A DISAGGREGATE SPEED CONSISTENCY MEASURE FOR THE SAFETY EVALUATION OF FREEWAY DIVERGING AREA

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ABSTRACT

The most commonly used aggregate speed consistency measures (e.g. ΔV_{85}) have ecological fallacy problem and overestimate safety performance. To weaken these pitfalls, this paper presents a disaggregate measure, the 85th percentile individual speed difference $85(\Delta V)$, to assess the safety performance of freeway diverging areas. A diverging area is divided into four elements, namely the upstream mainline, diverging area, downstream mainline and exit ramp. Individual speeds at the four elements of each site are shot using radar guns. The last three digits are recorded for tracing individual vehicles. More than 30,000 traceable individual speeds, together with geometric and volume information, are collected at 21 diverging areas along the freeway G42 and G2501 in Nanjing, China. The evaluation results indicate that ΔV_{85} is overestimation-prone, which may lead decision-makers to leave potential unsafe sites unattended. The ratio of $85(\Delta V)/\Delta V_{85}$ varies from site to site and linkage to linkage, ranging from 1.1 to 4.6. The difference between ΔV_{85} and $85(\Delta V)$ magnifies when the traffic conditions become diverse and complicated. The findings in this paper show that the disaggregate measure is more reasonable and persuasive in safety evaluation.

Keywords: safety evaluation, freeway diverging area, disaggregate measure, simulation

INTRODUCTION

The freeway diverging area plays an important role in connecting freeway basic segments and exit ramp to move goods and people from freeway to adjacent crossroads in a fast, safe and efficient manner. At diverging area, a vehicle trying to leave the freeway needs to make lane change, weave/diverge to their desired lane, or even brake sharply to avoid a collision. Owing to the intensity of conflicting maneuvers, diverging areas are prone to a relatively higher risk of crash in terms of crash frequency and severity compared with other sections along the freeway.

It is affirmed that there is a direct link between the lack of consistency of speed along a highway and increased crash risk, including both the expected frequency and severity (Elvik, 2004). Researchers also agreed that speed difference rather than speed should be responsible for the high crash occurrence (AASHTO, 2004 and Polus, 2004). From this perspective, many safety evaluation methods have been presented based on speed or speed difference (Fitzpatrick, 2000 and Krammes, 1995). Unfortunately, previous studies mainly focused on two-lane rural highways (Christopher, 1994; Gibreel，1999; Ali, 2010, Ivette, 2010), seldom on freeway diverging areas, at which the safety situation is also serious.

Many measures have been developed to assess the safety level for target segments. Crash-based statistics, such as crash frequency, crash rate and crash severity, were commonly used in the past decades. However, as crash is a stochastic and rare event. One cannot take it for granted that a section is unsafe even if an extraordinarily serious accident happened on that section, as this accident might be resulted from the driver’s carelessness or mechanical fault, etc. While assessing the safety performance of a roadway section, it is advisable to consider the combined interaction of driver’s personal characteristics (e.g., age, gender, fatigue, alcohol), vehicle attributes (make, model, year), roadway geometric, and traffic conditions. Standing on this viewpoint, Hassan et al. (2001) compiled different measures for evaluating design consistency. These measures include operating speed (commonly represented by the 85th percentile speed), vehicle stability, alignment indices, and driver workload. Gibreel et al. (1999) categorized previous research work into three main areas: (1) speed considerations; (2) safety considerations; and (3) performance considerations. Speed considerations address the different effects of geometric parameters on the prediction of operating speed. Safety considerations explain the different relationship between highway safety and highway/traffic elements, vehicle stability, and low-cost improvements. Performance considerations address the different effects on driver workload, driver anticipation, highway aesthetics, and interchange design. Alan (1998) defined the margin of safety as the difference between safe speed and design speed, where the safe speed was defined as the speed at which the demand side friction just equals the maximum value of side friction.

