Research on Speed Limit Value Model and Evaluation Method of Urban Trunk Road

Xin-wei LI¹ and Xiao-fei WANG² *

¹Guangzhou Expressway Co. LTD., Guangzhou, China, 510288
²School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, China, 510640

*Corresponding author

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Abstract. To reduce the probability or severity of traffic accidents, improve traffic capacity of road, and ensure efficient operation of traffic flow, speed limits have become an important traffic management method of urban truck road. Based on detailed analysis of the current method of determining the speed limit, multifactorial method of determining and evaluating speed limit is proposed. Firstly, considering the safety speed of linear and steady flow, determining the reference value, and the influence of the number of entrances and exits, road width, roadside disturbance, and road conditions are set as correction factors. Then the model of determining the speed limit value is established. Speed scatter and ratio of maximum-minimum of car-truck are put forward as elevation index. At last, a project example is provided to prove the method.

Introduction

Domestic agencies have not yet established unified and authoritative method for determining the speed limit of highways and urban roads. Usually, design speed is used as the basic value of speed limit, and which has a reduction of 10km/h or 20km/h for special road sections. However, for increasing requirements on safety and efficiency, more reasonable speed limit value is required. The researches on the theory of speed limit in recent years, there are some methods at home and abroad: ① Regulatory speed limit value [1]. ② Optimum speed limit. ③ V₈₅% speed.

There are some limitations: ① Regulatory speed limit value only does simple rules on certain sections and is lack of scientific basis. ② Optimum speed is a scientific method, but the urban traffic factors bring great difficulties to the calculation of the best speed limit model. ③ 85% speed, as a basis for the speed limit is more practical in the traffic management, which is also difficult to predict when the surrounding environment and the exit-entrance of the road have a large impact on urban traffic.

Thus, considering merit and demerit of above methods, research on urban arterial road speed limit value determination model and evaluation method will provide theoretical foundation to determine speed limit value in China.

Speed Limit Model Based on Multi-factors

For urban speed limit is restricted by many factors, the determination of speed limit is divided into 2 parts: the base value and the correction value. The base value is the speed limit in the ideal driving environment that the driving is only affected by alignment factors under the condition of stable traffic flow. The correction value is defined as a difference between the speed corresponding to specific roads and traffic conditions and the speed in the ideal condition, influenced by multi factors including the exit-entrance amount, the average width of the lane, the interference degree from wayside and the surface of the road. Therefore, the speed limit model of urban trunk road is defined as:
\[ V_{\text{SL}} = V_B + \sum_{i=1}^{N} VMF_i \]  

where:  
\( V_{\text{SL}} \) is speed limit value,  
\( V_B \) is base value and  
\( VMF_i \) is correction value.

**Determination of Base Value**

Safety, efficiency, economy and comfort can be achieved by the reasonable speed limit. To determine the base value, actual road alignment and safe speed under free traffic flow are mainly considered \[2\] [3]. The base value can be expressed as

\[ V_B = \min \{ V_{\text{Alignment}}, V_{\text{Stabletraffic}} \} \]  

where:  
\( V_{\text{Alignment}} \) is maximum safe speed according to the alignment and  
\( V_{\text{Stabletraffic}} \) is maximum safe speed under free traffic flow.

1. **Safe speed determined by alignment**  
\( V_{\text{Alignment}} \)

Different safe speeds can be maintained when vehicles are driving on different trunk roads with the same alignment design standard or different sections of the same road. According to parameters of the straight-line length, radius of circular curve, longitudinal gradient, and slope length, safe speed is calculated. Then:

\[ V_{\text{Alignment}} = \min \{ V_s, V_r, V_i \} \]  

