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Performance measure for reliable travel time of emergency vehicles

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ABSTRACT

Travel time is very critical for emergency response and emergency vehicle (EV) operations. Compared to ordinary vehicles (OVs), EVs are permitted to break conventional road rules to reach the destination within shorter time. However, very few previous studies address the travel time performance of EVs. This study obtained nearly 4-year EV travel time data in Northern Virginia (NOVA) region using 76,000 preemption records at signalized intersections. First, the special characteristics of EV travel time are explored in mean, median, standard deviation and also the distribution, which display largely different characteristics from that of OVs in previous studies. Second, a utility-based model is proposed to quantify the travel time performance of EVs. Third, this paper further investigates two important components of the utility model: benchmark travel time and standardized travel time. The mode of the distribution is chosen as benchmark travel time, and its nonlinear decreasing relationship with the link length is revealed. At the same time, the distribution of standardized travel time is fitted with different candidate distributions and Inv. Gaussian distribution is proved to be the most suitable one. Finally, to validate the proposed model, we implement the model in case studies to estimate link and route travel time performance. The results of route comparisons also show that the proposed model can support EV route choice and eventually improve EV service and operations.

1. Introduction

Emergency vehicles (EVs) are general terms for police cars, fire trucks or ambulances. When on a mission, they are designated and authorized to respond to firefighting, medical assistance, etc. which are highly pressed for time. To make a quick response, EVs expect and pursue possibly short and reliable on-route travel time to ensure the quality of emergency response.

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Over the past few decades, travel time reliability has been upheld as an important research topic and attracted increasing attentions (Abdel-Aty et al., 1995; Asakura and Kashiwadani, 1991; Bates et al., 2001; Bogers and Van Zuylen, 2004; Richardson and Taylor, 1978; Senna, 1994; Tu et al., 2012). The concept of travel time variability (reliability) is accepted as one of the key indicators for the performance of transport systems (Tu et al., 2012). One can also say that travel time reliability is an important measure for assessing the operating efficiency of signalized arterials (Skabardonis and Geroliminis, 2005). Checking the probability features of travel time is one of the most common approaches to the study of vehicle routing and reliability.

The probability methods are very popular in the travel time study in ordinary vehicles (OVs). What they have in common is that they all relate to the properties of the (day-to-day or within-day) travel time distributions and particularly to the shape of the distribution (Tu et al., 2012). Measures of travel time reliability derived from distribution can be divided into percent variation (standard deviation over average travel time), misery index (length of delay of only the worst trips) and buffer Time (the difference between the average travel time and the 95th percentile travel time) (Lomax et al., 2003). Further approaches extensively studied the total delay (a portion of travel time composed of link delay and intersection delay) of OVs on an arterial, and argued that intersection delay is the main influential factor (Lin et al., 2004). Distribution based analysis proves to be valid for OV travel time and is also expected to be a good approach to reveal the characteristics of EV travel time. However, to our best knowledge, there are very few previous studies on EV travel time. The EV travel time may still follow a right-skewed distribution, but the travel time features of EVs and OVs are quite different because of their different priority levels. First, the EVs run for specific and urgent tasks, whereas most of the OVs run for everyday commuting; sometimes, EVs are allowed to run over the speed limit (Henchey et al., 2014) whereas OVs must not. Second, EVs siren when they are on duty, and other on-site OVs have to make way for them. These privileges possibly make EVs less sensitive to traffic congestions than OVs and also maintain a higher running speed. Third, traffic signals at intersections can be preempted to grant "green" for EVs despite the existing traffic conditions. This preemption process is called emergency vehicle preemption (EVP), which is the control logic providing priority for specific users. EVP is usually unconditional, providing higher priority consideration than transit signal priority (He et al., 2012). A case study on U.S.1 shows the average duration of EVP ranges from 16 to 26 s with no significant variability by time-of-day (Gkritza, 2003). These signal duration for EVP may exert an impact on the non-emergence vehicles travel time (McHale and Collura, 2003), and the reallocation of green time that results from preempting a traffic signal has the potential to affect the flow of traffic negatively (Obenberger and Collura, 2001). One can say that EVP offers much higher preferential treatments for EV movements than OVs as the signal-caused delay for EVs is substantially reduced. In this paper, the records of EVP process are employed to extract EV travel time.

Due to these differences in operations between OVs and EVs, the study on EV travel time may also pose certain differences in several aspects. A good reliable index for EV travel time may have not only theoretical value but also practical significance. To do this, the first problem to be addressed is what the probability distribution of EV travel time follows. Previous literature for OVs applied several distributions on travel time in the past few decades including lognormal distribution (Herman and Lam, 1974), Gamma distribution (Polus, 1979), Weibull distribution (Emam and Ai-Deek, 2006), etc. Most of the distributions are right-skewed and have a complicated logarithmic calculation. To make the computation of distribution fitting less expensive, Taylor and Susilawati (2012) suggested the Burr distribution be a better statistical model than the lognormal distribution because of its relative computational advantages and sufficient "bent" to capture the spread of observations in the upper tail. Compared to OVs, EV travel time distributions are also important because they can unveil the mean and standard deviation of travel time, and distributions over different time periods can even reveal how EV travel time varies over time-of-day.

The second problem is how to quantify the EV travel time performance in different road links. Previous studies conducted questionnaire survey for OVs and travelers are asked to choose between alternatives that differ in terms of cost, average travel time, variability of travel times and departure time (Asensio and Matas, 2008). These considerations are certainly unrealistic for EVs. In contrast, theoretical analysis based on historical data of EV travel time may be applicable and give more meaningful results. Link travel time percentiles still play an important role in evaluating the travel time reliability of road links, suggested by van Lint et al. (2005). Besides the single statistical indicators derived from the travel time distribution such as mean or median, the unexpected delay must be incorporated into the model because the risk of encountering a travel time in the right-tail of that distribution should be considered (Tu et al., 2012). A statistical model is a good choice to quantify the travel time reliability, and provides a good indicator for evaluating the EV travel time performance.

This paper aims to close the gaps in travel time study between OVs and EVs, as the latter draws relatively less attention in the past few years (Westgate et al., 2013). Preemption records are employed to extract the travel times of EVs in this study with a couple of reasonable assumptions. The extracted travel time data is fully examined to reveal the different characteristics between EVs and OVs. The major contribution of this paper is to build a utility model to evaluate EV travel time performance with consideration of reliability. This utility-based model consists of three major parts: benchmark travel time, delay late and delay early. In the model, EVs that arrive earlier than benchmark are rewarded, and those arriving later are penalized. The model gives a straightforward indicator of whether the given road link or route is reliable or not and which is the best route for a given origin–destination pair.

The rest of this paper is organized as follows. Section 2 describes the raw data and the methods of collecting travel time. Section 3 examines the characteristics of EV travel time. Section 4 proposes a model to measure EV travel time performance. Several assumptions are validated through numerical studies in selected areas, and the characteristics of robust benchmark travel time and standardized travel time are revealed. In Section 5, case studies of the road network are conducted to present the travel time performance both in different time-of-day and different routes.