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Real-time prediction and avoidance of secondary crashes under unexpected traffic congestion

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ABSTRACT

According to the Federal Highway Administration, nonrecurring congestion contributes to nearly half of the overall congestion. Temporal disruptions impact the effective use of the complete roadway, due to speed reduction and rubbernecking resulting from primary incidents that in turn provoke secondary incidents. There is an additional reduction of discharge flow caused by secondary incident that significantly increases total delay. Therefore, it is important to sequentially predict the probability of secondary incidents and develop appropriate countermeasures to reduce the associated risk. Advanced computing techniques were used to easily understand and reliably predict secondary incident occurrences that have low sample mean and a small sample size. The likelihood of a secondary incident was sequentially predicted from the point of incident response to the eventual road clearance. The quality of predictions improved with the availability of additional information. The prediction performance of the principled Bayesian learning approach to neural networks (BNN) was compared to the Stochastic Gradient Boosted Decision Trees (GBDT). A pedagogical rule extraction approach, TREPAN, which extracts comprehensible rules from the neural networks, improved the ability to understand secondary incidents in a simplified manner. With an acceptable accuracy, GBDT is a useful tool that presents the relative importance of the predictor variables. Unexpected traffic congestion incurred by an incident is a dominant causative factor for the occurrence of secondary incidents at different stages of incident clearance. This symbolic description represents a series of decisions that may assist emergency operators by improving their decision-making capabilities. Analyzing causes and effects of traffic incidents helps traffic operators develop incident-specific strategic plans for prompt emergency response and clearance. Application of the model in connected vehicle environments will help drivers receive proactive corrective feedback before a crash. The proposed methodology can be used to alert drivers about potential highway conditions and may increase the drivers' awareness of potential events when no rerouting is possible, optimal or otherwise.

1. Introduction

1.1. Motivation

The integration of traffic and incidents databases provides an opportunity to examine the critical factors that cause incidents, and allows for the dynamic capture of traffic evolution as the primary incidents unfold. According to the Federal Highway Administration, nonrecurring congestion contributes to nearly half of the overall congestion. Temporal disruptions that take away part of the roadway from use are a major issue, because speed reduction and rubbernecking caused by primary incidents provoke secondary incidents. There is an additional reduction of discharge flow caused by secondary incident that significantly increases total delay. The likelihood of a secondary crash increases by 2.8% for each minute the primary incident continues to be a hazard (Khattak et al., 2012). To mitigate the impact of primary incidents in a timely manner, an optimal allocation of emergency response units (Park et al., 2016b) and performance measure (Park and Haghani, 2016b) have been proposed.

In addition to these post-crash strategy, it is important to prevent the secondary crash in advance with an effective prevention method. To enable this, we need to analyze the key cause with consideration of real-time traffic condition and incident duration (Fig. 1). There is a significant correlation between incident duration, the likelihood of a

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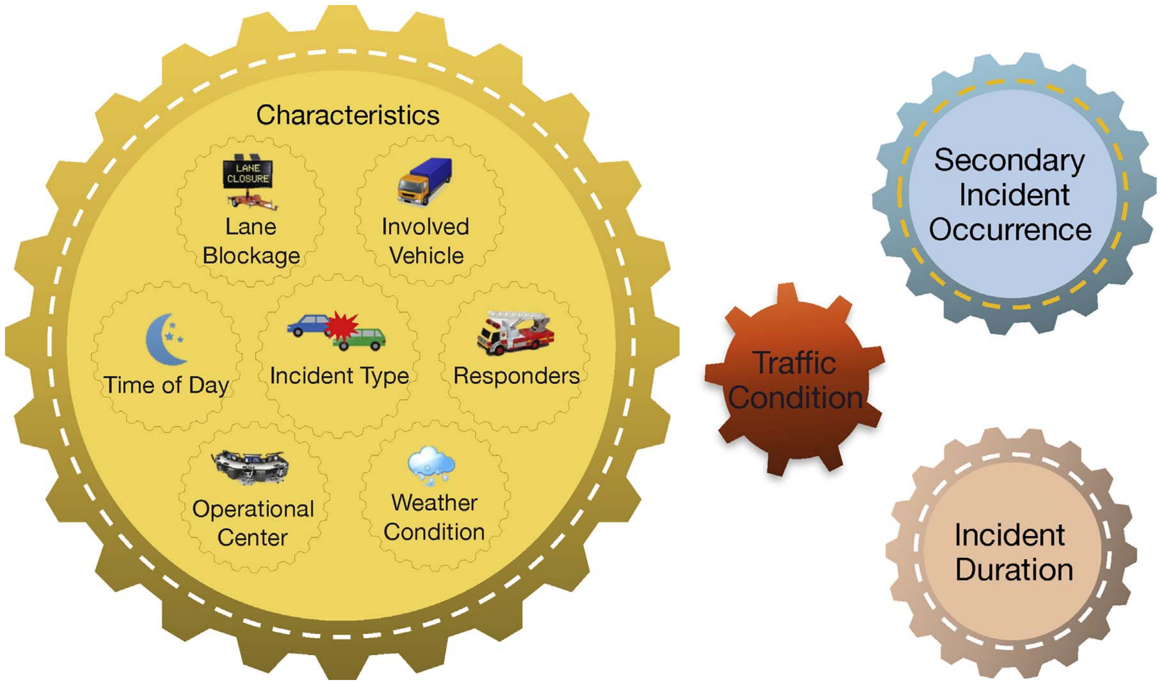