For a single element, the difference between operating speed V_{85} and design speed V_d is commonly adopted as a measure of speed consistency. The threshold of maximum speed difference on a specific element should not exceed 15 km/h, which is widely accepted in the United States. Design speed and posted speed are often determined based on V_{85} (Leisch, 1977; Lamm, 1988; Lamm, 1995; and Fitzpatrick, 1997). As far as successive elements are concerned, previous studies on speed consistency can be classified into two categories. The first one is aggregate speed-based measures including the difference between operating speeds, ΔV_{85}, and the difference of average speeds, ΔV. These methods draw aggregate sample data from independent population that follow a normal distribution. The other category is the disaggregate measures using individual speed data. $85MSR$ (the 85th percentile maximum speed reduction) introduced by McFadden (2000) and $\Delta_{85}V$ developed by Misaghi (2003) are of this category. Their remarkable finding is that aggregate speed-based measures overestimate safety performance compared with the disaggregate ones.

The primary objective of this study is to introduce a disaggregate safety evaluation method for freeway diverge area. The secondary objective is to compare the relationship between conventional aggregate measure, ΔV_{85}, and the newly proposed measure, $85\Delta V$. The last but not the least is to present a procedure for safety evaluation on different successive elements at freeway diverging area.

COMPARISON OF DISAGGREGATE AND AGGREGATE METHODS

Compared with the disaggregate methods, the conventional aggregate ones have some natural defects, such as ecological fallacy (Freedman, 1999) and overestimation of safety. The operating speed based measures, including the difference in operating speed, ΔV_{85}, and the difference between operating speed and design speed, V_{85} - V_{Design}, are typical representatives of the aggregate measures.

Ecological Fallacy

The so called “ecologic fallacy” describes the phenomenon that what seems true for a group may not be true for the individual, as some information gets lost during the aggregation process (Freedman, 2001; and King, 1997). Using aggregate methods rather than the disaggregate ones maybe misleading. Figure 1 illustrates an example of ecological fallacy. We assume that roadway segment A and B are composed of elements with various radii, and that the average radius is larger for A. Generally, drivers drive faster on the elements with bigger radii. So the speed profile line ascends with the increase of radius, which holds true for both A and B. And the profile line of A is above B. All these phenomena accord with our common sense. However, if we use the aggregate speed measures, such as the average speed or the operating speed, to regress the relationship with radius, the fitting lines descends with the increase of radius, which contradicts with the truth in transportation engineering. The reason for this contradiction results from the aggregation to the speeds on segment A and B. Aggregate speed measures fail to capture the speed attributes of the elements on segment A and B.

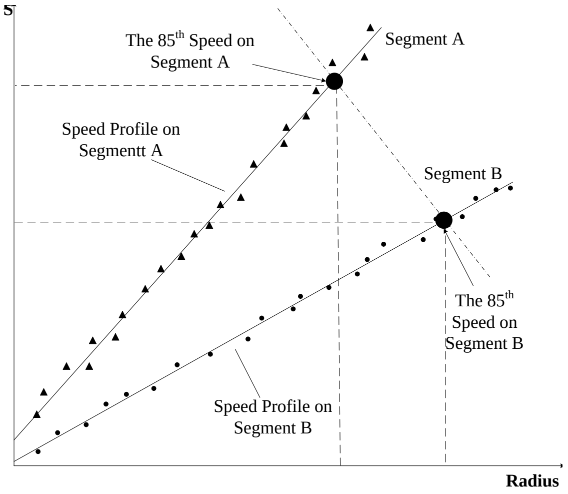

Figure 1 An illustrative example of ecological fallacy

The practical implications of ecological fallacy can be quite serious. Decision-makers may draw misleading conclusion that the operating speed on segment B is higher than that on segment A, and then take no consideration for increasing the radii of some elements on segment B. The consequence is that sharp speed reduction occurs on B and thus a higher risk of crash exists. To avoid ecological fallacy, it is necessary to adopt disaggregate measures if possible.

