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# Research of speed guidance for urban expressway with model predictive control

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**Abstract**

In order to improve the efficiency and safety of urban expressway, the macroscopic dynamic traffic flow model is extended using speed guidance control. Speed guidance as control variable was introduced into the urban expressway control system, and the macroscopic dynamic traffic flow model was established. Model predictive control is presented to calculate the optimal speed guidance under the objective function of total travel time and changes of speed guidance. Speed guidance control of urban expressway was designed and optimized. Simulation analysis is carried out in simulation platform based on the case of mutations traffic in the downstream. The results show that the speed guidance under safety constraints has a good control effect to smooth traffic flow, alleviate traffic congestion and improve traffic safety which can be applied in practice to provide a theoretical basis for active traffic management.

*Keywords – urban expressway, traffic management, macroscopic dynamic traffic flow model, model predictive control, speed guidance control*

## 1. Introduction

As the main backbone of the metropolitan transportation, expressway system shares a large proportion of urban traffic. With the advance of rapid urbanization and motorization, expressway congestion and accident are getting more and more frequent, which seriously restricts the urban expressway function. At present, the engineering measures, traffic management, and control measures are mainly focused on the improvement of the traffic flow efficiency. All these means have sacrificed traffic safety as hidden costs to a certain extent [1]. The main reason is that the innovation of traffic management method of urban expressway system lags behind the construction of expressway [24].

In the past ten years, the rapid development of electronic information and wireless communication technology promoted communication between vehicles and vehicles, roads and vehicles. American traffic department of transportation pointed out that the road vehicle coordination is a necessary stage in the research of intelligent transportation system (ITS), and put it as one of nine future development areas. The European Union and Japan also carried out a series of road vehicle coordination research and demonstration project. Chinese Ministry of science and technology has placed the road vehicle coordination system as one of the five major research areas [22].

With the rapid development of ITS technology, active traffic management (ATM) theory and method has become a hot research topic in recent years. As the next generation of advanced traffic management system, ATM aims at realizing the maximum benefit of the existing transportation infrastructure. The main methods of ATM include managed lanes, speed harmonization, hard shoulder running, junction control, dynamic re-routing and traveler information service [21].

The active traffic control and management has great application value for the dynamic change and stochastic nature of the traffic demand. It is the trend of future to solve the traffic problems using active control methods. The core idea of active traffic control is that the initiative measures to be taken before things happen according to predetermined plan goals [20]. It can solve the traditional process control in the presence of time delay effect, to the maximum extent possible to change the passive situation of deviation, and has been widely used in many areas.

The main purpose of the active traffic management is to ensure the stability and reliability of the trip and to improve the safety of the travel. Dynamic speed harmonization, the core component of the active traffic management, has been clearly put forward as one of the main means to optimize the network traffic flow in the five-year ITS strategic plan. Therefore, speed optimization theory, method system, and control mechanism should be constructed to provide theoretical support from the perspective of traffic accident prevention and risk control.

Detailed analysis can be carried out for the implementation of road vehicle coordination technology which has not yet been application using the traffic flow modeling and simulation. The traffic simulation technology also can guide the implementation system more effective and propose the optimization suggestions without any interference on the existing traffic system. Complex system modeling and traffic simulation software interface technology provide mature technical foundation and platform support. Simulation experiment platform, based on virtual reality theory, offers the environment for speed guidance control and provides a continuous data environment from the macro and micro levels.

Speed guidance control is introduced into urban expressway management system in this paper. Based on the expansion of macro dynamic urban expressway traffic flow model, model predictive control (MPC) is presented to calculate the optimal speed guidance under the objective function of total travel time and changes of speed guidance. Simulation analysis is carried out in MATLAB simulation platform based on the case of mutations traffic in the downstream.

## 2. Problem background

Expressway system has become the urban mass rapid transit corridor and the framework of urban road systems. Ramp metering is the main method to control expressway traffic at present. Papageorgiou reviewed ramp metering algorithms researches comprehensively. The classical and widely practiced ramp metering method is Alinea which is a feedback control method. Ramp metering can control the flow into the expressway, but after entering the expressway the effect of using ramp metering alone to improve the traffic flow is not very well [4, 5]. In recent years, taking active traffic management to expressway has become the development trend and one of the main methods is utilizing variable speed limits (VSL) to control mainline traffic. In fact, there have been several VSL applications in Germany, Netherlands, UK and other countries in Europe [14-16].

