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Time-varying effects of influential factors on incident clearance time using a non-proportional hazard-based model

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ABSTRACT

Incident clearance time is a major performance measure of the traffic emergency management. A clear understanding of the contributing factors and their effects on incident clearance time is essential for optimal incident management resource allocations. Most previous studies simply considered the average effects of the influential factors. Although the time-varying effects are also important for incident management agencies, they were not sufficiently investigated. To fill up the gap, this study develops a non-proportional hazard-based duration model for analyzing the time-varying effects of influential factors on incident clearance time. This study follows a systematic approach incorporating the following three procedures: proportionality test, model development/estimation, and effectiveness test. Applying the proposed model to the 2009 Washington State Incident Tracking System data, five factors were found to have significant but constant (or time independent) effects on the clearance time, which is similar to the findings from previous studies. However, our model also discovered thirteen variables that have significant time-varying impacts on clearance hazard. These factors cannot be identified through the conventional methods used in most previous studies. The influential factors are investigated from both macroscopic and microscopic perspectives. The population average effect evaluation provides the macroscopic insight and benefits long-term incident management, and the time-dependent pattern identification offers microscopic and time-sequential insight and benefits the specific incident clearance process.

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1. Introduction

Traffic Incident Management (TIM) has been an important research topic over the last several decades due to the increasing negative effects of traffic incidents (Papageorgiou, 1995; Shah et al., 2008). Understanding the influential factors and their impacts on incident duration is the basis of TIM. In the long run, the analysis on the relationship between the incident duration and the influential factors helps the TIM agencies find out the bottlenecks in the current management process and develop highly targeted improvement plans. In the short term, when choosing an appropriate response to a certain incident, the factor–duration relationship is necessary for evaluating the incident severity and predicting the incident duration as accurately as possible.

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The definition for incident duration varies in different studies. A generally accepted definition was proposed by the Highway Capacity Manual (TRB, 1994), which broke incident duration down into the following four phases: incident detection time (from the incident occurrence to the notification), response time (from the incident notification to the response team's arrival), clearance time (from the response team's arrival to the incident clearance), and traffic recovery time (from the incident clearance to the traffic recovery to the normal condition). The incident clearance phase is the emphasis of this paper, since it is the primary action that the incident management agencies can control. The clearance time is an important measure of the TIM agencies' ability to remove obstacles from travel lanes.

A lot of efforts have been made in exploring the influential factors and their effects on clearance time or other phases of incident duration. The incident duration in the following parts refers to incident detection time, response time, clearance time or the combinations. Depending on whether or not a quantitative relationship is built up between incident duration and influential factors, previous studies can be classified mainly in two categories: parametric studies and semi/non-parametric studies. For the first category, popular methods include standard regression model (Ozbay and Kachroo, 1999; Wang, 1991) and probability regression model (Garib et al., 1997; Giuliano, 1989; Golob et al., 1987; Sullivan, 1997). For the second category, typical methods include artificial neural network (Wei and Lee, 2007), nearest-neighbor method (Smith and Smith, 2001; Smith et al., 2002), decision trees (Ozbay and Kachroo, 1999), fuzzy logic (Kim and Choi, 2001; Teodorovic, 1999), Bayesian classifier (Boyles et al., 2007), and Bayesian network (Ozbay and Noyan, 2006).

Most of the previous studies focus on either the incident duration or the probability of an incident lasting for a certain time. Incident clearance is typically considered as an outcome rather than a process. However, the time-sequential clearance process is also an important focus of the TIM agencies. Khattak et al. (1995) and Wei and Lee (2007) conducted a series of predictive models to provide sequential updates of incident duration with the update of input variables, respectively. But their research still does not take the duration dependence into consideration. Compared with the conventional methods, hazard-based duration models (HBDMs) provide the benefit of capturing not only the duration probability but also the duration dependence (Heckman and Borjas, 1980). By introducing the concept of hazard, which is the conditional likelihood of the duration ending in the next short interval given how long it has lasted, HBDMs take the duration as a time-sequential process and make it feasible to explore the time-varying properties during the process.

HBDMs have been extensively used in the fields of biostatistics to analyze diseases' and patients' lifetime (Fleming and Harrington, 1990; Kalbfleisch and Prentice, 1980). Hazard-based analysis therefore can also be referred to as survival analysis and duration as lifetime. Hensher and Mannering (1994) elaborated how HBDM could be applied to transport analysis, and after that increasing quantities of studies utilized this method to analyze the duration data in the transportation area (Bhat et al., 2004; Chang and Yeh, 2007; Hamed and Mannering, 1993; Hasan et al., 2013; Kharoufeh and Goulias, 2002; Mannering et al., 1994; Mohammadian and Doherty, 2006; Ruiz and Timmermans, 2008; Wang, 1996; Yamamoto and Kitamura, 2000; Yee and Niemeier, 2000).

A few outstanding achievements have been made in the area of traffic incident duration analysis and prediction using HBDMs. Both parametric (Alkaabi et al., 2011; Chung, 2010; Jones et al., 1991; Nam and Mannering, 2000) and semi-parametric (Lee and Fazio, 2005) models were utilized to formulate the hazard distribution when external variables are at the baseline level. The accelerated failure time (AFT) (Alkaabi et al., 2011; Chung, 2010; Jones et al., 1991) and proportional hazard (PH) (Lee and Fazio, 2005; Nam and Mannering, 2000) models were two primary alternatives to formulate the interaction between the duration and the explanatory variables.

Although previous studies have gained remarkable achievements, there is still plenty of room for improvement indicated as below:

(1) Incident duration analysis using HBDMs is still a fresh research topic considering the small amount of applications. The applicable methods and estimated results were far away from conclusion in each study.
(2) Since hypotheses are inherent in both the PH and AFT models, indiscriminate or rash use of them may result in biases on determining hazard ratio and key factors. Thus the hypothesis test is required before the model utilization, which was not included in previous studies.
(3) Modeling efforts have been made in analyzing the time dependence of baseline hazard functions by fitting statistical duration distributions. However, the time dependence of the explanatory factors' effects, which is also an important concern for incident management, was not discovered. Thus the advantage of HBDMs was not explored to the full extent.

To fill up the gap, this study attempts to conduct a systematic approach on the basis of the non-proportional hazard-based model for analyzing incident clearance time. This study will help the incident management agencies understand the time-varying effects of different influential factors on incident clearance time. On this basis, the incident management agencies can better allocate their limited resource to reduce the incident clearance time and predict clearance time for traffic control purpose.

An integrated flow of procedures are followed in this study: hypothesis test, model development/estimation and effectiveness test. The hypothesis test provides empirical supports for the utilization of the non-proportional model, while the effectiveness test verifies the model's validity. The approach was applied to investigating the influential factors and their time-varying effects with the freeway incident data collected in 2009 from I-5 in Seattle area.