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A novel dynamic segmentation model for identification and prioritization of black spots based on the pattern of potential for safety improvement

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ABSTRACT

Road segmentation is one of the most important steps in identification of high accident-proneness segments of a road. Based on the ratio of the Potential to Safety Improvement (PSI) along the road, the objective of the paper is to propose a novel dynamic road segmentation model. According to the fundamental model assumption, the determined segments must have the same pattern of PSI. Experimental results obtained from implementation of the proposed method took four Performance Measures (PMs) into consideration; namely, Crash Frequency, Crash Rate, Equivalent Property Damage Only, and Expected Average Crash Frequency with Empirical Bayes adjustment into the accident data obtained from Highway 37 located between two cities in Iran. Results indicated the low sensitivity of the method to PMs. In comparison with the real high accident-proneness segments, identified High Crash Road Segments (HCRS) obtained from the model, demonstrated the potential of the method to recognize the position and length of high accident-proneness segments accurately. Based on the road repair and maintenance costs limitation index for safety improvement, in an attempt to compare the proposed method of road segmentation with conventional ones, results demonstrated the efficient performance of the proposed method. So as to identify 20 percent HCRS located on a read, the proposed method showed an improvement of 38 and 57 percent in comparison with the best and worst outcomes derived from conventional road segmentation methods.

1. Introduction

As the main transportation infrastructure, roads play crucial role in the social, economic and cultural development of urban and sub-urban areas. One of the major consequences of the road insecurity is vehicle crashes leading to enormous human and financial costs. Therefore, the most effective way to improve the safety of road networks is to prevent the occurrence of accidents (Neuman et al., 2003). The accidents can be studied in two stages, prevention and treatment (Vistisen, 2002). The main purpose of the prevention is to avoid accidents by identifying the high accident-proneness segments and potential risks along the road (Farnsworth, 2013). In contrast, the main goal of the treatment is to reduce a number and

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severity of crashes by identifying High Crash Road Segments (HCRS) performing corrective actions, and providing accident casualties with urgent emergency aid.

A typical procedure to identify HCRSs begins with classification of a road network into a number of groups with similar characteristics, called reference population. Then, a reference population is segmented. Finally, the road network is screened by an appropriate Network Screening Method (NSM) using one or more Performance Measure (PM) to identify HCRS (AASHTO, 2010). Relevant studies has been carried out in the field of HCRS identification which can be classified into three main categories: (1) to improve segmentation of a reference population, (2) to develop a more effective PM, and (3) to improve the NSM (Chung et al., 2009; AASHTO, 2010; Kwon et al., 2013). Previous studies (Jorgensen, 1966; McGuigan, 1981; Persaud et al., 1999; Tarko, 2004; AASHTO, 2010) proposed different PMs (e.g., Crash Frequency, Crash Rate, Equivalent Property Damage Only, and Expected Average Crash Frequency, etc.) to evaluate their ability to diminish a number of crashes or crash severity at a site. Other studies (Cheng and Washington, 2005; Elvik, 2007; Huang et al., 2009) evaluated the efficiency of these measurements in correct identification of HCRS in terms of minimizing false positive (i.e., requiring a site for a safety analysis, while it is not needed) and false negatives (i.e., not requiring a site for a safety analysis, while it is needed). Another study (Kwon et al., 2013) evaluated different NSMs. Although, there has been no comprehensive review on different roadway segment definitions, their effects have been investigated in the number of studies (Kwon et al., 2013; Boroujerdian et al., 2014). Towards this end, current road segmentation methods are comprehensively reviewed in the paper, and a novel method for efficient segmentation of a road network is proposed. Performance of the proposed method is compared with two currently used Sequential Fixed-Length (SFL) and Floating Fixed-Length (FFL) segmentation methods using the crash data from Hamedan-Malayer axis. In so doing, four different PMs were analyzed including Crash Frequency (CF), Crash Rate (CR), Equivalent Property Damage Only (EPDO), and Expected Average Crash Frequency with Empirical Bayes Adjustment (EACF with EB). A crash data was the only requirement for the first aforementioned PM. For the second and the third PMs, not only the crash data, but also, traffic volume and crash severity were essential, respectively. The fourth PM requires a Safety Performance Function (SPF) in addition to the crash data and traffic volume. Since the I.R. of Iran Road Maintenance and Transportation Organization (I.R. RMTO) as the legal authority, has not developed any SPF for the studied axis, a SPF was fitted to the road network using the same functional form established in previous studies (AASHTO, 2010; Harwood et al., 2010; Tegge et al., 2010; Kwon et al., 2013). According to the I.R. RMTO instruction, accuracy of the proposed method to identify HCRS was evaluated by means of identified hot spots. Finally, to reach a practical comparison between the proposed method and two studied conventional segmentation methods, the limitation index of road repair and maintenance costs for road safety improvement was taken into account (Boroujerdian et al., 2014).

2. Current segmentation methods

In order to identify HCRS, one of the most important steps is the road segmentation (Boroujerdian et al., 2014). Segmentation provides a platform on which, a safety specialist assigns accidents to specific road segments leading to identify HCRS. A roadway segment is a portion of a facility that has a consistent roadway cross-section, and is defined by two endpoints (AASHTO, 2010). These endpoints can be defined at specific distances, or being based on any sudden changes in roadway traffic, geometry, and/or environmental characteristics. In some countries such as Germany (Elvik, 2008), road segmentation process is done visually. Despite the advantages of having an expert opinion, and also, maximum use of existing supplementary information; the aforementioned method contains human error due to an operator personal opinion. Moreover, by an increase in a length of a road, owing to the non-systematic nature of the method, the processing time and probability of error would enhance as well. In some countries such as Iran (Iran Traffic Institute, 2007) and the United Kingdom (UK) (Elvik, 2008), regardless of the geometric and traffic information, the road is divided sequentially into a set of fixed-length segments (1000 and 300 m for Iran and UK, respectively). Then accidents occurred in each year are counted. The main advantage of the sequential fixed-length segmentation (SFLS) method is the computational simplicity. However, the inconsistency of the true position and length of HCRS with those obtained from this segmentation method is considered as its most important weaknesses (Fig. 1).

In many European countries (Elvik, 2008) and the Unites States (US) (Kononov and Allery, 2000) to compensate for the inconsistency in the different lengths of HCRSs and the resulted segments, long-term statistical studies have been carried out on road traffic accidents. Then each country proposed an optimal length for the segmentation process. As an example, in Romania (Elvik, 2008) the length of the segments was considered as 100 or 1000 m. In Norway (Vegvesen, 2007) and Portugal (Hauer, 1997), the required length were proposed to be 1000 and 2000 m, respectively. However, in the published documents, a unique value could not be found for a length of HCRS in the US. According to Federal Highway Administration (Federal Highway Administration report, 1981), the length of HCRS was equal to 0.3 miles in road segmentation, and according to Texas Transportation Institution (Bonneson and Zimmerman, 2006) this value should be at least 0.1 miles. In Ohio (Prahlad et al., 2003), the minimum allowable length of HCRS was chosen to be 0.25 miles.

In many European countries such as Austria (Troche, 2007), Denmark (Vistisen, 2002), Belgium (Geurts, 2006), Romania (Elvik, 2008), Norway (Vegvesen, 2007), Portugal (Hauer, 1997), Switzerland (Elvik, 2008), and also, in the US (Kononov and Allery, 2000) to compensate for the inconsistency in the positions of HCRSs and the obtained segments, the floating fixed-length segmentation (FFLS) method has been taken into consideration. In this method, a fixed-length template was moved over the entire road, and a number of accidents enclosed in the template were counted after each movement. Wherever a