

Characteristics of Speed Dispersion in Urban Expressway

Fujian Wang, Shubin Ruan, Meiwei Dai

Abstract—Speed dispersion has tight relation to traffic safety. In this paper, several kinds of indicating parameters (the standard speed deviation, the coefficient of variation, the deviation of V85 and V15, the mean speed deviations, and the difference between adjacent car speeds) are applied to investigate the characteristics of speed dispersion, where V85 and V15 are 85th and 15th percentile speed, respectively. Their relationships are into full investigations and the results show that: there exists a positive relation (linear) between mean speed and the deviation of V85 and V15; while a negative relation (quadratic) between traffic flow and standard speed deviation. The mean speed deviation grows exponentially with mean speed while the absolute speed deviation between adjacent cars grows linearly with the headway. The results provide some basic information for traffic management.

Keywords—Headway, indicating parameters, speed dispersion, urban expressway.

I. INTRODUCTION

THE urban expressway is designed for solving the traffic congestion, while in fact, the increasing number of vehicles has weakened its advantages. The traffic congestion is still a big problem that it needs a more scientific and efficient traffic management.

Any traffic management cannot leave the real data. The traffic flow, density, and speed are three key parameters that depict the characteristics of real data [1]. The speed can be used to indicate the traffic condition that a high speed may reflect the free-flow condition and a low speed may reflect the traffic congestion [1]. The difference of velocity may be depicted by the speed dispersion. It's a very important parameter that it is closely related to the traffic accident and people investigate the relations from different aspects. For example, [2] took the deviations between individual car speed and mean speed as speed dispersion parameter and found that the larger the deviations, the higher the traffic accident rates. Cheng [3] used the value of (V85 - V15) (the deviation between 85th and 15th percentile speed) to analyze the relation between speed dispersion and traffic accident and [4] used the average speed difference to study the relations. Their

Fujian Wang is with the College of Civil Engineering and Architecture, Zhejiang University, Hangzhou (310058), China (corresponding author, phone: (86) 13858043622; fax: (86) 0571-88208685; e-mail: ciewfj@zju.edu.cn).

Shubin Ruan is with the College of Civil Engineering and Architecture, Zhejiang University, Hangzhou (310058), China (e-mail: 1458088264@qq.com).

Meiwei Dai is with the Zhejiang Provincial Institute of Communications Planning, Design & Research, Hangzhou (310058), China (e-mail: 21212117@zju.edu.cn).

results show a consistent agreement in the positive relation between speed dispersion and car accident.

The speed dispersion is greatly affected by weather, lanes, car types, and drivers' behaviors [5]-[8]. Different drivers may have different speed expectations thus different behaviors in the same traffic conditions: the aggressive drivers may speed up to reach their optimal velocity while the timid drivers may adjust their expectations and slow down. The speed dispersion caused by drivers' behavior is into full consideration in this paper.

For a better investigation of the speed dispersion in urban expressway, the typical congested place (the expressway between Sitong Bridge and Lianxiang Bridge in Beijing) is chosen for analysis. Data was obtained by video and was surveyed in three sites (the upstream of on-ramp, the downstream of on-ramp and the downstream of off-ramp) in 6:30-8:30 AM in June 24th, 2012. The inner, middle, and outside lanes of each site were included.

II. INDICATING PARAMETERS OF SPEED DISCRETENESS

A. Standard Speed Deviation

The standard deviation of the traffic speed can be applied to describe the speed dispersion. The formula is defined as:

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (u_i - \bar{u})^2}{N - 1}}, \quad (1)$$

where σ represents the standard deviation of vehicle speed (km/h); u_i represents single vehicle speed (km/h); \bar{u} represents the average vehicle speed (km/h); N represents the number of vehicles during the survey period. The measured data in the upstream of on-ramp is for analysis and the results show that the distributions of speed deviation in the three lanes have their similarities (Fig. 1 and Table I): they obey the Weibull distributions.

