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A simplified methodology for road safety risk assessment based on automated video image analysis

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Abstract

To support the assessment of road safety risks on the primary roads, the World Bank asked for piloting a new simplified methodology to quickly identify critical sections and at low cost even without sufficient road traffic crash database.

The objective was the development of a methodology for road safety assessment based on the automated analysis of video images. The methodology was tested and validated through an assessment of 500 km of National Highways in Mozambique.

The methodology is based on the common definition of Risk given by the combination of Danger, Vulnerability and Exposure. Various road attributes associated with Crash Modification Factors are considered to calculate these factors.

Three road user categories are considered (motor-vehicles, cyclists and pedestrians) and Danger and Vulnerability scores are calculated for each 100m road section. In addition, a Global Risk Score (GRS) is also calculated in order to consider pedestrian and cyclist flows.

Risk levels are categorized so that, for pedestrians and cyclists, risk varies with the motor-vehicles' flow speed, while, for the motor-vehicles and for GSR, risk intervals are fixed.

A software solution was implemented allowing to:

- automatically recognise road attributes from video images;
- calculate road users' risks and the GRS according to the simplified methodology;
- provide outputs on assessed risks (every 100m) both graphically and through table values;

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- download all the computed outputs for further analysis.

The software solution works with few inputs: a video of the road to be assessed, an output file from an App for assessment of road surface conditions, an image of a calibration sheet and few road attributes to be inputted manually.

A survey of about 500 km of National Highways was performed in Mozambique in August and September 2018. Risk assessment performed using the simplified methodology and the software for automated video analysis are discussed in the paper.

Keywords: Risk Assessment; Road Safety; Developing Countries; Automated Analysis

1. Background

Based on the WHO's estimation (World Health Organization, 2018), Mozambique had 8,665 fatalities in 2016 or 30.1 fatalities per 100,000 population, which is one of the worst figures in the world. While the World Bank, as well as other international donors, has been engaged in road infrastructure development in Mozambique since the end of the civil war in 1992, the road safety aspects have not been particularly emphasized until now.

To support the assessment of road safety risks on the primary roads in Mozambique, the World Bank sook to pilot a simplified methodology to quickly identify critical sections and at low cost even without sufficient crash database.

This project was developed by FRED Engineering in cooperation with the Research Centre for Transport and Logistics of "Sapienza" University of Rome, according to the following main objectives:

- Establishing a methodology for simplified road safety assessment based on the analysis of road infrastructure attributes (i.e. on their contribution to the risk of road traffic crashes).
- Establishing the standard for video filming to be used for the road safety assessments.
- Developing an automated image analysis and coding tool for the methodology developed.
- Conducting a pilot assessment of 500 km of National Highways in Mozambique.
- Providing the results of the road safety assessment on the piloted subsection.

A methodology has thus been developed using low cost dashcam to be installed on a surveyor vehicle (a normal car). Few other equipment has been used, such an App for road surface condition estimation.

1.1. Review of knowledge from available literature

A number of methodologies, mostly based on the physical characteristics of a road, have been proposed by road safety research so far to assess the safety performance of road infrastructures.

Probably, the most known methodology is the international Road Assessment Program (iRAP) consisting of a number of evaluation tools. Among them the most relevant to this project is the Star Rating Score (SRS). The SRS module assigns a road infrastructure safety level basing on how effectively the infrastructure prevents crashes and protects users involved in crashes (Lynam, 2012). Based on the calculated Road Protection Score (RPS) the road section is classified according to a five-level ranking (Star Rating).

The New Zealand Road Infrastructure Safety Assessment (RISA) estimates the safety performance of road infrastructures based on intersections features along a road section, road surface and other infrastructural features. The approach shows how the total risk of the entire road network can be calculated starting from the average risk of a sample of road sections (Appleton, 2009).

The European project RANKERS evaluates six different topics strongly linked with safety: road alignment, roadside, junctions, pavement, overtaking and road layout consistency (Perandones & Ramos, 2008).