Bertini evaluated the VSL strategy used at Autobahn 5 in Germany using the empirical data, the result showed that the effectiveness of VSL strategy in reducing congestion at bottlenecks was significant [3]. On the other hand, some VSL experiment had been carried out which concluded that VSL experiment had a significant effect in reducing speed variation and the number of shockwaves [8, 10, 12]. Representative researches of Hegyi have shown that the traffic shock wave can be better smoothed by VSL under MPC [9].

The relationship between speed standard deviation and accident rate was modeled. The results show that the speed distribution is more dispersed, the accident rate is higher. The study requires a large number of real-time traffic data, at present these high precision data is difficult to get [18]. Variable speed limits and ramp metering were integrated to ease traffic congestion. Simulation results are very good, but the model is too complex to use in practice. The cooperative strategy simulation analysis was launched by VISSIM based on ramp regulating and dynamic speed control. The results were road traffic capacity increased by 10% and average travel time decreased by 30% [23]. In order to improve the highway traffic efficiency, the control strategy of variable speed limits was designed and the real-time rear-end accident risk of the vehicles was predicted [2].

Based on predictive control, the dynamic accident risk in expressway was quantified and the active intervention was carried out by the means of speed guidance control [6]. These studies were mainly conducted with the perspective of mathematics modeling without considering the complexity of road traffic and the compliance rate of vehicle. Driver obedience for the speed guidance value affected the effect directly. The effect might also lose even play a negative role when the traffic demand reached a certain level [7].

Speed management is currently focusing on variable speed limits. Much more attention should be paid to speed guidance control which is one of the most important methods in the context of active traffic safety which provides a new way to solve the general road traffic problems. Meanwhile, control strategies are based on default rules, not the quantify traffic safety-oriented. VSL control method has essential uncertain characteristics about speed limits value for drivers; they generally choose the driving speed among a range. For example, if the value of VSL is 80km/h, then vehicle speed not exceeding 80km/h is legitimate, maybe 30km/h, 50km/h or 60km/h which will cause the control not precisely enough. This paper focused on speed guidance control which provides the driver with a clear speed value which is the biggest difference compared with others research.

## 3. Dynamic traffic flow model

Control-oriented macro dynamic traffic flow model describes the relationship among traffic flow over space and time even traffic control variables. LW model was proposed by British scholar Lighthill and Whitham in 1955 [11]. Against the defects, Payne proposed dynamic relationship between speed and density [17]. The model was further extended considering off-ramp, on-ramp and lane change factors by Papageorgiou [13]. Scholars between domestic and foreign have also proposed various models which are mostly around dynamic relationship between speed and density. The model proposed by Payne and Papageorgiou is widely used in practice. Second order dynamic METANET model is used to describe the traffic flow. To make the calculated optimal speed guidance value more realistic and accurate, dynamic traffic flow model is described as Equations (1-4).

$$q_i(k) = \rho_i(k) v_i(k) \lambda_i \tag{1}$$

$$\rho_i(k+1) = \rho_i(k) + \frac{\mathrm{T}}{L_i \lambda_i}[q_{i-1}(k) - q_i(k) + r_i(k) - s_i(k)] \tag{2}$$

$$v_i(k+1) = v_i(k) + \frac{\mathrm{T}}{\tau}[v(\rho_i(k)) - v_i(k)] + \frac{\mathrm{T}}{L_i} v_i(k)[v_{i-1}(k) - v_i(k)]$$
$$-\frac{\eta \mathrm{T}}{\tau L_i}[\frac{\rho_{i+1}(k) - \rho_i(k)}{\rho_i(k) + \kappa}] + \frac{\gamma \mathrm{T}}{\tau L_i}[\frac{v_{sg,i+1}(k) - v_{sg,i}(k)}{v_{sg,i}(k)}] \tag{3}$$

$$v(\rho_i(k)) = \min[\mathrm{v_f} \exp[-\frac{1}{\mathrm{a}}(\frac{\rho_i(k)}{\rho_{\mathrm{crit}}})^{\mathrm{a}}], v_{sg,i}(k)] \tag{4}$$

where

$q_i(k)$ is the traffic flow rate that leaving section *i* at time *k*T;
$\rho i(k)$ is the traffic density of section *i* at time *k*T;
$v_i(k)$ is the space mean speed of section *i* at time *k*T;
$r_i(k)$ is the on-ramp inflow of section *i* at time *k*T;
$s_i(k)$ is the off-ramp outflow of section *i* at time *k*T;
$\lambda_i$ is the number of lanes of section *i*;
$L_i$ is the length of section *i*;
$v_{sg,i}(k)$ is the speed guidance value of section *i*; *k* is the simulation time step index;
T is the simulation time step length.
$\tau$, $\eta$, $\gamma$ and a are the model parameters;
$\mathrm{v_f}$, $\rho_{\mathrm{crit}}$ and $\rho_{\mathrm{max}}$ are the free flow speed, the critical density and jam density, respectively.