TABLE I
COMPARATIVE ANALYSIS OF STANDARD SPEED DEVIATION IN DIFFERENT LANES

Lane	Distribution pattern	The P value of K-S test	Standard deviation (km/h)
Inner lane	Weibull	0.34	4.94
Middle lane	Weibull	0.92	6.82
Outside lane	Weibull	0.17	9.78

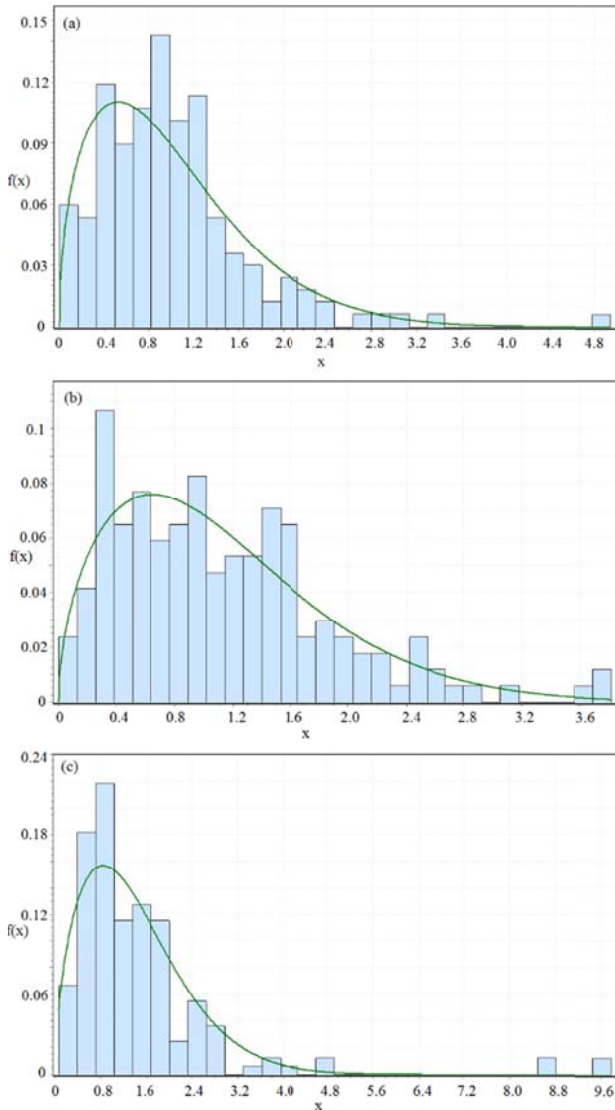


Fig. 1 Probability density distribution of standard deviation of speed in inner (a), middle (b), and outside (c) lane

The comparative analysis of the standard deviation of the vehicle in different lanes shows that: the standard deviation of speed in three lanes (from inner to outside) is 4.94, 6.82, and 9.78 km/h, respectively. The maximum deviation in the outside lane may be due to the impact of vehicle's converging or diverging, which causes the instability of the traffic flow.

B. Coefficient of Variation

The coefficient of variation is always used to indicate the speed dispersion. It shows great advantage when data shows great deviations or data unit is not the same. It can also avoid the effects induced by the different mean speed. The coefficient of variation can be expressed as the ratio of standard deviation and mean speed:

$$CV = \frac{\sigma}{\bar{v}} \quad (2)$$

$$\bar{v} = \frac{1}{n} \sum_{i=1}^n v_i \quad (3)$$

where \bar{v} is the mean speed of traffic flow (km/h); v_i represents single vehicle speed (km/h); n is the number of the vehicles. Similar to the analysis of the standard deviation of speed, the measured data at the upstream position of on-ramp is chosen for analysis again. The probability density distributions of speed variation coefficient are shown in Fig. 2 which indicates that they obey the Burr distribution. The P value of K-S test in the three lanes (from inner to outside) is 0.33, 0.91, and 0.94, respectively.

C. The Deviation of 15th and 85th Percentile Speed

The deviation of 15th percentile speed (V_{15}) and 85th percentile speed (V_{85}) is also used to investigate the speed dispersion. The 85th percentile speed means the speed that 85% vehicles cannot reach. Similarity, the 15th percentile speed represents the speed that 15% vehicles cannot reach. The deviation of them can reflect the degree of speed dispersion. That is, the greater the deviation is, the greater the degree of dispersion will be, and vice versa. In this paper, we use ($V_{85} - V_{15}$) to represent the deviation.