The Italian Safety Index (SI) is a methodology based on combining three risk components: the exposure of road users to road hazards, the probability of a vehicle being involved in a crash, and the consequences of a crash. The safety performance can be qualitatively determined for the analyzed road section (Cafiso, La Cava, & Montella, 2007).

A recent European project, SafetyCUBE (www.safetycube-project.eu), proposes a comprehensive taxonomy of road infrastructure risk factors and investigates the existing relationship with crash-risk and injury-risk based on existing relevant literature.

2. Simplified road risk assessment methodology

When dealing with risk assessment, it was decided to refer to a certain level of granularity making possible to put together the estimated risks on longer road sections (depending not only on the fact the road characteristics can change but also of eventual changes in the environment or in the road users). The methodology has been intentionally maintained with a level of granularity of 100 meters.

In order to obtain a synthetic **Risk index [R]**, it is universally recognized that it must be the result of a combination of at least two key factors: **Danger [D]** (likelihood that a crash can happen) and **Vulnerability [V]** (risk of injury of road users given a crash occurred).

Another important factor is also the **Exposure [E]** (i.e. the amount of “activity” a user is exposed to a risk). However, this factor is hardly available in developing countries.

The resulting (general) formula used for risk assessment is as follows:

$$R = D \times V(\times E) \quad (1)$$

The risk assessment is performed for three road user categories: pedestrians, cyclists and motor-vehicles (including cars, motorcycles, trucks).

For each road user category, the Danger is calculated (every 100m) depending on the road characteristics (i.e. based on Crash Modification Factors). This is done both for road users travelling “along the road” and for road users crossing an “intersection” or for pedestrians “crossing a road”. Similarly, the Vulnerability is then calculated based on the road characteristics (CMFs).

The CMFs considered in this study were taken from the following sources: iRAP, 2013, Elvik et al., 2009, AASHTO, 2010.

A risk score for each road user category is then calculated.

The CMFs for each road attribute have been considered for the following main road conditions:

- Along the road (i.e. when a road user is travelling or walking along the road).
- At intersections (i.e. when a road user is crossing an intersection while travelling along the road – valid for motor-vehicles and bicycles).
- While crossing a road (valid for pedestrians).

The methodology also allows to calculate of a synthetic indicator called Global Risk Score (GRS) allowing to globally assess the quality of the road sections for all road users and to take into consideration the pedestrian and cyclist flows counted from the videos.

2.1. Danger or crash likelihood assessment

The currently most common method for estimating the combined effect of several treatments is the method of “common residuals” (Elvik, 2009a). The method assumes that the effects of treatments are independent and remain unchanged when other road safety measures are introduced.

For each crash type, the Danger score is calculated according to the combined effect formula as follow:

$$Dcr = CMF1 \times CMF2 \times \ldots \times CMFn \quad (2)$$

where *Dcr* is the danger score on a 100m road section for a crash type, while *CMF1*, *CMF2*, … *CMFn* are modification factors affecting the injury crashes likelihood.

The formula applied to road sections with intersections/accesses is slightly different:

$$Dci = (Aint + Aacc) \times CMF1 \times CMF2 \times \ldots \times CMFn \quad (3)$$

where:

- *Dci* is the danger score on a 100m road section with an intersection/access point, for a crash type.
- *Aint* is the CMF of the attribute "Intersection type".
- *Aacc* is the CMF of the attribute "Access points".
- *CMF1*, *CMF2*, *CMFn* are the modification factors values affecting safety performance at an intersection/access point.

2.2. Vulnerability or crash severity assessment

The Vulnerability is given by three main factors: Operating speed, Median type and Roadside severity.

$$V = SW \times A1 \times A2 \times \ldots \times An \quad (4)$$

where:

- *SW* is the attribute related to speed.
- *A1* … *An* are the attributes affecting crash severity (Median type and Roadside severity).