1. Safe speed at maximum and minimum length of the straight road  
\( V_s \)

To avoid the reverse curve illusion of straight lines between curves, the minimum length of the straight line between the same direction curves should be limited. With the greater speed limit value, the longer straight length is required. The smallest straight line between the same direction curves within speed limit sections can be noted as  \( S_{\text{syntropy}} \) (in meters), that the minimum length (in meters) is approximately 6 times of driving speed (km/h) numerically \[4\]. To ultra-high or widening transition sections, the minimum length between curves (\( S_{\text{reverse}} \)) (in meters) is approximately 2 times of driving speed (km/h). Then:

\[ V_s \leq S_{\text{syntropy}} / 6 \quad \text{and} \quad V_s \leq S_{\text{reverse}} / 2 \]  

2. Safe speed at horizontal curve  
\( V_r \)

The influence of the radius of curves on driving safety are reflected in the centrifugal force. With certain ultra-high and radius, the safety speed should meet the following condition \[4\]:

\[ V_r \leq \sqrt{127R(\mu \pm i_b)} \]  

where:  
\( \mu \) is Lateral force coefficient, and  
\( i_b \) is ultra-high slope.

According to domestic characteristics of vehicles,  \( \mu = 0.067 \) \[4\]. The value of ultra-high can be set \[4\].

3. Safe speed at longitudinal gradient and slope length  
\( V_i \)

The influence of longitudinal grade and slope length on safe driving is mainly reflected in the climbing performance. Safe speeds under different longitudinal grade conditions are shown in table 1.

4. Safe speed at stable traffic flow  
\( V_{\text{Stabletraffic}} \)

18 months of coil flow data and speeding data belonging to 11 trunk roads are analyzed. When the speeding situation is worst, the corresponding traffic density is between 0 ~10veh/km, that the traffic flow is free or stable. Considering the most unfavorable situation, the safe speed is discussed, that traffic density is 10veh/km, and vehicles have obvious following characteristics. The following
driving model has been analyzed by recent researchers [5][6], and the relationship among speed, speed difference and traffic flow density has been established as following:

Table 1. Safe speed at Certain Grade and Slope Lengths.

<table>
<thead>
<tr>
<th>Slope length</th>
<th>The maximum value of safe speed(km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>i = 3%</td>
<td>900 950 1000 1050 1100 1200 1300</td>
</tr>
<tr>
<td>i = 4%</td>
<td>700 750 800 850 900 950 1000 1000</td>
</tr>
<tr>
<td>i = 5%</td>
<td>600 700 800 800 800 800 800 800</td>
</tr>
<tr>
<td>i = 6%</td>
<td>400 350 600 600</td>
</tr>
<tr>
<td>i = 6.5%</td>
<td>350 300 300 300</td>
</tr>
</tbody>
</table>

\[ v_{\text{stable}} \leq \frac{6000/k - 72 + \Delta V^2}{13.2 + 2\Delta V} \]  
(6)

where: \( k \) is traffic density (vel/km) and \( \Delta V \) is speed difference between two vehicles.

**Correction Value**

The Exit & entrance amount, average lane width, roadside disturbance, and road surface condition are the impact factors on speed limit.

1. **Exit & entrance amount Correction**

The influence of exit & entrance amount on driving speed was acquired by VISSIM simulation test. The trunk road in the test has two-way four lanes with plane intersections. The vehicle type is simplified as a bus and data acquisition device is arranged within the range of 100m before and after each entrance to collect speed data. In this simulation, exit-entrance amount of arterial road with design speed of 60 km/h ranges from 1 to 4. The results of the simulation are shown in Figure 1. With the increase of the entrance & exit density, the traffic flow showed a significant turbulence, and thus the correction value of the entrance quantity is determined in Table 2.

![Figure 1. The number of exit&entrance effect on driving speed simulation.](image)

Table 2. Exit & entrance amount correction.

