ANALYSIS OF TRAFFIC FEATURES IN VEHICLE ACCESS ROADS TO LARGE PUBLIC BUILDINGS IN THE URBAN AREA

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ABSTRACT

Vehicle access roads to large public buildings in urban areas seem to be the link between the inner city traffic and the outer urban traffic, making them important nodes in the urban road network. An analysis of the traffic features of vehicle access roads would be of assistance in choosing logical traffic management measures for the connecting node between the building traffic and urban traffic. At the beginning of this analysis, the behaviour and attitudes of motorists are analysed, which are the basis of the traffic features. The traffic flow characteristics are then discussed in detail in terms of the following aspects: vehicle queuing model, car-following model and vehicle diversion model. Finally, the effect of pedestrians and cyclists is examined. Because of the stochastic properties of pedestrian and bicycle flow, any disturbance has a great impact on the state of traffic operations. It is therefore necessary to separate the flow of pedestrians and cyclists from the vehicle flow.

1. INTRODUCTION

Vehicle access roads to large public buildings seem to be the link between building inner roads and urban outer roads. It is necessary for these roads to connect with urban traffic in an orderly manner, and the function is also coupled to the internal traffic. These roads are important nodes in a city’s traffic network. Analysis of the traffic features of vehicle access roads to large public buildings in China and other countries includes access management analysis and traffic impact analysis. Access management strategies are aimed at improving access to all levels of road in the surrounding blocks (Zhang et al., 2006). Traffic impact analysis considers the impact of traffic on the surrounding road network, with any necessary new construction. However, the access management strategies applied in urban areas of China need to be further researched. Traffic impact analysis needs a unified technology platform, especially since the traffic characteristics analysis is currently neither adequate nor systematic.

This paper discusses the basic traffic flow characteristics of access roads to large public buildings. First, a psychological analysis of the vehicle drivers on the access roads is given, and then the characteristics of the motor vehicles are considered. Finally, the paper examines the effect of pedestrian and bicycle traffic on motorised traffic. The findings on the traffic characteristics will help with the organisation and management of traffic accessing large public buildings, and will lay the foundation for related transport planning.

2. ANALYSIS OF DRIVER BEHAVIOUR AND PSYCHOLOGY

Data on traffic flow collected in the vicinity of access to large public buildings show that the traffic volume is relatively high, and therefore traffic congestion occurs from time to time. Urban traffic and construction traffic, motor vehicles, pedestrians and cyclists all meet on the access roads, leading to disorder. These access roads are thus prone to traffic accidents. Drivers on the access roads are often faced with a complex environment, so driver behaviour and psychological factors should be carefully analysed.

2.1 Analysis of driver behaviour

Driver actions taken include:

1. Adjusting the speed of the vehicle in accordance with the prevailing situation on the access road. Because the traffic situation is complex, a timely change of speed could improve the road capacity and promote the flow of traffic.
2. Choosing an appropriate lane and observing the traffic signals, signs and markings. As different traffic organisation methods are used on the different building access roads, drivers have to choose a suitable lane with the guidance of traffic signals, etc.
3. Being cautious of accidents and avoiding other vehicles and pedestrians. Because there are many potential points of traffic conflict and a high frequency of accidents on these roads, drivers need a fast response time to avoid other vehicles and pedestrians.

2.2 Psychological analysis of drivers

The main psychological factors of drivers on access roads that will have an impact on the traffic operation are:

- *The quality of the driver's attention*: The quality of the driver's attention includes span, stability, allocation and transfer (Li, 2002). Drivers with good quality of attention can maintain a wider attention span and a longer attention time, allocate attention appropriately and transfer attention as needed. Drivers with poor attention are unable to keep important information in their minds, which is bad for traffic safety and traffic flow.
- *The driver's judgment of information*. This includes speed and distance (Li, 2002):
  - Judgment of speed: These characteristics involve estimating the response and speed of moving objects. Ability to judge speed is related to a driver's age, visual functions and ability to make decisions and judgments. The judgment of speed depends on the driver's perception and is vital for avoiding traffic accidents.
  - Judgment of distance: These characteristics involve estimating the distance between the vehicles to either side and the headway distance. The judgment of distance depends on the visual ability to grasp the basic behaviour of vehicles, such as their position within the lane markings. Misjudgement of distance is the reason for about 70% of all accidents, so the ability to judge distance is very important for drivers.
- *Characteristics of the driver's reaction*: These characteristics relate to the driver's reaction in the moment after he or she has perceived the information and the corresponding responses. Reaction mainly involves reaction time, and reaction time varies with age, technical proficiency at driving, judgmental ability, decision-making ability, fatigue, alcohol, drugs and so on. A fast reaction speed and taking the correct avoiding actions can reduce traffic accidents and ensure road safety.

