Behavior analysis and simulation modeling of overtaking in two-lane highway

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Abstract

The majority of highway systems are two-lane highways in China. It is showed that accidents on two-lane highways are relatively more than other road infrastructures according to the statistics of road traffic accidents. Overtaking behavior is rather dangerous and the traffic accident often happens in the course of overtaking on two-lane highway. In the course of overtaking, the driver must observe the opposite vehicles and find an appropriate acceptable clearance .Then the overtaking vehicle could return to the original lane.

In this paper, a new overtaking model is established based on analyzing overtaking behavior and the existent models. In the model, the course of overtaking is divided into five steps. This paper explains each step and makes out the corresponding simulation frameworks. At last, the model was validated by making use of the field data. It is useful for studying the overtaking behavior on two-lane highway.

Key words: Overtaking Behavior, Simulation Modeling, Two-lane Highway

Introduction

The majority of the highway systems are two-lane highways in China. According to the highway grade classification, the two-lane highways include second-grade highway third-grade highway and part of fourth-grade highway. Seen from the table 1 it is shown that the traffic accident ratio on second-grade highway is nearly 37% and on third-grade highway is over 29%. Thus the number of traffic accident on two-lane highway is not less than 66%. It is also found that the number of people died on second-grade highway is a percentage of 38 and the number is a percentage of 32 on third-grade highway. The sum is 70 percent. Therefore, it is a severe traffic safety problem on two-lane highway.

Table 1   Percentage of length, accident and death on different highways in China in 2003 [7]

highway grade	freeway	first-grade	second-grade	third-grade	fourth-grade	under-grade
length%	1.83	1.79	12.39	17.93	47.09	18.97
accident%	4.56	12.61	36.93	29.18	12.16	4.56
death%	2.14	10.21	38.34	32.03	11.35	5.93

The overtaking is dangerous and the traffic accident often happens in the course of overtaking on two-lane highway. Overtaking an impeding vehicle on a two-way, two-lane highway is relatively particular. It is different from other road infrastructures considering that the passing vehicle overtakes a slower impeding vehicle by traveling in the opposing lane. At course of overtaking, the driver must observe the opposite vehicle and find an appropriate acceptable clearance. Then the vehicle could return to the original lane. So it is very important to study the overtaking on two-lane highway.

Literature review

Research on overtaking was started in the 1930's. Matson and Forbes [2] studied the overtaking based on the starting and ending condition in 1938. They used the term ″flying″ to describe the overtaking where the passing vehicle traveled at a constant speed and completed the overtaking without slowing down, and the term ″accelerative″ to describe the overtaking where passing vehicle followed behind the impeding vehicle and increased speed to complete the overtaking. They further categorized the overtaking by using the term ″forced″ and ″voluntary″. Overtaking was ″forced″ by opposing traffic or a short sight distance, otherwise, it was ″voluntary″. In 1939, Normann[2] studied the single overtake, where the passing vehicle overtook only one impeding vehicle. Then he studied the ″clearance distance″, which the driver could see that the left lane was clear. For more analysis, further data was collected over the following two years, totaling approximate 21,000 overtakes. Prisk [2] selected data for single overtake. He classified the overtaking as four types using the following qualitative description. Type A – the overtaking start was delayed because of an oncoming car. Type B – the overtaking vehicle hurriedly return to right lane. Type C – the overtaking start was delayed and the return was hurried. Type D – free overtaking with no opposing traffic.

In the last of 1970′s and the early of 1980′s, simulation system became a new useful method for analyzing the traffic with the development of the computer simulation technology. And some research institutes developed some traffic simulation system. The three of more famous two-lane highway traffic simulation systems are TWOPAS (Two-lane Passing), TRARR (Traffic on Rural Road) and VTISIM. The traffic simulation system could structure road, traffic and other environments about traffic. It could fully simulate the running of the road infrastructure. It was convenient, quick, being - controlled, and being - repeated. So, more and more researcher thought that it was appropriate to analyze the overtaking by using traffic simulation system. Recently, Jenkins and Rilett [2] analyzed the overtaking using an integrated simulation that combined a driving simulator and a VISSIM simulation.

