Speed regulation of motor vehicles has widely affected the living environment and standard of residents in urban areas. It is believed that lower speed of motor vehicles could decrease the traffic accident rate on roads. However, lower speeds may cause many problems indirectly to social development and the health of residents. The average speed of motor vehicles in urban areas in China may be among the lowest in the world due to its mixed traffic environment and vehicle properties. In most central areas of large Chinese cities, the average speed of motor vehicles has been lower than 25km/h. However, this does not mean a safer system for transportation. For example, the death toll of transportation systems in China has exceeded 70,000 every year and is among the highest in the world.

This paper analyses the general situation of various speed regulations on motor vehicles in China. A brief review on the relationship between speed and safety on urban transport has been described. Authors believe that the most important factor to menace transport safety is the coordination of motor vehicles with bicycles and pedestrians especially in urban areas. A quantitative assessment on indirect effects of speed regulation has then been discussed. The assessment covers four aspects. Firstly, it estimates the additional emissions resulted from speed regulation. Secondly, it calculates the contribution to road traffic density of extra stay of vehicles caused by speed change. Thirdly, it analyses the change of passenger journey time caused by speed regulation in urban areas. Finally, the paper calculates the energy consumption of vehicles related to speed regulation.

The paper also discusses the policy on speed regulation from viewpoint of sustainable development of urban society. It concludes that higher speed of motor vehicles is of better sustainability in the current situation of Chinese urban areas. Some suggestions on speed regulation for different situations in China have also been presented.

The research has been part of the project funded by the Natural Science Foundation of China (No. 70173014) and the Royal Society of UK.

1.1 History of speed regulation

The phrase “speed kills” has been well known as a slogan and also supported by many researchers. The early framework for speed regulation was developed in the 1920s and 1930s in USA (TRB Special Report 254). The national speed limit of 55mph was legislated in 1974 due to the energy crisis between 1973 and 1974, which resulted in a decline in freeway deaths per mile driven. However, in 1987 the 55mph limit was relaxed when the Surface Transportation and Uniform Relocation Assistance Act allowed individual states to raise their speed limits to 65mph on rural freeways. Many studies on the effects of increased speed limit to fatal accidents have been carried out since then. Gallagher et al. and Brown et al. analysed the cause of fatalities in traffic accidents and reported an 18% increase in fatal accidents in Alabama and 93% in New Mexico in the USA respectively. However, the studies by McKnight and Klein showed a 27% increase on 65mph highways and also a 10% increase in fatal accidents on 55mph highways in those states where the speed limits remained unchanged. Lave and Elias even reported that the higher speed limit resulted in fewer fatalities. Due to these various findings, a question on whether the increased fatal accidents were purely and simply caused by the higher speed limit or a combination with other factors (such as increase in traffic volume, change of driving behaviours, etc.) remains unanswered. The National Highway Traffic Safety Administration concluded that the speed limit increase was responsible for a 30% increase in rural freeway fatalities in these states that adopted the higher speed limit.

All opponents to higher speed limits, such as Kaye, Mulrine and Wu, have drawn on the “speed kills” hypothesis that assumes that higher speed reduces the amount of time a driver responds to an emergent event. However, speed regulation also relates to many social aspects including safety, journey time, energy efficiency, etc. The findings from research evaluating higher speed limits did not provide a clear indication as to which of these limits best describes the experience of the states. Recently, the American government revised its policy relating to the national speed limit and gave individual states the power to set their own speed limits. In 1987,
there were 39 states that adopted a 65mph speed limit. By the end of 1995, this number increased to 45. By the end of 1997, there were 27 states that raised their speed limits to at least 70mph.

1.2 Speed regulation in urban transport

In fact, different transport systems should have their own speed regulations due to the great variety in speed. For example, Andre et al. found that the average speeds under urban driving conditions varied from very low values to about 60km/h. Road speeds range between 20 and 110km/h. Motorway speeds vary from 70 to more than 130km/h.

In the urban areas of Edina, Minnesota, the speed limit is 48km/h whereas in the urban areas of Berlin the speed limit is set as 30km/h.

The research by Australia came to the following conclusions (Australia Bureau of Road Transport, “Children and Road Accidents”, 1985).

* The higher the speed limit is, and the more drivers blame pedestrians and cyclists for traffic crashes;
* At marked crossings drivers behave surprisingly rudely;
* The understanding of traffic behaviours can only be gained from experiences. Young children have no experience and little safety education.

