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Risk Assessment by Vehicle Speed Difference in Climbing Lanes

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Abstract : The speed difference in mountainous area is known causing traffic conflicts and accidents. Thus, climbing lanes have popularly been installed in mountainous roads around the world. In the present paper, vehicle speeds within and around climbing lanes of Ho-nam and Jung-ang expressway were collected and evaluated. The evaluation was performed in terms of coefficient of variations which represent dispersion of vehicle speed in climbing lanes. Results show that speed dispersion is more significant at segments before and after climbing lanes than those within climbing lanes. The estimated accident risk was evaluated using The Solomon's u-shaped curve. It was identified that the accident risk is also a lot significant at the same segments as much as 2.2 times greater than those of climbing lanes.

Key words: climbing lane, speed difference, coefficient of variation, traffic accident

1. Introduction

Korea consists of 70% mountainous areas. As road itself needs a network for its efficiency, mountainous areas are inevitably within road networks and specific highway lines. On the other hand, vehicles experience difficulty in being operated in mountainous roads because they have their own powers limited by weights.

Thus, the installation of climbing lanes is needed in mountainous roads while research show that the speed difference in mountainous area is known causing traffic conflicts and accidents.

The research has been diversified about the relationship between speed dispersion and traffic accidents. Park et al. [1] contended that there is reduction of traffic accidents after the point to point speed enforcement which is intended to limit speeding and reduce speed dispersion.

TRB Special Report 254 [2] provided comprehensive research about speed dispersion such that conflicts occur when individual vehicle experiences reduction or acceleration of vehicle speed.

Garber and Gadiraju [3] were interested in speed and accident together and concluded that speed deviation is related to traffic accidents.

There have been empirical studies on the speed deviation. Lamm et al. [4] was interested in highway geometrics and traffic accidents while focusing on the relationship between the speed and geometry. The study also suggested that the variation of highway geometrics is associated with traffic accidents.

Solomon [5] explained probable accident involvement of individual vehicles caused by their difference from the averaged aggregated speed. It was identified that the speed least likely to be involved with traffic accidents is slightly higher than the average speed.

Cirillo [6] provided similar results with Solomon's while adding one more variable to existing research. The variable introduced was highway geometrics. He implied that highway geometrics are much associated with traffic accident likelihood.

Fildes et al. [7] confirmed Solomon's work. It was concluded that a lowered-speed among highly speeding vehicles has higher risks of traffic accidents.

Based on the previous research, it may be indicated that speed difference or variation of highway geometrics is associated with traffic accidents. Thus, the present study was focused on speed dispersion within and near locations of climbing lanes. Additionally, the traffic accidents rate was estimated by the location within and near climbing lanes such a way that the accidents rate from the Solomon's curve is applied to speed dispersion.

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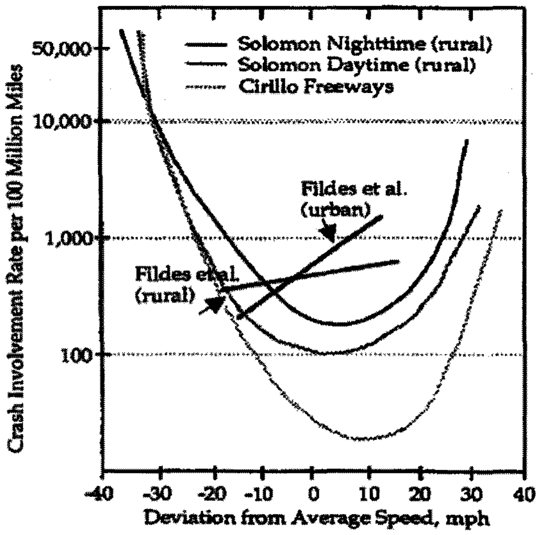

Fig. 1. Solomon's U-shape curve (1964).

2. Methodologies

2.1 Expression of Speed Dispersion

$$\text{Standard Deviation} = \sqrt{\left|\frac{(x_1 - \bar{x})^2}{n}\right|} \quad (1)$$

$$\text{COV} = \frac{\text{Standard Deviation}}{\text{Mean Values}} \quad (2)$$

To express the speed dispersion in the climbing lane, speed dispersion should be characterized into a specific form. As shown in Equation 1, the standard deviation can be a good indicator for speed dispersion because it explains difference between average speed and individual speed. However, it has limitation in application of different level of speed. For example, on two conditions of average speeds of 100 km/h and 5 km/h, one standard deviation of 1 km/h means differently 1% and 20% of the average speeds.

