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Impacts of the vehicle's fuel consumption and exhaust emissions on the trip cost allowing late arrival under car-following model

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HIGHLIGHTS

- Two trip costs for each commuter allowing late arrival are proposed.
- The effects of exhaust emissions on the trip cost I are explored.
- The effects of exhaust emissions on the trip cost II are explored.

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ABSTRACT

In this paper, we apply car-following model to study the influences of the vehicle's fuel consumption and exhaust emissions on each commuter's trip cost allowing late arrival. Our results show that considering each commuter's fuel cost and emission cost only enhances his trip cost and the system's total cost, but does not influence on his optimal time headway at the origin under the minimum total cost. The results can help commuters to optimize their time headway at the origin.

1. Introduction

In 1969, Vickrey proposed the first bottleneck model [1], which was extended to explore each commuter's trip cost from different perspectives [2–10]. Although the bottleneck models can describe each commuter's trip cost from different perspectives, they cannot give the explicit relationship between each commuter's trip cost (particularly the trip cost considering the fuel consumption and exhaust emissions) and his departure time since they cannot obtain each commuter's instantaneous acceleration, position, and speed. To overcome this limitation, Tang et al. [11] used car-following model to study each commuter's trip cost allowing late arrival and found that each commuter's trip cost is related to his time headway at the origin, but they did not consider the influences of the vehicle's fuel consumption and exhaust emissions on each commuter's trip cost, so this model cannot completely describe each commuter's trip cost allowing late arrival. Thus, we in this paper extend the work [11] to study the effects of the vehicle's fuel consumption and exhaust emissions on each commuter's trip cost.

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Table 1
The related coefficients in Eq. (10).

	Fuel	CO	HC	NOx
$K^e_{0,0}$	−0.679439	0.887447	−0.728042	−1.067682
$K^e_{0,1}$	0.135273	0.148841	0.012211	0.254363
$K^e_{0,2}$	0.015946	0.030550	0.023371	0.008866
$K^e_{0,3}$	−0.001189	−0.001348	−0.000093243	−0.000951
$K^e_{1,0}$	0.029665	0.070994	0.024950	0.046423
$K^e_{2,0}$	−0.000276	−0.000786	−0.000205	−0.000173
$K^e_{3,0}$	0.000001487	0.000004616	0.000001949	0.000000569
$K^e_{1,1}$	0.004808	0.003870	0.010145	0.015482
$K^e_{1,2}$	−0.000020535	0.000093228	−0.000103	−0.000131
$K^e_{1,3}$	5.5409285E−8	−0.000000706	0.000000618	0.000000328
$K^e_{2,1}$	0.000083329	−0.000926	−0.000549	0.002876
$K^e_{2,2}$	0.000000937	0.000049181	0.000037592	−0.00005866
$K^e_{2,3}$	−2.479644E−8	−0.000000314	−0.000000213	0.00000024
$K^e_{3,1}$	−0.000061321	0.000046144	−0.000113	−0.000321
$K^e_{3,2}$	0.000000304	−0.000001410	0.000003310	0.000001943
$K^e_{3,3}$	−4.467234E−9	8.1724008E−9	−1.739372E−8	−1.257413E−8

2. Model formulation

First, we give the following basic assumptions:

(i) The N commuters are homogeneous.
(ii) Each commuter leaves the origin with a fixed time headway, i.e., $t_0 = t_{n,0} - t_{n-1,0} =$ constant, where $t_{n,0}$ is the nth commuter's departure time at the origin; the nth commuter's arrival time at the destination is t_n.
(iii) When the nth commuter gets to the destination, he automatically leaves the road and his following vehicle becomes the leading vehicle.
(iv) The road is a single-lane system whose length is L.
(v) The proportion of the late arrival is η.

Based on the above assumptions, we can divide the nth commuter's motion behavior into the following three stages:

(a) The nth commuter does not enter the road when $t < t_{n,0}$, i.e.,

$$\begin{cases} x_n(t) = 0 \\ v_n(t) = 0 \\ \dfrac{\mathrm{d}v_n(t)}{\mathrm{d}t} = 0, \end{cases} \tag{1a}$$

where x_n, v_n are respectively the nth commuter's position and speed.

(b) When the nth commuter moves on the road according to the car-following equation, i.e.,

$$\begin{cases} \dfrac{\mathrm{d}v_n(t)}{\mathrm{d}t} = \begin{cases} f(v_n, \Delta x_n), & \text{if } n = 1 \\ f(v_n, \Delta x_n, \Delta v_n, \ldots), & \text{if } n > 1 \end{cases} \\ v_n(t+\Delta t) = v_n(t) + a_n(t)\Delta t \\ x_n(t+\Delta t) = x_n(t) + v_n(t)\Delta t + 0.5a_n(t)(\Delta t)^2, \end{cases} \tag{1b}$$

where f is the acceleration function determined by the nth commuter's current traffic state, Δt is the time-step length, Δx_n, Δv_n are respectively the nth commuter's headway and relative speed. Eq. (1b) cannot give the nth commuter's exact arrival time at the destination, so we here define t_n as $\bar{t} + \Delta t$ when $x_n(\bar{t}) < L$ and $x_n(\bar{t} + \Delta t) \geqslant L$.

(c) The nth commuter automatically leaves the road when $t > t_n$.

In this paper, we define two trip costs, where the trip cost I consists of the cost of the vehicle's fuel consumption, the travel cost, early arrival cost and late arrival cost, and the trip cost II consists of the tolling of the vehicle's exhaust emissions and the trip cost I. Applying the same method [10], the nth commuter's trip cost I and II can be defined as follows:

$$T_n^{\mathrm{I}} = \alpha(t_n - t_{n,0}) + \beta \max\{t_{m^*} - t_n, 0\} + \gamma \max\{t_n - t_{m^*}, 0\} + P_{\mathrm{Fuel}} \cdot (\mathrm{Fuel})_n, {}^{1} \tag{2a}$$

$$T_n^{\mathrm{II}} = T_n^{\mathrm{I}} + P_{\mathrm{CO}} \cdot (\mathrm{CO})_n + P_{\mathrm{HC}} \cdot (\mathrm{HC})_n + P_{\mathrm{NO_X}} \cdot (\mathrm{NO_X})_n, \tag{2b}$$

where T_n^{I}, T_n^{II} are respectively the nth commuter's trip cost I and I; m^* is the commuter who punctually reaches the destination; α is the per unit cost of travel time; β is the per unit cost of early arrival time; γ is the per unit cost of late arrival

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[1] Note: before the nth commuter enters the road and after it leaves the road, the commuter has no travel cost, so Eq. (2) should only consider his travel cost during the second stage of Eq. (1).