The experiences in Paris show that the average speed of buses is as low as 10km/h when mixed with the general traffic. Speed may be 2km/h higher on special bus-only lanes with less disturbances.

Cohen, Harry et al. warned that higher speed may lead to more trips and consequently require more roads to be built. He studied the elasticity of vehicle travel with respect to travel time and estimated that total vehicle travel could decline by 2% in the short term and up to 10% over a long term if average travel speeds are reduced by 10%. The speed limit has been used as one of the measurements to reduce traffic volume. However, it needs more studies to specify the appropriateness of speed regulation at various areas.

1.3 Methodology

This paper reviews the variation of vehicle speeds in the urban areas in China. It analyses the appropriateness of speed regulation from the viewpoint of sustainable urban transport systems. A quantitative evaluation, including road capacity, total journey time, energy consumption and pollutants, has been carried out using Beijing as a case study. Finally the paper discusses the necessity of keeping appropriate speeds for motor vehicles, especially public vehicles, in the Chinese urban areas as well as the suggestions to improve road safety in urban transport operations.

Many Chinese cities have rapidly expanded and new cities have been formed during the last two decades as a result of the nationwide economic reform. By the end of 1999, the total number of cities in China reached 667 with the non-agricultural population of 260.2 million, which is equal to 28% of the total population in China. Among these cities, there are 37 with more than 1 million people. Issues resulting from urban transport such as traffic jam and air pollution attracted wide attention of citizens and experts. A study in road capacity in 41 big cities showed that 88% of the cities had insufficient capacity and 49% suffered from severe problems such as traffic congestion. In Shanghai, there were more than 7 million bicycles in 2000, equivalent to 1 million motor vehicles. The speed of public transport vehicles has been reduced to less than 8km/h in the central urban areas at peak times, which is lower than that of bicycles. Survey shows that 90% of residents believe that the traffic deterioration was caused by excessive motor vehicles.

Statistics from Beijing showed that the average speed of public transport declined from 16.7km/h in 1990 to 9.2km/h in 1996, its punctuality (i.e., the percentage of buses that arrive at their final stations on time as scheduled) was reduced from 70% down to 8.4%. There are 53 restriction points in the central urban areas of the city. Public transport services on more than 1,000 routes had to be cancelled due to traffic jams. The average journey time of passengers by public transport modes had increased by 22 minutes. Currently, public transport, including trolley buses and subways, shares 40% of total trips excluding pedestrian trips.

Main roads in the central business districts in Shanghai are saturated with traffic. The average speed was 23.5km/h for all road traffic and 12km/h for public transport at the beginning of the 1990s. In 1997, public transport shared only 36% of total trips. The total number of motor vehicles exceeded 0.7 million in 1999.

In Xi’an, there are more than 7 million residents, 0.3 million motor vehicles and 2.6 million bicycles. The average speed of motor vehicles in the central urban area was lowered to 10km/h at peak hours. The average speed
of public transport declined to 8–9km/h and its punctuality was reduced from 78% to less than 15%. The average delay of public bus routes was 12 minutes, which increased passengers’ journey time by 20 minutes.

Table 1 lists the operational data of public transport in part of Chinese cities during the 1990s\(^\text{14}\). The average speed here refers to the speed between the first and the last stations, including dwell time between all middle stations.

It is easy to see that the average speed of road public transport in all the cities was lower than 20km/h. This situation greatly depressed the attraction of public transport and as a result, more and more people tend to use private cars, which would lead to more severe traffic congestion in urban streets. The unacceptable travel speed in urban areas has become an important issue that the government, residents and passengers are concerned about.

### 3.1 Speed and safety

The most important issue for speed regulation is safety on which higher speed would impact. As mentioned earlier, the mechanism of impact of speed on pedestrians/residents is complicated. Limpert\(^\text{15}\) showed that the severity of pedestrian injury increases with the square of vehicle speed. The percentages of pedestrians suffering from fatal injuries, when hit by motor vehicles, are 3.5% at 15mph, 37% at 31mph and 83% at 44mph respectively.

However, this is not always true elsewhere. For example, in China, the average speed of public vehicles as well as other motor vehicles, though no statistic data available for the latter, in the city areas has been decreasing while traffic accidents are continuously increasing during the past decades as shown in Figure 1. Also, 32.9% of traffic accidents in urban areas were caused by motor vehicles and bicycles as indicated in Figure 2.