To overcome the disparity, one convenient statistical means was introduced, called coefficient of variation (COV). COV has been widely used in expression of speed dispersion in road safety audits (RSAs). Equation 2 represents COV which is the expression of difference between average speed and individual speed. Now, as COVs is introduced, speed dispersion can be equally weighted and then comparatively evaluated.

2.2 Research Target

This study was performed on climbing lanes of Ho-nam and the Jung-ang expressway lines. Two lines are two-way four lane expressways. The design speed of the two lines is 100 km/h. Most segments of the two lines are located in rural area at which traffic is uncongested and speed dispersion is easily observed.

Table 1. Description of segment

Line	Destination	Location
Ho-nam	North	32.733.4 (0.7 km)
Ho-nam	South	27.225.2 (2.0 km)
Jung-ang	South	290.5289.5 (1.0 km)
Jung-ang	North	289.0290.0 (1.0 km)

2.3 Data Collection Period

Vehicle speeds were collected in 2005. The data was collected by the on-site observation of vehicle speeds of which sampling was standardized. The data is listed on the publication [8] of Korea Expressway Corporation (KEC).

3. Climbing Lanes

3.1 The Definition of Climbing Lane

Climbing lane is defined a graded segment of highway which is located outside lane of highways for lower speeding vehicles to yield the travel way to the faster vehicles. [9] Following types of climbing lanes exists.

3.2 Climbing Lane Installation Standards

(1) Korean Highway Design Guideline

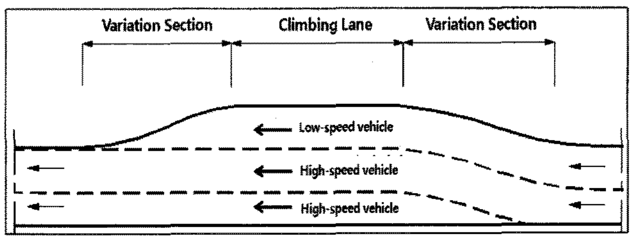

Fig. 2. Climbing lanes.

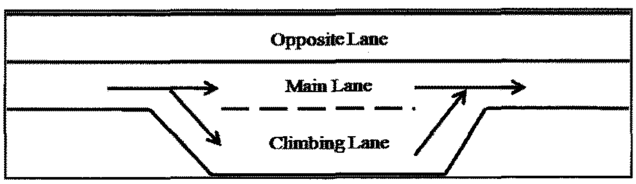

Fig. 3. Climbing lane (type 1).

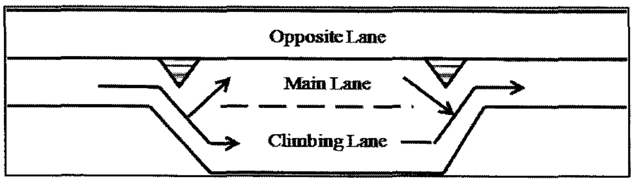

Fig. 4. Climbing lane (type 2).

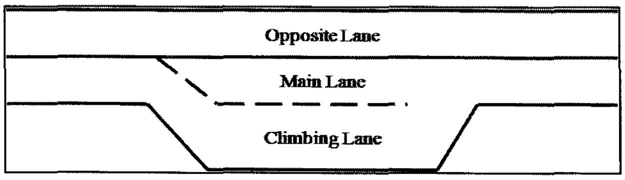

Fig. 5. Climbing lane (type 3).

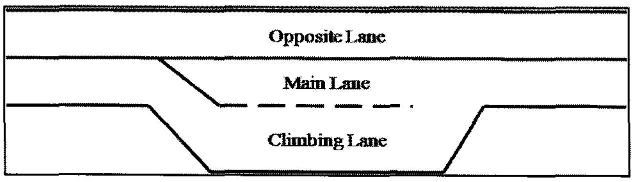

Fig. 6. Climbing lane (type 4).