Fig. 1. Framework for studying the analysis and prevention of secondary crashes.

secondary incident, and the characteristics of a primary incident (Khattak et al., 2012). Various strategies (e.g., variable speed limits) have been proposed to reduce secondary crashes (Junhua et al., 2016; Sarker et al., 2017; Li et al., 2014). Accurate prediction and suggestions in easy to understand format helps traffic operators to develop incident-specific strategic plans for rapid emergency response and clearance.

Previously proposed prediction models for secondary incident likelihood have focused on the predictive power of the models and independent variables (Vlahogianni et al., 2012). Such singular prediction models assume that all information is available when the incident is reported. On the contrary, Park and Haghani (2016a) proposed a new model to continuously predict secondary incident likelihoods with the availability of additional information from the time point of incident response to the eventual road clearance.

Most solutions of machine learning algorithms have been perceived as black boxes. They might yield accurate predictions for the future, but the way those results are produced is hardly interpretable. A statistical model, in contrast, aims at quantifying the relation between the input and the expectation of the output via an interpretable function. The authors were faced with a critical issue of selecting the appropriate methodology and evaluating the efficiency of the developed model, thereby motivating the interpretation of machine learning models in statistical terms. In this study, the authors tested the accuracy and comprehensibility of models predicting secondary incident likelihoods. Accurate and understandable information provided by the tool may help emergency operators by improving their decision-making capabilities and lead to the development of collision warning systems that can prevent the occurrence of potential secondary events.

1.2. Background

Spatial and temporal influences of a primary incident on road users are closely related to occurrences of secondary incidents. Negative impacts of severe primary incidents cause congestion at upstream traffic, with a critical increase in secondary incident likelihoods. Since it takes time for upstream traffic to be congested, lower probability of secondary incidents with higher errors are expected at the initial incident clearance stages.

Defining and analyzing secondary incidents significantly depend on the performance of data collected from sensors. Previous studies commonly used inductive-loop detectors that are prone to various errors caused by malfunctions and communication failures. Recently, Park and Haghani (2016a) used real traffic data collected from vehicle probes for estimations of traffic congestion caused by incidents. The high-quality data collected from vehicle probe data, generally satisfying the requirements of applications for real-time travel time display, would yield reliable prediction results.

Previously, Vlahogianni et al. (2010), Imprialou et al. (2014), Yang et al. (2013a,b); Yang et al. (2014a,b), Junhua et al. (2016) focused on the classification of secondary incidents. While Dong et al. (2015) have studied safe driving behaviors within work zones, no predictions of secondary incident likelihood were made. To date, the research by Khattak et al. (2012), proposing linear models for the prediction of incident duration and secondary incident likelihood, continues to be among a handful of studies examining secondary incidence likelihood prediction. Compared to primary incidents, secondary incidents exhibit a lower sample mean and a small sample size. The wide variety of causes and impacts of nonrecurring congestion makes it difficult to quantify random and complex incident natures at a system level. As a result, crash prediction models have been over-fitted and have poor predictive performance. Since accident prediction models are non-normal and functional forms are typically nonlinear, it is shown that R^2 is not an appropriate measure (Miaou et al., 1996). It has been difficult to validate secondary incident occurrence and associated delays, owing to the lack of appropriate field data.

Recent studies have used neural network models to present top factors associated with secondary accident likelihood (Vlahogianni et al., 2012; Yang et al., 2014c). To avoid the over-fitting problem while retaining the interpretation of the model, two types of decision trees are used. While producing more understandable rules, decision trees discretize the classifier-separating hyperplane, thus leading to some information loss. In this study, two algorithms were used to overcome the shortcomings of traditional decision tree algorithms. First, Stochastic Gradient Boosted Decision Trees (GBDT), an ensemble method that combines the predictions of several models built with a given learning algorithm, was used to improve the generalizability over a single tree model. The importance of variables to prediction was estimated for different incident clearance stages.