![Average Speed of Public Vehicles and Deaths in Traffic Accidents](image)

It is therefore believed that the most important factor to menace transport safety is the coordination of motor vehicles with bicycles and pedestrians. Furthermore, too low a speed may result in changes in driving behaviours such as shorter headways between vehicles and more frequent changes of lanes, which may cause road accidents. Some research\(^\text{16}\) pointed out that it may be better to improve the traffic operations of bicycles and pedestrians.

### 3.2 Indicators for speed appraisal

Speed control measures are primarily used to address speeding problems by changing vertical and horizontal alignments, and narrowing the roadway. Volume control measures normally try to smoothen the traffic. The distinction between the two types of measures is not as clear as it appears since speed control measures frequently divert traffic to alternative routes whereas vol-
ume control measures usually slow down the traffic. It is therefore necessary to make a sustainable appraisal for speed regulation systematically.

Figure 3 describes the sustainable interactions of travel speed with other aspects of urban society according to the methodology in System Dynamics \(^{17,18}\).

It is easy to see that lower vehicle speed directly results in higher emission levels and greater energy consumption. Low speeds also cause certain increases of traffic flow in the urban road network modelled.

There are multiple interactions between speed and safety. First, low speed may curtail the number and severity of traffic accidents and fatalities. Secondly, low speed increases the density of road traffic, journey time of passengers and the possibility of traffic accidents. This would further deteriorate the public transport performance and attraction. Deteriorated public transport may lead to an increase of private vehicles, more severe congestion and an increase of possible occurrence of road traffic accidents. These complicated interactions need more analysis.

Speed regulation may be thought of as part of a sustainable urban transport system. At this point, efficient transport process, low emission levels, low energy consumption and high safety may be four important indicators to be used in speed regulation. In the following sections, we will address these issues in detail.

### 3.3 Impact of speed on road capacity and passenger journey time

Under the same vehicle-km, low speed leads to low road flows and long journey times on roads. For example, the Beijing government has invested much on road construction. As a result, more than one million square meters of road acreage is built each year. However, the situation of urban transport has been continuously worsening due to the reduced speed of motor vehicles of the whole network. Road construction seems regressive when compared with the development of traffic volume. Statistics \(^{13}\) show that the increasing rates of motor vehicles and bicycles are 14 and 6 times of that of road mileage respectively.

In one day, roads offer same operational time for all vehicles while speed changes. If all vehicles run the same total vehicle-kms, lower speeds will lead to longer time on roads and greater traffic density. The additional rate of road traffic density may be calculated as follows:

\[
\text{FlowDensityAddRate} = \frac{(\sum N_i S_i / V_i - \sum N_0 S_i / V_0)}{\sum N_i S_i / V_0} \quad ...........(1)
\]

where \(N_i\) is the number of \(i^{th}\) vehicles, \(S_i\) is the daily running kilometerage of \(i^{th}\) vehicle, and \(V_i\) is the speed of \(i^{th}\) vehicle. Subscript 0 represents the initial speed state and 1 for the final speed state.

For constant service time of public vehicles, it has to increase the number of operational vehicles to compensate for the reduction of the average speed of vehicles. The additional number of vehicles in operation is given below:

\[
\text{AddVehNumber} = \left[\frac{V_0}{V_1} - 1\right] N_0 \quad .................(2)
\]

where \(N_0\) is the number of public vehicles before speed varies.

To keep the kilometerage run by the \(i^{th}\) type of vehicles the same, the additional passenger journey time due to the speed change is as follows:

\[
\text{AddJourneyTime} = \left[\frac{V_0}{V_1} - 1\right] T_0 \quad .................(3)
\]

where \(T_0\) is the initial journey time before speed changes.

### 3.4 Impact of speed regulation on environment and energy consumption

Low speed increases the emissions such as CO and HC from operational motor vehicles. Most vehicle models display that the lower the speed, the greater the emissions for the same running mileage.