The volume of section 0 and section 1 are assumed to be calculated by Equations (5-7).

$$q_0(k) = \min[q_{lim,1}(k), d_0(k) + \frac{w_0(k)}{\mathrm{T}}] \tag{5}$$

$$q_{lim,1}(k) = \begin{cases} \mathrm{q_{cap,1}} & ;\text{ if } v_{lim,1}(k) \geq v_0(\rho_{\mathrm{cirt}}) \\ v_{lim,1}(k)\rho_{\mathrm{crit}}[-a\ln(\frac{v_{lim,1}(k)}{\mathrm{v_f}})]^{\frac{1}{\mathrm{a}}} & ;\text{ if } v_{lim,1}(k) < v_0(\rho_{\mathrm{cirt}}) \end{cases} \tag{6}$$

$$v_{lim,1}(k) = \min(v_1(k), v_{sg,1}(k)) \tag{7}$$

where

$q_0(k)$ is the volume of section 0 at time kT;
$d_0(k)$ is the traffic demand;
$w_0(k)$ is the mainline queue length;
$q_{lim,1}(k)$ is the traffic flow under speed guidance control of section 1;
$v_{lim,1}(k)$ is the traffic speed of section 1 under speed guidance control;
$v_0(\rho_{\mathrm{crit}})$ is the is the speed of mainline at which the traffic flow becomes unstable;
$\mathrm{q_{cap,1}}$ is the capacity of section 1.

$$q = \min[\mathrm{Q}_i \frac{\rho_{\mathrm{max}} - \rho_i(k)}{\rho_{\mathrm{max}} - \rho_{\mathrm{crit}}}, d_i(k) + \frac{w_i(k)}{\mathrm{T}}] \tag{8}$$

$$w_i(k+1) = w_i(k) + \mathrm{T}[d_i(k) - q_i(k)] \tag{9}$$

The onramp flow rate is shown in Equation (8) if the road sections contain onramp facilities. Queuing model of ramp entrance and the beginning section of the expressway are shown in Equation (9), where $d_i(k)$ is the on-ramp traffic demand at time kT; $w_i(k)$ is the onramp queue length and $Q_i$is the onramp capacity.

Considering traffic safety, speed change should be smoothing both temporally and spatially. So the control speed variation should be less than 10km/h over time or distance interval, the following constraints are adopted in Equation (10).

$$\overline{V}_{\min} \le u_i(k) \le \overline{V}_{\max} \tag{10}$$

where

$\overline{V}_{\min}$ and $\overline{V}_{\max}$ are the minimum and maximum control speed for speed guidance control respectively; $\overline{V}_{\min}$ taken as 20 km/h and $\overline{V}_{\max}$ taken as 80 km/h.

The macroscopic dynamic traffic flow models which are extended under the traditional model by speed guidance control are listed from Equation (1) to Equation (10). The extended macroscopic dynamic traffic flow model is used as the foundation of model predictive control to improve the operational efficiency and safety level of the urban expressway.

## 4. Model predictive control of speed guidance

Model predictive control is widely used in the field of process control and the three mechanisms are model prediction, rolling optimization and feedback correction [19, 25]. Based on the established system model and the initial state values, the optimal controlling parameters were calculated under performance index for the multiple control cycles of future. The optimal controlling parameters of the current moment would be put into effect. Prediction and control continue at the next moment.

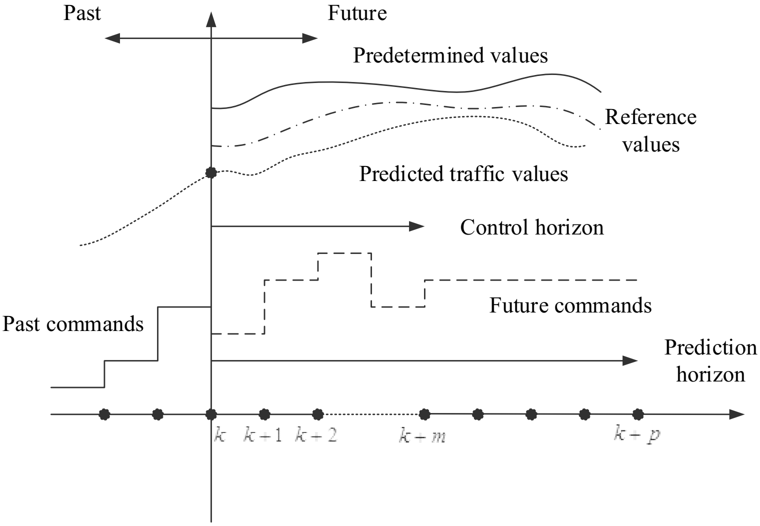

Fig. 1 - Fundamental principle of model predictive control

Model predictive control optimization is a finite period of rolling optimization, at each sampling time, the optimization performance index relates only to a limited future period of time. In the next sampling time, the optimization time goes forward, and the optimization is not offline, but online repeatedly. The principle of model predictive control principle is shown in Figure 1. The parameters $m$ and $p$ are the number of control time periods and predict time periods respectively.