Relationship between ΔV_{85} and 85(ΔV)

Subtracting the operating speeds on two successive elements produces the operating speed difference, ΔV_{85}, which is expressed as in Equation (1). $V_{1,\,85}$ and $V_{2,\,85}$ are the 85th percentile value of the speed set on element 1 and element 2. To obtain the 85th percentile individual speed difference, 85(ΔV), we first subtract the individual speed of each vehicle on element 1 and element 2 to get the individual speed difference set, and then calculate the 85th percentile value of the individual speed difference set. The expression of 85(ΔV) is given in Equation (2).

$$\Delta V_{85} = V_{1,\,0.85} - V_{2,\,0.85} \tag{1}$$

$$85\Delta V = (V_1 - V_2)_{0.85} \tag{2}$$

Where：

$V_{1,\,85}$ and $V_{1,\,85}$: the operating speed on element 1 and element 2

V_1 and V_2: the individual speed of a single vehicle on element 1 and 2

Young-Jin et al. (2006) deduced their relationship between ΔV_{85} and 85(ΔV) and concluded that $\Delta V_{85} \leq 85(\Delta V)$. If the speed distribution on element 1 and element 2 are strictly identical, ΔV_{85} is equal to 85(ΔV). In reality, however, the distribution is not necessarily identical as the speed varies from location to location, vehicle to vehicle and driver to driver. The 85th percentile driver at the prior element is not necessarily the same 85th percentile driver at the following element either. In this case, ΔV_{85} is smaller than $85(\Delta V)$.

The fundamental differences between ΔV_{85} and $85\Delta V$ stem from (1) the different assumption that $85(\Delta V)$ rather than ΔV_{85} allows dependency between V_1 and V_2 over two elements; and (2) the different data attributes that ΔV_{85} is aggregate and $85(\Delta V)$ disaggregate. The theoretical basis of $85(\Delta V)$ is superior to that of ΔV_{85}. In other words, the measure $85(\Delta V)$ is more reasonable and capable in capturing the inherent characteristics of driving behavior. Poe et al. (1996) concluded that the aggregate measure fails to recognize the speed distribution in each curve and also inflates the coefficient of determination (R^2). The level of explanation of an aggregate model indicates adequacy but inadequate for a disaggregate model.

The conclusion $\Delta V_{85} \leq 85(\Delta V)$ implies that ΔV_{85} underestimates the speed difference thus overestimate the speed consistency and safety performance. Using ΔV_{85} to evaluate safety level may mislead decision-makers to accept inconsistent unsafe elements. As a result, potential hazardous location or elements may be unattended.

DATA COLLECTION

Procedure

The freeway diverging area and its influencing area are divided into four elements, namely the upstream mainline, diverging area, downstream mainline and exit ramp. Individual speeds are collected using radar guns at the four elements following the procedure below:

(1) Pre-investigation: search candidate diverging areas on Google Earth.
(2) Speed-taking location determination: point speeds of individual vehicles are shot by radar guns at the location from ① to ④, as shown in Figure 2.
(3) Observer assignment: assign two observers for each lane at each location. One is the radar-gun holder and the other the recorder. The radar-gun holder is in charge of shooting speed, reading the last three digits of plate number, and informing the recorder of the information.
(4) Record match: The last three digits are for record match. It is a valid record if and only if the last three digits recorded at the locations ①, ②, ③ or ①, ②, ④ are the same. Otherwise, it is a mismatch, which should be discarded.
(5) Traffic counting: An additional observer is located near the diverging area to count both the through and exiting traffic volume. This is an important task as the speed consistency measures are not a good tool to assess the safety performance for congested traffic conditions. The traffic volume collected is to calculate the volume-to-capacity ratio and so as to determinate whether the level of service is equal to or better than level C, which describes at or near free-flow operations. If the operations go worse to level D, the flow becomes unstable (TRB, 2010). The volume of heavy vehicles is also counted to obtain pcu (per car unit).

