	
Pavement conditions	
Roadside obstacles	
Description of dangerous road users behaviours	
Description of the potential accident scenario	
Schematic plan of the site	

3.4 Brainstorming

In the office, the review team focuses on the results of inspections and on safety problems. The whole review team and the supporting personal of the client should participate to the brainstorming.

First, a preliminary task consisting of elaboration of the data acquired during the inspection has to be carried out. Location of the road segments and of the specific sites on a digital map can be carried out. Inspection modules for sections and junctions have to be analysed. Photos have to be analysed and classified. Photos classification is aimed at providing reference material when discussing safety issues.

Secondly, potential accident scenarios have to be identified. Accident scenarios are groups of accident which show similarity in the link of events and casual relationships in the different phases which lead to the collisions.

Thirdly, all the reviewers, independently each other, should write a list of safety problems taking into account potential accident scenarios. Each safety problem is discussed by the team and the observers in order to assess if it is really a potential contributory factor of road accidents and if countermeasures for his elimination or mitigation can be carried out. Cross fertilisation of ideas in this phase is very important. It is helpful do divide safety issues in general and specific problems. General problems are frequently present along the route, specific problems are present in one or a few sites (e.g. a bend). For each problem, the review team makes a preliminary discussion about recommendations, which are engineering solutions to the reported problem. Recommendations should be based on reliable control data, that is, information on costs and benefits of the solutions that have already shown their effectiveness in the accidents reduction in circumstances similar to those under review. Review team can use checklists, which are a prompt aimed at ensuring that important safety problems are not overlooked Checklists are not a substitute for knowledge and experience, that is, checklists should aid using safety engineering experience and judgment and should not be used as tick sheets [15]. New safety reviewers find checklists very useful, whilst as their experience grows they use checklists less often [16]. Checklists, although in different forms, are included in all the international road safety audit guidelines and reflect what safety engineers believe are the most common safety problems. However, checklists can never cover all the safety aspects, and as checklists become more voluminous in order to be comprehensive, they become intimidating and overwhelming. Experienced safety reviewers typically find large checklists redundant since the lists miss the interactivity between road elements, and threaten some of the independent and intelligent creativity of the reviewer. Basing on these considerations, IASP checklists are only a short list of prompts for the review team (see Table 2). It is suggested to fill in the checklist by dividing the segment in short subsections (e.g. 200 m long). Selected road features have been selected taking into account that proven quantitative relationships between each feature and accidents do exist [17].

3.5 Night time site inspections

Night time inspections differ from daytime inspections since they are focused only at understanding how the road is perceived in the night. Consequently, main focus is on markings, delineation and legibility of the road alignment. Stopping in specific sites during the night is not recommended. Videos of the road and comments of the auditors should be recorded. Location of specific night time problems may be carried out by using a GPS receiver in dynamic modality.

Night inspection are a valuable opportunity to have a further look of the road after a preliminary study has been already done.

TABLE 2 Synthetic checklist.

General issues	Detailed issues
Markings	
	Edge lines missing or inadequate
	Center line missing or inadequate
	No overtaking line missing
Longitudinal rumble strips	
	Audible edge lines missing
	Audible center line missing
Pedestrian crosswalks	
	Missing or ineffective crosswalks in areas with pedestrian activity
Delineation	
	Chevron missing or ineffective on severe curve
	Guideposts (or barrier reflectors) damaged or missing
Signs	
	Curve warning missing or not visible on severe curve
Alignment	
	Missing alignment legibility
	Severe alignment perceived
	Inadequate sight distance on horizontal curves caused by removable obstacles (<0.75 SSD)
	Inadequate sight distance on crest curves (<0.5 SSD)
Pavement	
	Smoothing surface pavement
Roadside	
	Unshielded embankment (3<h<6m and i>0.5)
	Unshielded embankment (h>6m and i>0.5)
	Embankment shielded with very low containment (or ineffective) safety barrier (3<h<6m and i>0.5)
	Embankment shielded with very low containment (or ineffective) safety barrier (h>6m and i>0.5)
	Ditch
	Trees
	Rigid utility poles
	Rigid obstacles
	Not breakaway barrier terminals
	Missing transition between barriers (or between barrier and wall)
	Inadequate bridge rails
Cross section	
	Lane width
	very narrow <2.75 m
	narrow <3.25 m
	Shoulder width
	very narrow <0.3 m, unpaved, not practicable
	narrow <1.0 m
	Missing passing lane in section where there are not passing opportunities
	Missing climbing lane where high speed difference between cars and trucks do exist in mountainous terrain
Accesses	
	Excessive density of uncontrolled accesses (>10/km)

3.6 Safety Review Report

After the night time video has been studied and the further problems stemming from the night inspections have been discussed by the whole team, it is appropriate that only the team leader and one or two members write the draft report. As a matter of fact, experience has shown that too many people writing the report is ineffective.

The review report is written in “problem/recommendation” format, where the problem is described in terms of an accident risk to a road user, and the recommendation is an engineering solution to the reported problem.

During the review, there may arise safety issues for which there are no specific short term remedies. In this case, the safety issues should not be ignored but identified for further investigation.

As above said, a draft review report can be written by only some members of the team. All the members should read the draft report before the final report is edited and signed.

For each road, a separate report should be written. A general report summarizing the main results of the reviewed road is helpful for the client.

Each road report contains all the information regarding job procedures, inspections, meetings with the client, and the results of the analysis. The IASP report format contains the following sections: road name and location, dates of inspections and other phases of the review, review team members and qualifications, information on meetings, information on data provided by the client, description of the procedure used to conduct the review, detailed description of the safety problems, and the potential accidents caused by the problems (photos exemplifying the problems should be provided), description of recommendations aimed at eliminating or alleviating the safety problems, synthesis, in tabular format, of problems and recommendations, concluding statement, names and signatures of reviewers.

In the IASP methodology review report is written as a formal and self contained document, but a final safety report is written taking into account both review and theoretical-experimental models results.

4. CONCLUSIONS

In roads characterized by lack of sufficient information referring both to the real state of the road and to the accident situation, usual methodologies of hazard sites identification based on the statistical analysis of the accident data, are ineffective. The proposed methodological approach overcomes this weakness by combining accident prediction models, design consistency evaluations and safety reviews.

Accident prediction models do appear effective in identifying hazardous locations only if Empirical Bayesan (EB) procedure is used with the accident data. On low volume roads, where also black spot sites are characterized by few accidents, using CPM with EB estimate can improve the accuracy of the analysis. Design consistency evaluations supply a greater degree of efficiency and objectivity in identifying alignment defects which affect road safety. However, these analyses do not highlight all the potential accident contributory factors, such as factors related to accesses density, lack of markings and signs, or roadside obstacles. Hence, the safety review process has showed a good efficiency in addressing the safety problems not identified in the previous steps of the safety evaluation procedure.

Main differences between the proposed inspection methodology and the existing methodologies relate to the role of the client and to the definition of a detailed framework and a precise activities chain for the whole process.

On the other hand safety reviews, due to the subjective nature of the process, may give rise to disagreements which limit their effectiveness and the theoretical-experimental models solve this flaw with respect to geometric features and alignment defects.

The methodological framework presented in the paper will be applied in the Province of Catania (Italy) as part of the “IASP” project financed by European Commission.

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