3. ANALYSIS OF VEHICLE OPERATING CHARACTERISTICS

When vehicles enter or leave large public buildings, they cause a lot of diversion, merging, parking, weaving, lane crossing, etc. To describe the operating characteristics of the vehicles, this paper focuses on the theories of cars queuing, car following and vehicle diversions.

3.1 Cars queuing

To better illustrate the characteristics of cars queuing, entrances and exits are discussed separately.

3.1.1 Cars queuing model in the exit

When vehicles on a building's inner road drive away from the building, in order to comply with the priority right of urban road vehicles, the leaving vehicles merge into the urban road traffic only when there is a suitable headway (gap) in the traffic. When the time headway on the urban road does not allow the leaving vehicles to drive away continuously, a queue forms on the building's inner road. This phenomenon often occurs in the vicinity of important large public buildings on both sides of a major road during peak hours. The queuing phenomenon is shown in Figure 1.

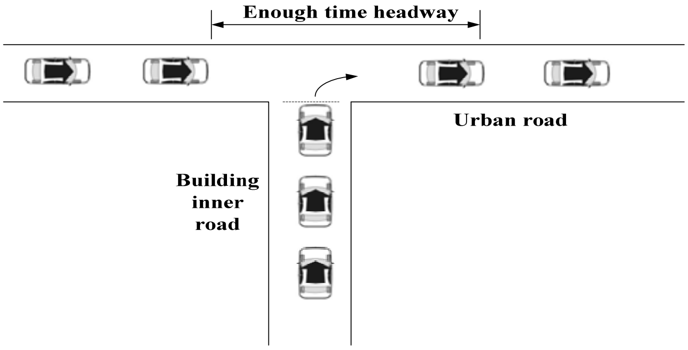

Figure 1. Cars queuing in the exit

The queuing system has three components:

1. *Input process:* It is assumed that vehicles on the building's inner road obey Poisson's distribution, which is the time headway obeying the negative exponential distribution. To describe with the shift in negative distribution, f(t) is the probability density function:

$$f(t) = \begin{cases} \lambda e^{-\lambda(t-\tau)}, t \geq \tau \\ 0, t < \tau \end{cases} \qquad (1)$$

Where:

λ = vehicle arrival rate (pcu/s)
τ = minimum time headway(s).

2. *Queuing rules:* The rules of the queuing system are "first come, first served". When vehicles have arrived at the exit but the urban road is congested and cannot provide sufficient time headway, then the vehicles queue on the inner road.
3. *The service mode:* The 'service' means that drivers on the building's inner road estimate whether there is enough time headway on the urban road, and then enter and merge into the traffic stream on the major road. As there is only one inner road connected to the urban road, only one service channel exists. The service time means the time from the moment when a car becomes the first one in the queue to the moment when it has merged into the urban road. It is assumed that the service time obeys the negative exponential distribution.

The major quantitative indicators in the queuing system are:

- Mean waiting time: $\overline{w}$

$$\overline{w} = \frac{\lambda}{\mu(\mu - \lambda)} \qquad (2)$$

Where:

μ = vehicles' service rate (pcu/s), i.e. the number of vehicles per unit of time entering the urban road – associated with the time headway of the urban road traffic flow.

- Mean queuing length: $\overline{q}$

$$\overline{q} = \frac{\rho^2}{1-\rho} \tag{3}$$

Where:

p = service intensity or traffic load intensity, $\rho = \lambda / \mu$.

Vehicles turning left into the building's inner road face a similar situation, and the service mode and service rules in the queuing system are almost the same as those of vehicles driving away from the exit, but have different parameters.

3.1.2 Cars queuing model in the entrance

Vehicles from the urban road that enter the building's inner road first look for parking spaces outside the building. If the parking spaces are all full, the vehicles simply drive away from the building without waiting. This model also has three components:

(1) Input process: Similarly to the exit model, it is assumed that the distribution of arriving vehicles obeys Poisson's distribution, which is the time headway obeying the negative exponential distribution.

(2) Queuing rules: The rules of queuing are "first come, first served", a single service channel and 'loss waiting'. Loss waiting means that if all the parking spaces are occupied, the vehicle that arrived first at the entrance simply drives away without waiting.

(3) Service mode: The 'service' means that drivers on the urban road first look to see whether there are any unoccupied parking spaces outside the public building, and then decide whether or not to drive into the building's inner road. The service channel is the parking spaces and the service time is the vehicle parking time. It is assumed that the service time obeys the negative exponential distribution.