Korean Highway Design Guideline [9] provides the installation standard. First of all, diagram on relationship between speed and grade should be drawn based on the standard design truck. If the truck speed is less than an allowable speed, the climbing lane begins.

On the other hand, if the speed is recovered to the speed greater than the allowable speed, the climbing lane ends. Conditionally, the length of the climbing lane should be over 500 m. If less, lengthening needed.

(2) AASHTO Green Book

AASHTO Green Book [10] also provides the installation standard. Both of the following conditions should be satisfied to justify a climbing lane:

a. A 15 km/h or greater speed reduction is expected for a typical heavy truck.

b. The service volume on an individual grade should not exceed that attained by using the next poorer level of service from that used for the basic design. The one exception is that the service volume derived from employing Level of Service D should not be exceeded.

If the analysis indicates that a climbing lane is required, an additional check must be made to determine if the numbers of lanes required on the grade are sufficient even with a climbing lane.

(3) Example of Installation

Example of the installation of climbing lanes based

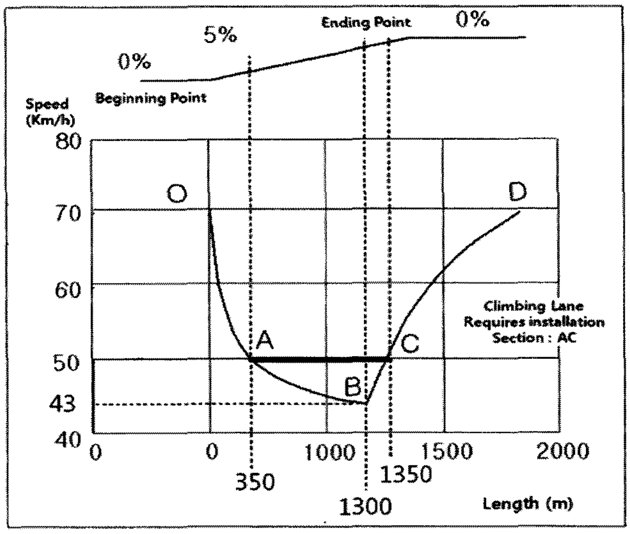

Fig. 7. Example of installation of climbing lane (KHCM, 2004.)

on speed and grade length. [9]

In Fig. 7 the principle of climbing lane installation is explained. For example, when one vehicle is driving the distance from 0 to 350 m, the speed begins at 70 km/h and down to 50 km/h, 20 km down from initial speed. Without the climbing lane, at 1300 m, the speed is down to 43 km/h which is one risky speed due to expected speed dispersion. With the climbing lane the speed at 1300 m is maintained at 50 km/h as well as those at 350 m and 1350 m. Based on the relationship, climbing lane with total length of 1,000 m is necessary.

3.3 The Effect of Climbing Lanes

Climbing lane is to increase the speed of vehicles in crowded or conflicted segments of highway. If a low-speeding vehicle is on the main lane, the lane may be congested and conflicted by following vehicles faster than the low-speeding vehicles. By installing the climbing lane, it is intended to relieve congestion and conflict, and to improve the speed. Furthermore, it is also intended to get the result the consequent reduction of carbon dioxide emissions.

4. Difference in Speed in Climbing Lanes

Speed measurement points were designated based on the distance from the beginning and ending points of a climbing lane.

Speed measurements in a climbing lane were performed at 3 points. Point ① is the point 100 m upstream of a climbing lane. Point ② is the ending

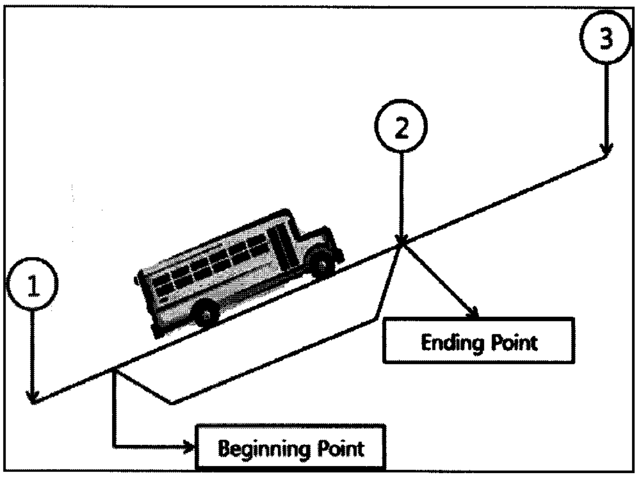

Fig. 8. Speed measurement points.

point of a climbing lane while point ③ is defined at the location 200 m downstream of the ending point.