According to the macro dynamic traffic flow model and speed guidance values, future parameters of traffic flow are predicted. The total vehicle cost time and changes of speed guidance values are chosen as the objective function taking into account the traffic safety and road operating efficiency. The current speed guidance values which are the part of optimization results are applied to the traffic control system. During the next control period, the traffic system will update the parameters and continue to roll forward the optimization again. The objective function is shown in Equation (11).

$$F = \mathrm{T}\sum_{k=1}^{\mathrm{N}_2-1}\left\{\sum_{i=1}^{\mathrm{N}_3}\rho_i(k)L_i\lambda_i + w_i(k)\right\} + \beta\sum_{k=1}^{\mathrm{N}_1-1}\sum_{i=1}^{\mathrm{N}_3}(v_{sg,i}(k) - v_{sg,i}(k-1))^2 \tag{11}$$

where

T is the sampling time of macro dynamic traffic flow model;

$k$ is the time interval counter;

$\mathrm{N}_1$ is the control horizon of speed guidance;

$w_i(k)$ is the queue length;

$\mathrm{N}_2$ is the prediction horizon of traffic flow model;

β is the weight for the total changes of speed guidance control;

$\mathrm{N}_3$ is the number of road sections.

The process of speed guidance using model predictive control on a freeway is shown in Figure 2. The control was applied in a rolling horizon scheme. At each time instant a new optimization was performed over the prediction horizon, and only the first value of the resulting control signal was applied to the process. The next time instant the same procedure is repeated. To reduce complexity and improve stability a control horizon was introduced, and after the control horizon has been passed the control signal is taken to be constant. The advantage of this rolling horizon approach was that resulted in an on-line adaptive control scheme which allows us to take changes in the system parameters into account by regularly updating the model of the system.

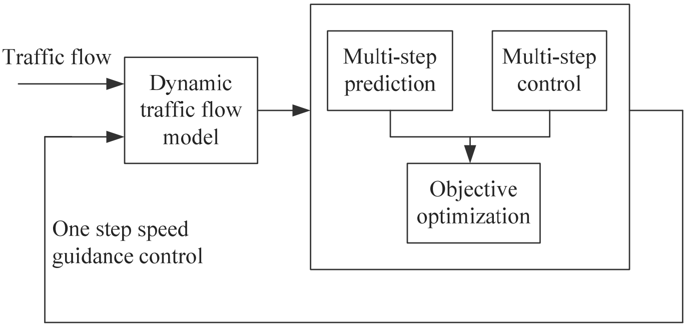

Fig. 2 - Framework of speed guidance optimal control under MPC

## 5. Simulation results

Expressway of 5 km long in Shanghai city was chosen as the simulation example, and the sections of the urban expressway were shown in Figure 3.

The expressway was divided into eight sections and each part has speed guidance control respectively as shown in Figure 4. The cycle of speed guidance control was 1 min, so the traffic flow model iteration number was 6. Then control step size was 42 and prediction step size was 60. The simulation time is 90 minutes. The eighth section of the expressway is used to simulate the sudden change of the downstream traffic flow.

Considering the practical application, the maximum and minimum value of speed guidance are 80 km·h$^{-1}$ and 20 km·h$^{-1}$ respectively. The value of speed guidance is also an integer multiple of 10 km·h$^{-1}$. On the other hand, the difference of speed guidance value between adjacent time periods and adjacent road sections is less than 10 km·h$^{-1}$ because of security constraints. The results of speed guidance control and expressway simulation are shown in Figures (5-7).