D. Absolute Deviation of Speed in Adjacent Vehicles

The average speed deviation can be depicted by the absolute value of adjacent vehicle velocities. The deviation can be calculated using:

$$|\overline{\Delta u}| = \frac{\left| \sum_{i=1}^{n-1} (u_{i+1} - u_i) \right|}{N-1} \quad (4)$$

In similarity, the speed deviation between two adjacent vehicles is defined as:

$$|\Delta u| = |u_{i+1} - u_i| \quad (5)$$

where u_i represents single vehicle speed (km/h); N is the number of the vehicles.

III. THE RELATIONSHIP BETWEEN AVERAGE SPEED AND THE VALUE OF ($V_{85} - V_{15}$)

The relationship between mean speed and the value of ($V_{85} - V_{15}$) is shown in Fig. 3. It is obvious that the value of ($V_{85} - V_{15}$) increases with the mean speed. The fitting function can be expressed as:

$$y = 0.0837x + 4.5077, R^2 = 0.6459. \quad (6)$$

Two parts can be divided according to Fig. 3. When the speed is less than 40 km/h, the value of ($V_{85} - V_{15}$) is relatively small. The main reason may be that the traffic flow is in congestion, velocities were subjected to be consistent. Thus, the discreteness of speed is relatively small. When the

speed is in the range of 40 ~ 80 km/h, the value of (V85 - V15) is large because vehicles are in free-flow condition and the speed can be depended on drivers themselves.

data points are more concentrated. In this condition, traffic flow will be in congestion and the interaction of other vehicles will increase, leading to a more consistent traffic velocity.

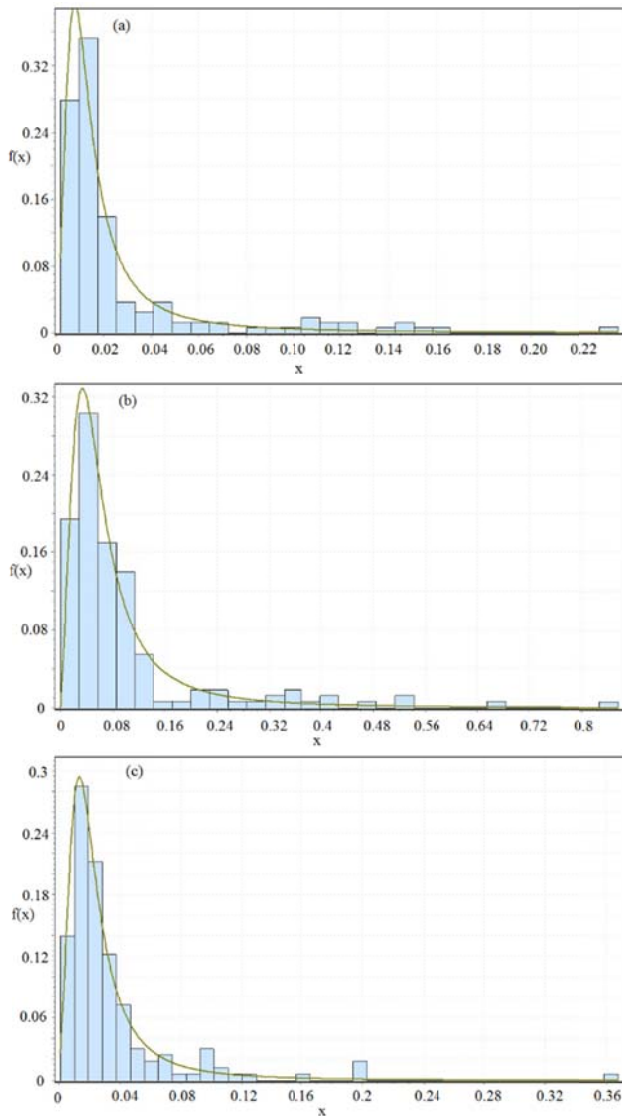


Fig. 2 Probability density distribution of speed variation coefficient in inner (a), middle (b), and outside (c) lane

IV. THE RELATIONSHIP BETWEEN FLOW AND STANDARD SPEED DEVIATION

The standard deviation of speed increases when the traffic flow decreases (Fig. 4), and the relation can be depicted by:

$$y = 2E - 0.6x^2 - 0.0061x + 6.4992, R^2 = 0.6714. \quad (7)$$

It can be seen that, when the traffic flow is in the range of 0~1000 veh/h, the data points are few and not concentrated. This may be due to the fact that traffic flow is in free-state. In this condition, vehicles have little impact on each other and the speed can go up depending on drivers' behaviors. However, when the traffic flow is more than 1000 veh/h, the