<table>
<thead>
<tr>
<th>Exit-entrance amount (per km)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMF₁(km/h) of different design speed</td>
<td>60km/h</td>
<td>0</td>
<td>-8</td>
<td>-9</td>
<td>-9</td>
<td>-1</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td>50km/h</td>
<td>0</td>
<td>-5</td>
<td>-5</td>
<td>-5</td>
<td>-6</td>
<td>-6</td>
<td>-6</td>
<td>-6</td>
</tr>
<tr>
<td>40km/h</td>
<td>0</td>
<td>-2</td>
<td>-2</td>
<td>-3</td>
<td>-3</td>
<td>-4</td>
<td>-4</td>
<td>-4</td>
</tr>
</tbody>
</table>

2. **Average lane width correction VMF₂**

Based on the influence of the average width of lane on operating speed prediction [6][7], the following correction value can be obtained:
Table 3. Average lane width correction

<table>
<thead>
<tr>
<th>Average lane width (m)</th>
<th>3.0</th>
<th>3.25</th>
<th>3.5</th>
<th>3.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMF₂ (km/h)</td>
<td>-7.0</td>
<td>-5.0</td>
<td>-3.0</td>
<td>0</td>
</tr>
</tbody>
</table>

③ Roadside interference correction VMF₃

Compared with other roads, urban road has prominent feature that there are wayside traffic problems. Increasing demand for road facilities by pedestrians, bicycles, and slow-vehicle traffic, etc. The interference of traffic on the main line traffic seriously affects the road speed, service quality and traffic safety. The roadside disturbance intensity index (FRIC [8]) was used to calculate the correction value. Through the qualitative classification of wayside interference intensity and considering the conditions of the land on both sides of urban roads, correction values shown in table 4.

Table 4. Roadside interference correction

<table>
<thead>
<tr>
<th>Level</th>
<th>Intensity</th>
<th>Conditions of the land on both sides of urban roads</th>
<th>VMF₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0-50</td>
<td>Both sides are blocked</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>50-100</td>
<td>There are a few pedestrians</td>
<td>9.0</td>
</tr>
<tr>
<td>2</td>
<td>100-150</td>
<td>There are a few pedestrians, vehicles, gas stations and small shops</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>&gt;150</td>
<td>There are many pedestrians, vehicles, along with residential, commercial centers and schools</td>
<td>27</td>
</tr>
</tbody>
</table>

④ Road surface correction VMF₄

According to Satish’s research results [8], there is a certain relationship between road roughness and vehicle speed. The smoothness index IRI is selected as the basis for the classification of road surface conditions. The reduction of speed will be:

\[ VMF₄ = V_{ff} \times 1.9 \times IRI / 50 \] (7)

where: \( V_{ff} \) is driving speed at free traffic flow

Speed Limit Assessment

The speed limit values from the model still need further safety assessment. A specific road has a simulation analysis based on the situations of the specific sections and traffic facilities. The speed data can be extracted and assessed. Finally, the speed limit value can be determined.

Speed Discreteness Indicator

In the statistical time interval, there are \( n \) vehicles passing through the observation site and the velocity data of the vehicle passing the observation site are recorded. Then, speed discreteness (SD) defined by standard deviation is calculated:

\[ SD = \sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (v_i - \bar{v})^2} \] (8)

where: \( v_i \) is speed value of a vehicle (callout ‘i’) and \( \bar{v} \) is average speed.

As early as 1964, Solomon made research on the relationship of accident and vehicle speed and found that it can be expressed by a ‘U’ shaped curve. It can be expressed as:

\[ I = 10^{0.000062} \Delta V^2 - 0.00675 \Delta V + 2.23 \]

where: \( I \) is accident rate (per 105veh·km) and \( \Delta V \) is speed difference which is the difference between running speed and average speed (km/h).

There is an obvious exponential relationship between the standard deviation of the speed of the vehicle and the accident rate. Greater speed discreteness, the higher the accident rate. The tolerance
value of speed discreteness SD=25km/h is used as the evaluation threshold. When speed discreteness is higher than the threshold, the speed limit value should be re-adjusted.

