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# A cellular automata model for car–truck heterogeneous traffic flow considering the car–truck following combination effect

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## HIGHLIGHTS

- A new cellular automata-based car–truck traffic flow model is proposed.
- The model discriminates differences among the four car–truck following combinations.
- The effect of car–truck following combinations is limited to a certain density range.
- Traffic congestion can be reduced up to 6.3% by mixing cars and trucks.
- When the density is high, trucks will aggravate traffic congestion obviously.

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## ABSTRACT

To better understand the characteristics of car–truck heterogeneous traffic flow that is very common on freeway, a cellular automata-based traffic flow model is proposed for single lane traffic in this paper. The proposed model discriminates the four types of car–truck following combination, car-following-car (CC), car-following-truck (CT), truck-following-car (TC) and truck-following-truck (TT). The four combinations are considered in terms of the safety distance, reaction time and randomization probability. The parameter values in the proposed model are derived from NGSIM data. Simulations are conducted based on the new model and some new conclusions about the characteristics of the car–truck traffic flow are drawn. First, in the density range of (23–36) vehs/km, the fundamental diagram mainly depends on the car–truck following combination, especially, on the proportion of CC combination. In this range, the fundamental diagram curves with the same proportion of CC gather into a cluster, and the flow rate increases with the increment of the proportion of CC for the same traffic density. Second, traffic congestion can be effectively reduced up to 6.3% by increasing the proportion of TC or CT combination. This finding provides a possible way to alleviate traffic congestion on freeway. Third, reducing randomization probability of the four combinations can effectively increase traffic capacity and alleviate traffic congestion.


## 1. Introduction

Car–truck heterogeneous traffic flow is very common on freeway. Studies have shown that although the number of trucks on freeway is relatively smaller than the number of cars, it has a significant influence on traffic flow characteristics [1–8].

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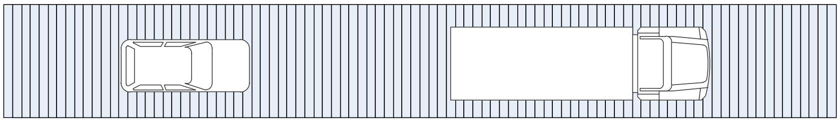

**Fig. 1.** Schematic of vehicle occupying cells.

Regarding the car–truck traffic flow, early researchers mainly focused on investigating the difference between following a car and following a truck. Huddart and Lafont [3], Sayer et al. [8] and McDonald et al. [9] compared the headway differences between the two cases: car-following-car and car-following-truck, but their studies did not reach the conclusion that which case had larger headway. Peeta et al. [4,5] analyzed the interaction of cars and trucks in multiple lanes. However, the above studies [3–5,8,9] did not recognize that the driving behavior also depends on the lag vehicle type (car or truck). Ye's study [10] first explores the impact of the lag vehicle type on traffic flow. He concluded that the four types of car–truck following combination should be taken into account in the study of the car–truck heterogeneous traffic flow: car-following-car (CC), car-following-truck (CT), truck-following-car (TC) and truck-following-truck (TT). Sarvi [6] also studied the driving behavior of the three following combinations, CC, TC and CT, but neglecting the TT combination. Sarvi et al. [7] further studied the distance headway, time headway, reaction time and car-following threshold variations among the four types of combination based on NGSIM data. They concluded that the effect of car–truck mixture on traffic flow was not only determined by the leading vehicle type, but also influenced by the lag vehicle type.

One major limitation of the early studies on car–truck mixed traffic flow is their lack of modeling of the dynamic flow characteristics. It still needs an effective model focusing on features of the traffic flow consisting of the four following combinations. Mason and Woods [11] developed the homogeneous Optimal Velocity (OV) car-following model into a heterogeneous traffic flow model to describe the interaction between cars and trucks. The authors of this paper also extended the original OV car-following model to its heterogeneous form and further studied the stability of the car–truck heterogeneous traffic flow [12]. However, the in-depth analysis on characteristics of car–truck heterogeneous traffic flow consisting of the four following combinations has not been performed, such as the influence of four types of following combination on fundamental diagram and traffic congestion characteristics.

This paper attempts to propose a cellular automata-based car–truck traffic flow model taking into account the car–truck combination effect. As an important tool for research in microscopic traffic simulation, cellular automata models, have the merits of simple rules, fast calculation speed and easy realization, and are favored by many scholars [13–18]. Since 1990s, cellular automata has been widely used in many fields, e.g., epidemic spreading [19–21], personal social behavior [22–24], dynamical systems [25–27], traffic flow [14,28,29], etc. In 1986, Cremer and Ludwig [30] first applied cellular automata in describing the transport system and proposed the first cellular automata traffic flow model. In 1992, Nagel and Schreckenberg [14] improved the No.184 cellular automata model and extended the maximum speed of the vehicle to the case of more than one, and introduced the randomization probability into the model. NaSch model [14] is the most representative cellular automata model for freeway traffic flow. Takayasu and Takayasu [15] and Fukui and Ishibashi [16] further developed and improved NaSch model and greatly enriched the freeway cellular automata-based traffic flow model. In 2003, based on the famous NaSch and improved FI model [16], Moussa and Daoudia [17] studied the impact of truck on traffic flow. In 2010, Jetto and Ez-Zahraouy [31] studied the traffic flow characteristics consisting of vehicles with different lengths and different velocities, and they found that the transition from active phase to absorbing phase depended on the length of the slow vehicles. In 2004, Ez-Zahraouy et al. [32] used numerical simulations with both open and periodic boundaries to explore the traffic flow mixed by different lengths of vehicles. However, the existing cellular automata-based car–truck traffic flow models did not discriminate the differences among the four car–truck following combinations, CC, CT, TC and TT, which will be considered in this paper. The differences between cars and trucks considered in this paper are their occupying cellular numbers, maximum velocities, maximum decelerations etc. The differences among the four types of following combination are the randomization probability, driver's reaction time and safe distance adopted. The model parameter values are derived from NGSIM data. Based on the proposed cellular automata model, simulations are further conducted to analyze the characteristics of the heterogeneous car–truck traffic flow.

## 2. Model description

This paper uses one-dimensional discrete cellular to simulate the single-lane traffic flow. Every cellular grid has two states at any time $t$, which are free or occupied by a vehicle. The length of a single cellular is $L$. Due to the different lengths of cars and trucks, this paper refines the cellular size and defines $L$ equals 0.5 m, as shown in Fig. 1.

Following is the proposed cellular automata car–truck traffic flow model.

a. Safe distance rule

Safe distance is a space that vehicles must maintain to the preceding vehicle so as to avoid rear-end collision when the preceding vehicle brakes emergently. The safe distance is with respect to the braking ability of both the lag and preceding vehicles and the reaction time of the driver of the lag vehicle, as shown in Fig. 2. Thus, due to the different braking abilities of cars and trucks and the different drivers' reaction times for the four following combinations, the safe distances are different among the four following combinations as well.