Because the service mode is time loss in waiting, there is neither a mean waiting time nor a mean waiting length of queue.

3.2 Car-following model

Car-following theory consists of a mathematical model and a theoretical analysis. Car following occurs when vehicles move in a single lane, one behind the other. The car-following phenomenon manifests itself mainly when vehicles on the urban road are ready to enter the buildings, but there are restrictions due to the vehicles in front, i.e. a vehicle has to follow the vehicle in front of it. The phenomenon often occurs when large numbers of vehicles try to enter the public building's inner road.

Here a linear following model based on the expected headway (Jia and Juan, 2000) is selected to describe the car-following phenomenon in the entrance to a public building. The basic idea of this model is that the vehicle in front slows down when it is ready to enter the building, and the vehicle following it has to adjust its speed to maintain the expected headway. The expected headway has nothing to do with the actual speed, but is related to the driver's psychology, driving habits, etc. Different drivers choose different expected headways. The expected headway makes two following cars move at the same speed and acceleration, thus achieving a relatively static state. Car following is depicted in Figure 2.

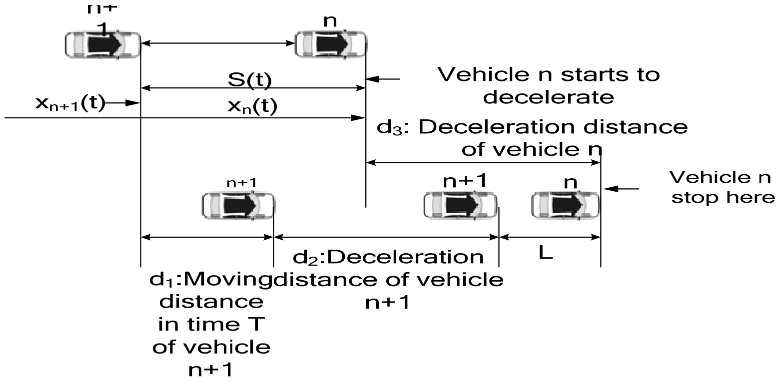

Figure 2. Car following in the entrance

Key:

$S(t)$	=	time headway at time t (m)
$x_{n+1}(t)$	=	position of vehicle n+1 at time t
$x_n(t)$	=	position of vehicle n at time t
T	=	reaction time(s)
d_1	=	moving distance of vehicle n+1 in time T (m)
d_2	=	deceleration distance of vehicle n+1 (m)
d_3	=	deceleration distance of vehicle n (m)
L	=	expected headway(m)
$\dot{x}_n(t)$	=	speed of vehicle n at time t (m/s)
$\ddot{x}_n(t)$	=	acceleration rate of vehicle n at time t (m/s^2).

$$S(t) = d_1 + d_2 + L - d_3 \tag{4}$$

$$d_1 = \dot{x}_{n+1}(t+T)T \tag{5}$$

Assume that the expected headway and the speed of the later vehicle at time t+T follows the linear relationship:

$$L = \alpha \dot{x}_{n+1}(t+T) + \beta \tag{6}$$

Where: α, β = calibration parameters used throughout the experiment, related to the drivers' psychology.

Assuming that the two following vehicles have the same deceleration distance, then:

$$S(t) = d_1 + L \tag{7}$$

$$x_n(t) - x_{n+1}(t) = \dot{x}_{n+1}(t+T)T + \alpha \dot{x}_{n+1}(t+T) + \beta \tag{8}$$

Derived from t:

$$\dot{x}_n(t) - \dot{x}_{n+1}(t) = \ddot{x}_{n+1}(t+T)T + \alpha \ddot{x}_{n+1}(t+T) \tag{9}$$

$$\ddot{x}_{n+1}(t+T) = [\dot{x}_n(t) - \dot{x}_{n+1}(t)]/(T+\alpha) \tag{10}$$

The key to this model is to determine the appropriate values of α, β .

3.3 Vehicle diversion model

Traffic flow diversion means that vehicles moving on the urban road separate into two streams, one stream turning right into the public building, the other stream moving through. The through vehicles have to slow down because they are affected by the right-turning vehicles and this brings the traffic capacity down. To describe the extent of this impact, an access impact length model has been established.

The access impact length is the length (in metres) to which a vehicle turning right into the public building affects the following through vehicle, as shown in Figure 3.

