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Distribution models for start-up lost time and effective departure flow rate

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ABSTRACT

Due to its importance, lots of investigations had been carried out in the last four decades to study the relationship between phase duration and vehicle departure amount. In this paper, we aim to build appropriate distribution models for start-up lost time and effective departure flow rate, by considering their relations with the frequently mentioned departure headway distributions. The motivation behind is that distribution models could provide richer information than the conventional mean value models and thus better serve the need of traffic simulation and signal timing planning. To reach this goal, we first check empirical data collected in Beijing, China. Tests show that the departure headways at each position in a discharging queue are very weakly dependent or almost independent. Based on this new finding, two distribution models are proposed for start-up lost time and effective flow rate, respectively. We also examine the dependences of departure headways that are generated by three popular traffic simulation software: *VISSIM*, *PARAMICS* and *TransModeler*. Results suggest that in *VISSIM*, the departure headways at different positions are almost deterministically dependent and may not be in accordance with empirical observations. Finally, we discuss how the dependence of departure headways may influence traffic simulation and signal timing planning.

1. Introduction

Start-up lost time, effective departure flow rate and departure headway are frequently-used measures to determine intersection capacity and vehicle delays.

Usually, departure headway is defined as the elapsed time between every two consecutive vehicles, when they cross the stop line one by one after the light turns green (Niittymaki and Pursula, 1996). As proven in many literatures, departure headways decrease sequentially with respect to vehicle queue positions, because the first few departure headways include driver reaction time and vehicle acceleration time. Conventionally, the saturation departure headway is assumed to be reached when the fifth vehicle cross the stop line (Highway Capacity Manual, 2000). It is inverse proportional to the saturation flow rate that is defined as the maximum number of vehicles that can be serviced in an hour of green (Branston and Van Zuylen, 1978; Stokes, 1988; Bonneson, 1992a, 1992b).

Correspondingly, start-up lost time denotes the underutilized time due to vehicle accelerating process (Li and Prevedouros 2002). It is often defined as the total time difference between the saturation headway and the first four headways; see Fig. 1.

In practice, the cycle times of many intersections are usually less than 5 min. As a result, the duration for one phase is just several minutes (seconds) long. If we directly use the product of saturation flow rate and the phase duration as the effective departure flow rate, we may over-estimate the number of vehicles that can be indeed released (Dion and Rakha, 2004).

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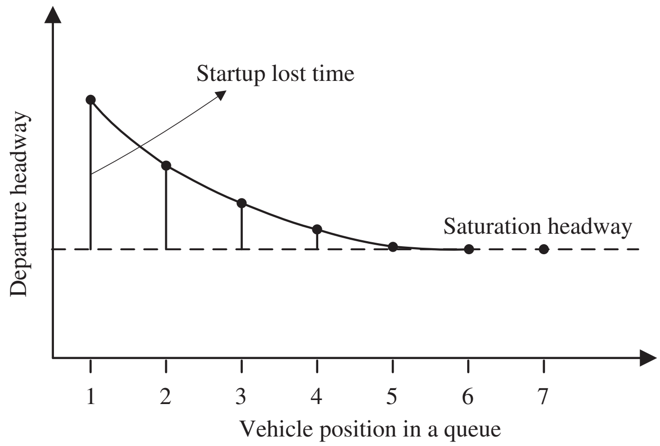

Fig. 1. An illustration of start-up lost time, departure headway and saturation headway.

Nevertheless, the conventional models just gave the mean values of departure headways and departure flow rates. However, because of uncertainty of driving behaviors, the collected departure headways are not constant. Since inaccurate estimation of departure flow often leads to inappropriate signal timing plan, great efforts had been devoted in finding better models for effective departure flow rate (King and Wilkinson, 1977; Ruehr, 1989; Yin, 2008; Yao et al., 2009; Xuan et al., 2011).

In some recent studies, stochastic feature of departure headways had been emphasized and various distribution models for departure headways were proposed (Lee and Chen 1986; Teply and Jones, 1991; Luttinen, 1992). For example, it was shown in Jin et al. (2009) and Yin et al. (2011) that departure headways approximately follow position-dependent log-normal distributions. This finding is in accordance with our observations on uninterrupted traffic flow in different cities (Greenberg, 1966; Knospe et al., 2002; Zhang et al., 2007; Thiemann et al., 2008; Li et al., 2010; Chen et al., 2010): *vehicle headways in both free flow and congested flow follow some certain log-normal distributions*.

Obviously, distribution models contain richer information and thus help us make more accurate estimation of traffic efficiency (Abdelwahab et al., 1994; Al-Ghamdi, 1999; Michael et al., 2000; Hung et al., 2003; Tong and Hung, 2002). However, based on them, we still cannot estimate the distributions of start-up lost time and effective departure flow rate, because the dependences between departure headways in a discharging queue had not been studied in almost all previous approaches.

To solve this problem, the rest of this paper is arranged as follows: Section 2 examines the dependence of empirical departure headways collected in Beijing, China. Statistical test shows that the departure headways at each position in a queue are very weakly dependent or almost independent. Based on this result, Sections 3 and 4 propose distribution models for start-up lost time and effective departure flow rate, respectively. Moreover, in Section 5, we examine the dependences of departure headways that are generated by three popular traffic simulation software: *VISSIM*, *PARAMICS* and *TransModeler*. Results suggest that the departure headways produced by VISSUM are almost deterministically dependent. This leads to a larger variance of the departure flow rate than that of the empirical flow, even if the mean departure flow rates are the same for both cases. Finally, Section 6 gives the conclusions.

2. The statistics of empirical departure headways in Beijing

The departure headway data used in this paper were collected at several typical intersections in Beijing, China by using video cameras. The recording time is from 9:00 AM to 10:00 AM in several days. The departure processes of more than 400 vehicle queues (which include at least five fully stopped vehicles) in the through lanes were recorded after the light turns green. For the dataset, we had filtered the records to make sure that the departure processes studied in this paper were not disturbed by pedestrians/bicycles or traffic congestion. Only the vehicles that had already stopped and waited in the queue will be considered; those vehicles, which arrive and join the discharging queue after the green light turns on, are neglected.

As addressed in previous research (Jin et al., 2009), the mean values of departure headways in Beijing tend to decrease sequentially respect to the queue positions. The KS-test results show that the departure headways at different positions follow log-normal distributions with different parameters, respectively.

Generally, the lognormal probability density could be defined as

$$f(x) = LN(\mu,\sigma)(x) = \frac{1}{\sqrt{2\pi\sigma^2}x}\exp\left[-\frac{(\ln\ x-\mu)^2}{2\sigma^2}\right],\quad x>0 \tag{1}$$

where μ and σ^2 are parameters.