It is later that the research about overtaking modeling on two-lane highway in China. But, it develops quite quickly. During the ″Nine-Five″, Research Institute of Highway Ministry of Communications, Southeast University, and Beijing University of Technology achieved the program, ″The Research of Highway Capacity″ [3]. They simulated the overtaking on two-lane highway. Chen Hongren, who is in Harbin University of Technology Traffic Engineering Institute, categorized the overtaking using the overtaking desire and the feasibility that overtaking vehicle traveled in opposing lane [1]. Shen Jianwu, who is in Wuhan Technology University of Surveying & Mapping, and Yan Baojie, who is in Chang′an University, set up a mathematical model about overtaking for two-lane highway based on the theory of probability [4]. Wang Yuanqin, who also is in Chang′ an University, categorized the overtaking into the overtaking achieving confluence and the overtaking failing confluence based on the ending condition [5].

In recent years, the road and traffic condition have changed enormously in two-lane highway. In face of the situations, Research Institute of Highway Ministry of Communications and Beijing University of Technology work together to accomplish the research program, ″The Research of Two-lane Highway Capacity on Mountain Areas″. They investigated the traffic characteristic of the two-lane highway in China in detail over the two years and developed the TWOSIM (Two-lane highway simulation) system. In this paper, the overtaking characteristic is analyzed and the overtaking model is established, which laid the foundation of the TWOSIM system.

Analysis

The course of overtaking is divided into five mostly steps: "having overtaking desire", "determining overtaking type", "checking overtaking requirement", "executing overtaking" and "stopping overtaking and return forcibly".

Having overtaking desire

A vehicle would try to overtake, when the vehicle comes close to an impeding vehicle and travels with the speed which is lower than the desire speed. Then the vehicle changes the state from follow or freedom to overtaking. So it is said that the vehicle has an overtaking desire.

Determining overtaking type

The vehicle having an overtaking desire would overtake in different types according to the former state of the vehicle. When the former state of overtaking vehicle is freedom, it would be a "constant overtaking". In the constant overtaking, the overtaking vehicle travels at a high speed, which may be up to the free-flow speed. When the former state of overtaking vehicle is follow, it would be an "accelerative overtaking". In the accelerative overtaking, the speed of the overtaking vehicle is 5-20 km/h higher than the impeding vehicle. In the model, the speed difference between the overtaking vehicle and impeding vehicle is the boundary of the two types overtaking. If the speed difference between the overtaking vehicle and impeding vehicle is not less than 20km/h, it will belong to constant overtaking. Otherwise, it will belong to accelerative overtaking.

Checking overtaking requirement

The vehicle, which could start overtaking, must satisfy the two requirements. One requirement is that there is an appropriate acceptable return clearance in the same direction flow. The other is that the space between the overtaking vehicle and the opposite oncoming vehicle is not less than the "overtaking sight distance". Overtaking sight distance is defined as the distance, which the driver of the overtaking could see a sufficient distance ahead, clear of traffic. It is the distance for overtaking vehicle to complete the overtaking safely without meeting an opposing vehicle during the maneuver. It is required that there are proper sections with overtaking sight distance in proper spacing for two-lane highway from "The Highway Engineering Technical Standard" [6]. Overtaking sight distance is shown in figure 1.
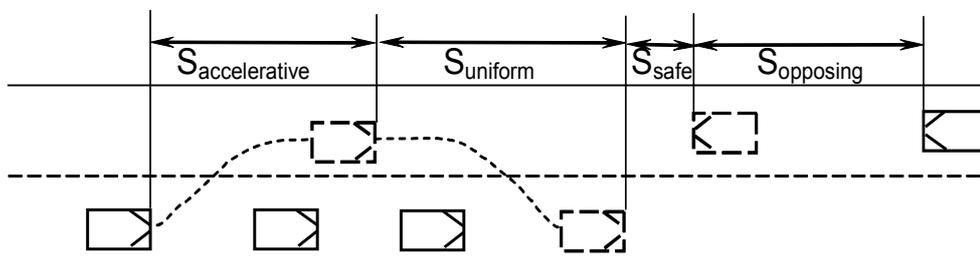