SW is obtained using a sigmoid function of the operating speed, as shown in Figure 1 (Wramborg, 2005). It should be noted that these curves are hypothetical. However, they represent a good assumption to assess the attribute related to speed, since it is used mainly to differentiate the risk of fatal crash for pedestrians and vehicles. It is used in this study as a calibration factor for the estimation.

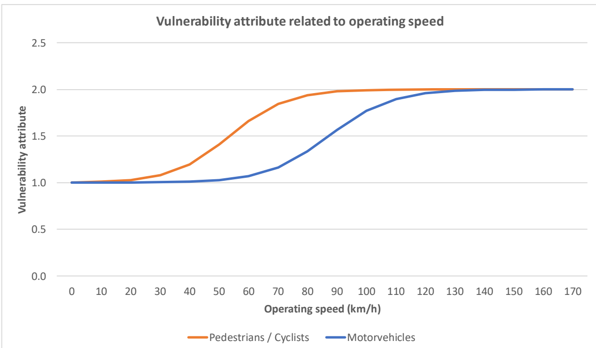

Figure 1 Vulnerability attribute related to operating speed.

2.3. Total risk score by road user category

The methodology provides three risk scores for each road user categories. The "road user risk scores" are independent of the vehicle flows (i.e. exposure to risk). The final score for each crash type is obtained as follow:

$$S\_x = (Dcr + Dci) \times V \quad (5)$$

2.4. Global Risk Score

Based on the three "road user risk scores" calculated, a Global Risk Score (GRS) is also calculated, allowing to consider the pedestrian and cyclist flows.

The basic assumption is that, due to high speeds and road characteristics, some roads (e.g. a motorway) should be unsafe for pedestrians and cyclists. However, on those roads (e.g. motorways) pedestrians and cyclists should not be allowed and thus should have intrinsically a low global risk score (if they are correctly designed). Thus, if pedestrians or cyclists are not counted on those roads, the GRS will be close as value to the motor-vehicles' risk scores (S_MV). On the contrary, on other roads where pedestrians and cyclists are allowed to travel, the GRS should be correlated to the effective presence of these road users. On roads where pedestrians or cyclists are counted, the GRS will be close as value to the pedestrians' and/or cyclists' risk scores (S_PED/S_CYC).

Nevertheless, the use of the GRS should mainly be considered for a generic analysis, while more details and precise information should be taken from the single risk assessed by road user category.

GRS is given by:

$$GRS = (S\_PED \times w\_PED + S\_CYC \times w\_CYC + S\_MV)/(w\_PED + w\_CYC + 1) \quad (6)$$

where:

- S_PED = total risk score for pedestrians.
- S_CYC = total risk score for cyclists.
- S_MV = total risk score for motor vehicles.
- w_PED = is a weight calculated based on the pedestrians' flow on the assessed road (recognized automatically by the video analysis).
- w_CYC = is a weight calculated based on the cyclists' flow on the assessed road (recognized automatically by the video analysis).

The weights are proportional to the probability of crossing pedestrians and/or cyclists on the analyzed road (assessed using a Gamma distribution with parameters "a" and "b" meaning that we expect to cross "a" pedestrians or cyclists in "b" 100m road sections).

2.5. Risk scores categorization

To assess the risk, the score must be linked to intervals that are different based on the type of road users. For each road user category, five risk intervals are considered:

- Green = very low risk.
- Yellow = low risk.
- Dark orange = medium risk.
- Red = high risk.
- Black = very high risk.

It was deemed unrealistic to have a low risk at high motor-vehicle flow speed for pedestrians and cyclists. On the other hand, a possible scenario could be travelling on a motor-vehicle at high speed and recording a low risk (of course this depends on the characteristics of the infrastructure). Thus, two kinds of risk levels were considered:

- for pedestrians and cyclists, the set of risk level assumes intervals ranging with motor-vehicles' speed (Figure 2);
- for the motor-vehicles and GRS, those intervals are fixed (Figure 3).

The coloured lines in the figures indicate the limits for changes from a score range to another, so that:

- Scores values under the green line represent a low risk (green area).