Table 2 is about measured speeds in climbing lanes in segment 1.

In Table 2, the standard deviation and average were compared location by location or lane by lane. On average speeds, the difference between cars and trucks ranged 10-26 km/h at points 1 and 3 while about 10 km/h at point 2. For calibration of the size of the average speed, the standard deviation and average was transformed to COVs. In Table 3, the trend of COVs are expressed, COVs of passenger cars at lane 2 shows that point 1 is critical in terms of speed dispersion and that the trend is getting narrower as it goes out of the climbing lane. The trends are more significant over COVs of passenger cars at lane 2. These are visually expressed in Fig 9.

When the traffic accidents were estimated following the Solomon's U-Shaped curve, those at point 1 were estimated 2.1 times higher than those at other points.

Table 2. Measured speeds in segment 1

Point	List	Sample	Ave(km/h)	S.D
①	Lane 1, Car	40	106.30	11.90
	Lane 2, Car	40	94.10	13.10
	Lane 2, Truck	5	80.60	4.510
②	Lane 1, Car	50	111.50	10.80
	Lane 2, Car	29	100.90	8.58
	Lane 2, Truck	5	104.20	5.93
③	Lane 1, Car	40	105.65	9.06
	Lane 2, Car	40	103.65	7.55
	Lane 2, Truck	5	86.20	5.07

Table 3. COVs in segment 1

Point	List	COV
①	Lane 1, Car	0.11
	Lane 2, Car	0.14
	Lane 2, Truck	0.06
	Climbing lane Truck	0.08
②	Lane 1, Car	0.10
	Lane 2, Car	0.09
	Lane 2, Truck	0.06
	Climbing lane Truck	0.08
③	Lane 1, Car	0.09
	Lane 2, Car	0.07
	Lane 2, Truck	0.06
	Climbing lane Truck	0.07

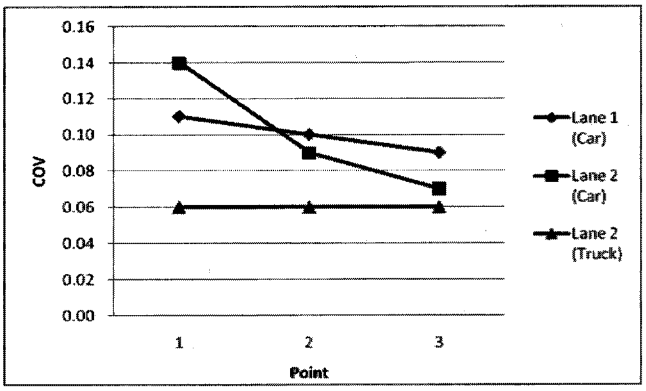

Fig. 9. Trend of COV in segment 1.

Table 4 is about measured speeds in climbing lanes in segment 2.

Table 4, the standard deviation and average were

Table 4. Measured speed in segment 2

Point	List	Sample	Ave(km/h)	S.D
①	Lane 1, Car	40	106.30	10.80
	Lane 2, Car	40	97.00	12.60
	Lane 2, Truck	5	75.20	7.85
②	Lane 1, Car	50	103.26	8.09
	Lane 2, Car	30	92.30	7.72
	Lane 2, Truck	5	90.00	7.38
③	Lane 1, Car	40	104.80	10.10
	Lane 2, Car	40	98.90	7.55
	Lane 2, Truck	5	86.60	5.18

Table 5. COVs in segment 2

Point	List	COV
①	Lane 1, Car	0.10
	Lane 2, Car	0.13
	Lane 2, Truck	0.10
	Climbing lane Truck	0.17
②	Lane 1, Car	0.08
	Lane 2, Car	0.08
	Lane 2, Truck	0.08
	Climbing lane Truck	0.09
③	Lane 1, Car	0.10
	Lane 2, Car	0.08
	Lane 2, Truck	0.06
	Climbing lane Truck	0.13

compared location by location. On average speeds, the difference between cars and trucks ranged a lot great as 18-30 km/h at points 1 and 3 while about 13 km/h at point 2. For calibration of the size of the average speed, the standard deviation and average was transformed to COVs.