Figure 1   Overtaking sight distance

The overtaking sight distance is determined as following formula.

$$S_{overtaking} = S_{acceletative} + S_{uniform} + S_{oppo\sin g} + S_{safe}$$

$$= \left\{ \left(\frac{V_0}{3.6} \times t_a + \frac{a \times t_a^2}{2} \right) + \frac{V}{3.6} \times t_u + V_{opposing} \times (t_a + t_u) + S_{safe} \right\}$$

In especial,

$S_{overtaking}$ overtaking sight distance, meter

$S_{accelerative}$ the distance of overtaking vehicle traveling accelerative, meter

$S_{uniform}$ the distance of overtaking vehicle traveling with a uniform speed on opposing lane, meter

$S_{oppo\sin g}$ the distance of opposing oncoming vehicle traveling, from overtaking beginning to overtaking end, meter

S_{safe} the distance between the overtaking vehicle and the opposing oncoming vehicle, when the overtaking end, meter, $S_{safe} = 30 \sim 100$ meter, usually, $S_{safe} = 40$ meter

V_0 the overtaking vehicle's speed at the beginning of overtaking maneuver, km/h

V the speed of the overtaking vehicle beginning uniform notion, $V = V_0 + a \times t_a$ km/h

$V_{opp\sin g}$ the speed of the opposing oncoming vehicle, km/h

t_a the accelerative time, second

t_u the time of the overtaking vehicle traveling with a uniform speed in opposing lane, second

a the average acceleration of the overtaking vehicle, m/s^2

Executing overtaking

The vehicle would execute overtaking, when the vehicle has overtaking desire and the overtaking requirements are satisfied. In the execution of the overtaking, the vehicle would examine whether the overtaking requirements are satisfied at intervals. If it is also satisfied, the execution will go on. Otherwise, the vehicle will break off overtaking and return original lane forcibly. For modeling conveniently, the execution of overtaking is categorized into two types, executing constant overtaking and executing accelerative overtaking.

Stopping overtaking and return forcibly

The vehicle has to stop overtaking and return to original lane forcibly, when the overtaking requirements are not satisfied in the examination. In this step, the vehicle preparing return looks for an objective vehicle in the original lane and decelerates voluntarily. Then a lane-changing request is asked for to the vehicle, which is behind the objective vehicle. The vehicle receives the request and slowdowns to enlarge the space, which is enough to accept the return vehicle. The return is forcible, because that the return vehicle has to insert into the space to avoid collision with the opposing oncoming vehicle.

