Journal of Southeast University (English Edition) Vol.19 No.4 Dec. 2003 ISSN 1003—7985

Analysis of distance headway

Zhou Wei

(China Academy of Transportation Sciences of Ministry of Communications, Beijing 100029, China)

Abstract: By means of the relationship between speed and distance headway, this paper attempts to directly determine the road capacity based on a new concept. At first it makes a comprehensive analysis of distance headway, including safe distance headway and desired one. The former is decided by the demand for the degree of safety, and the latter depends on the motorists' behavior, i.e. the model of traffic flow. Both of them are functions of speed. According to the characteristics of their curves, we can find a crossing point that is the capacity of a road segment. This capacity represents the maximum flow rate meeting the minimum safety requirement.

Key words: safe distance headway; desired distance headway; capacity analysis

1 The Distance Headway Characteristics

Distance headway and speed directly determine the capacity. To understand the concept of capacity, it is essential to understand the relationship between speed and distance headway. A feasible range for speed and distance headway can be illustrated by the speed-distance diagram (shown in Fig.1), where l represents the minimum distance headway, i.e., a vehicle's physical dimension plus the minimum gap between two vehicles, and V_f the maximum speed or the free-flow speed. Generally, the distance headway increases as the speed increases. The points on the h-axis represent the stop condition with different densities, while the points on the horizontal line at distance l from the V-axis represent the racecar situation. The vertical line at V_f represents the free-flow condition. The hatched area bounded by these three lines represents a feasible range for speed and distance headway[1].

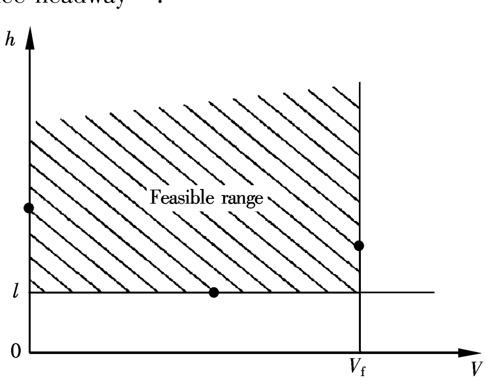

Fig.1 The speed and distance diagram

Received 2003-06-19.

Biography: Zhou Wei (1959—), male, doctor, professor, zhw59@hotmail.com.

2 Safe Distance Headway

Although any point within the feasible range represents a possible vehicle-following condition, each point indicates a different level of safety. To avoid collision, the general distance headway is determined by travel speed and deceleration rate from Eq.(1)[2].

$$h_g = l + V\delta + \frac{V^2}{2d_2} - \frac{V^2}{2d_1} \tag{1}$$

where l is the vehicle length plus minimum gap between two successive vehicles (m); V is the speed (m/s); δ is the perception-reaction time (s); d_2 is the following vehicle's deceleration rate (m/s^2); d_1 is the leading vehicle's deceleration rate (m/s^2).

Safe distance headway varies with the speed and deceleration rates of the leading and following vehicles. The difference between two vehicles' deceleration rates results in different levels of safety. Generally, the leading vehicle brakes harder than the following vehicle ($d_1 \geqslant d_2$) because the following vehicle can only detect the situation by the brake lights of the leading vehicle. Under the extreme case, the leading vehicle stops instantly (d_1 is infinite); there is then the sufficient distance headway:

$$h_s = l + V\delta + \frac{V^2}{2d_2} \tag{2}$$

If deceleration rates of both vehicles are the same, only the first two terms in Eq.(2) remain. This yields the minimum distance headway as shown in Eq.(3).

$$h_m = l + V\delta \tag{3}$$

The distance headways defined above provide the safety requirements under three operating situations. The degree of safety increases as the required distance headway increases from the minimum distance headway in Eq. (3), to the general distance headway in Eq. (1), and then to the sufficient distance headway in Eq.(2). Although the minimum distance headway provides a safe operation, it is hard to meet this requirement for motorists in a real world situation. The observed distance headway varies depending on the highway geometric design, traffic condition, and characteristics of the individual motorist. When motorists' desired safe operation condition matches the required safe operation condition, the actual distance headway is close to the required safe distance headway. Thus, from a traffic-management point of view, it is important to establish the proper traffic control devices and regulations to reduce the gap between the desired and actual safe distance headways.

