Analysis of High-Fatality Accident on Toll Road and Its Countermeasures (Case Study: Tol Cipularang KM 91)

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Abstract

Traffic accident often occurred on toll-roads in Indonesia. The free flow speed and good road conditions indirectly encourage the driver to drive a vehicle at high speed. However, the driver's inability to control the vehicle at high speed can actually increase the probability of traffic accident. One of the toll roads that is prone to accidents is the Cipularang Toll Road. At the end of 2019, there was a high-fatality crash at KM 91 of the toll road. Moreover, this road section is one of the blackspots of the Cipularang Toll Road. Road geometric factors and vehicle conditions are the main factors for the accidents. The high number of light and heavy vehicles also increases the chance of accidents given the difference in speed and size between the two types of vehicles. Some recommendations that can be implemented to reduce accidents include the application of incident management tools, installation of chevron markers, and construction of escape ramps.

Keywords: toll-road, high-fatality crash, road geometric, escape ramp, blackspot

INTRODUCTION

Traffic accident is one of the main problems of a transportation system particularly in Indonesia. Based on World Health Organization (WHO) in 2014, traffic accidents in Indonesia contribute for 1.2 million death and around 50 million injury (WHO, 2015). All aspect of transportation has the risk of accidents, including toll roads, a road segment dedicated to serving long-distance and high-speed trips. The main objective of toll road development is to provide a freeway network in order to shorten the travel time for road users to their travel destinations. Ironically, the impact of shorter travel time due to high-speed driving, the accident death rate on toll roads in Indonesia reaches 56% of the total accidents (Adelaide, 2011)

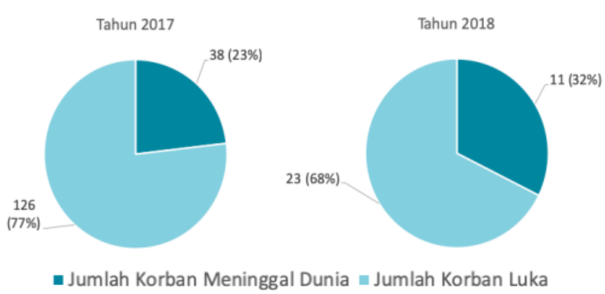

Figure 1. Accident Casualties Composition at Cipularang Tollroad

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The most recent high-fatality crash occurred on the Cipularang Toll Road. Some experts argue that Cipularang toll road is one of the most accident-prone toll roads in Indonesia. The Cipularang Toll Road, particularly between the Jatiluhur Interchange and the Cikamuning Exit Ramp, is the toll road segment with the highest rate of fatal accidents. Based on data from the Integrated Road Safety Management System (IRSMS), there were 38 accidents that occurred on the Cipularang Toll Road (21 fatal accidents) with a total of 38 deaths and 126 injuries. Meanwhile, in 2018, the number of accidents decreased to only 11 accidents (7 fatal accidents) with a total of 11 deaths and 23 injured.

METHODOLOGY

In order to determine the effective and precise recommendations in order to mitigating and preventing traffic accidents, especially in the context of toll roads, it is necessary to have a methodological framework in order to implement the results of the study. The procedure in this research consist of:

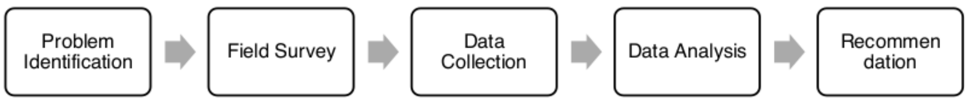

Figure 2. Research methodology framework

1. **Problem Identification**: In this study it was found that there was a high-fatality accident at KM 91. In the identification process, all components involved in the problem need to be observed before carrying out the further study procedure.
2. **Field Survey**: After the problem has been identified, several hypotheses will arise regarding the associated factors towards the problem. In this study, field visits were carried out by visiting the accident site and analyzing the geometric conditions on the road.