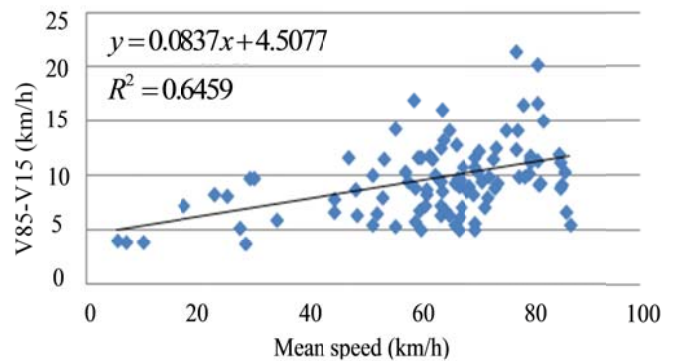


Fig. 3 Relationship between mean speed and the value of (V85 - V15)

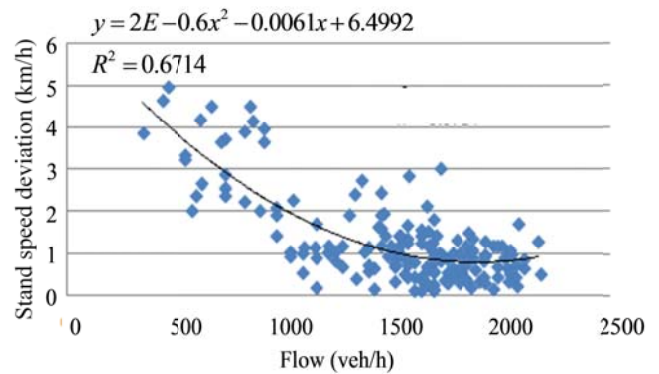


Fig. 4 The relationship between flow and standard speed deviation

It can be concluded that the characteristics of velocity dispersion is different in different flow ranges (traffic states). When traffic flow is in free-flow condition, speed dispersion is large and it's determined by driver's behavior. When traffic flow is in congestion, speed dispersion is small due to the consistent speed. It is also worthy to note that the analysis above can only reflect the speed dispersion of traffic flow in a certain range instead of individual traffic flow.

V. THE RELATIONSHIP BETWEEN MEAN SPEED AND MEAN SPEED DEVIATION

The relation between mean speed and mean speed deviation shows an exponent-function relation (Fig. 5) which can be depicted by:

$$y = 1.2582e^{0.0191x}, R^2 = 0.6419. \quad (8)$$

In Fig. 5, the speed deviation increases with the mean speed. When mean speed is between 0~40 km/h, the speed deviation is small due to the fact that traffic flow is in congestion and speeds were restricted to be consistent. When speed is in the range of 40~100 km/h, the speed deviation is relatively large and the distribution becomes more discrete. This may be due to the weak interaction of adjacent vehicles.

In this condition, if there exists a high speed deviation, it might mean that there must be some slow speeds in the high speed flows. Traffic state in this condition is unstable and drivers will be made to be tense which may threaten the traffic safety.

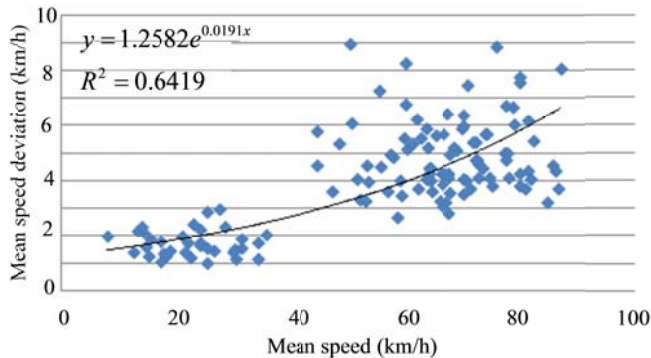


Fig. 5 The relationship between mean speed and mean speed deviation

VI. THE RELATIONSHIP BETWEEN HEADWAY AND THE ABSOLUTE DEVIATION OF ADJACENT SPEED

The shortage of the standard deviation relies on its disability to reveal the relationship between adjacent vehicles, thus, it cannot be used to investigate the discreteness of speed for adjacent vehicles. The absolute deviation of adjacent car speed has advantages to depict the characteristics of speed dispersion.