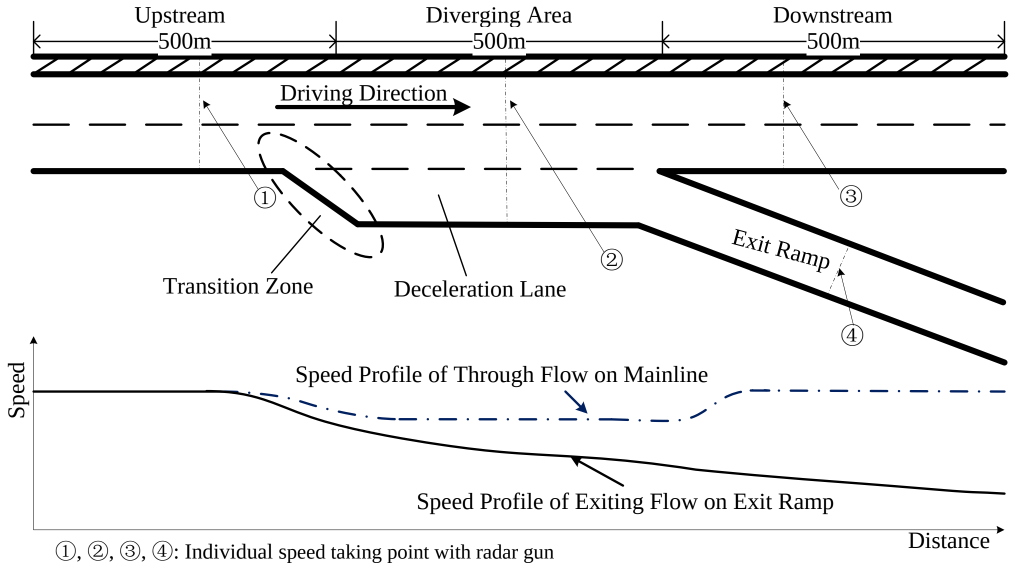

Figure 2 Influencing area division and individual speed collection scheme

Site Selection

The following criterion is imposed for site selection:

- Free flow condition: traffic are running at level A, B or C to ensure that the vehicle speed is not significantly affected by other vehicles in the flow.
- Low traffic volume: volume ≤ 1000 vehicle per hour per lane;
- Parallel exit type: the upstream and the deceleration lane is connected by a transition zone, which is common along the freeway G42, as is shown in Figure 2;
- Number of lanes on mainline = 2, and 1 deceleration lane at the diverging area ;
- HOV%: ≤ 6%, which is to limit the effects from heavy vehicles.
- No abnormal conditions cause sharp speed change: such as bad sight distance;
- Other general conditions: marked pavement with constant lane width, super elevation and grade are within the range controlled by ramp design guidelines.

With the criteria above, 21 diverging areas along the freeway G42 and G2501 in Nanjing, China were chosen as target sites. Geometric information (length of deceleration lane, length of ramp, number of lanes, and radius of ramp) was measured on Google Earth. The duration for speed collection at each site was 2 hours.

Effects of Using Radar Guns

Although radar gun is economical and convenient for speed collection, biases exist due to personal error and device error. There are mainly two concerns of using radar gun while taking speed. The first one is the effect of presence on passing vehicle. Drivers are very likely to reduce their speeds if they notice someone is taking speed with a radar gun. Misaghi (2003) found that the speed reduced 7km/h if a radar gun was exposed. In this paper, the difference is 7.6 km/h for deceleration lane and 5.5 for exit ramp. The similar results indicate that the presence of radar gun imposes speed reduction on passing vehicles, and that the radar guns should be hidden well enough to minimize the adverse impacts. Our study also shows that the difference between real speed and the speed taken with radar guns well hidden is not significant if angle between the shooting direction and driving direction is less than 15^{o}.

