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Evaluation of incident management impacts using stochastic dynamic traffic assignment

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Abstract

In this paper, a dynamic traffic assignment (DTA) formulation with probabilistic capacity constraints is suggested in order to incorporate accident-induced random capacity reductions into evaluation of incident management strategies. For this purpose, a cell transmission model (CTM) based system optimal dynamic traffic assignment (SODTA) formulation is used as the underlying network model. Hypothetical scenarios are devised in which the potential incident management (IM) strategies are assumed to reduce either the average or the variation of the incident duration. For each case, a small scale Monte Carlo simulation is also performed and compared with the analytic results of the stochastic DTA model. It was shown that the stochastic DTA model not only provides the changes in total system travel time within the reliability measure, but it also provides the analytical results which requires significantly less computational burden. The model also incorporates the impacts of rerouting which is not possible with a queuing theory based analysis on a single link. The results also show that rather than reducing the average duration, comparable delay reductions can be achieved by reducing the variance while keeping the average accident duration unchanged. Hence, IM strategies, solely targeting average duration may be deemed not to be successful, yet, they may be an effective policy to reduce delay. Overall, the proposed model provides a computationally efficient network-wide analysis of incident induced delay without ignoring the highly stochastic nature of roadway incidents.

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Keywords: Dynamic Traffic Assignment; Stochastic Programming; Incident Management

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1. Introduction

Traffic incidents are one of the main causes of inefficiency in transportation networks. In case of a crash, safety concerns such as injuries and fatalities also arise along with economic impacts due to property damages. Vehicle emissions due to traffic incidents is also an environment sustainability issue. In order to reduce the adverse impacts of incidents, incident management strategies and traffic safety policies are developed to primarily avoid the occurrence of incidents, and secondly, to dissipate their adverse impacts once they happened.

The effectiveness of such strategies and policies can be assessed by comparing the actual impacts (e.g. delay, safety, economic cost) of a specific incident management policy/strategy that are measured before and after its implementation. Considering that most of the incident management and safety strategies involve major capital investments (especially in terms of ITS infrastructure), a prior estimation of the benefits of policies are thus necessary before their actual implementation. For that matter, simulation has been used as the primary tool for such evaluations (Fries et al. 2010; Ozbay et al. 2009; Ozbay and Bartin, 2003; Sisiopiku et al, 2007; Kamga et al., 2011).

Incidents are probabilistic events. Whether an incident would occur on a certain location, whether it is only a disablement or there will be a personal injury or just property damage, and how long it will take to clear a given incident are all random events. Realistic assessment of incident management strategies should address the stochasticity in the link capacities and impacts of incidents in a transportation network. In this paper, each incident is assumed to result in a temporary random capacity reduction. Accordingly, we approach the problem from a reliability perspective using dynamic traffic assignment as the evaluation tool. Cell transmission model (CTM) based system optimal dynamic traffic assignment (SODTA) formulation (Ziliaskopoulos, 2000) with probabilistic capacity constraints is used as the underlying model. Compared to traditional queuing theory based incident delay calculations, the CTM based approach allows a network-wide analysis in which the illustrated effects of alternative routes (Wirtz et al., 2005) are taken into account. In addition, the analytical stochastic programming approach is more efficient compared to computationally expensive sampling based simulation, e.g. Monte Carlo simulation. The proposed stochastic DTA model can incorporate the IM policy related changes in roadway capacity reduction distributions and calculate the network-wide impacts in terms of total system travel time. System optimal nature of the assignment also provides the best-case-scenario which can serve as a benchmark level to further assess the effectiveness after policy implementation.

2. Literature review

There are two main components of incident modeling which in turn define the characteristics of the random capacity reduction: frequency and duration. Frequency (or occurrence) of an incident is probabilistic in nature. An incident can happen due to various reasons which cannot be deterministically predicted, i.e. disablement due to mechanical malfunction, flat tire, accident due to human error. Duration of an incident also varies based on the type of incident (disablement, property damage, injury/fatality, availability of response vehicles etc.) and different average values are reported for different regions and facility type, e.g. freeway vs. arterial (Yazici et al., 2010). As a result of the variance in incident durations, researchers suggest using probability distribution to model the distribution of incident durations, e.g. Lognormal (Golob et al, 1987; Guiliano, 1989;Garib et al., 1997), Log-Logistic (Jones et al., 1991; Wu et al., 1998), Gaussian (Jones et al., 1991; Wu et al., 1998), Weibull (Nam and Mannering, 2000).

The past literature recognize that the traffic flow capacity is a stochastic variable already without accounting the incidents (Brilon et al., 2007; Geistefeldt, 2011; Tu et al., 2010). Incidents introduce additional randomness on roadway capacity and traffic flow (Gursoy et al. 2008). Related to the nature of an incident (e.g. disability, property damage, injury/fatality) and location (e.g. disabled vehicle at the shoulder, lane that an accident occurred) the roadway capacity reduction also varies. Smith et al. (2003) studies the changes in traffic flow before and after multiple incidents. They suggest that the capacity reduction due to accidents should be modeled as a random variable. Based on the observations of single and two-lane blocking incident, beta distribution is proposed as the best probabilistic distribution to represent the incident induced capacity reduction. Knoop et al. (2008) also study the traffic flow during incident conditions and detect varying flow distributions, however no specific probability distribution is identified.

In terms of car accidents, incident management strategies (IMS) first aim to reduce the frequency of accidents by legal enforcement, suggesting safer geometric road designs etc. Once the accident happens, IMS aim to respond to