In Table 5, the trend of COVs are expressed, COVs of passenger cars at lane 2 shows that point 1 is critical in terms of speed dispersion and that the trend is getting narrower as it goes out of the climbing lane. The trend is more significant over COVs of passenger cars at lane 2.

When traffic accidents were estimated following the Solomon's U-Shaped curve, those at point 1 were estimated 1.8 times higher than those at other points

Table 6 is about measured speeds in climbing lanes in segment 3. In Table 6, the standard deviation and average were compared location by location. On average speeds the difference between cars and trucks ranged a lot great as 20-36 km/h at points 1 and 3 while about 8 km/h at point 2. For calibration of the size of the average speed, the standard deviation and average was transformed to COVs.

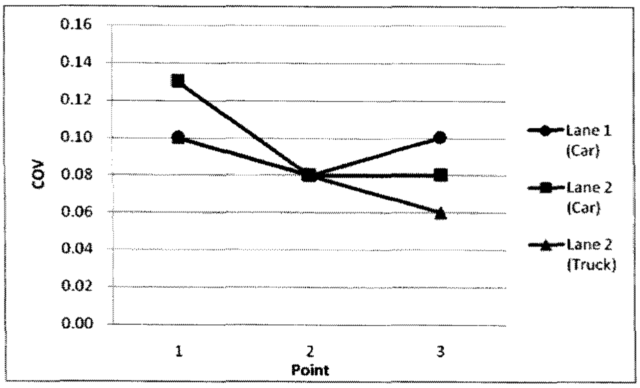

Fig. 10. Trend of COVs in segment 2.

Table 6. Measured speed in segment 3

Point	List	Sample	Ave(km/h)	S.D
①	Lane 1, Car	40	115.50	13.70
	Lane 2, Car	40	96.90	18.40
	Lane 2, Truck	5	79.60	11.70
②	Lane 1, Car	50	117.64	9.12
	Lane 2, Car	30	103.30	11.10
	Lane 2, Truck	5	109.00	10.60
③	Lane 1, Car	40	116.90	7.63
	Lane 2, Car	40	100.20	11.80
	Lane 2, Truck	5	96.60	4.39

Table 7. COVs in segment 3

Point	List	COV
①	Lane 1, Car	0.12
	Lane 2, Car	0.19
	Lane 2, Truck	0.15
	Climbing lane Truck	0.13
②	Lane 1, Car	0.08
	Lane 2, Car	0.11
	Lane 2, Truck	0.10
	Climbing lane Truck	0.11
③	Lane 1, Car	0.7
	Lane 2, Car	0.12
	Lane 2, Truck	0.05
	Climbing lane Truck	0.06

In Table 7, the trend of COVs are expressed, COVs of passenger cars at lane 2 shows that point 1 is critical in terms of speed dispersion and that the trend is getting narrower as it goes out of the climbing lane.

The trends are more significant over COVs of passenger cars at lane 2. These are visually expressed in Fig 11.

When traffic accidents were estimated following the Solomon's u-shaped curve, those at point 1 were estimated 2.0 times higher than those at other points.

Table 8 is about measured speeds in climbing lanes in segment 4. In Table 8, the standard deviation and average were compared location by location. On average speeds the difference between cars and trucks ranged a lot great as 30-40 km/h at points 1 and 3 while about

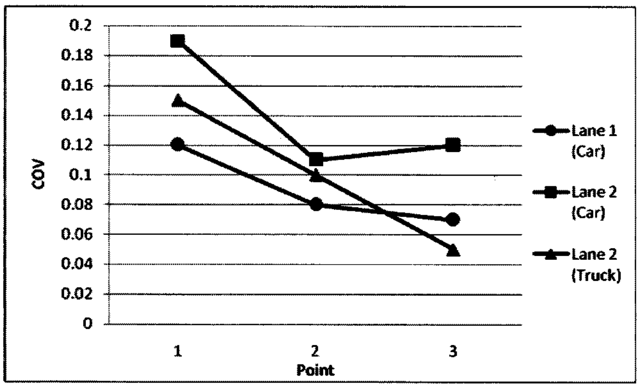

Fig. 11. Trend of COVs in segment 3.