The second concern is the systematic error generated by the existence of angle between radar gun and driving direction while taking speed. If the radar gun is in a direct line with the driving direction, the measured speed is exact. In practice however, if you move the radar gun off the centerline, the measured speed will decrease. This phenomenon is called the Cosine effect as the measured speed is directly related to the cosine of the angle between the radar gun and the target's direction of travel. The larger the angle is, the bigger the error. If the angle is smaller than 15^{o}, the radar gun corrects the Cosine effect by itself. If larger than 15^{o}, we correct it by dividing a Cosine value.

Data

In this study, the individual speed data together with traffic volume, geometric information of 21 sites are collected. The volume-to-capacity ratio ranges from 0.25 to 0.55, which shows that the LOS is better than level C. Table 1 summarized the speed measures for the three linkages.

Table 1 Summary of speed measures for three linkages

Sections	Volume(veh/h)	V_{85}(km/h)	ΔV_{85}(km/h)	$85(\Delta V)$(km/h)	$85(\Delta V)/\Delta V_{85}$
Upstream	1077~2164	74.4~92.8	5.6~32.8	9.8~54.0	1.2~4.6
Diverging	1077~2164	66.3~87.6	-2.7~9.9	-3.7~17.0	1.1~2.3
Downstream	934~1825	69.2~90.3	6.0~24.5	17.3~29.6	1.6~2.9
Ramp	283~519	25.5~57.7			

The ratios of $85(\Delta V)/\Delta V_{85}$ on the three linkages range from 1.1 to 4.6. This is strong evidence that the individual speed difference is always greater than the operating speed difference. As the speed attributes captured using individual speed measures is more persuasive, $85(\Delta V)$ is recommended as speed consistency measure.

METHODOLOGY

Aggregate Measure- V_{85} and ΔV_{85}

With the individual traceable speeds collected at each section, the operating speed, V_{85}, for upstream section, diverging area, downstream section and exit ramp can be obtained by calculating the 85th percentile value of the individual speed data set. The difference of operating speed, ΔV_{85}, is produced by subtracting the operating speed of successive elements. Together with the geometric information (number of lanes, length of deceleration lane, length of exit ramp, radius of ramp, etc.) and traffic parameters (speed limit on mainline/exit, volume on mainline/exit), the operating speed at the diverging area is regressed in SPSS as follows:

$$V_{85\_\mathrm{DIV}} = -58.138 + 2.013 V_{85\_\mathrm{UP}} - 0.207 L_{\mathrm{DIV}} \qquad R^2 = 0.962 \tag{3}$$

The operating speed differences for the three linkages are given as:

$$\Delta V_{85,\ \mathrm{UP\text{-}DIV}} = 58.138 - 1.013 V_{85\_\mathrm{UP}} + 0.207 L_{\mathrm{DIV}} \qquad R^2 = 0.943 \tag{4}$$

$$\Delta V_{85,\ \mathrm{DIV\text{-}DOWN}} = -58.138 + 1.082 V_{85\_\mathrm{UP}} - 0.207 L_{\mathrm{DIV}} \qquad R^2 = 0.928 \tag{5}$$

$$\Delta V_{85,\mathrm{DIV\text{-}RAMP}} = -112.365 + 2.013 V_{85\_\mathrm{UP}} - 0.207 L_{\mathrm{DIV}} + \frac{1286.172}{R} \qquad R^2 = 0.905 \tag{6}$$

where:

$V_{85\_\mathrm{UP}}, V_{85\_\mathrm{DIV}}$: the operating speed on upstream mainline, diverging area;

$\Delta V_{85,\ \mathrm{UP\text{-}DIV}}$, $\Delta V_{85,\ \mathrm{DIV\text{-}DOWN}}$, $\Delta V_{85,\ \mathrm{DIV\text{-}RAMP}}$: the operating speed difference of the upstream-diverge linkage, diverge-downstream linkage and diverge-ramp linkages;

L_{DIV} : the length of diverging area;

R : the radius of exit ramp.