- Scores values between the yellow and green lines represent a medium-low risk (yellow area).
- Scores values between the dark orange and yellow lines represent a medium risk (dark orange area).
- Scores values between the red and dark orange lines represent a high-medium risk (red area).
- Scores values above the red line represent a high risk (black area).

The parameters describing the intervals (i.e. slope of the curve and y-axis intersection) were calibrated on a real case scenario of roads in Mozambique.

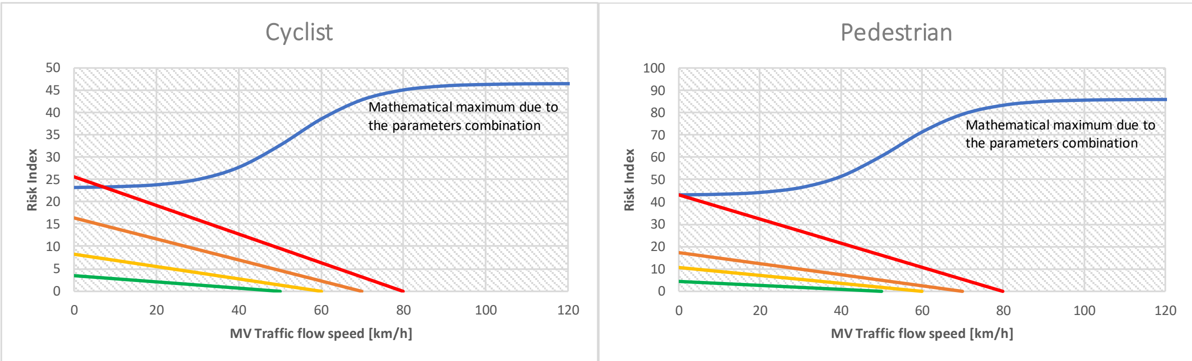

Figure 2 Cyclists' and Pedestrians' risk range variation.

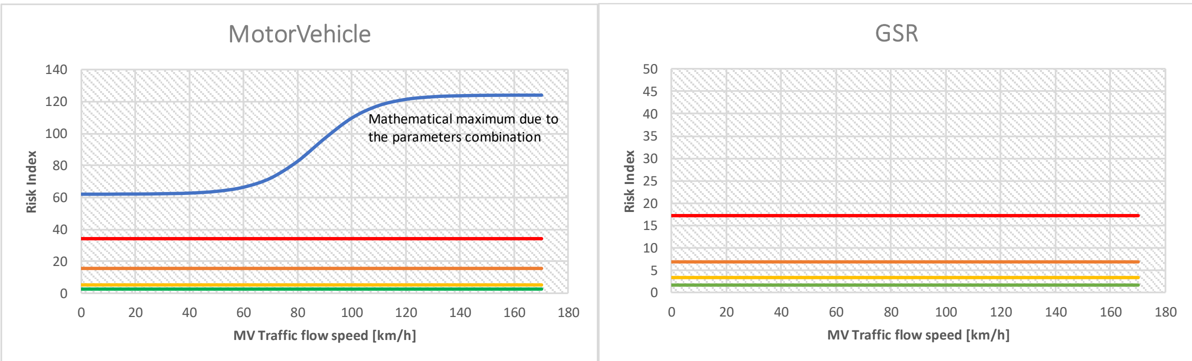

Figure 3 Motor-vehicles' and GRS' risk range variation.

3. Road risk attributes

Based on the analysis of literature and on a sample of videos from Mozambique (used as pilot test), the road attributes that should be used in the risk assessment methodology were identified.

