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RESEARCH PAPER

# BP Simulation Model and Sensitivity Analysis of Right-turn Vehicles' Crossing Decisions at Signalized Intersection

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**Abstract:** Inter-crossing behavior model of motor vehicles and bicycles is the key part of micro-simulation for mixed traffic at signalized intersection. The microscopic behaviors of the motor vehicles passing through the bicycle flow at a two phased signalized intersection were analyzed to reproduce the passing behavior of motor vehicles. A BP neural network model was proposed to describe the motor vehicles' passing decision. Based on the field data at two typical intersections in Beijing, the model was validated and compared with the Logistic model. The results indicated that the BP model was more effective than the Logistic model and had better prediction accuracy. First derivative sensitivity matrix of the BP model was established. The sensitivity analysis showed that the most important factor impacting on the motor vehicles' passing decision-making behavior is the gap allowing motor vehicles to pass through. The passing decision-making behavior is the most sensitive to the gap when it lies between 2.76 s and 2.96 s.

**Key Words:** traffic engineering; interference between motor vehicles and bicycles; passing decision-making model; BP neural network; gap acceptance; lag acceptance; sensitivity analysis

## 1 Introduction

Mixed traffic is a typical characteristic of urban traffic in China, especially at road-intersections. Motor vehicles are frequently disturbed by bicycles from different directions at the same phase. These interferences not only significantly decrease the intersection capacities but also increase the probabilities of traffic crash. Targeting on these problems, this study focuses on the crossing behavior between motor vehicles and bicycles and explores the interference mechanism exploration. It also proposes a foundation for the development of a mixed traffic signalized intersection simulation system.

The automobile-bicycle mutual crossing through behavior analysis has drawn much attention from domestic and international scholars, and some achievements have been obtained. To summarize, there are two research concepts at present: (1) The probability choice model based on gap acceptance theory is used: Ferrara[1] established a probability choice model of bicycle crossing through bi-directional and four lanes and investigated the stop accepted gap and non-stop accepted gap of the two vehicle flows when bicycles crossing through. Taylor and Mahmassani[2] conducted a research on the crossing and converging behavior between the bicycle flow and automobile flow at three lower speed intersections near the campus. A probability model based on the gap acceptance behavior was formulated. (2) The discrete choice Logit model represents the crossing decision of motor vehicles and the probability to accept a gap: Raksuntorn[3] developed a discrete choice Logit model to describe the behavior of the right-turning motor vehicle only considering the gap. Wu *et al*.[4] developed a probability choice model of gap acceptances for bicycles crossing motor vehicles based on critical gap at signalized intersection. Sun *et al*.[5] summarized three types of conflicts between vehicles and pedestrians, and a binary Logit approach was selected to model the pedestrian gap acceptance behaviors. Qian and Huang[6] analyzed the factors affecting the crossing behaviors using the statistical method, including the motor vehicle speed before crossing, the number of bicycles in the conflict zone when motor vehicles are entering, the gap between bicycles allowing motor vehicles to cross through

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and the speed of following-bicycle after crossing. Based on this, one mathematical model describing the crossing behavior was developed by applying the Logistic regression model.

The studies mentioned above have theoretical and practical significances. However, the critical gap model proposed in concept (1) is established with large gap acceptance sample considering various circumstances. The premise of building Logistic regression model proposed in concept (2) is that the outcome variable obeys binomial distribution corresponding to the independent variable. Compared with the existing studies, a BPN (BP neural network) simulation model representing the behavior of motor vehicle crossing through the straight-moving bicycles on neighbor lanes was proposed. The BPN model was established based on mining the rules of vehicle's crossing decision, and it was implemented easily with higher accuracy. First, the vehicle's crossing behavior at intersection was analyzed to determine the factors affecting the vehicle's crossing behavior as the inputs of the BP neural network. Then, the BPN model was trained using the training sample. The right-turning motor vehicle's crossing decision was recognized using the trained neural network which is discussed in the last section of this study.