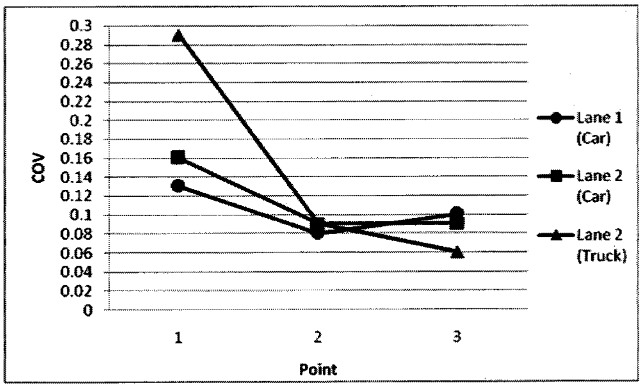

Fig. 12. Trend of COVs in segment 4

28 km/h at point 2. For calibration of the size of the average speed, the standard deviation and average was transformed to COVs.

In Table 9, the trend of COVs are expressed, COVs of trucks and passenger cars at lanes 1 and 2 show that point 1 is critical in terms of speed dispersion and that the trend is getting narrower as it goes out of the climbing lane. The trends are more significant over COVs of trucks at lane 2. Variation of truck speeds in segment 4 is apparent. These are visually expressed in Fig 12.

Table 8. Measured speed in segment 4

Point	List	Sample	Ave(km/h)	S.D
①	Lane 1, Car	40	102.90	13.1
	Lane 2, Car	40	89.50	13.9
	Lane 2, Truck	5	73.20	21.1
②	Lane 1, Car	40	108.70	10.5
	Lane 2, Car	40	99.25	8.76
	Lane 2, Truck	5	86.00	5.52
③	Lane 1, Car	50	114.18	9.28
	Lane 2, Car	30	106.60	10.10
	Lane 2, Truck	5	86.60	7.80

Table 9. COVs in segment 4

Point	List	COV
①	Lane 1, Car	0.13
	Lane 2, Car	0.16
	Lane 2, Truck	0.29
	Climbing lane Truck	0.34
②	Lane 1, Car	0.08
	Lane 2, Car	0.09
	Lane 2, Truck	0.09
	Climbing lane Truck	0.15
③	Lane 1, Car	0.10
	Lane 2, Car	0.09
	Lane 2, Truck	0.06
	Climbing lane Truck	0.10

When traffic accidents were estimated following the Solomon's u-shaped curve, those at point 1 were estimated 3.0 times higher than those at other points.

5. Conclusions

It has been contended that speed difference or variation of highway geometrics is associated with traffic accidents. Thus, much of engineering countermeasures have been focused on reducing speed variance. Climbing lanes are installed in the highway of mountainous area to reduce the speed dispersion between vehicles. The effects of climbing lanes are expected to be uniform over the whole upgrades.

However, still apparently much dispersion has been observed before and after the climbing lane of expressways. Sometime this has led to traffic accidents due to speed conflicts. Thus, the existing speed dispersion around climbing lanes should be clearly defined.

The present study provides speed dispersion, COVs and estimated traffic accidents by 3 points of climbing lanes in 4 segments of expressways. Speed observations were performed at climbing lanes of 4 segments of expressways. The standard deviation and average were compared location by location, lane by lane. On average speeds the difference between cars and trucks ranged as much as 30-40 km/h at points 1 and 3 while about 10 to 28 km/h at point 2. This figures show that these locations are still risky in terms of speed conflicts.

For convenience of calibration of the size of the average speed, the standard deviation and average was transformed to COVs. The trend of COVs of passenger cars show that points 1 and 3 are still risky in terms of speed dispersion and that point 2s are relatively safe. Generally, the trends are consistent over COVs of truck speeds at lane 2.

As traffic accidents were estimated, the accidents at point 1 were estimated 2.2 times higher than those at other points.

This means that it is necessary to identify the new and safer countermeasures in existing climbing lanes. The improvement may be performed into reduction of vehicle speed before and after the existing climbing lane. Another improvement may be increase of length of climbing lane which may be accomplished by increasing the allowable design speed or increasing the performance of the standard design truck.

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