Disaggregate Measure-85(Δ*V*)

The four parts adjacent to the diverging area constitute three successive elements, upstream-diverging linkage, diverging-downstream linkage, and diverging-exit linkage. The 85th percentile individual speed differences for the three linkages are modeled respectively.

For the upstream-diverging linkage and diverging-downstream linkage, they are considered as a tangent followed by another tangent. For the diverging-ramp linkage, it is treated as a tangent followed by a curve.

$$85\Delta V_{\mathrm{UP\text{-}DIV}} = 59.635 - 0.971 V_{85\text{-}\mathrm{UP}} + 0.146 L_{\mathrm{DIV}} \qquad R^2 = 0.843 \tag{7}$$

$$85\Delta V_{\mathrm{DIV\text{-}DOWN}} = -55.376 + 1.115 V_{85,\ \mathrm{UP}} - 0.158 L_{\mathrm{DIV}} \qquad R^2 = 0.802 \tag{8}$$

$$\Delta V_{85,\ \mathrm{DIV\text{-}RAMP}} = -108.163 + 2.117 V_{85\_\mathrm{UP}} - 0.195 L_{\mathrm{DIV}} + \frac{1194.255}{R} \qquad R^2 = 0.776 \tag{9}$$

Where:

$85\Delta V_{\mathrm{UP\text{-}DIV}}, 85\Delta V_{\mathrm{DIV\text{-}DOWN}}$ and $\Delta V_{85,\ \mathrm{DIV\text{-}RAMP}}$: the 85th percentile individual speed difference for the three linkage mentioned above.

All the variables are significant under 95% confidence level. It is noteworthy that the coefficients of determination of the individual speed difference models are smaller than that of the operating speed difference models. This result is in line with the conclusion drawn by Poe et al. (1996).

Safety Evaluation

Here we use the criterion below suggested by Lamm et al. (1995) to evaluate the design and LOSS (level of service of safety) of successive elements.

- Good design (safe): $\Delta V_{85} \leq 10$km/h (consistency exists)
- Fair design (Fair): $10 < \Delta V_{85} \leq 20$km/h (minor inconsistency exists)
- Poor design (Poor): $\Delta V_{85} > 20$km/h (strong inconsistency exists)

This criterion is aggregate-based. To compare the difference between aggregate and disaggregate measures, we still use the same threshold values in this paper. The safety evaluation results for the 21 diverging areas using the two different measures are listed in Table 2.

Table 2 Safety Evaluation for Different Linkages Using Three Measures

Safety Level	Upstream-Diverging		Diverging -Downstream		Diverging -Ramp	
	ΔV_{85}	$85\Delta V$	ΔV_{85}	$85\Delta V$	ΔV_{85}	$85\Delta V$
Good	10	7	11	10	11	1
Fair	8	10	10	9	9	14
Poor	3	4	0	2	1	6

From Table 2, we can see that ΔV_{85} produces more good levels than $85(\Delta V)$ does, which is an indication that ΔV_{85} is overestimation-prone.

The following Figure 3 shows the safe zone distribution of the two measures at the diverging-ramp linkage. Three levels of safety are defined according to the Lamm criterion, whose critical threshold values are 10 km/h and 20 km/h.