Some preliminary considerations need to be made concerning some important road attributes:

- The Annual Average Daily Traffic (AADT) is possibly the most important risk factor contributing to road crashes. However, this attribute is hardly detected either by means of a video analysis or a traditional road safety inspection. It would require specific surveys and/or traffic modelling. It is worth mentioning that in developing countries (i.e. the main target areas for this study) information on traffic are quite always not available. On the contrary, counting of the number of pedestrians and of cyclists is possible and reliable through video analysis.
- Average Traffic Speed would require specific and detailed surveys. However, a sufficiently reliable assessment has been obtained using the surveyor vehicle as a proxy (called hereinafter Operating Speed).
- According to the findings in the literature review, the Terrain Type attribute requires specific considerations. This attribute covers horizontal and vertical alignment deficiencies, however in a qualitative way that it is not easy to

be objectively coded. In replacement of this attribute the following were considered curvature (in order to catch low curvature radius) and grade (in order to catch high grade).

Various road attributes, identified from the literature review, have been considered and selected based on the following criteria:

- Consistency with the general approach; i.e. the selected attributes must describe both the likelihood and the severity of a crash. The exposure of vulnerable road users was also considered.
- Feasibility of attribute recognition through video image analysis.
- Need for a simplified methodology for risk assessment (i.e. reduce as much as possible the number of attributes to be collected manually).
- Provision of a minimum set of attributes guarantying the reliability of the risk assessment.

The first criterion suggests that, even if some attributes cannot be automatically recognised, they should be appraised anyway as they are necessary for a methodologically coherent assessment. Consequently, collection of some attributes using other techniques than video analysis or manual post-processing recognition have been considered.

The Table 3.1 provides:

- The list of attributes mostly used in the methodologies found in the literature (main references are: iRAP, 2013, Elvik et al., 2009, AASHTO, 2010).
- The minimum set of attributes retained for the risk assessment.
- The recognition method to be used for each attribute.

Even if the pilot test has been tested and calibrated on Mozambique roads (where some the attributes are not present), the selection of the minimum set of attributes has been done independently of this, with the aim of providing a risk assessment methodology applicable also in other countries (where some attributes could be present). For instance, for this reason attributes like “median” have been considered.

Table 1. List of attributes considered for the simplified risk assessment methodology.

No.	Road attributes	Recognition method
1	Bicycle observed flow	Video
2	Pedestrian observed flow	Video
3	Operating speed	Video
4	Median type	Manual
5	Intersection type	OpenStreetMap
6	Area type	OpenStreetMap
7	Property access points	OpenStreetMap
8	Number of lanes	Video
9	Lane width	Video
10	Curvature	Video
11	Grade	Video
12	Road surface conditions	App
13	Delineation	Video
14	Pedestrian crossing	Video
15	Speed management / traffic calming	Manual
16	Paved shoulder width	Manual

No.	Road attributes	Recognition method
17	Roadside severity - distance	Video
18	Sidewalk	Manual
19	Facilities of bicycling	Manual
20	Motorcycle dedicated lane	Manual

4. Road risk assessment in Mozambique

A field survey campaign was performed in Mozambique in August and September 2018. The survey included two National Highways. Eight road sections have been driven while recording video and collecting data on road surface conditions (through an App). The total length of the surveyed roads was about 466 km.

Both highways are mostly set in a rural environment, although they cross several urban areas along their paths. Furthermore, it is common to find non-motorized vehicles (especially bicycles) or pedestrians (these last mostly close to urban areas) along the roadside. Accesses are often “T-type” intersections with no delineation and no acceleration/deceleration lane. Outside the urban areas, neither illumination nor protection are provided.

After collecting the videos and other basic information, the data were analyzed using the software where the simplified methodology described in Chapter 3 has been implemented.

Generally, some key issues were identified for the assessed roads:

- Quite complete absence of pedestrian crossings.
- Few sidewalks not well maintained and sometime obstructed by obstacles and parked vehicles.
- Complete absence of cycling or motorcycle facilities.
- Quite complete absence of traffic calming measures.
- Generally poor delineation and marking (very few physical medians).
- Shoulder width generally narrow or absent.
- High presence of obstacles near to the carriageway.

What mainly differentiate the road sections assessed was the operating speed and the number of pedestrians and cyclists using the road infrastructures.