3 Desired Distance Headway

To drive efficiently and comfortably, motorists have their own desired distance headway (h_e) based on the perceived highway environment and traffic condition. Under a stable traffic flow, the desired distance headway can be easily achieved. When there is a difference between the obtainable distance headway and desired distance headway, motorists have to adjust their speed to adapt to the situation. Sometimes, the adjustment can lead to unstable traffic flow.

In general, the selection of the headway by a motorist is affected by three factors: safety, efficiency and comfort. Safety and comfort require longer distance headway, while efficiency calls for shorter distance headway between vehicles. The risky distance headway refers to the situation where the actual (obtainable) distance is smaller than the minimum distance headway; the conservative distance headway refers to the situation where the actual (obtainable) distance is longer than the minimum distance headway; and the ideal flow condition occurs when the obtainable distance headway equals the minimum distance headway.

Selecting the desired distance headway is a fuzzy process that involves many factors, which are hard to model quantitatively. The most influential factor is speed. The general relationship between speed and distance headway can be observed and studied with statistical analysis. The linear relationship between speed and density described by the famous Greenshields[3] model can be used to derive the relationship between speed and desired distance headway as follows:

$$k = k_j\left(1 - \frac{V}{V_f}\right) \tag{4}$$

where k_j is the jam density (number of vehicles per meter, veh/m); V_f is the free-flow speed (m/s).

With $k = 1/h_e$ and $k_j = 1/l$, the desired distance headway becomes:

$$h_e = l\frac{V_f}{V_f - V} \tag{5}$$

Fig.2 depicts the distance headway as a function of speed for four different models. As expected, as the speed increases, the distance headway increases monotonously. At any given speed, there is the relationship: $h_s > h_g > h_m$. Within the feasible range of speed and distance as displayed in Fig.1, the points below the curve of the minimum distance headway represent risky operation, while the points above this curve indicate conservative operation as discussed previously.

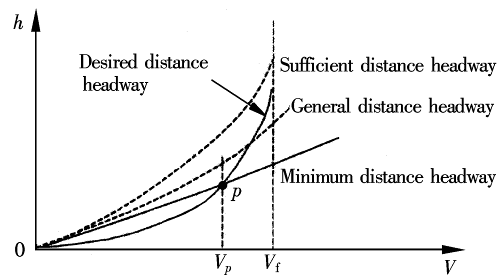

Fig.2 The desired and safe distance headway

The curve representing the desired distance headway defined by Eq. (5) approaches infinity when the speed is close to the free-flow speed, and it intersects the minimum distance headway curve at speed V_p as shown in Fig.2. When $V < V_p$, the desired distance headway curve is below the minimum distance headway; when $V > V_p$, the desired curve is above the curve of minimum distance headway. In other words, as speed increases, the operating condition changes from risky to the conservative type. This change is understandable since, at low speed, the efficiency generally outweighs safety; and when speed is high, motorists are more concerned about safety and comfort. It is particularly true on high-speed freeways where the desired distance headway is generally far above the minimum distance headway for the majority of motorists.

Let Eq.(3) equal Eq.(5), V_p can be calculated by

$$V_p = V_f - \frac{l}{\delta} \tag{6}$$

The safe distance headways defined by Eqs. (1),

(2) and (3) are independent of the free-flow speed, while the desired distance headway is a function of the free-flow speed. As the free-flow speed decreases, the curve representing the desired distance headway moves upward. Mathematically when $V_f \leqslant l/\delta$, $V_p \leqslant 0$, the desired distance curve is entirely above the curve of the minimum distance headway. Higher free-flow speed results in a larger portion of the desired distance headway positioned below the curve of the minimum distance headway.

4 Determination of Capacity[1,4,5]

Based on the fundamental relationship between flow rate, speed and density $q = kV$ and $k = 1/h$, the relationships between flow rate and speed for the four headway distance models are shown in Fig.3. All the four curves are within a triangle defined by the horizontal axis of speed, vertical line at $V = V_f$, and a straight line of $q = V/l = Vk_j$ that represents the racetrack conditions with a fixed density or distance headway. Any point on or within this triangle theoretically represents a feasible traffic flow state.

