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Effect of bottleneck on route choice in two-route traffic system with real-time information

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HIGHLIGHTS

- We studied the effect of a bottleneck on the route choice in two-route traffic system.
- We proposed the extended two-route traffic model to take into account the bottleneck on a route.
- We clarified the dependence of the travel time and density on the bottleneck' strength.

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ABSTRACT

We study the traffic behavior in the case that there exists a bottleneck on a route in the two-route traffic system with real-time information. We introduce the bottleneck into the two-route dynamic model proposed by Wahle et al. When there is a bottleneck on route A, a traffic jam occurs behind the bottleneck on route A. The drivers try to avoid the congestion by the use of real-time information. We derive the dependence of the travel time and mean density on the bottleneck's strength. We show where, when, and how the traffic jam occurs by the bottleneck. We clarify the effect of the bottleneck on the traffic behavior in the route choice. We show that the dynamic transition occurs from the oscillating jam to the stationary jam with increasing blocking probability.

1. Introduction

Recently, physicists have been attracted much attention to traffic flow [1–5]. Physicists have proposed the simplified traffic models including a few factors at most to clarify the cause and effect. The traffic systems include so many factors that it is difficult to discover the essential factors affecting the traffic behavior. The physical models and concepts have been applied to transportation systems [6–15]. The traffic flow and pedestrian flow have been studied from the point of view of statistical mechanics and nonlinear dynamics [16–25].

Information is a key commodity in many socio-economic systems like traffic systems. In traffic flow, advanced traveler information systems provide real-time information about the traffic conditions to road users by means of communication such as variable message signs, radio broadcasts or on-board computers. The real-time information helps the individual road users to minimize their personal travel time. The information has an important effect on the traffic dynamics.

Wahle et al. have proposed the dynamic model for traffic flow with real-time information [26]. The traffic flow with real-time traffic information has been studied using a route choice scenario. The route-choice strategy has been extended to the three-route and crossing traffic systems [26–29]. In the two-route and three-route traffic systems, there are no traffic signals. However, it is important and necessary not only to obtain the real-time traffic information but also to know the control strategy of signals because the city traffic is generally controlled by many signals [30]. Tobita and Nagatani have

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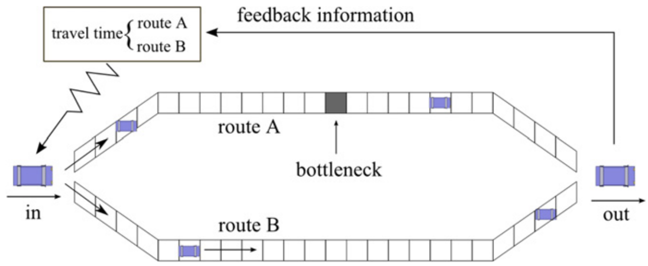

Fig. 1. Schematic illustration of the two-route traffic system with a bottleneck on route A. Two types of vehicles are introduced: dynamic and static vehicles. When vehicles enter the system, a so-called dynamic driver will make a choice on the basis of the travel-time feedback, while a static driver enters route A (B) with probability 1/2 (probability 1/2) ignoring any advice.

extended the two-route traffic system with real-time traffic information to that controlled by signals [31]. They have clarified the effect of signals on the two-route traffic flow. The vehicular motion varies not only with the route choice but also with signal's characteristic in the two-route traffic system using real-time traffic information.

Tang et al. have studied the effect of heterogeneity on the traffic flow on a road to take into account two kinds of vehicles [32]. Also, Tang et al. have investigated the effect of the road structure on traffic flow on a single road [33–37]. The road structure affects the route-choice behavior. Until now, it is unknown how the road structure with a bottleneck affects the route-choice behavior. The traffic information affects not only the route-choice behavior but also the traffic flow on a road. Tang et al. have studied the effect of the driver's forecast and honk on the road traffic [38–41]. The driver's individual property affects not only the route-choice behavior but also the traffic flow on a road. Tang et al. have studied the effect of the driver's individual property on the road traffic [42]. Tang et al. have investigated the effect of the road condition on traffic flow on a road [43,44]. The road condition affects the route-choice behavior.

In real traffic, there exist bottlenecks on roads. The bottleneck induces a traffic jam. The traffic jam by bottlenecks has been studied extensively by many researchers [45–48]. The bottleneck on a road will have the important effect on the route choice. For example, drivers try to avoid the congestion by the use of real-time information. The traffic jam induced by the bottleneck varies with the use of real-time information. As a result, the traffic jam at the bottleneck occurs or disappears with time. However, the effect of bottlenecks on the route choice has not been investigated in the physical traffic models.

The combination of the two-route traffic with the bottleneck is not a simple problem of the bottleneck' effect superimposed on the two-route traffic. The travel-time feedback with real-time information changes by the bottleneck's effect, while the bottleneck' effect changes by the travel-time feedback contrary. Then, the traffic in the two-route traffic with a bottleneck shows the traffic behavior different definitely from the original two-route traffic proposed by Wahle et al.

In this paper, we study the effect of a bottleneck on the two-route traffic system at the travel-time feedback strategy. We introduce a bottleneck on a route into the dynamic model proposed by Wahle et al. We study how the bottleneck affects the traffic behavior. We investigate how the traffic jam induced by the bottleneck varies with time due to the real-time information. We derive the dependence of the travel time and the density on the bottleneck's strength on the route. We clarify the effect of bottleneck on the route choice for the two-route traffic system with real-time information.

2. Dynamic model for two-route system with a bottleneck

We consider the two-route traffic system in which there exists a bottleneck on route A. In order to demonstrate the effect of the feedback loop, Wahle et al. have studied the two-route traffic system using the scenario with dynamic information. We extend the dynamic model to the two-route system with a bottleneck. When vehicles enter the system, vehicles move either on route A or B. We apply the travel-time feedback strategy to the route choice.

Fig. 1 shows the schematic illustration of the two-route traffic system with a bottleneck on route A. Two types of vehicles are introduced: dynamic and static vehicles. When vehicles enter the system, a so-called dynamic driver will make a choice on the basis of the travel-time feedback, while a static driver enters route A (B) with probability 1/2 (probability 1/2) ignoring any advice. The dynamic driver always chooses the route with the shortest travel time at the entrance. The densities of dynamic and static drivers are S_{dyn} and $1-S_{dyn}$ respectively. Here, we introduce the bottleneck on route A into the original model proposed by Wahle et al. The bottleneck is set at a position on route A. Vehicles pass through the bottleneck with probability $1-p_b$ and are stopped at the bottleneck with probability p_b. The blocking probability p_b represents the strength of the bottleneck on route A. If the blocking probability is zero, the dynamic model is consistent with that proposed by Wahle et al. The static driver enters route A (B) with probability 1/2. The density of the static drivers on route A equals that on route B.

However, if the blocking probability is not zero, a part of vehicles are blocked at the bottleneck. The traffic jam occurs at the bottleneck. The drivers try to avoid the congestion by the use of real-time information and go to route B. In time, route B results in a congested state. When route B is congested, the drivers with the real-time information go to route A. The process is repeated. Thus, the traffic flow on route A is strongly affected by the bottleneck. Also, the congestion by the bottleneck will be reduced by the use of real-time information. The traffic flow on route A shows the different behavior from that on route