Simulation Model

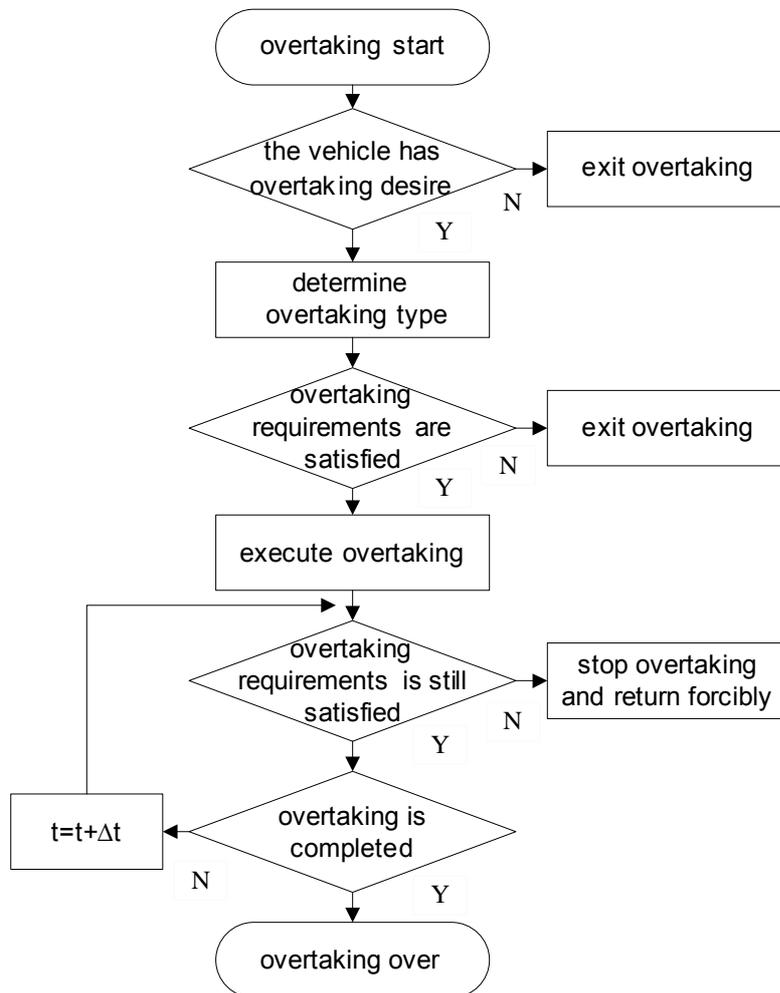The simulation framework of the whole overtaking course is shown in figure 2.

```
                    ┌──────────────────┐
                    │  overtaking start │
                    └──────────────────┘
                             │
                      ◇ the vehicle has ───N──→ ┌──────────────┐
                        overtaking desire        │ exit overtaking│
                             │ Y                  └──────────────┘
                    ┌──────────────────┐
                    │    determine      │
                    │  overtaking type  │
                    └──────────────────┘
                             │
                      ◇ overtaking ──────N──→ ┌──────────────┐
                        requirements are       │ exit overtaking│
                        satisfied              └──────────────┘
                             │ Y
                    ┌──────────────────┐
                    │ execute overtaking│
                    └──────────────────┘
                             │
                      ◇ overtaking ──────N──→ ┌──────────────────┐
                        requirements is still  │ stop overtaking   │
                        satisfied              │ and return forcibly│
                             │ Y               └──────────────────┘
                      ◇ overtaking is ──N──→ ┌─────────┐
                        completed             │ t=t+Δt  │
                             │ Y              └─────────┘
                    ┌──────────────────┐
                    │  overtaking over  │
                    └──────────────────┘
```