There are two kinds of models to determine the additional emissions. When a unit emission quantum (g/sec) applies, it is necessary to calculate the augment due to speed change, the first item below, and then the augment due to the extra stay time on road, the second item below:
AddEmissions = \sum_i \left( E_{i0} - E_{i1} \right) \frac{S_i}{V_{i0}} + \left( \frac{1}{V_{i1}} - \frac{1}{V_{i0}} \right) S_i E_{i1} \quad \ldots (4)

where $E_{i0}$ and $E_{i1}$ represent the initial and final unit emissions of the $i^{th}$ vehicle in g/sec. $S_i$ is the daily running kilometerage of the $i^{th}$ vehicle.

The additional rate of energy consumption may be obtained according to running mileage of vehicles at different speeds. The model is as follows:

AddEnergyConsumptionRate = \sum_i S_i \left( E_{i1} - E_{i0} \right) / S_i E_{i0} \quad \ldots \ldots \ldots (5)

where $E_{i0}$ and $E_{i1}$ represent the initial and final energy consumption levels of the $i^{th}$ vehicle in g/km.

### 3.5 Case analysis

The following is an example in Beijing when different average speeds are assumed.

Statistics show that there were about 1.7 million motor vehicles at the end of 2001. The constitution of these vehicles is listed in Table 2\textsuperscript{19}. In the table, the car and light vehicles refer to vehicles with a length of or less than 7 meters. Middle vehicles refer to those vehicles with a length from 7 to 10 meters and large vehicles refer to vehicles longer than 10 meters.

The emission parameters are referred to from other studies. Table 3\textsuperscript{20-22} gives a summary of the data used.

Table 4 gives some comparative consequences in Beijing when the average speeds of all vehicles vary from 10km/h to 35km/h, among which the base point for the comparison is at the speed of 25km/h.

It is obvious that the change of speeds has a great impact on urban sustainability. Vehicle characteristics display that there is a rapid increase when speed becomes less than 25km/h. For example, the VOC emission increases up to 352.8% when the average speed declines from 25km/h to 10km/h, while energy consumption increases by about 57.5%. Of the emission, the contribution due to the extra in-road stay of vehicles is as high as 271.7% in the second item of Equation (4). That is why most Chinese big cities have experienced worse air pol-

### Table 2: Vehicle Composition in Beijing

<table>
<thead>
<tr>
<th>Type</th>
<th>Percentage</th>
<th>Number of Vehicles in 2001 ('000)</th>
<th>Daily Kilometerage per Vehicle (km,1996)</th>
<th>Daily Kilometerage of All Vehicles (km,'000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car and Light Vehicles</td>
<td>85.0</td>
<td>1,445</td>
<td>111.7</td>
<td>161,407</td>
</tr>
<tr>
<td>Middle Vehicles</td>
<td>11.3</td>
<td>192.1</td>
<td>78.9</td>
<td>15,157</td>
</tr>
<tr>
<td>Large Vehicles</td>
<td>3.7</td>
<td>62.9</td>
<td>65.5</td>
<td>4,120</td>
</tr>
<tr>
<td>Weighted Sum</td>
<td>100</td>
<td>1,700</td>
<td>106.3</td>
<td>180,684</td>
</tr>
</tbody>
</table>

Source: Hao et al. (2001), pp. 85-89\textsuperscript{19}.

### Table 3: Emission and Fuel Consumption Parameters

<table>
<thead>
<tr>
<th>Speed Bin</th>
<th>CO Emission (g/km)\textsuperscript{*}</th>
<th>CO\textsubscript{2} Emission (g/km)\textsuperscript{*}</th>
<th>VOC Emissions (g/km)\textsuperscript{***}</th>
<th>Fuel Consumption (g/km)\textsuperscript{**}</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>4.85</td>
<td>310</td>
<td>4.8</td>
<td>130</td>
</tr>
<tr>
<td>15**</td>
<td>3.825</td>
<td>275</td>
<td>3.9</td>
<td>113</td>
</tr>
<tr>
<td>20</td>
<td>2.80</td>
<td>240</td>
<td>3.0</td>
<td>96</td>
</tr>
<tr>
<td>25****</td>
<td>2.425</td>
<td>220</td>
<td>2.65</td>
<td>87.5</td>
</tr>
<tr>
<td>30</td>
<td>2.05</td>
<td>200</td>
<td>2.3</td>
<td>79</td>
</tr>
<tr>
<td>35</td>
<td>1.875</td>
<td>185</td>
<td>2.05</td>
<td>72</td>
</tr>
<tr>
<td>40</td>
<td>1.70</td>
<td>170</td>
<td>1.8</td>
<td>65</td>
</tr>
<tr>
<td>50</td>
<td>1.25</td>
<td>150</td>
<td>1.5</td>
<td>55</td>
</tr>
<tr>
<td>60</td>
<td>1.15</td>
<td>145</td>
<td>1.4</td>
<td>48</td>
</tr>
<tr>
<td>70</td>
<td>1.05</td>
<td>138</td>
<td>1.3</td>
<td>43</td>
</tr>
<tr>
<td>80</td>
<td>0.95</td>
<td>130</td>
<td>1.25</td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>0.8</td>
<td>110</td>
<td>1.05</td>
<td>50</td>
</tr>
</tbody>
</table>