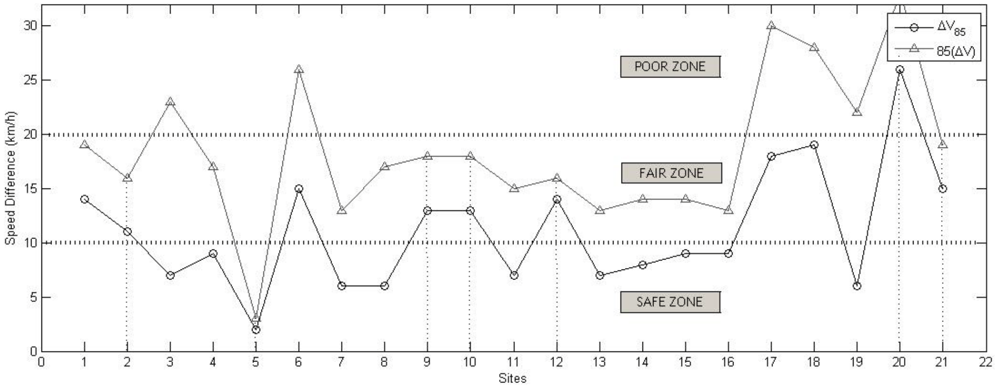

Figure 3 Zone distribution of the two measures at diverging-ramp linkage

The LOSS can be determined easily from Figure 3. If both of the two measures are located in the same safe zone, the safety level is the one in which the measures are located. If the two measures are located in different zones, the LOSS for that site is determined by the higher measure to provide more conservative safety estimate. Generally, for the sites at which the two measures do not reach agreements, we should take the evaluation results of 85(ΔV) as final. Based on this assumption, these sites (3, 6, 17, 18, 19 and 20), which have poor level of safety, require redesign or reconstruction.

SIMULATION AND VALIDATION

As the historical crash data for the 21 diverge areas are not available, the process for model validation is carried out by means of simulation in VISSIM and SSAM, (Surrogate Safety Assessment Model), a powerful conflict analysis tool developed by Federal Highway Administration. The influencing area of each diverging zone starts from the upstream 500 m to the downstream 500 m, including a length of 500 m of the exit ramp. The volume counted in field is assigned to each site.

The trajectory files for the 21 sites, extracted from VISSIM, are exported to SSAM, in which the summary of the total number of conflicts broken down by type of conflicts is output. The four types of conflicts defined in SSAM are (1) Unclassified; (2) Crossing; (3) Rear-end and (4) Lane- change. SSAM utilizes a default TTC value of 1.5 seconds (FHWA, 2008), and a default PET value of 5.0 seconds. As vehicles travel much faster on freeways than on highways, the threshold values are specified smaller, which is 1.2 seconds for maxTTC, and 4.0 seconds for maxPET. The total numbers of the four types of conflicts at each site are then extracted to validate the proposed speed consistency measures. The simulations are run for 10 times to eliminate possible bias that may exist in a single run. The final numbers of conflicts are averaged.

In this study, the total number of crashes per hour (TMC/h) for each site is classified three levels based on the following criterion corresponding to Lamm's criterion:

- Good safety level (G): $TC/h \leq 100$ (small probability of crash occurrence)
- Fair safety level (F): $100 < TC/h \leq 200$ (general probability of crash occurrence)
- Poor safety level (P): $TC/h > 200$ (big probability of crash occurrence)

Based on the field data collected on freeways, the simulated data from SSAM, the speed consistency measures proposed and the appraisal criteria introduced in this paper, the validation results are summarized in Table 3. The values of the two measures are from the diverging-ramp linkage, at which the safety performance is the worst compared with the other two linkages.

Among the LOSS of all the 21 diverging areas, ΔV_{85} and 85(ΔV) are completely consistent with SSAM at 8 sites (1, 2, 9, 10, 12, 20 and 21); 3 sites (3, 16 and 19) have completely inconsistent results. For the remaining 10 sites, 6 (4, 6, 7, 14, 15 and 18) are consistent with 85(ΔV) only and 4 (8, 11, 13 and 17) are consistent with ΔV_{85} only. The statistics shows that 85(ΔV) is closer to the simulation results. Both Table 2 and Table 3 show that the newly proposed disaggregate measure 85(ΔV) is more competitive in safety evaluation.