Figure 2   Framework of overtaking on computer simulation

The simulation framework of "having overtaking desire" is shown in figure 3.

```
              ┌──────────────────────────┐
              │ "having overtaking desire" │
              └──────────────────────────┘
                         │
                   ◇ time headway ──────N───┐
                     3 seconds               │
                         │ Y                 │
                   ◇ Overtaking              │
                     vehicle's speed  the desire ──N──┐
                     speed                            │
                         │ Y                          │
              ┌────────────────────────┐  ┌──────────────┐
              │"determining overtaking  │  │ exit overtaking│
              │ type "                 │  └──────────────┘
              └────────────────────────┘
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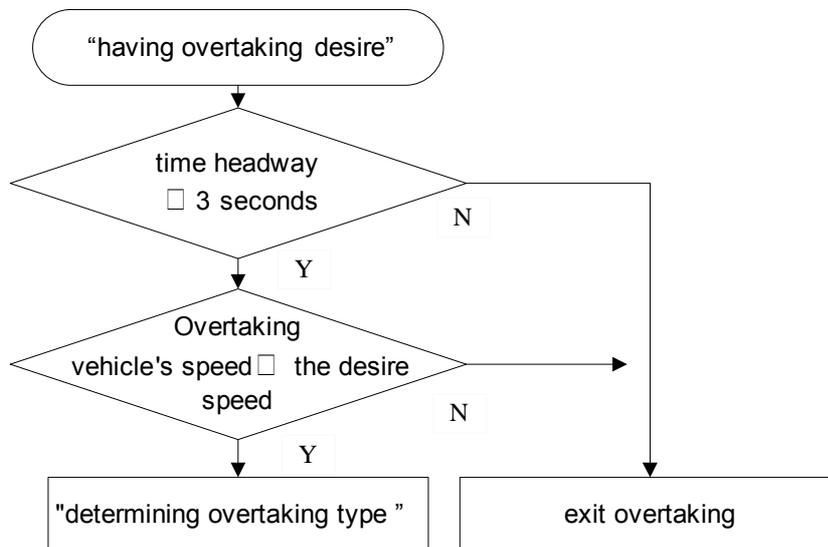
Figure 3   Simulation framework of "having overtaking desire"

The simulation framework of "determining overtaking type" is shown in figure 4.
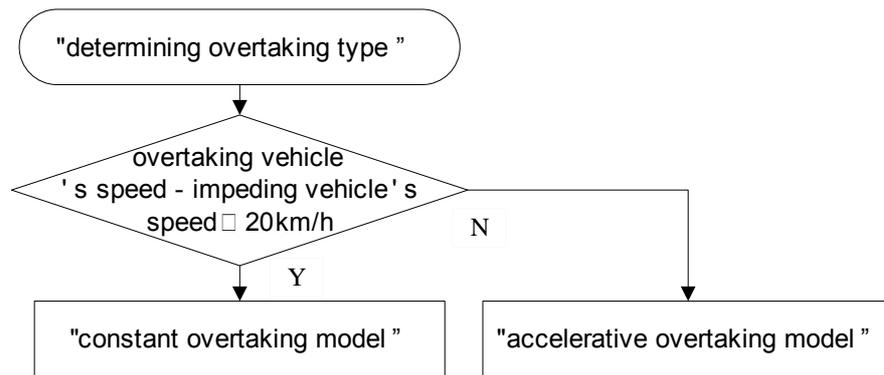