The desired velocity is decided by the driver's behavior and characteristics of the vehicles. In the free-flow state, drivers may try to keep their own desired speed by constantly speeding up or changing lanes. Therefore, there is no obvious regularity for the relationship between absolute deviation of the speed and headway. However, in the car-following state, vehicles have great impact on each other and the speed maybe changed. Therefore, there may exist some relationship between headway and absolute deviation of adjacent speed in car-following condition.

The relationship between absolute deviation of the speed and headway in different sites may differ a lot. Cars will be in the car-following condition when the headway is less than 5 seconds [9]. In this paper, the headways that are less than 5 seconds are used to analyze the relationship between headway and the absolute deviation of adjacent speeds.

According to Fig. 6, when in car-following state, the absolute deviation of adjacent car speed shows an almost linear increasing trend when the headway increases. This phenomenon exists in all the three surveyed sites (upstream and downstream of on-ramp, and downstream of off-ramp). While each site has its own properties: in the upstream of the on-ramp, the ratio of absolute deviation of speed and headway is the largest. In the downstream, the ratio is 0.88 and it ranked second and the third site has the smallest ratio. As for the time of strong and weak car-following state, their ratios in three investigated sites are 1:3, 1:2.2, and 1:1.47, respectively. It's obvious that the ratio is the largest in the upstream of on-ramp

and is smallest in the off-ramp. They share the common features with the ratio of speed deviation and headway. So, conclusions can be drawn that drivers' different behaviors will cause different time ratio of strong and weak car-following state, thus different ratio of speed deviation and headway. They are positively related.

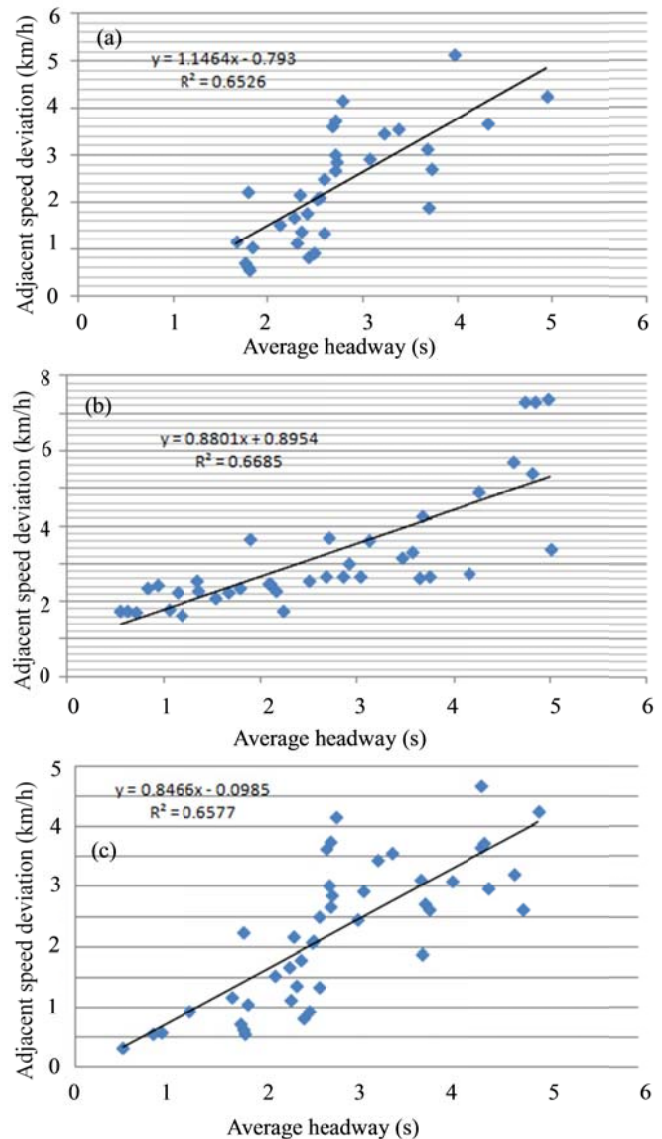


Fig. 6 The relationship between the average headway and absolute deviation of adjacent speeds in the upstream of on-ramp (a), downstream of on-ramp (b), downstream of off-ramp (c)

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