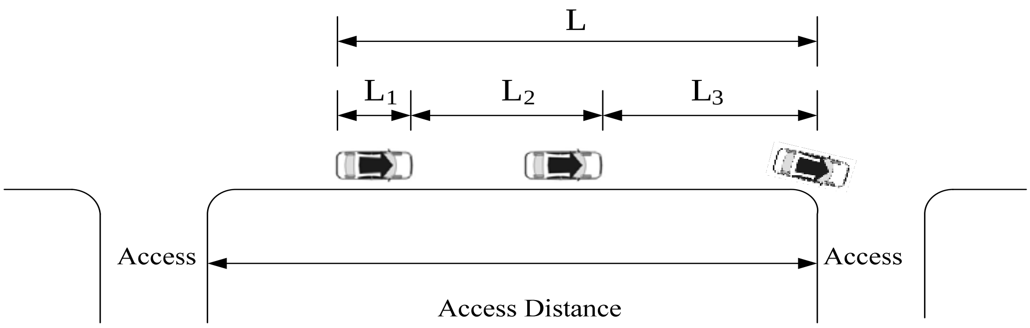

Figure 3. Access impact length model

Where:

L = access impact length (m)
L_1 = vehicle length (m)
L_2 = reaction distance (m)
L_3 = right-turning vehicle's impact length (m).

$$L = L_1+L_2+L_3 \quad (11)$$

- For the vehicle length L_1, the length of a standard passenger car or the length of the majority of vehicles near the access road is used.
- The reaction distance L_2 is calculated approximately from the following equation:

$$L_2 = \frac{Vt}{3.6} \quad (12)$$

Where:

V = the operating speed of the through vehicle (km/h)
T = the reaction time of the through vehicle driver to the right-turning vehicle in front. It is related to the drivers' psychology and the road environment, adopted as being from 1.5 s to 2.0 s.

- The impact length L_3 of the right-turning vehicle is the distance over which the through vehicle starts to decelerate when it is affected by the vehicle in front getting into position to turn right. It is an important part of the access impact length, and is directly related to the vehicle's speed and braking performance.

$$L_3 = \frac{V_t^2 - V^2}{2*3.6^2*a} \quad (13)$$

Where:

V = initial speed of the through vehicle (km/h)
V_t = spot speed of the through vehicle at the access road (km/h)
A = deceleration rate of the through vehicle (m/s^2).

If the right-turning traffic volume and the traffic operating speed are fixed, the access impact length L could be a linear correlation with the percentage of through vehicles affected by the right-turning vehicles. This would be conducive to understanding the extent of the impact on through vehicles by right-turning vehicles.

4. IMPACT ANALYSIS OF PEDESTRIANS AND CYCLISTS

The access road to a large public building is the link between the building's inner road and the urban outer road and is the key node where traffic problems are complex. Because of the mixed traffic environment in China, non-motorised vehicles and pedestrians are bound to have an impact on the motor vehicle traffic on the vehicle access roads and to have a greater influence on the traffic safety.

4.1 Analysis of pedestrian characteristics

Pedestrian traffic flow is significantly different from motor vehicle flow at the access to public buildings and has the following characteristics: low velocity, mobility, randomness, diversity and vulnerability.

Pedestrian behaviour has the following specific characteristics:

1. If not in a hurry, pedestrians tend to walk at their most comfortable walking speed through the building access.
2. Pedestrians always maintain a certain distance from other pedestrians. This distance may be reduced when people are running in haste or if there is an the increase in pedestrian density.
3. When the density of pedestrians increases, the walking speed and length of stride will obviously decrease.

Due to their high degree of mobility, the uncertainty of their behaviour, and having the fewest limitations, pedestrians are given excessive traffic freedom in a traffic system, which makes a clear analysis of the characteristics of pedestrians difficult.

4.2 Analysis of cyclist characteristics

In China, bicycle traffic represents a large proportion of the urban traffic modes. Large public buildings attract a large number of cyclists, so it is necessary to provide a certain number of bicycle parking spaces.

Cyclist behaviour has the following specific characteristics:

1. The running track is snake-like and is very hard to keep straight. If the width of a cyclist's track's increases, he or she is at increased risk.
2. Cyclists cannot maintain a certain distance between them, but converge into groups.
3. Bicycles can turn flexibly, and the cyclists' reaction is agile. The riding speed and direction often change suddenly.

Some of the cyclists' psychological characteristics, such as moving quickly, fear of motor vehicles, separating from others and following others, promote conflict between motorised and non-motorised vehicles, which results in deterioration of safety on access roads.

4.3 Analysis of disturbance by pedestrians and cyclists

4.3.1 Analysis of disturbance by pedestrians

Pedestrian flow at the access to public buildings is hard to control, and causes considerable disturbance to the motor vehicles, including the following:

1. Pedestrians going through the access may suddenly enter the vehicles' trajectory if they are not watching carefully, which makes vehicle drivers take emergency actions.
2. Pedestrians going through the access or crossing the road at will make the vehicle drivers slow down their speed, so the capacity of the access road is lowered.
3. The uncertainty as to pedestrians' walking speed and the difficulty of control lead to the risk of vehicles following pedestrians on the access road.