Figure 4   Simulation framework of "determining overtaking type"

The simulation framework of "checking overtaking requirement" is shown in figure 5.
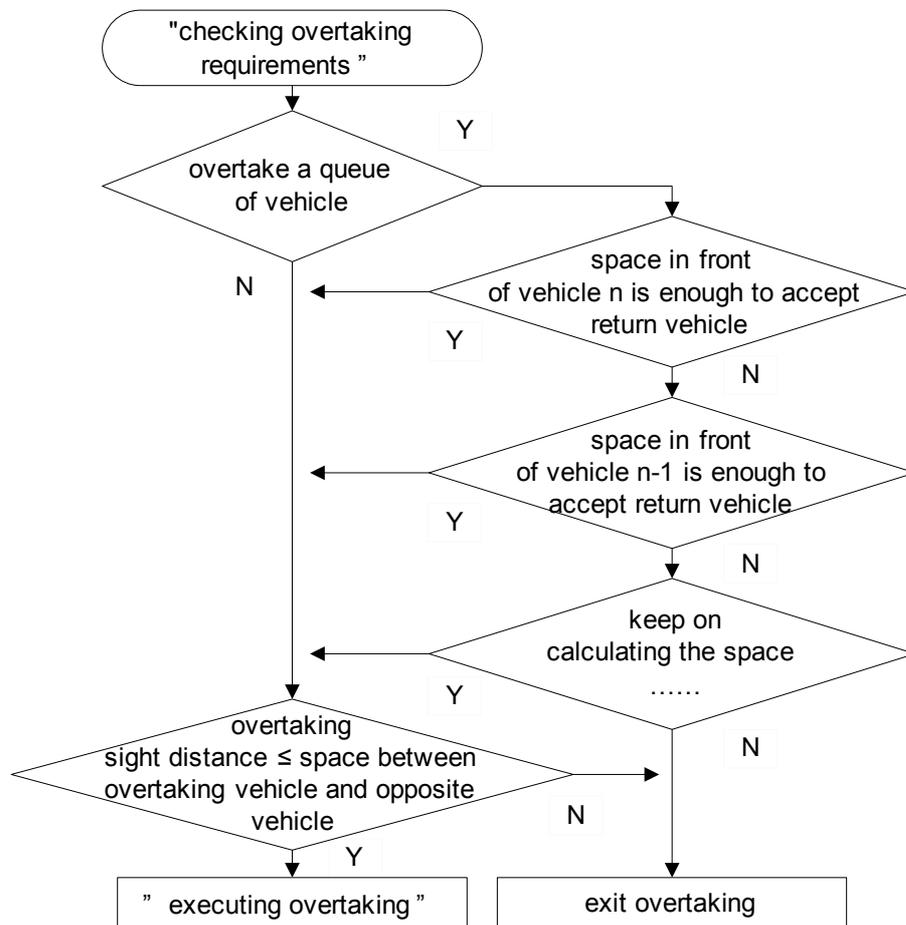

Figure 5   Simulation framework of "checking overtaking requirement"

The simulation framework of "executing constant overtaking" is shown in figure 6 and the simulation framework of "executing accelerative overtaking" is shown in figure 7.
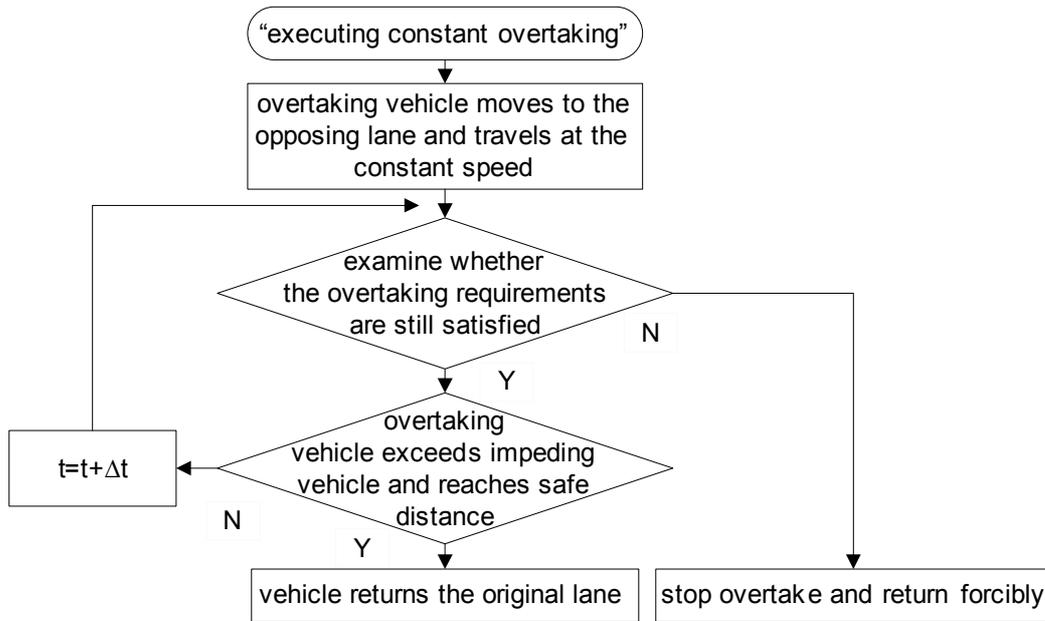
"executing constant overtaking"

↓

overtaking vehicle moves to the opposing lane and travels at the constant speed

↓

examine whether the overtaking requirements are still satisfied — N

Y ↓

overtaking vehicle exceeds impeding vehicle and reaches safe distance — N → t=t+Δt

Y ↓

vehicle returns the original lane | stop overtake and return forcibly

Figure 6   Simulation framework of "executing constant overtaking"

"executing accelerative overtaking"

↓

overtaking vehicle moves to the opposing lane and accelerates

↓

examine whether the overtaking requirements are still satisfied — N

Y ↓

overtaking vehicle catches the impeding vehicle — N → t=t+Δt

Y ↓

overtaking vehicle begins uniform notion

