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Analysis of the trip costs of a traffic corridor with two entrances and one exit under car-following model

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HIGHLIGHTS

- The three trip costs in a traffic corridor with two entrances are defined.
- The effects of departure interval on trip costs at each entrance are analyzed.
- The effects of the distance between the two entrances on each trip cost are analyzed.

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ABSTRACT

In this paper, we first define each commuter's first, second and third trip costs, and then apply the full velocity difference model and the VT-Micro model to explore each commuter's three trip costs and the system's corresponding total trip costs in a traffic corridor with two entrances and one exit. The numerical results show that one entrance has prominent effects on the commuter's three trip costs and the system's corresponding total trip cost and that the impacts are directly related to the commuter's departure interval at this entrance. The results can provide some suggestions for reducing the commuters' trip costs in a traffic corridor with two entrances and one exit.

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1. Introduction

To date, many models have been developed to describe the complex traffic system [1–17]. For example, Vickrey developed the first bottleneck model [1], which was widely extended to study the commuter's trip cost from different perspectives [2–12]. However, the bottleneck model [1] and the extensions have a basic assumption that a vertical queue representing congestion will occur when the commuter's arrival rate is larger than the bottleneck capacity. Hence, the bottleneck models [1–12] cannot describe the dynamics of rush-hour congestion which is produced the queue at the bottleneck upstream. In order to conquer this limitation, Newell [13] used the LWR (Lighthill–Whitham–Richards) model [14,15] to investigate the commuter's trip cost during the morning rush hour, where a fixed number of identical commuters must travel on a road of constant width. Recently, DePalma and Arnott [17] gave a detailed analysis of a special case of the Newell model [13], derived a closed-form solution for the system optimal (SO) problem and a quasi-analytical solution for the user equilibrium (UE) problem, and further studied the economic properties of the two solutions. However, the above models cannot obtain each commuter's instantaneous parameters (e.g., speed, acceleration, etc.) since they are not proposed to study each commuter's micro driving behavior. Hence, the above models fail to describe the explicit relationships between

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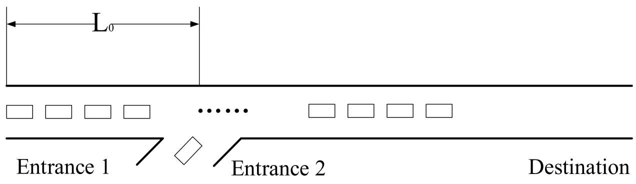

Fig. 1. The scheme of a traffic corridor with two entrances and one exit.

each commuter's micro driving behaviors and trip cost. To describe the quantitative relationships between each commuter's micro driving behavior and trip cost, Tang et al. [17–20] used a car-following model to explore each commuter's trip cost under two typical cases (i.e., without late arrival and allowing late arrival) and the impacts of the fuel cost and the emission toll on each commuter's trip cost and the total cost. Leng et al. [21,22] used the similar method in Refs. [17–20] to study each commuter's trip cost and the total cost when his traffic tools are electric vehicles. Tang et al. [23] defined the equilibrium under the car-following model and used the FVD full velocity difference model [24] to study each commuter's trip cost at the equilibrium state and the influences of the energy consumption cost (that includes the fuel cost and electricity cost) and the emission toll on each commuter's trip cost at the equilibrium state [25]. However, researchers studied each commuter's trip cost on a road with one entrance and one exit in Refs. [17–23,25]. In this paper, we utilize a car-following model to study each commuter's trip cost in a traffic corridor with two entrances and one exit. The rest of this paper is organized as follows: the related models are introduced and each commuter's three trip costs are defined in Section 2; some numerical tests are carried out to investigate each commuter's three trip costs in a traffic corridor with two entrances and one exit in Section 3; and some conclusions are summarized in Section 4.

2. Model formulation

In this paper, we study each commuter's trip cost in a traffic corridor with two entrances and one exit. Before studying this topic, we need first give the following basic assumption and notations:

(a) The traffic corridor has two Entrance 1, Entrance 2, and one exit, where the traffic corridor's length is 10 km and the distance between two entrances is L_0 (see Fig. 1); the numbers of commuters at Entrance 1 and Entrance 2 are respectively 100 and 50, where all commuters and vehicles are homogeneous (i.e., the related parameters can be defined as constant).
(b) When a commuter reaches the destination, he will automatically leave the road and his following commuter will become the leading one.
(c) The nth commuter's departure time, departure interval and arrival time at Entrance 1 are $t_{1,\mathrm{n,d}}$, $\Delta t_{1,\mathrm{n,d}} = t_{1,\mathrm{n-1,d}} - t_{1,\mathrm{n,d}}$, $t_{1,\mathrm{n,a}}$, respectively. $t_{1,1,\mathrm{d}}$ is set as 0 and $\Delta t_{1,\mathrm{n,d}}$ is a constant.[1]
(d) As for any commuter at Entrance 2, he should consider the traffic situation near Entrance 2 when enters the road, i.e., if the traffic situation does not allow him to enter the road, he need slightly adjust his departure time. We neglect the slight adjustment of the departure time, so $\Delta t_{1,\mathrm{m,d}}$ is defined as a constant. The first commuter at Entrance 1 has left Entrance 2 when the first one at Entrance 2 enters the road while the last one departing from Entrance 1 does not reach Entrance 2 when the last one at Entrance 2 enters the road. For simplicity, $t_{2,1,\mathrm{d}}$ is randomly generated based on the above condition, but $t_{2,50,\mathrm{d}}$ is calculated by the commuter's departure interval at Entrance 2 and the above condition.

In order that we can utilize a unified car-following model to describe each commuter's motion, and define his trip costs, we need here give another following assumptions and notations:

(1) i denotes the ith commuter who reaches the destination.
(2) $x_\mathrm{i}(t)$, $v_\mathrm{i}(t)$, $a_\mathrm{i}(t)$ respectively denote the ith commuter's position, speed and acceleration on the road at t, where the origin of the x-axis is Entrance 1.
(3) $t_{\mathrm{i,d}}$, $t_{\mathrm{i,a}}$ respectively denote the ith commuter's departure time and arrival time.

Based on the above basic assumptions and notations, we can utilize a generalized car-following model to describe each commuter's movement behavior as follows:

(i) The ith commuter does not enter the road when $t < t_{\mathrm{i,d}}$ and leaves the road, so we do not need to care this commuter's movement behavior at this time.

[1] n in $\Delta t_{1,\mathrm{n,d}}$ and m in $\Delta t_{2,\mathrm{m,d}}$ are greater than 1 in this paper.

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