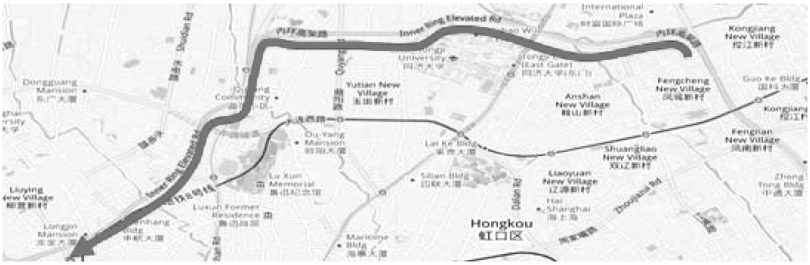

Fig. 3 - Map of the urban expressway

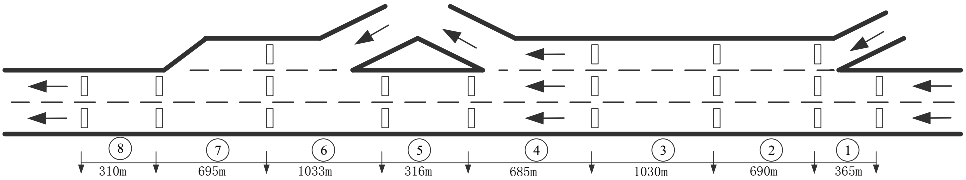

Fig. 4 - Abstract figure of urban expressway

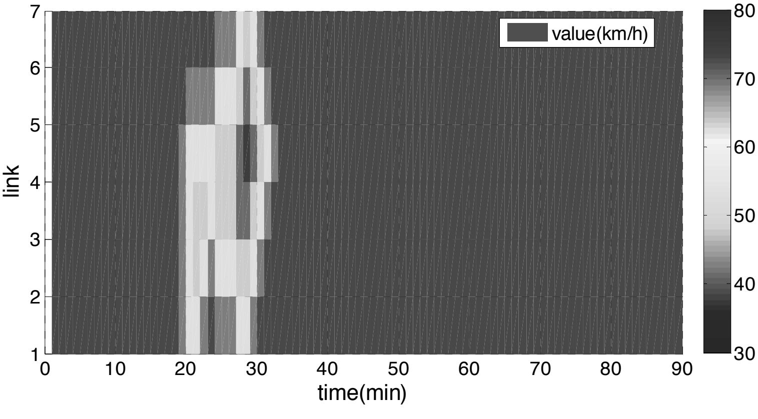

Fig. 5 - Speed guidance value

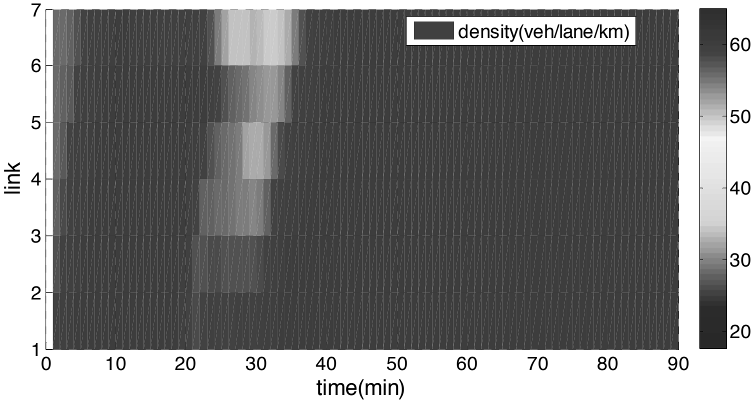

Fig. 6 - Evolution of the density

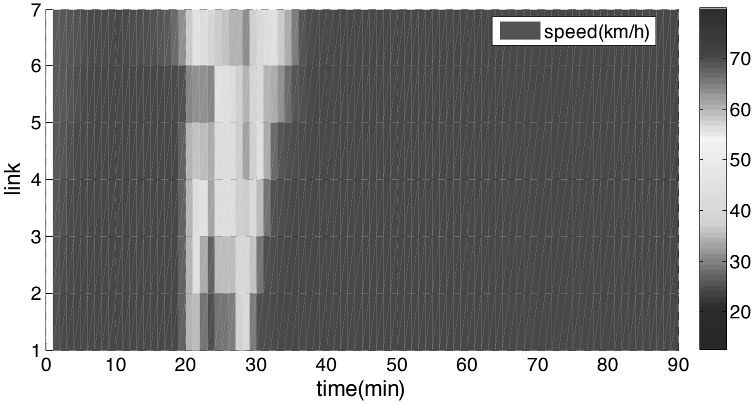

Fig. 7 - Evolution of the speed

## 6. Conclusions

Based on the expansion of urban expressway macro dynamic traffic flow model, the model predictive method was adopted to manage the vehicle speed under speed guidance control using the concept of active traffic management.

The simulation analysis was carried out in VISSIM on a real urban expressway. The simulation results show that the effect of speed guidance under model predictive control is significant. The efficiency and safety level of expressway are improved which can provide theoretical support for the construction of active traffic management system.