Risk levels calculated for the various roads surveyed allowed to compare results. For instance, when dealing with risk conditions for pedestrians, most of the road sections (6 out of 8) have high or very high crash risk (Figure 4). Generally, about 369 out of 466 km are high or very high risky for pedestrians (95 km are Black).

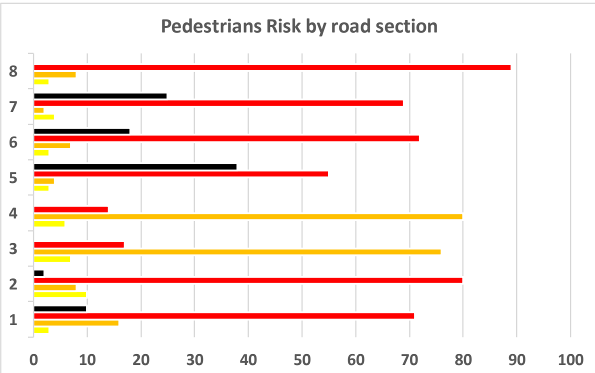

Figure 4 Crash risk for pedestrians by road section.

5. Conclusions and discussions

A simplified methodology for road risk assessment has been developed, allowing to calculate risk levels on road sections at low cost and quite rapidly. The procedure entails the use of low-cost equipment (a commercial dashcam, a smartphone to use an App) and driving on the roads to be assessed to collect video and some other information.

The collected information is analyzed through a software solution implementing the risk assessment methodology and allowing to download risk maps and risk scores/levels for further analysis.

The central aspect of this study was the application of a simplified road risk assessment methodology on roads in developing countries. The methodology allows to identify critical road sections:

- Quickly (current methods for risk assessment are usually time consuming).
- At low cost (current procedures can be costly due for instance to use of equipped vehicles, etc.).
- Even without enough traffic crash database (in many developing countries, crash databases are not reliable or not existing).

The simplified methodology mainly focuses on rural areas. However, it should also be considered that, in most of developing countries, national highways often cross built up (urban) areas.

To develop the methodology, extensive use of literature has been made. The basic concept is to assess the road risk based on crash modification factors linked to road characteristics. The number of possible road characteristics can be high, depending also on the type of road user for which the risk is assessed (pedestrian, cyclist, car occupant, etc.).

However, it is worth mentioning that some limitations occur for the methodology development, since:

- Not all the road attributes can be automatically recognized from videos with enough reliability and precision. Several algorithms exist that can be used for video analysis. Not all of them are still sufficiently precise.
- Inclusion of some road attributes (such as type of roadside obstacle) to be collected manually would be highly time consuming (and thus would contradict the project scope).
- Reliable crash modification factors are not always available for all the road attributes.

An in-depth analysis of video analysis capabilities and of the existing literature (to identified most important road attributes) led to the final selection and thus defined the methodology boundaries.

To increase as much as possible the number of road attributes, the automated video analysis is also combined with other methods: Manual checking looking at videos or during the survey (as much as possible limited); Use of specific Apps during the survey (i.e. for road surface conditions); Use of open source web information from OpenStreetMap (e.g. rural / urban area).

The methodology and the correlated software are completely open source. This means, for instance, no licenses to be purchased and no specific requirements for the software installation, except the use of some specialized software.

It is also important to well understand how this tool can be used. Since it is a simplified methodology, it cannot be considered comprehensive and cannot be used to directly identify road safety interventions. The simplified methodology provides an overview of the traffic crash risks for different road user categories. It helps to identify road portions that should be more prone to crashes than others. To define specific interventions on these portions, further analysis (such as crash surveys or road safety inspections) should be necessary.

The simplified methodology is also particularly useful when road traffic crashes are not collected or are not reliable (e.g. not geo-referenced), so that precise analysis of crash contributing factors cannot be done.

The simplified methodology helps to identify road portions that should be "more crash prone" than others. However, to define specific interventions on these portions, further analysis (e.g. road safety inspections) should be necessary.

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