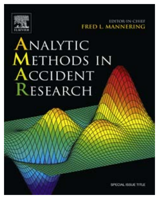
Analytic Methods in Accident Research 13 (2017) 1–15

Contents lists available at ScienceDirect

Analytic Methods in Accident Research

journal homepage: www.elsevier.com/locate/amar



The effect of long term non-invasive pavement deterioration on accident injury-severity rates: A seemingly unrelated and multivariate equations approach

Md Tawfiq Sarwar [a], Panagiotis Ch. Anastasopoulos [b,*]

[a] Department of Civil, Structural and Environmental Engineering, Engineering Statistics and Econometrics Application Research Laboratory, University at Buffalo, The State University of New York, 204B Ketter Hall, Buffalo, NY 14260, United States
[b] Department of Civil, Structural and Environmental Engineering, Institute for Sustainable Transportation and Logistics, Engineering Statistics and Econometrics Application Research Laboratory, University at Buffalo, The State University of New York, 241 Ketter Hall, Buffalo, NY 14260, United States

ARTICLE INFO

Article history:
Received 26 May 2016
Received in revised form
15 October 2016
Accepted 15 October 2016
Available online 18 November 2016

Keywords:
Pavement deterioration
Non-invasive
Accident injury-severity
Seemingly unrelated regression equations (SURE)
Multivariate tobit

ABSTRACT

This paper seeks to measure the effect of long term non-invasive pavement deterioration on accident injury-severity rates, and demonstrate the potential of considering safety as one of the criteria in the pavement management decision making process. Using data from Indiana, a system of seemingly unrelated regression equations (SURE) is estimated to predict pavement deterioration curves over a 30-year projection period based on three commonly used pavement performance indicators. The annual predictors of the pavement roughness, rutting depth, and pavement condition rating are then used in a multivariate tobit equations model of vehicle accident injury-severity rates. The results provide the expected change of the no injury, injury, and fatality rates, due to the non-invasive pavement deterioration, and are compared to a budget-unrestricted scenario under which rehabilitation occurs routinely. Even though the aim of the paper is not to provide an optimal pavement management program, the findings suggest that safety should be considered as one of the decision making criteria.

1. Introduction

Pavement condition has frequently been found to play a significant role in accident occurrence and injury-severity. Several studies have identified that pavement roughness, rutting depth, and the overall pavement condition have variable effects on accident occurrences – accident frequencies, rates, or injury-severities (Mayora and Piña, 2009; Anastasopoulos et al., 2012a, 2012b; Li et al., 2013; Buddhavarapu et al., 2013; Dong et al., 2015; Anastasopoulos, 2016). For example, Al-Masaeid (1997) found that pavement roughness, international roughness index (IRI), and present serviceability rating have significant impact on accident rates; while, Mayora and Piña (2009) showed that higher pavement friction significantly reduces accident rate on wet pavements. Similarly, Anastasopoulos et al. (2012a, 2012b) found that higher pavement friction reduces accident injury-severity rate, while rougher pavements, excess rutting depth and poor overall pavement condition generally increase accident rate. Furthermore, Li et al. (2013) showed that poor pavement condition – in terms of IRI, skid

* Corresponding author.
E-mail addresses: mdtawfiq@buffalo.edu (M.T. Sarwar), panastas@buffalo.edu (P.Ch. Anastasopoulos).

http://dx.doi.org/10.1016/j.amar.2016.10.003
2213-6657/Published by Elsevier Ltd.

score, ride score, condition score, and distress score – is associated with higher accident injury-severity, while very good pavement condition is associated with relatively higher injury-severity. In a similar context, Buddhavarapu et al. (2013) studied the relationship between pavement condition and injury-severity on horizontal curves of two-lane undivided highways, and found that smooth pavements (in terms of IRI and pavement distress index) increase injury-severity. Relatively recently, Li and Huang (2014) used four types of pavement performance indicators (condition score, distress score, ride score, and IRI), and found that excellent pavement condition is associated with significantly lower accident rates; Dong et al. (2015) found that IRI has a significant effect on truck-only accident occurrences; Lee et al. (2015) found that poor pavement condition decreases the injury-severity of single-vehicle accidents on low-speed roads; and Anastasopoulos (2016) showed that high pavement friction significantly reduces accident injury-severity rates and frequencies.