However, the gradient difference of speed guidance value is 10 km·h$^{-1}$ which cannot be able to capture the variability of traffic flow in practical applications.

Therefore, the quantitative security analysis model is needed; besides, the research is limited to hypothesis condition because of the reason of time and the lack of the roof in practice, which will be continued in the further study.

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# Research on type dividing of school zones in Beijing based on speed characteristics analysis

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**Abstract**

Measures of traffic organization and traffic management in school zones, key protection areas for traffic safety, have been increasingly discussed by government administrations at all levels and researchers as well. Juveniles' trips occur frequently near school areas, especially in primary and secondary school zones. The sensitive topic of these vulnerable road users encountering traffic accidents tends to draw the whole society's attention. In this regard, the paper analyzed different traffic characteristics of 20 primary school zones in Beijing. With the starting point of traffic safety in the area, the paper divided these school zones by type, which was then verified preliminarily reliable and proper, by means of field measurement and driving simulation test, with speed characteristics as the major basis for judgment. By doing this, the authors look forward to providing a theoretical basis for carrying out measures of traffic organization and traffic management.

*Keywords – traffic engineering, school zone, type division, speed characteristics, field study, driving simulation test*

## 1. Introduction

Recently, along with the rapid economic development in Beijing, capital of China, the number of cars in the locality has already reached 5.3 million. The boom in its peak-hour traffic volume in school zones has posed an increasingly prominent problem of traffic management and traffic safety. Traffic safety in school areas is bound up with life safety of students and school staff, as well as school security order and its security and stability. Taking a road accident in Beijing as an example, 24 pedestrians were involved in a van crash near the gate of Machangying Central School, Pinggu District, at 7am (the rush hour) on June 2, 2011, causing 3 deaths and 21 injured. Except for 2 passersby, the casualties were all students in that school. Such disaster leads to noteworthy social influence. Therefore, to build up harmonious schools, it is necessary to pay attention to traffic safety around school zones. According to some studies, there are several causes to traffic accidents near school zones, including pick-up-induced road congestion during rush hours [1], underdeveloped traffic calming devices in school speed zones (the predominant cause) [2], and lack of traffic safety awareness for primary and secondary school students [3].

In this connection, what traffic calming facilities should be set for schools of different types? Is it necessary for various kinds of schools to have the same traffic calming devices? Considering diversified road traffic conditions and ambient situations for different school zones, the traffic safety devices demanded for them are supposed to differentiate from each other. However, there has been no clear-cut article in any rules or laws in China concerning the standard of traffic safety devices near different types of school zones. Even the mere regulation of uniform traffic signs and lines in school speed zones lacks details, leaving alone its poor pertinence and operability [4]. Accordingly, local standards of traffic safety devices near different types of school zones bloom across the country. For instance, in 2010, based on real conditions in the province, Zhejiang Municipal Public Security Bureau regulated uniform traffic signs and lines, as well as crossing safety devices within the range of 150m from school entrances and exits [5]. In the same year, Shenzhen Traffic Management Bureau specified the norm of road safety facilities around school zones, in which it is required for all stretches of school roads to have yellow squares, speed bumps, and corresponding signs. Despite the fact that such traffic calming norms, either national or local, are intended to safeguard traffic near school zones, they are too general to detail traffic calming devices adaptable to school zones of different types. By contrast, American counterparts are specific and operable. Section 7 of the national Manual on Uniform Traffic Control Devices (MUTCD), the authoritative norm for traffic safety device in America, stipulates traffic control devices near school zones [6], including corresponding general requirements, sign installation, relevant index design standards, and the definition of school zone. After fully taking into account traffic environment in roads around schools, MUTCD regulates traffic control devices in school areas, and further creates a traffic control device system with school characteristics. This manual is instructional to installation of road calming devices in school zones across America.

Due to discrepancies of traffic cultures and driving habits between China and any foreign country, foreign traffic safety standards, more mature though, are not completely adaptive to China. Therefore, the paper conducted preliminary studies on school types, in order to fill in gaps of school zone type classification. First, the characteristics of road conditions and ambient situations near school zones were obtained through field measurement. Then, starting mainly from traffic safety in school areas, school conditions were analysed comprehensively, which was followed by type classification of primary and secondary school zones in Beijing. Finally, with speed characteristics as evaluation indices, the paper used field test and driving simulation test to verify the correctness and reasonability of the proposed school zone type division. The research result is expected to provide theoretical basis for engineering practice, to lay foundation on setting targeted traffic safety devices near school zones of various kinds, and to improve traffic safety near school areas accordingly.