4.3.2 Analysis of disturbance by cyclists

Cyclists are present in large numbers and they move flexibly. Not only on the urban road but also on the public buildings' access roads, bicycles have a serious effect on the motorised traffic.

The disturbance that bicycles cause to motor vehicles is often lateral interference, which is caused mainly by the difference in speed between motorised and non-motorised vehicles and the instability of non-motorised vehicles. Lateral interference could be divided into 'block interference' and 'friction interference'. Block interference means that non-motorised vehicles block the movement of motorised vehicles, forcing the motorised vehicles to stop or slow down. Friction interference occurs when the motorised vehicles are moving close to the non-motorised vehicles and the motorised vehicles have to take some action to enlarge the lateral gap between them. Obviously, block interference results in a greater degree of disturbance. The four types of block interference are explained as follows (shown in Figure 4):

Type 1: Obtuse angle conflict: The cyclist is on the right-hand side of the motor vehicle before the conflict. This happens at the moment when the motor vehicle is ready to enter the building's inner road while the cyclist already on the inner road is intending to turn left into the urban road at the access.

Type 2: Obtuse angle conflict: The cyclist is on the left-hand side of the motor vehicle before the conflict. This happens at the moment when the motor vehicle is ready to leave the building's inner road while the cyclist on the urban road is intending to turn right into the building's inner road at the access.

Type 3: Acute conflict: The cyclist is on the right-hand side of the motor vehicle before the conflict. This happens at the moment when the motor vehicle is ready to leave the building's inner road while the cyclist already on the inner road is intending to turn left into the urban road at the access.

Type 4: Acute conflict: The cyclist is on the left-hand side of the motor vehicle before the conflict. This happens at the moment when the motor vehicle is ready to enter the building's inner road while the cyclist on the urban road is intending to turn right into the building's inner road at the access.

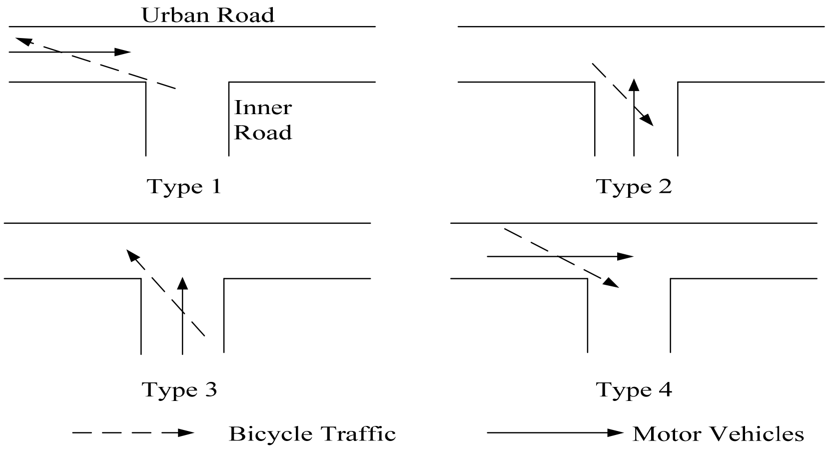

Figure 4. Four types of block interference

The disturbance caused by pedestrians and non-motorised vehicles at the access will lead to considerable deterioration in the order of public building access, resulting in an increase in the rate of traffic accidents and in a decrease in transportation efficiency. It is therefore essential to adopt a reasonable traffic management method and to implement traffic separation measures to co-ordinate all the traffic modes using access roads to large public buildings (Zhuo, 2006).

5. CONCLUSIONS

The paper has analysed chiefly the behaviour and psychological characteristics of drivers at the access to public buildings, explaining the vehicle traffic flow from the human factors perspective. Motor vehicles' operating characteristics were then analysed in detail, i.e. in terms of the cars queuing model, the car-following model and the vehicle diversion model. These three aspects cover the major actions taken by vehicles at the access to public buildings. Finally, the disturbance caused by non-motorised vehicles and pedestrians, including the extent of the impact and the type of interference, was taken into consideration, which lays the foundation for measures to separate motorised and non-motorised traffic.

Analysis of the traffic features of vehicles accessing large public buildings in urban areas is the foundation of research into site planning and traffic management design for access roads. These research results should be of some value as a reference in dealing with the problem of co-ordinating inner city traffic and urban outer traffic.

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