**Ratio of Maximum-Minimum of Car- Truck**

The relationship of safety and variation of difference between car and truck is analyzed preliminarily by extracting the maximum and the average of difference of car-truck. Furthermore, considering the maximum and the average do not reflect the discreteness of car-truck’s difference, ratio of maximum-minimum of car-truck is calculated as:

\[
M = \frac{\max(m_i) - \min(m_i)}{\bar{m}}
\]

(9)

where M is ratio of maximum-minimum of car-truck, \(m_i\) is difference (km/h) between the maximum and the minimum for each section, \(\bar{m}\) is average difference (km/h) for each section.

Based on the results of researches [5][9][10][11][12], the ratio of maximum-minimum of car-truck can be set to \(M=0.2\) as a threshold of the assessment of expressway car-truck velocity dispersion. When the ratio of maximum-minimum of car-truck is higher than the threshold, the speed limit value should be reset. On the other hand, measures of speed limit on different types of vehicles and lanes can be taken and then the process of speed limit should be re-evaluated.

**Example Analysis**

An urban trunk road is selected as an example, the length 8.1Km, design speed 60km/h, road width 40~44 meters, two-way and 8~10 lanes, both sides have bus lanes. The section from \(k0+000\)~\(k3+000\) is analyzed.

Step 1: Determine the speed limit base value

The alignment can meet the requirement of \(V_{\text{Alignment}}=120\)km/h which is in good shape. Video recognition technology is used to extract the running speed of vehicles. According to Equation 2, the maximum safe speed is 109km/h.

Step 2: Determine the speed limit correction value

There are 4 intersections within \(K0+000\)~\(K1+000\), 6 intersections within \(K1+000\)~\(K2+000\) and 5 intersections within \(K2+000\)~\(K3+000\). The correction value (VMF1) is -10km/h. A lane width is 3.5m and the correction value of lane width (VMF2) is -3km/h. The interference from wayside is serious which interference degree is Level 3. Thus, VMF3 is -29km/h. The surface of road is in good condition and VMF4 is 0km/h.

Step 3: Calculate the speed limit value

\[
V_{\text{Sl}} = V_b + \sum_{i=1}^{4} VMF_i = 109 - 10 - 3 - 29 = 67\text{km/h}
\]

Thus, speed limit value can be 70km/h.

Step 4: Assessment

The evaluation index is acquired from the simulation analysis, which is based on the actual road and traffic situations. The speed limit value is set on a section and vehicles’ running speed at the corresponding acquisition points is recorded. Then the speed scatter and the ratio of maximum-minimum of car-truck are calculated. The simulation experiment shows that speed limit value as 70km/h can meet the requirements of the assessment indicators.

**Conclusions**

Speed limit, as one of main methods of traffic management, plays an important role of reducing the probability and the severity of traffic accident. In addition, the capacity and efficiency of traffic flow can be effectively improved. However, there are current limitations in speed limit research and practical application. According to the characteristics of urban traffic, a theory is proposed that speed value only affected by the road alignment when traffic flow is stable can be taken as speed
limit base value. And with comprehensively considering multiple factors such as exit&entrance
amount, average lane width, roadside disturbance and road surface condition, the speed limit model
can be set to determine the correction value. At the meantime, the speed discreteness and the ratio
of maximum-minimum of car-truck can also be calculated. At last, an example is analyzed to
provide a basis for the design of speed limit on urban road and verify the rationality and feasibility.

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Reference
Committee of the National People's Congress, 2011
the People's Republic of China, 2009
Communications of the People’s Republic of China, 2017
[4] CJJ 37-2012, Code for design of urban road engineering[S].Beijing, Ministry of Housing and
Urban-Rural Development, 2016
[6] Kang Liuqing, Research on Speed Limit on Urban Street[D], South China University of
Technology, 2015
Beijing, China Communication Press. 2010
[8] Satish Chandra Effect of Road Roughness on Capacity of Two- Lane Roads Journal of
[10]Li Wenbin, Sun Chao, Shao Yuan, Research on Urban Road Speed Management for Traffic
Administration
Relationship between Posted Speed Limit and Operating Speed in Urban Expressways [J]. Journal