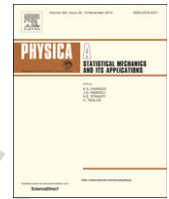




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Q1 Studies of vehicle lane-changing dynamics and its effect on traffic efficiency, safety and environmental impact

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HIGHLIGHTS

- Presented a combined model of vehicle lane-changing with road bottleneck.
- Studied effects of vehicle lane-changing on traffic, safety and energy economy.
- Discovered situations when vehicle lane-changing can be beneficial.
- Studied negative consequences of lane-changing.

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ABSTRACT

Drivers often change lanes on the road to maintain desired speed and to avoid slow vehicles, pedestrians, obstacles and lane closure. Understanding the effect of lane-changing on the traffic is an important topic in designing optimal traffic control systems. This paper presents a comprehensive study of this topic. We review the theory of microscopic dynamic car-following models and the lane-changing models, propose additional lane-changing rules to deal with moving bottleneck and lane reduction, and investigate the effects of lane-changing on the traffic efficiency, traffic safety and fuel consumption as a function of different variables including the distance of the emergency sign ahead of the lane closure, speed limit, traffic density, *etc.* Extensive simulations of the traffic system have been carried out in different scenarios. A number of important findings of the effect of various factors on the traffic are reported. These findings provide guidance on the traffic management and are important to the designers and engineers of modern highway or inner city roads to achieve high traffic efficiency and safety with minimum environmental impact.

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1. Introduction

Traffic flow includes strong interactions among various participants such as different types of vehicles, bicycles, pedestrians and so on. There have been a large number of theoretical and simulation studies of traffic systems in order to achieve transportation efficiency. The theory of microscopic car-following models has played an important role in helping us understand the vehicle longitudinal in-lane behavior [1–4]. However, the vehicle lateral behavior such as lane-changing received not enough attention in the past, but is important to gain better understanding of the dynamics in multi-lane traffic.

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1 This paper presents a comprehensive analysis of the effect of lane-changing on traffic efficiency, safety and environmental
2 impact.

3 Several lane-changing models have been developed in the literature [5]. Hidas [6,7] proposed an ARTEMiS lane-changing
4 model that takes three drive modes into consideration, i.e. free mode, cooperative mode and forced mode. The intelligent
5 agent concept was described for modeling of vehicle interactions. In this model, the choice of the lag vehicle to provide
6 courtesy or not to the subject vehicle which desires to change lane in the congested traffic is determined by the characters
7 of the drivers involved, and is a result of a checking sequence. The MOBIL (minimizing overall braking induced by lane
8 change) lane-changing model developed by Kesting et al. [8] introduces a politeness factor that makes the interactions of
9 drivers in the lane-changing process more cooperative. This feature allows a driver to prevent lane-changing for a marginal
10 advantage if the subject vehicle will obstruct other drivers, and permits an aggressive driver to take over a slower one ahead.
11 The particle-hopping models of two-lane traffic with a mix of faster and slower vehicles were developed by Chowdhury
12 et al. [9] where both symmetric and asymmetric rules are considered. According to the asymmetric model, fast vehicles are
13 able to avoid being trapped behind slow ones if the drivers of fast vehicles can anticipate such possibilities, which leads
14 to higher traffic flow. Toledo et al. [10] presented a framework of integrated driving behavior based on the concepts of
15 short-term goal and short-term plan. A symmetric two-lane cellular automata model was proposed by Jia et al. [11] to
16 investigate the aggressive lane-changing behavior of fast vehicles and the influence of different lane-changing probability on
17 traffic performance. Naito et al. [12] investigated the safety-collision transition when an oncoming vehicle carries out lane-
18 changing disregard the possible collision with nearby vehicles. It was demonstrated that the dynamic transition depends
19 highly on the headway, vehicle speed, sensitivity, and velocity difference. Kanaris et al. [13] calculated the minimum
20 safety spacing for lane-changing to prevent collision for the rest of the vehicles when a vehicle executes an emergency
21 braking.

22 In the literature, the duration of lane-changing is usually ignored and the process is regarded as an instantaneous move-
23 ment in most models [8,14–16]. However, the influence of lane-changing duration on the traffic is significant and cannot
24 be disregarded [17]. Lv and colleagues [18] established a microscopic lane-changing process model and took lane-changing
25 angle and duration into account. The lane-changing process is simplified to longitudinal car-following model by controlling
26 fictitious vehicles.

27 Road bottlenecks and the resulting vehicle merging are common in multi-lane traffic systems [19–22]. Lane-changing are
28 usually forced to occur near the merging point [23]. Large vehicle density, aggressive lane-changing [24] and lane-squeezing
29 further reduce traffic capacity of the road [25]. The vehicle interactions are complicated in lane-changing due to a road
30 bottleneck such as lane reduction and moving bottleneck. A two-lane traffic model was proposed by Kurata et al. [26] to study
31 traffic congestions due to accidents. Zhang et al. [27] analyzed the traffic characteristics of lane reduction with microscopic
32 simulation approach. The asymmetric lane-changing rules in the slow-down section and the lane-squeezing behaviors near
33 the bottleneck were considered. Macro and microscopic characteristics of the merging before a city road bottleneck was
34 analyzed by Lv et al. [28]. It was pointed out that lane-changing can improve the traffic efficiency in low vehicle density.
35 In high density, it makes the situation worse. The traffic behaviors in the upstream of the lane reduction bottleneck was
36 investigated by Jia et al. [29]. The traffic characteristics at a moving bottleneck was studied by Kerner et al. [30] based on the
37 numerical analysis with a discrete stochastic traffic flow model in the framework of the three-phase traffic theory. It was
38 observed that there is a critical speed of a moving bottleneck where traffic breaks down spontaneously when the upstream
39 flow rate is large enough.

40 This paper combines the existing well-established lane-changing models to simulate the traffic when the road bottleneck
41 occurs, and presents comprehensive analyses of traffic characteristics in different situations. Three traffic performance
42 measures are considered: transportation efficiency, energy economy and safety. Three types of lane-changing on a two-lane
43 road are studied. (1) Free lane-changing. Vehicles change lane to take over others in order to achieve higher speed. (2) Road
44 bottleneck due to lane reduction where one section of a lane is closed. Vehicles must change lane to merge. (3) Moving
45 bottleneck due to slow moving vehicles. Vehicles change lane to pass slow ones. This paper is focused on the last two types
46 of lane-changing.

47 Growing number of vehicles in the world consume more energy and impact the environment more severely [31,32].
48 Traffic congestions caused by road bottlenecks in both urban area and highway significantly worsen the situation with
49 increased energy consumption and air pollution. Hence, we pay an extra attention to vehicle energy consumption in this
50 study.

51 The paper starts with the review of the microscopic model including both longitudinal and lateral movements in
52 Section 2. The comparison between the presented model and the well established MOBIL lane-changing model is provided
53 in Section 3. Numerical simulations of the effect of road bottlenecks are presented in Section 4. We close the paper with
54 conclusions in Section 5.

55 2. Model description

56 Vehicles travel longitudinally in a single lane and move laterally when changing lane. There is a popular car-following
57 model that we can adopt to describe the single-lane movement of vehicles. For the lane-changing movement, we shall
58 present a combined and improved model based on the well-established lane-changing models in the literature.

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