Source: \textsuperscript{*} Joumard\textsuperscript{20}, 1999; \textsuperscript{**} Samaras, 1998\textsuperscript{21}; \textsuperscript{***} Leon\textsuperscript{22}, 1997; \textsuperscript{****} Inferred by linear interpolation.
SUSTAINABILITY ASSESSMENT OF SPEED REGULATION OF URBAN TRAFFIC

B. MAO, H. CHEN, S. CHEN

For a developing country like China, the more serious problem may be the inadequate road space in urban areas where the resources are limited per capita. The decline of speeds of motor vehicles in many big cities contribute much to road traffic density, which has led to surprising traffic jam.

The paper discussed the impacts of speed regulation on sustainability of urban society. These impacts need to be balanced for developing countries. As analysed, the additional emissions when speeds are lowered from 25km/h increase very rapidly, ranging from 40% to 400% while energy consumption increases by a maximum 57.5%.

As is well known, the urban traffic in China has been characterised with a typical mixed traffic in which bicycles play an important role. Low speeds of motor vehicles have been commonly seen in many big cities. However, is there enough evidence to confirm that increasing speed leads to higher traffic accidents? Or is it more important to build some separation between the motorized and non-motorized flows? Authors believe that the biggest obstacle for transport safety is not speed of motor vehicles especially in urban areas.

In 2000, the Ministry of Public Security of China started to implement the “Speed Engineering” aiming to increase speeds of motor vehicles in urban areas without putting too much investment to infrastructure. Some progress has been achieved in the project. For example, the average speed of motor vehicles in Guangzhou increased from 15km/h to 25km/h. The average speed of public transport vehicles in Kunming increased from 9.6km/h to 15.2km/h in the central urban areas of the city. In Beijing, 3,900 new traffic signs have been installed, 2,400 new public vehicles have been put in service and 80 bus lines have been extended during the project since 2001. The average speed of public vehicles increased by 10%. At the same time, the electronic police devices reported 580,000 traffic violations of motor vehicles and more than 14 million users were fined due to their peccancy in 2001. Some experts suggest the 50km/h may be applied for important main roads and 30km/h for other roads in Chinese urban areas.

### Table: Impact of Speed Regulation on Emissions and Energy Consumption

<table>
<thead>
<tr>
<th>Indices – speed</th>
<th>10km/h</th>
<th>15km/h</th>
<th>20km/h</th>
<th>25km/h</th>
<th>30km/h</th>
<th>35km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions varied (%)</td>
<td>CO</td>
<td>+400</td>
<td>+162.9</td>
<td>+44.3</td>
<td>0</td>
<td>−29.6</td>
</tr>
<tr>
<td>CO₂</td>
<td>+253.3</td>
<td>+108.3</td>
<td>+36.4</td>
<td>0</td>
<td>−24.2</td>
<td>−39.9</td>
</tr>
<tr>
<td>VOC</td>
<td>+352.8</td>
<td>+145.3</td>
<td>+41.5</td>
<td>0</td>
<td>−27.7</td>
<td>−47.7</td>
</tr>
<tr>
<td>In-road vehicles (%)</td>
<td>+150</td>
<td>+67</td>
<td>+20</td>
<td>0</td>
<td>−17</td>
<td>−29</td>
</tr>
<tr>
<td>Journey time (%)</td>
<td>+150</td>
<td>+67</td>
<td>+20</td>
<td>0</td>
<td>−17</td>
<td>−29</td>
</tr>
<tr>
<td>Energy consumption (%)</td>
<td>+57.5</td>
<td>+29.1</td>
<td>+9.7</td>
<td>0</td>
<td>−9.7</td>
<td>−17.7</td>
</tr>
</tbody>
</table>