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Modelling total duration of traffic incidents including incident detection and recovery time

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ABSTRACT

Traffic incidents are key contributors to non-recurrent congestion, potentially generating significant delay. Factors that influence the duration of incidents are important to understand so that effective mitigation strategies can be implemented. To identify and quantify the effects of influential factors, a methodology for studying total incident duration based on historical data from an 'integrated database' is proposed. Incident duration models are developed using a selected freeway segment in the Southeast Queensland, Australia network. The models include incident detection and recovery time as components of incident duration. A hazard-based duration modelling approach is applied to model incident duration as a function of a variety of factors that influence traffic incident duration. Parametric accelerated failure time survival models are developed to capture heterogeneity as a function of explanatory variables, with both fixed and random parameters specifications. The analysis reveals that factors affecting incident duration include incident characteristics (severity, type, injury, medical requirements, etc.), infrastructure characteristics (roadway shoulder availability), time of day, and traffic characteristics. The results indicate that event type durations are uniquely different, thus requiring different responses to effectively clear them. Furthermore, the results highlight the presence of unobserved incident duration heterogeneity as captured by the random parameter models, suggesting that additional factors need to be considered in future modelling efforts.

1. Introduction

Traffic congestion has steadily increased in urban areas due to the growth of population and associated motorisation. Traffic congestion in turn leads to significant increases in traveller delays, travel time variability, air pollution, fuel consumption, and negative social and economic impacts.

Traffic congestion is caused by recurrent and non-recurrent events. Recurrent congestion is predictable and is the result of chronically exceeded roadway capacity. Non-recurrent congestion, in contrast, is triggered by unpredictable events where the capacity of a road is temporarily reduced and typically includes traffic incidents, work zones, adverse weather such as rain or fog, and where peak demands are higher than normal as a result of special events (Al-Deek and Emam, 2006).

Traffic incidents are the key sources of non-recurrent congestion, and account for 25–60% of total congestion on highways (Skabardonis et al., 2003; CamSys/TTI, 2005). In this regard, the importance and impacts of traffic incidents vary from place to place as a function of local conditions. Acknowledging the influence of incidents on traffic congestion, understanding factors that influence traffic incident duration is vitally important for improving the management of traffic incidents, as it would allow appropriate strategies to be implemented to alleviate the traffic impacts of incidents through an efficient allocation of equipment and personnel (Konduri et al., 2003).

Prior studies focused on modelling incidents have defined incident duration as the elapsed time from the moment an incident is detected until the incident cause is removed from the scene (Garib

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et al., 1997; Nam and Mannering, 2000). An additional component, recovery time, has largely been overlooked in prior analyses. As is known, the extent of congestion that results from an incident includes three time components: time elapsed between event occurrence and detection; time elapsed between detection and incident clearance; and time elapsed between incident clearance and non-recurrent congestion clearance. Thus, including all three time components in the analysis will lead to a more comprehensive understanding of the nature of traffic incidents and their associated delays.

The purpose of this paper is to provide an effective and practical methodology for studying total incident duration on freeways. In this regard, a methodology is proposed to obtain total incident duration—defined as the length of time between incident occurrence and a return to normal traffic conditions. The study is focused on identifying critical factors that influence incident duration by applying hazard-based duration models. The models also account for unobserved heterogeneity arising from potentially omitted factors. The results are intended to yield insights for improving incident management strategies and plans.

The paper begins with a review of previous research on incident duration. This review is followed by the details of the modelling approach presented here. Attention is then directed towards describing the methodology to extract total incident duration. Australian incident data and traffic measures are then examined. The subsequent section describes the modelling results including estimation of model parameters, identifying significant model variables, and the selection of the 'best' incident duration model from among various specifications. The final section concludes with a summary of the analysis findings and identifies areas for future research.

2. Literature review

Numerous prior studies have defined incident duration as the elapsed time from the moment an incident is detected until the cause is removed from the scene (Garib et al., 1997; Nam and Mannering, 2000). Therefore, recovery time was not considered in these analyses.

Research during the past few decades has demonstrated that various methodologies and techniques have been employed to analyse and model incident duration, mainly on freeways. These models have determined the relationships between incident duration and influencing variables. Sets of variables affecting incident duration have been reported, such as incident characteristics (e.g. incident type and severity; the number and type of vehicles involved; environmental effects; temporal characteristics; geometric characteristics; and operational factors).