## 2. Division of school zone types

The investigation directed at primary schools in Beijing, and thus selected 20 such schools as its objective. According to such criteria as road conditions and ambient situations near school zones, existing traffic safety devices in front of school gates, traffic flow conditions, and major traffic modes during rush hours, the 20 schools were divided into two categories: roadside schools (Type A, the same below), and schools in residential areas (Type B, the same below). Below are their respective characteristics.

### *2.1. Characteristics of Type A*

Figure 1 is the diagram of a typical roadside school, whose features are:

a. Mainly located at the roadside of freeways, trunk roads, or sub-arterial roads in urban areas
b. High-speed motor vehicles predominate the traffic types in front of school gates, thus raising high demands for traffic safety.

c. The parking demand for motorists is mainly temporary parking. Motorists stay in the cab, keep the engine running, and drive the vehicle away upon dropping occupants off.
d. The road in front of the school is so wide, mainly in the form of dual carriageway, that motor vehicles and non-motor vehicles can be effectively separated by a single yellow line, for example.
e. With few traffic nodes. Students that are concentrated near traffic nodes during peak hours are linearly distributed, with few crossing demands.
f. It is safer for students to commute along pedestrian bridges and pedestrian subways; as a comparison, it is potentially danger for students to cross streets along a crosswalk according to traffic signals, in case of collisions with running vehicles.

### *2.2. Characteristics of Type B*

Figure 2 is the diagram of a typical school in a residential area, whose features are:

a. Mainly located on branch roads or in a residential area
b. Low-speed non-motor vehicles and pedestrians predominate the traffic types in front of school gates, thus raising low demands for traffic safety.
c. The parking time demand for motorists is relative long (over 5 minutes in general). Motorists turn off the engine, get off the vehicle, and walk occupants to school before driving away.

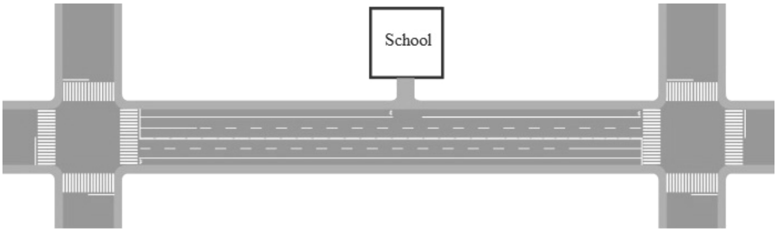

Fig. 1 - Roadside schools

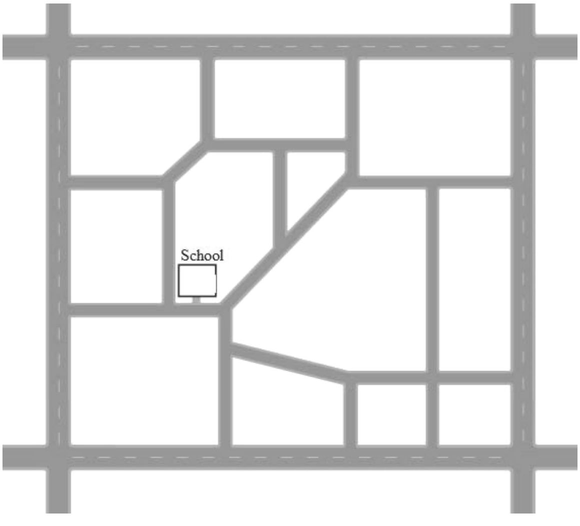

Fig. 2 - A school in a residential area

d. The road in front of the school is so narrow, mainly in the form of single carriageway, that blending the running of motor vehicles and non-motor vehicles. In addition, there are many cars parked roadside for a long time, which occupy the road.
e. With a large number of scattered traffic nodes. Students that are in a planar distribution among different traffic nodes during peak hours have high crossing demands.
f. Students cross streets directly or along a crosswalk according to traffic signals, thus tending to collide with running vehicles.

Speed is one of the major factors for people to consider in choosing routes and modes of transport. Motor vehicles running near school zones with overly high velocity will endanger traffic safety in the locality, because speeding can weaken motorists' capability of identifying road conditions, prolong braking distances, and potentially lead to serious accidents especially when primary and secondary school students appear suddenly in front of the running vehicle, which is one of their frequently unexpected behaviours. Too high speed will result in grave road accidents [8]. Research shows that speeding is an important cause to traffic accidents in school areas. The faster a car runs, the severer the accident that it may cause is [9]. Given this, according to the noted traffic characteristics of Type A and Type B, the paper took comprehensive consideration of traffic safety for the two types, and selected speed characteristics as the predominant evaluation indices for school zone type classification. By means of field measurement and driving simulation test, the speed data of motor vehicles for both types were acquired. Through significance analysis of speed differences between these types, the proposed classification method in the paper was verified effective. Guangming Primary School (as Type A) and Fangcaodi Primary School (as Type B) in Beijing were selected as examples of case study in the research, which lay at the roadside of a trunk road and of a branch road, respectively.