Table 3 Summary of validation results

Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
TMC/h	143	167	184	71	54	236	123	93	155	196	98	135	89	84	133	278	189	321	174	447	191
LOSS	F	F	F	F	G	P	F	G	F	F	G	F	G	F	F	P	F	P	F	P	F
ΔV_{85}	F	F	G	G	G	F	G	G	F	F	G	F	G	G	G	G	F	F	G	P	F
85(ΔV)	F	F	P	F	G	P	F	F	F	F	F	F	F	F	F	F	P	P	P	P	F
Consistency	√[a]	√	×	※	√	※	※	◇	√	√	◇	√	◇	※	※	×	◇	※	×	√	√

[a]: √=consistent; ×=inconsistent; ※=only 85ΔV is consistent; ◇= only ΔV_{85} is consistent.

PROCEDURE FOR SAFETY EVALUATION USING 85(ΔV)

Below is the procedure for LOSS evaluation of freeway diverging areas using the disaggregate measure, 85(ΔV):

1. Site selection: Preselect candidate sites on Google Earth or Google Map applying the site selection criterion mentioned above.

2. Field investigation: Collect geometry and volume data at each site. Remove the sites that do not meet the site selection criterion

3. Data collection: At each element, three observers are required, with the first one for speed shooting and plate number reading, the second one for data recording, and the third one for volume counting. Make sure that all the observers are well hidden to minimize their presence effects on passing vehicles.

4. Data processing and analysis: Match the records using the last three digits; Calibrate the individual speeds considering the observers' presence effect and the Cosine effect; Calculate ΔV_{85} and 85(ΔV) for the three linkages at each site.

5. Safety evaluation: Assess LOSS for each site using the two measures, ΔV_{85} and 85(ΔV) applying the Lamm criterion.

6. Simulation and validation: Run simulation in VISSIM, and export the .trj files to SSAM. Conduct the conflict analysis in SSAM and output the summary of conflicts and other surrogate safety measures. Validate the measure proposed measures with the total number of conflicts per hour generated in SSAM.

7. Conclusion: Determine LOSS for each site and give suggestions to decision-makers to improve the safety performance for potential hazardous diverging areas.

CONCLUSIONS AND DISCUSSIONS

This paper presented a safety evaluation method for freeway diverging areas based on disaggregate speed consistency. This research was to avoid the pitfalls of conventional aggregate measures including ecological fallacy, overestimation and fail to capture inherent individual driving behavior. The main findings of this paper can be summarized as follows:

The pitfalls (ecological fallacy and overestimation of safety performance) of aggregate speed difference measures are illustrated. Using ΔV_{85} for safety evaluation will produce smaller speed difference and more safe sites. So disaggregate measure are recommended in practice to avoid leaving potential unsafe roadway segments unattended.

The procedure for collecting individual speeds using radar guns is introduced. Although this method is economical and convenient, there are some adverse impacts, such as the speed reduction imposition and the Cosine effect. The data collected in this paper are rectified considering the two effects.

The ratio of $85(\Delta V)/\Delta V_{85}$ varies from site to site, ranging from 1.1 to 4.6. The value is close to 1 if the traffic conditions have no big difference between the two successive elements. This value magnifies when the traffic conditions become diverse and complicated. It is not an unexpected result. The 85th percentile value may get closer after the aggregation, while the individual speed difference corresponds with reality.

This paper presents an alternative validation method when historical crash data is not available. The conflict analysis conducted in SSAM by exporting the .trj files from VISSIM shows that the proposed disaggregate speed consistency measure is more reasonable and persuasive.

Further study is recommended to focus on the following areas: (1) Promoting the application of disaggregate measures in other fields, such as entrance ramp, merging areas and urban roads; (2) Taking traffic volume and personal factors into consideration while modeling; (3) Developing other safety evaluation measures rather than speed based ones for congested traffic conditions; and (4) Quantifying the relationship between crash and conflicts in SSAM.

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