The most representative approaches for incident duration models can be categorised into: (1) linear regression analyses (Garib et al., 1997; Valenti et al., 2010); (2) non-parametric regression methods and tree-style classification models (Smith and Smith, 2001); (3) support vector regression (Wu et al., 2011); (4) conditional probability analyses (Jones et al., 1991; Nam and Mannering, 2000; Chung, 2010); (5) probabilistic distribution analyses (Golob et al., 1987; Giuliano, 1989); (6) time sequential methods (Khattak et al., 1995); (7) discrete choice models (Lin et al., 2004); (8) Bayesian classifier (Boyles et al., 2007; Kim and Chang, 2012); (9) fuzzy logic models (Kim and Choi, 2001); and (10) artificial neural networks (Wang et al., 2005).

Incident duration has been found to follow a log-normal distribution in numerous studies (Golob et al., 1987; Giuliano, 1989; Skabardonis et al., 1999), while other studies have shown that the duration of incidents is characterised by a log-logistic distribution (Jones et al., 1991; Nam and Mannering, 2000; Chung, 2010).

A hazard-based duration modelling approach is suitable for dealing with duration data that are positive, censored, and time-varying (Bhat and Pinjar, 2008). This hazard-based approach is common in many disciplines including the biomedical, social sciences, and engineering (Hensher and Mannering, 1994). In the transport field, this method has been applied in modelling of many time-related events including safety, traffic studies, vehicle ownership, and activity based models over the last two decades. Examples include time between planning and execution of an activity (Bhat and Pinjar, 2008), duration of shopping activity (Bhat, 1996), length of traffic delay (Mannering et al., 1994), and the analysis of urban travel time (Anastasopoulos et al., 2012c).

This method has been applied to model the duration of traffic incidents in a number studies (Jones et al., 1991; Nam and Mannering, 2000; Chung et al., 2010; Tavassoli Hojati et al., 2013b). In a recent study (Chung and Yoon, 2012), total incident duration was extracted and modelled using hazard-based duration modelling approach. However, the influences of unobserved heterogeneity across data were not considered.

Many of the research studies on incident duration cannot be generalised to other locations because: (1) the research was based on small sample sizes of up to several hundred incident records; (2) the duration data were incomplete or of poor quality; and (3) the results cannot be generalised to other locales as the characteristics of the modelled factors were inconsistent with one another, or the factor(s) were not available in other locales.

While this research may not address all of these shortcomings, an analysis of traffic incidents on Australian urban roads was undertaken to validate the factors arising in the literature, to uncover other potential factors that might influence the total duration of traffic incidents, and to better understand incident duration effects in the Australian context. A more comprehensive and intuitive definition of incident duration is uniquely implemented, and the incorporation of traffic operations data distinguishes and builds upon previous work by these same authors (Tavassoli Hojati et al., 2013b).

3. Model development

Hazard-based duration concepts in probabilistic methods are well suited for data analysis for which the outcome variable of interest is time until an event occurs (or ends). Incident duration is the length of the time from the moment an incident affected traffic movement until the traffic returned to its normal condition. This length of time is a continuous random variable T with a cumulative distribution function $F(t)$ and Probability Density Function $f(t)$. $F(t)$ is also known as the failure function and gives the probability of having an incident before some specified time t. Conversely, the survival function, $S(t)$, is the probability of the duration being greater than some specific time t.

$$F(t) = Pr(T \le t) = 1 - Pr(T > t) = 1 - S(t) \quad (1)$$

The hazard function $h(t)$ gives the instantaneous potential per unit time for the event to occur, given that the individual has survived up to time t (Washington et al., 2011).

$$h(t) = \frac{f(t)}{1 - F(t)} = \frac{f(t)}{S(t)} = \lim_{\Delta t \to 0} \frac{Pr(t + \Delta t \ge T \ge t | T \ge t)}{\Delta t} \quad (2)$$

To explore the effect of explanatory variables in hazard models, an accelerated failure time (AFT) approach can be employed in which the key assumption is that survival time accelerates (or decelerates) by a constant factor when comparing different levels of covariates. In addition, the AFT assumption allows for the estimation of an acceleration factor which can capture the direct effect of an exposure on survival time (Kleinbaum and Klein, 2012). The