The three widely used pavement performance indicators (i.e., IRI, pavement condition rating – PCR, and rutting depth) have direct effects on vehicle maneuverability and control. The international roughness index (IRI) measures (in inches per mile, with higher values indicating rougher pavements) pavement surface irregularities due to rutting, potholes, patching, etc. (Noyce and Bahia, 2005; Shafizadeh and Mannering, 2003, 2006). Rutting depth (measured in inches) plays a significant role on vehicle tracking, with excessive rutting leading to poor vehicle control (Anastasopoulos et al., 2012c). The pavement condition rating (PCR) uniformly measures (on a scale of 0, indicating completely deteriorated pavements, to 100, indicating pavements in excellent condition) the overall pavement distress in terms of severity and extent (Anastasopoulos and Mannering, 2014). Generally, good pavement condition (as indicated by the three pavement condition indicators) can result in high friction and can allow for better vehicle maneuverability and control, whereas poor pavement condition can lead to loss of vehicle control, low friction, and in turn in higher likelihood of accident occurrence (Anastasopoulos, 2009).

Roadway Agencies have developed sophisticated methods that allow them to select pavement treatments for implementation on the basis of prior or existing pavement condition, availability of resources, cost, and budgetary constraints (Haas et al., 1994; Chan et al., 2001; Abaza et al., 2004; Chootinan et al., 2006; Abaza and Murad, 2007; Durango-Cohen and Sarutipand, 2009; Scheinberg and Anastasopoulos, 2010; Ng et al., 2011; Medury and Madanat, 2013; Fan and Wang, 2014; Anastasopoulos et al., 2014). For example, Chan et al. (2001) used genetic algorithms to develop a pavement maintenance program using budgetary and resource (i.e., manpower, equipment, and material) constraints. Abaza et al. (2004) and Medury and Madanat (2013) developed decision making tools (e.g., Markov decision processes, and approximate dynamic programming) for pavement preservation, using only budgetary constraints. Chootinan et al. (2006) developed simulation-based genetic algorithms for multi-year pavement maintenance programming, using budgetary and pavement condition constraints. Abaza and Murad (2007) expanded the pavement management programming framework by including budgetary, resource (restoration cost), user cost, and pavement condition constraints. Durango-Cohen and Sarutipand (2009) considered as constraints the pavement condition, and traffic demand, in a quadratic programming framework for pavement management programming. Anastasopoulos et al. (2014) developed a multi-year, multiple-objective hybrid (in terms of in-house and public-private partnership pavement preservation) pavement management program, using budget and pavement condition as constraints. And, recently, Anastasopoulos et al. (2016) developed analytically determined pavement performance thresholds for pavement rehabilitation using random parameters modeling and mathematical optimization (multi-objective optimization and goal programming).

The review of these studies illustrates that the effect of pavement deterioration on roadway safety seems to have little or unclear role in the decision making process on treatment selection. To that end, this paper seeks to explore the long-term effect of non-invasive pavement deterioration on roadway safety (in terms of motor-vehicle accident injury-severity rates), and to demonstrate the potential of considering roadway safety as an additional criterion in the treatment selection decision making process.

Using a system of seemingly unrelated regression equations (SURE) to model simultaneously the three pavement condition indicators, the pavement condition is projected over a 30-year time horizon (the typical design pavement life; Anastasopoulos, 2009) under two extreme scenarios: first assuming that no rehabilitation treatment is employed on the studied network throughout the time horizon; and second assuming rehabilitation treatment is routinely employed on the studied network (with the additional assumption that there are no budgetary constraints). The projected pavement condition values are then utilized in a system of multivariate tobit model of accident injury-severity rates, to predict the expected injury-severity rates for the 30-year projection period and under the two scenarios. Literature-based cost values are assigned to treatment types and accident injury-severities, and the resulting costs indicate the significant and specific benefit of routine rehabilitation on total agency cost reduction, and – more importantly – on the reduction of accident injury-severities.

2. Methodology

Relatively recent research has demonstrated the potential of modeling pavement condition indicators as a system of seemingly unrelated regression equations (SURE) (Prozzi and Hong, 2008; Anastasopoulos et al., 2012c; Anastasopoulos and Mannering, 2014). The SURE approach (for a detailed model description, see Zellner, 1962, Washington et al., 2011) accounts for cross-equation error correlation among the dependent variables (i.e., the pavement condition indicators), thus addressing the expectation that pavements in poor condition will have high IRI and rutting measurements, and low PCR measurements, whereas pavements in excellent condition will have low IRI and rutting measurements, and high PCR