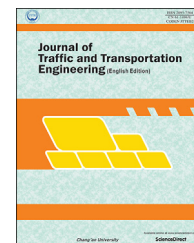


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## Original Research Paper

# Prioritization methodology for roadside and guardrail improvement: Quantitative calculation of safety level and optimization of resources allocation

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## HIGHLIGHTS

- Four categories of defects/elements that affect roadsides risk were detected.
- A method for analysing and planning maintenance of safety barriers was proposed.
- A cost-benefit analysis permitted to prioritize possible rehabilitation works.

## ARTICLE INFO

## Article history:

Received 22 September 2017

Received in revised form

16 March 2018

Accepted 16 March 2018

Available online xxx

## Keywords:

Roadside safety

Guardrail improvement

Optimization

Resources allocation

Road management

## ABSTRACT

The attention to road safety-related issues has grown fast in recent decades. The experience gained with these themes reveals the importance of considering these aspects in the resource allocation process for roadside and guardrail improvement, which is a complex process often involves conflicting objectives. This work consists on defining an innovative methodology, with the objective of calculating and analysing a numerical risk factor of a road. The method considers geometry, accident rate, traffic of the examined road and four categories of elements/defects where the resources can be allocated to improve the road safety (safety barriers, discrete obstacles, continuous obstacles, and water drainage). The analysis allows the assessment of the hazard index, which could be used in decision-making processes. A case study is presented to analyse roadsides of a 995 km long road network, using the cost-benefit analysis, and to prioritize possible rehabilitation work. The results highlighted that it is suitable to intervene on roads belonging to higher classes of risk, where it is possible to maximize the benefit in terms of safety as consequence of rehabilitation works (i.e., new barrier installation, removal and new barrier installation, and new terminal installation). The proposed method is quantitative; therefore, it avoids providing weak and far from reliable results; moreover, it guarantees a broad vision for the problem, giving a useful tool for road management body.

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Peer review under responsibility of Periodical Offices of Chang'an University.

<https://doi.org/10.1016/j.jtte.2018.03.004>

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## 1. Introduction

Roadsides, if not properly designed, would be a dangerous factor for vehicles which may run off the roadway. In fact, within these spaces discrete elements (e.g., trees, walls, buildings, etc.) or continuous obstacles (e.g., worn-out and broken roadside safety barriers, unprotected drainage channels, etc.) (AASHTO, 2011) could increase the consequences of a road exit of vehicles, as confirmed by Elvik (1995). Over the years, the problem of safety has led to the development of various strategies to reduce the number of deaths related to the local environment and road. Possible strategies to improve the safety of existing roadsides are: replacing or removing the obstacles; changing the roadside elements and protecting the obstacles with restraint devices (Elvik et al., 2004).

The European Directive 2008/96/EC (European Commission, 2008) on the safety management of road infrastructure establishes management procedures ensuring safety of road network. It encouraged the definition and use of road infrastructure safety management (RISM) on roads included in the trans-European transport network (TEN-T). Particularly, it set up guidelines for providing and maintaining safety barriers and obstacle-free roadsides. Furthermore, the European Union (EU) promoted the project Improving Roadside Design to Forgive Human Errors (IRDES) (Nitsche et al., 2011). It provided guidelines for the design of margins, which reduce the consequences of an excursion from the road. Another study focused on the roadside protection needs was the SAVeRS project (La Torre et al., 2016), which developed a practical and readily understandable method to select the most appropriate solution about restraint systems, specifically considering road and traffic conditions.

In Italy, the Legislative Decree 35/11 (Parlamento Italiano, 2011) advised to implement a RISM on four levels: network analysis; inspection; classification; and intervention. A RISM procedure permits to identify, plan, and schedule all the necessary works.

In the Italian territory, the often-complex orography limits the adoption of clear areas, largely used at international level (AASHTO, 2011), and implies the use of safety barriers. These devices safely redirect and prevent vehicles from crossing or leaving the roadway and engaging the roadside. Under these conditions, safety barriers also are obstacles. In order to properly perform their function, they should be well designed and maintained; otherwise, they can cause other unsafe conditions, as confirmed in the literature.

More than 50 years ago, Stonex (1960) has already revealed that the departure of the vehicle from the roadway causes 35% of fatal accidents. He also identified several factors (e.g., the presence of obstacles close to the road edge, such as steep slopes, deep ditches, and inadequate terminals of safety barriers) that increase the severity of the consequences in case of incident.

Several studies analysed the frequency and severity of accidents involving a collision with a specific “object” on the roadside (Gagne, 2008; Good et al., 1987; Kennedy, 1997; Lee and Mannering, 1999; Neuman et al., 2003; Ray, 1999; Road and

Traffic Authority NSW, 2004; Viner, 1995; Welford and Sicking, 1997). The risk analyses carried out on this type of accident show the severity of the crash depends essentially on the object hit by the vehicle, while its probability depends on other aspects that characterize the road (Cafiso et al., 2010). Indeed, the accident may be related to the width of lanes and shoulder, the horizontal curvature, and the access density (Abdel-Aty and Radwan, 2000; Bellini and Ristori, 2011; Cafiso et al., 2008; Pardillo and Llamas, 2003; Zhang and Ivan, 2005). As a consequence of the risk analysis, a method should provide a strategy for addressing the resources available and providing the necessary maintenance work (Jorgensen, 1966). At this scope, Pigman and Agent (1991) suggested that the management bodies keep an inventory of the existing barriers before allocating the funds. Usually, the optimization of the management of funds is based on objective functions, which maximize and/or minimize the considered decision variables (Bierman et al., 1997; Hillier and Lieberman, 2005; Lambert et al., 2003). For example, an adopted solution is to optimize safety benefits by maximizing the monetary value of avoided accidents (Mishra, 2013; Miccoli et al., 2014a). Cost-benefit analysis could be efficiently used to evaluate safety and economic impacts of barriers management, to compare the impact of different solutions, and/or to assess specific performances (Miccoli et al., 2014b; Loprencipe et al., 2017). Detailed finite element analyses may be performed to evaluate the acceptability of different barrier alternatives (Bonin et al., 2006, 2009).

As regard as benefit-to-cost and cost-effectiveness analysis methods, in recent decades, various agencies and research bodies made big efforts to identify and implement new procedures. Among the most important contributions, it should be noted that since 1970s and through 2010s, various methods were proposed in the context of the National Cooperative Highway Research Program (NCHRP). With reference to the aims of this paper, procedures for the safety performance evaluation of highway appurtenances can be already found in the NCHRP Report 230 (Michie, 1981); afterwards, NCHRP Report 350 focused on testing and in-service evaluation of roadside safety systems (Ross et al., 1993). A very innovative approach, which suggested some of the analyses developed in the present paper, came with NCHRP Report 492, that proposed the use of Monte Carlo simulation techniques (Mak and Sicking, 2003). Again, other procedures have been presented in the subsequent documents (Dixon et al., 2008; Mak, 2010).

On the basis of the above presented state of knowledge, the aim of this study is to provide a tool for analysing and planning maintenance of safety barriers using a cost-benefit approach. It derives from a railway methodology used to evaluate the service condition of bridges (RFI and CNIM, 2002). The proposed method considers the hazards associated with road stretches and their cost of rehabilitation (Miccoli et al., 2015), then it gives priority to those measures which maximize the gain in terms of overall safety of the road network. The intervention typologies considered in the proposed method take into account the experiences available in the literature. Therefore, they consider the inherent hazards, the hazard density (extension and/or

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