Driving Characteristics in Mixed Traffic and Replicability of Car-Following Models

その他のタイトル	車種混合交通における運転特性と追従モデルの再現性
学位授与年月日	2018-03-22
URL	http://doi.org/10.15083/00078118

博士論文（要約）

Driving Characteristics in Mixed Traffic and Replicability of Car-Following Models

（車種混合交通における運転特性と追従モデルの再現性）

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To address the traffic jam which has become a serious and worldwide problem, the effectiveness of jam reduction relying on the improvement of driving methods has been confirmed by many researchers. This approach for jam reduction is effective especially for both developing countries, as well as for developed ones, because it does not require the allocation of a huge amount of resources for infrastructure improvement. Traffic in some developing countries is composed of several types of vehicles, e.g., cars, trucks, motorcycles, bicycles, motorized three-wheelers, etc., and such traffic is called "mixed traffic." Owing to its heterogeneity, mixed traffic demonstrates different behavior from uniform traffic, and has recently attracted the interest of researchers. In order to replicate mixed traffic, many researches have applied car-following models, which were originally utilized to replicate uniform traffic [1, 2].

In this thesis, we clarify that drivers' recognition of their vehicles' agility and the visibility of the leading vehicles affect the followers' driving by extracting vehicle characteristics affecting the followers' driving. We also demonstrate the difficulty of replicating the behavioral changes of various types of vehicles with variable adjustments of existing car-following models. Based on the investigation, we propose that a model for mixed traffic should have asymmetric parameters for each operation phase. In addition, we also propose ideas of jam reduction methods for mixed traffic.

These results could be derived because we conducted a series of car-following experiments in a test circuit with known motorcycles, cars, and trucks. Our experiments with the motorcycles were made possible by means of miniaturized data recording devices. Furthermore, by means of the dynamic time warping algorithm and the decision tree learning based on the shapelets, we were able to not only extract the features of the observed driving patterns, but also compare the observation with the simulation results.

In Chapter 1, we first described the effectiveness of jam reduction without additional infrastructure. Following the introduction of mixed traffic in developing countries, we highlight the importance of physical investigation of mixed traffic. Based on our literature review regarding mixed traffic, we define the objective and importance of the thesis.

In Chapter 2, we describe how we conducted a series of car-following experiments in a test circuit with motorcycles, passenger cars, and trucks, in order to obtain data on the behavior of the known vehicles, i.e., the acceleration, steady driving, and deceleration. Since we obtained all the vehicle and driving characteristics of the leading and following vehicles, we were able to analyze the behaviors of the following vehicles by performing a multiple regression analysis. For example, Figure 1 shows the standardized regression model for the distance gap before the platoon starts accelerating (S_{start}). The values indicated next to or under the explanatory variables indicate the partial regression coefficients for respective variables. We could observe that although the distance gap increases when the length of the following vehicle (L^{f}) increases, the distance gap decreases when the length of the leading vehicle (L^{l}) increases.

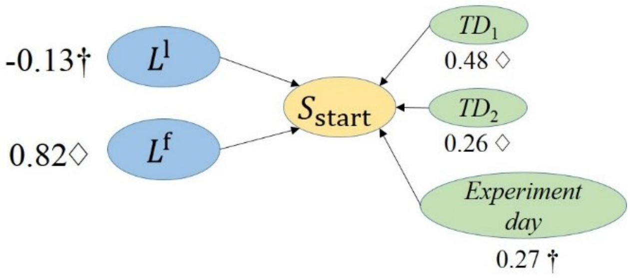

Figure 1: Multiple regression model for the distance gap before the platoon starts accelerating.

Through the regression analysis of the experimental results, we found that:

1. the maximum velocity and acceleration of the following vehicles are mainly affected by the driving behavior of the leading vehicle, and
2. the maximum deceleration, distance gap when the platoons starts, the maximum distance gap during a trial, and the delay in maximum acceleration timing, are also affected by the vehicle characteristics of the leading and following vehicles.

We have published these results in [3].

In Chapter 3, we first determined the characteristic behaviors of the respective vehicles through all the procedures, from the acceleration to deceleration, i.e., the “characteristic leaves.” By means of the dynamic time warping algorithm [4] and the decision tree learning based on the shapelets [5], we were able to extract the features of these characteristic leaves. From the decision trees for the distance gap, velocity difference, and acceleration, we obtained such characteristic behaviors of the motorcycles, cars, and trucks.

We have also compared the observed characteristic leaves of the three types of vehicles, and simulated characteristic leaves varied by the car-following model parameters. With this approach, we investigated the responses of the car-following models under the transient phases, which are ignored in the error minimization of the macroscopic values (e.g., flow), and the acceleration over the whole observed time range. Based on such comparison, we clarified and made the following conclusions:

1. Not only required features but also unnecessary features are caused by the variation in car-following model parameters.
2. There are no parameters in the car-following models that can replicate the differences observed in all the distance gaps, velocity differences, and followers’ acceleration when we change the types of the followers.
3. Although features in the distance gap can be replicated by some parameters in the models, the respective models are limited for different physical values with respect to feature replication.

It should be noted, that we utilized some standards to assess whether the simulated features follow the observed ones: (a) whether the simulated leaves are varied where the shapelets are, (b) whether the simulated leaves are not varied where observed leaves cannot be divided significantly from the perspectives of the information gain and margin between divided groups, etc.

In Chapter 4, we integrated the results obtained in Chapter 2 and 3, and concluded that the drivers' recognition of their vehicles' agility and the visibility of the leaders were the main factors affecting the followers' driving. We also proposed formulation of a car-following model replicating mixed traffic, jam reduction methods for current mixed traffic, and a jam reduction method for future mixed traffic comprising manual and autonomous driving vehicles. Through the discussion, we reached a concept of crowd optimization with emergent formation-control, which can be utilized for other crowd systems, as well as for vehicle traffic.

With respect to future works and prospects, it was noted that a decrease in the distance gap was observed when the height or size of the leading vehicles increases. This behavior in the distance gap needs to be thoroughly investigated for a better understanding of the psychological aspects of the drivers in relation to safety training, comfortable autonomous driving, etc.

It has been implied that when we focus on the transient phenomena, there is the possibility that errors are included in the discussions based on the existing car-following models. Thus, it is necessary to propose and validate new car-following models that accurately replicate the differences in the velocity difference and the acceleration of the various types of vehicles. Although we proposed some ideas for a new car-following model replicating mixed traffic, more detailed discussion regarding the replication performance of each parameter will help to develop the new model.

While we removed the effects of the individual drivers in the regression analysis by means of dummy variables, we could not completely remove these effects in the analysis based on the characteristic leaves, as this would require a huge number of trials with multiple subjects and various types of vehicles, in order to ignore the individual tendencies. Some data processing methods removing these effects from the time series will also make our discussion more accurate. Alternatively, if we obtain the characteristic leaves for real traffic of various countries, the differences between them, i.e., tendencies of drivers in respective countries, may be identified.

Furthermore, in order to realize the concept of crowd optimization with emergent formation-control in vehicle traffic, we need to investigate the order and formation of vehicles in current mixed traffic.

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