## 2 Vehicle's crossing behavior analysis

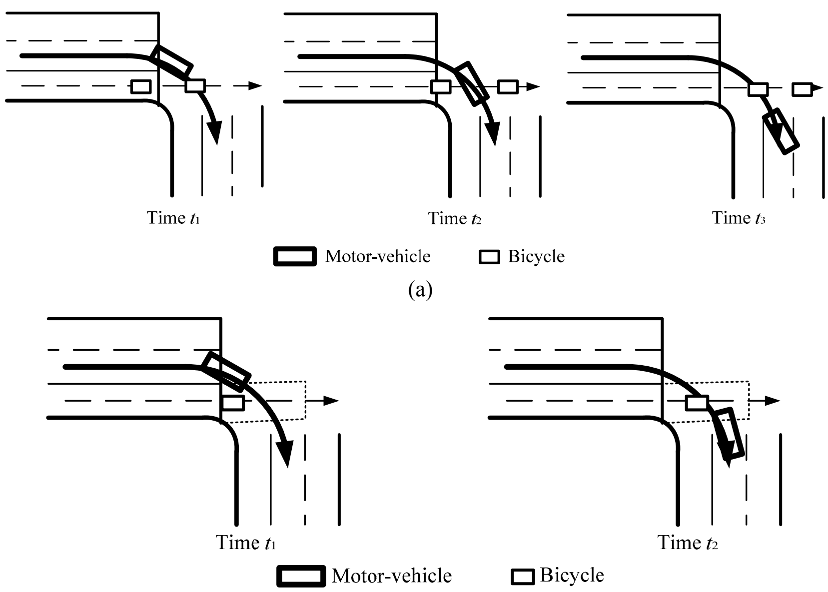
From an information perspective, there are two steps to accomplish the crossing behavior based on the analysis of drivers' micro-behavior[6]: decision-making stage and implementation stage. Drivers would observe the gap and the speed of the bicycles, as well as the current road conditions. Based on the received road traffic environmental information, drivers then make the decision whether to pass through the bicycles or not.

This paper focuses on the former and deals with the simulation of the right-turning motor vehicle and a conflicting straight-moving bicycle in the same approach, on an adjacent lane, during a green/yellow phase. In this study, there are two types of right-turning gaps according to the crossing through location: (1) A right-turning motor vehicle crossing through the bicycle group. This is referred to as "gap acceptance" (Fig. 1(a)). The gap begins at $t_1$ when the fore-bicycle reached the conflict point, the right-turning vehicle reached the conflict point at $t_2$, and the gap ends at $t_3$ when the following-bicycle reached the conflict point, then the accepted gap is $t=t_3-t_1$. If the vehicle does not accept the gap, there is no time $t_2$, then the rejected gap is $t=t_3-t_1$. (2) A right-turning motor vehicle crossing in front of the bicycle group. This is referred to as "lag acceptance" (Fig. 1(b)). The lag begins at $t_1$ when the right-turning vehicle reaches the conflict point $t_1$, the vehicle crosses through the bicycle, and the lag ends at $t_2$ when the following-bicycle reaches the conflict point, then the accepted gap is $t=t_2-t_1$. If the vehicle does not accept the lag, then the rejected lag is $t=t_2-t_1$. A gap is the time interval between the arrivals of two vehicles moving in the same direction at a point in the intersection. The gap is normally measured from the front of successive vehicles. And a lag is defined as the time interval needed for a vehicle to merge from a lag.

## 3 Vehicle's crossing decision-making model

### 3.1 Data collection and extraction

The criteria used to select sites in various intersections in Beijing for data collection includes: (1) The arrival and discharge pattern of right-turning vehicles without signalized




(b)

Fig. 1 Sketch of right-turn motor vehicle crossing through bicycle flow (a: right-turning motor vehicle crossing through bicycle flow based on gap acceptance; b: right-turning motor vehicle crossing through bicycle flow based on lag acceptance)