## 3. Verification by field measurement

### *3.1. Test and analysis of mean interval speed*

Mean interval speed is the average travel distance per unit time among all motor vehicles running in a specific stretch of road for a given duration. It reflects the concentration degree of speed data for a group of vehicles of the same property, and represents the travel speed in that road. The mean interval speed is able to summarize the characteristics of interval speed data [11]. Thus, the mean interval speed was chosen as an evaluation index in the paper, for which it was defined that the effective interval (represented by $S$) for a traffic safety device to function began at the first traffic sign of "School Ahead" and ended at the road section just in front of the school gate. The license plate method was used for the test. $T_1$ denoted the moment when a measured car passed through the first traffic sign of "School Ahead", and $T_2$ represented the moment for that car passing through the road section just in front of the school gate. The interval speed of that car was calculated by Equation 1.

$$V=S/(T_2-T_1) \tag{1}$$

where $V$ means the mean interval speed(km/h); $S$ means the effective interval for a traffic safety device to function began at the first traffic sign of "School Ahead" and ended at the road section just in front of the school gate; $T_1$ denoted the moment when a measured car passed through the first traffic sign of "School Ahead", and $T_2$ represented the moment for that car passing through the road section just in front of the school gate.

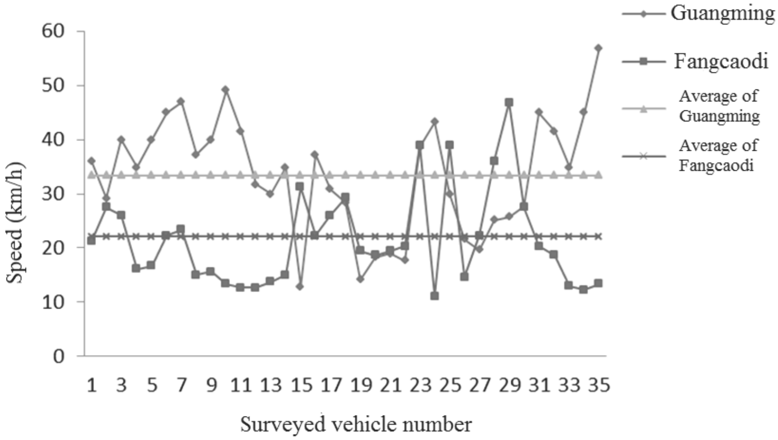

Fig. 3 - The in-situ interval speed

### *3.2. Analysis of in-situ interval speed data*

The two line segments in Figure 3 are the in-situ mean interval speeds in Type A zone and Type B zone, respectively, while the two curves represent the different measured interval speeds for the school examples. As can be seen from Figure 3, the interval speed in Guangming Primary School zone remarkably exceeds that in Fangcaodi Primary School zone. After averaging, the obtained mean interval speed in Guangming Primary School zone is 32.84 km/h, much higher than the obtained one of 22.09 km/h in Fangcaodi Primary School zone.

Anova was conducted on the interval speeds for both school examples. The corresponding result showed that $F=46.6$ and $p<=0.001$, which meant there were significance differences between the interval speeds for both school examples. Therefore, in light of speed characteristics, the proposed classification method in the paper was verified correct.

The collected speed data through field measurement may be disturbed by factors of objective environments or non-measured vehicles. Therefore, to better control research conditions during correctness verification, the paper gathered velocity data through driving simulation test. Switch of various factors such as traffic safety devices and ambient conditions are easy to achieve with driving simulators. What’s more, this test is free from multi-factor interactions, and can produce high-precision, fine-grained driving behaviour data to the advantage of refined data analysis.

## 4. Driving simulation test

### *4.1. Test equipment*

As a real driving simulator, the driving simulator platform employed for this test provided drivers with 130° horizontal vision and 40° vertical vision in front, as well as 30° horizontal vision and 40° vertical vision against left rear-view mirror, right rear-view mirror, and in the rear, respectively. As a way to reflect the precise driving action of a driving respondent, the driving simulator recorded parameters of the running vehicle itself at the frequency of 30 HZ, including velocity, acceleration, sway displacement, accelerator, brake, turn angle of steering wheel, clutch, and vehicle coordination. It also recorded the parameters of other running vehicles near the tested one at the same frequency. Figure 4 is the system of the driving simulation test.