↓

examine whether the overtaking requirements are still satisfied — N

Y ↓

overtaking vehicle exceeds impeding vehicle and reaches safe distance — N → t=t+Δt

Y ↓

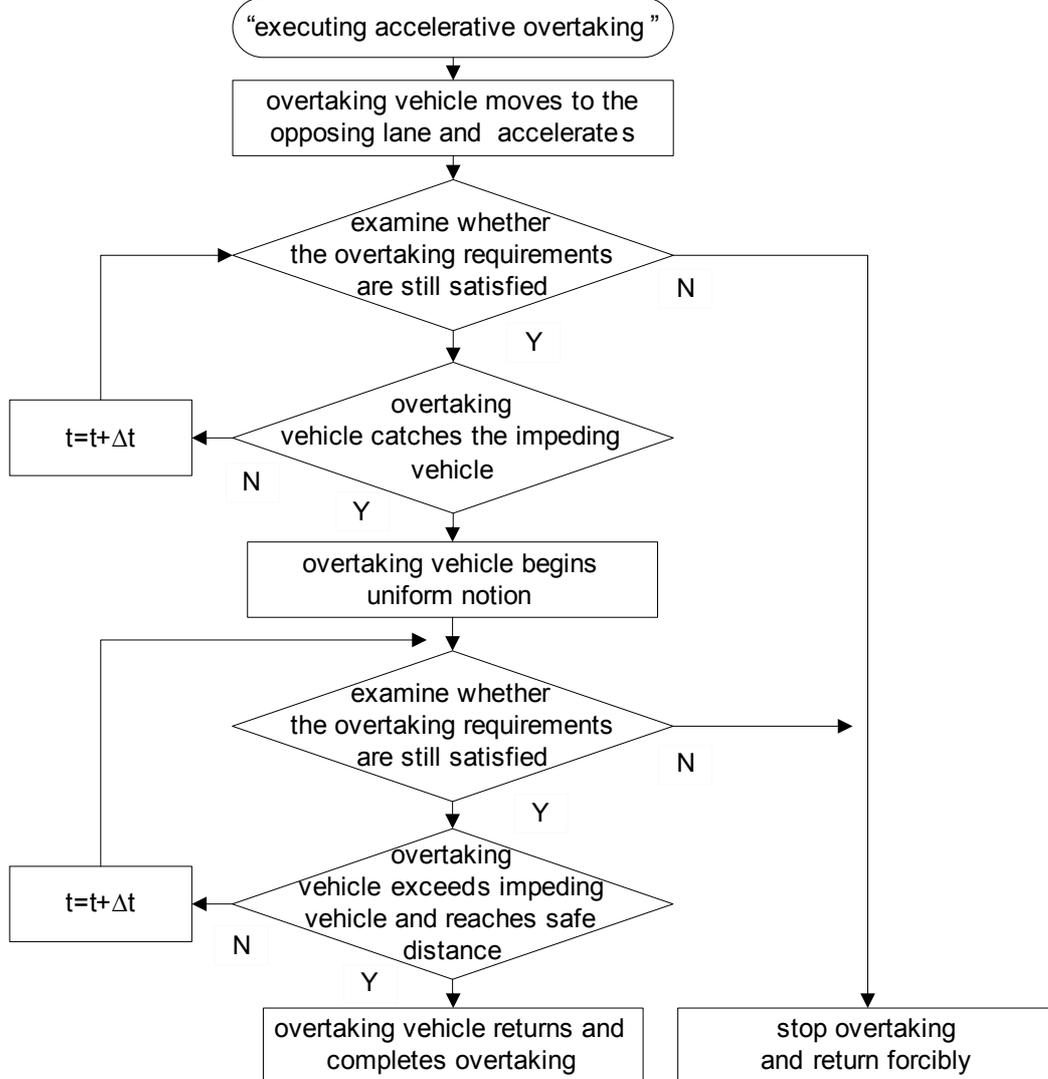overtaking vehicle returns and completes overtaking | stop overtaking and return forcibly

Figure 7   Simulation framework of "executing accelerative overtaking"

The simulation framework of "stopping overtaking and return forcibly" is shown in figure 8.
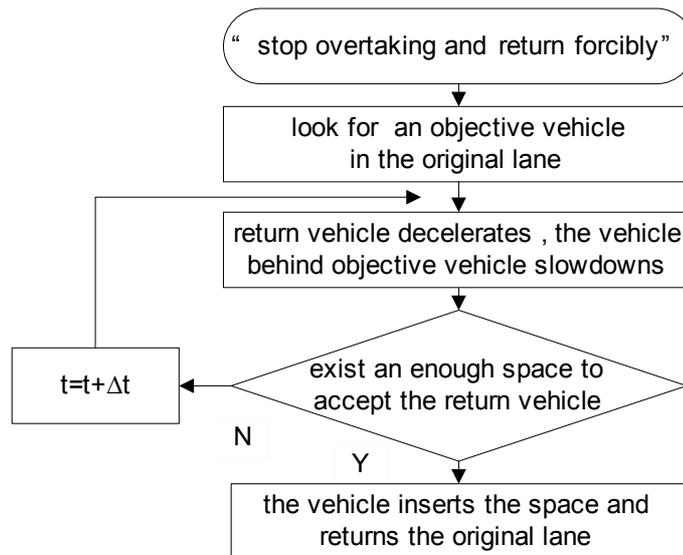

Figure 8   Simulation framework of "stopping overtaking and return forcibly"

Model verification

Ratio of overtaking and overtaken can directly reflect the percentage of overtaking vehicle and can indirectly represent the interference among vehicles. We could use them to compare the field data with the simulation result for validation. Ratio of overtaking is the ratio of overtaking vehicle number to vehicle total number in unit length. Ratio of overtaken is the ratio of overtaken vehicle number to vehicle total number.

It is shown in table 2 that the field data in comparison with the simulation result on Shunyi–miyun Highway in the suburb of Beijing. The comparison on Jichangfulu Highway is displayed in table 3. It is indicated that the relative errors of simulation are in allowable extent.

Table 2   Validation table of the Shunyi-miyun Highway

parameter	field value	simulative value	relative error (%)
ratio of overtaking (%)	31.2	32.4	3.8
ratio of overtaken (%)	50.4	46.0	8.7
average speed (km/h)	56.8	54.6	3.9

Table 3   Validation table of the Jichangfulu Highway

parameter	field value	simulative value	relative error (%)
ratio of overtaking (%)	24.2	23.4	3.3
ratio of overtaken (%)	42.0	38.3	8.8
average speed (km/h)	47.9	50.1	4.6

Conclusion

This paper analyzed the overtaking behavior and established the simulation model based on two-lane highways in China. In the model, the course of overtaking was constituted of five steps: "having overtaking desire", "determining overtaking type", "checking overtaking requirement", "executing overtaking" and "stopping overtaking and return forcibly". This paper explained each step and made out the corresponding simulation frameworks. At last, the model was validated by using the field data.

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