Based on its definition, the maximum flow rate at point A in Fig.3 should represent the capacity that is the product of the free-flow speed and jam density ($C = V_f k_j$). In reality, this value is, however, not attainable because of safety requirements. A different level of safety requirements leads to a different maximum flow rate, as manifested in Eq.(7):

$$q = \frac{V}{h_i} \tag{7}$$

where i represents g, s, m, and e.

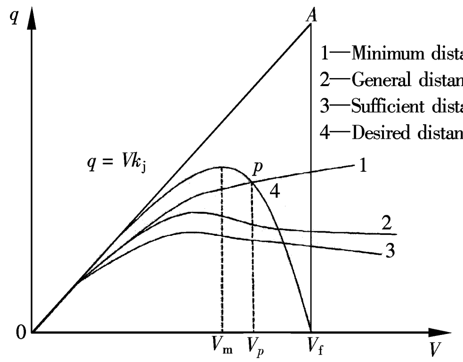

Fig.3 The relationships between speed and flow rate

The maximum flow rate associated with different levels of safety can be determined from Eq. (7) and Eqs. (1), (2) and (3). When h equals h_e of the Greenshields model in Eq.(5), the flow rate becomes:

$$q = \frac{V}{l}\left(1 - \frac{V}{V_f}\right) \tag{8}$$

This equation can be used to determine the maximum flow rate for the desired distance headway that is the curve 4 in Fig.3. At any given speed, a lower flow rate yields a higher level of safety.

Assuming that under a given prevailing condition the free-flow speed is V_f, and the desired distance headway is from the Greenshields model, the relationship between speed and flow rate is a parabolic curve as shown in Fig.3. The maximum flow rate occurs at the top point that is often defined as the capacity under the given condition. However, if this point is above the flow curve derived from the minimum distance headway, this capacity represents a risky traffic state as discussed previously. It is neither safe nor practical to use this value as the capacity.

Therefore, the practical capacity is the maximum flow rate that meets the safety requirement under the prevailing conditions defined by the geometric design, traffic composition, and motorists' characteristics. According to this definition, the maximum flow rate indicated by the top point in curve 4 should not be considered as the capacity if it is above the flow-rate curve derived from the minimum distance headway. Since the intersection at p in Fig.3 represents the maximum flow rate meeting the minimum safety requirement, it should represent the capacity with the corresponding speed V_p.

5 Conclusion

It is rather complicated to select a traffic flow model that gives the desired headway distance suitable to prevailing conditions. There are many developed flow models that can be used for distance headway studies. The selection of a proper traffic flow model is beyond the scope of this paper. Although the distance headway analysis in this paper is based on the Greenshields model, the logic can be easily generalized for other traffic flow models.

References

[1] Zhou Wei, Wang Binggang. Theoretical study about road section capacity [J]. *Journal of Traffic and Transportation Engineering*, 2001, **1**(2):92 - 98. (in Chinese)

[2] Papacostas C S, Prevedouros P D. *Transportation engineering and planning* [M]. Englewood Cliffs, USA: Prentice Hall Int, 1993.

[3] May A D. *Traffic flow fundamentals* [M]. New Jersey: Prentice-Hall, 1985.

[4] TRB special report. Highway capacity manual (Chapter 23)

[R]. Washington DC, 2000.
[5] Wang Y Q, Zhou W, Chen H. The case study of traffic flow characteristics [J]. *Highway Transportation Science*, 1999, **16** (Sup.2): 94 - 99. (in Chinese)

行车间距分析

周　伟

(交通部科学研究院, 北京 100029)

摘　要　本文试图通过分析行车间距与车速的关系,以新的理念和方法确定道路通行能力.首先综合分析了行车间距的特征,内容包括安全间距和期望间距等.前者取决于对安全程度的要求,后者则取决于驾驶员的行为特征,也可以说是交通流的模式.安全间距和期望间距都是速度的函数,根据它们的曲线形状,可以找到二者的交叉点,这个交叉点就是道路通行能力值所在,它代表了满足最小安全度要求的最大流率.

关键词　安全间距; 期望间距; 通行能力分析

中图分类号　U491.114