Figure 3. Warning sign of the downhill at Cipularang toll road

3. **Data Collection**: Apart from geometric conditions, this study also requires additional data regarding traffic flow conditions on the corresponding toll roads. Therefore, in this

study the data collected consists of traffic volume and vehicle speed. In the context of vehicle speed

a. The survey was conducted on Tuesday, September 10, 2019, 11:00 AM to 2:00 PM. The time is chosen in order to get traffic conditions that are close to the time of the accident.
b. Survey activities include recording vehicle speed using a speed gun and the headway between vehicles using video recording and measurement activities carried out at the laboratory

4. **Data Analysis**: After all the data has been collected, the next process is to analyze the data and find factors that might affect the accident. The analysis process also needs to be based on scientific and credible references.
5. **Recommendation**: Based on the results of the analysis, recommendations or strategies will emerge in order to prevent future problems.

RESULTS

Crash Chronology

On September 2, 2019 at around 12.30, there was a high-fatality accident (Lakajol) at KM 91 of the Cipularang Toll Road. The accident started when two dump trucks travelled from Padalarang to Cikarang through Purbaleunyi toll road. Due to the declining road geometric conditions (KM 91 + 200), the two trucks experienced difficulties in the braking process. A few moments later, the truck in front had a single accident due to difficulties in controlling the vehicle. As a result of this accident, the truck rolled onto the road and blocked the flow of vehicles heading towards Jakarta.

The other vehicles from behind are able to control their respective vehicles and are able to stop before hitting a truck that is stopped due to an accident. However, the latter truck which was also experiencing braking difficulties came from behind and ended up crashing into 17 vehicles which had stopped between the first and the latter truck. The impact of successive collision, the front truck, which was being stopped, rolled towards the left side of the road.

Figure 4. Footage from the high-fatality accident at KM 91

Figure 5. Cipularang toll road

Cipularang Toll Road

Cikampek-Purwakarta-Padalarang Toll Road (abbreviated as Cipularang Toll Road) is a toll road in Indonesia that connects Purwakarta and Bandung districts. This toll road was completed at the end of April 2005. This toll road stretches from Cikampek - Purwakarta to Padalarang. This toll road crosses Karawang Regency, Purwakarta Regency and West Bandung Regency. As a result of located on the mountains area, this toll road have an up and down road geometry and also has many long and high bridges to connect the network between mountains.

Cipularang Toll Road Development is divided into 2 phases, namely:

Phase 1: Cikampek-Sadang (Introduced on 1 Agustus 2003) and Padalarang-Cikamuning (Introduced on 21 September 2003) (17,5 km)

Phase 2: Sadang-Cikamuning (Introduced on 26 April 2005) (41 km)

Toll Road Traffic Accident

Toll roads have an important influence towards the national transportation system, especially as a crossing between regions. Several studies have analyzed the road safety aspect on several toll roads in Indonesia. One of the studies regarding the analysis of accidents on toll roads was conducted by Pradana (2013) who analysed blackspots location on the Serang Timur - Merak toll road section KM 72 - KM 98. Using the *Accident Equivalent Number* Method, the authors identified several blackspots on the toll road segment namely KM 73, 74, 77, 78, 88, and 91 (Pradana, Budiman, & Andriyani, 2013). Another crowded toll road segment is the Jakarta - Bogor - Ciawi (Jagorawi) toll road, which is one of the first toll roads in Indonesia. A study has identified road segments that are classified as blackspots, precisely at KM 8-9, KM 33-37, and KM 39-43 (Darmawan & Arifin, 2020). As a freeway or expressway, accidents that occur on toll roads are closely associated to high speed. Moreover, a traffic accident that associated with speed, particularly high-speed collision, will increase the probability of a fatal accident occurrence and resulting on the number of death victim.

Accidents that occur on expressways not only occur in Indonesia but also occur in other countries. For example, a research carried out in India using GIS-based software, the authors can identify the location of the blackspot on the freeway, more precisely at KM 119 - KM 120 on the NH (National Highway) 58 section (Apparao, Mallikarjunareddy, & Raju, 2013). Another study in the same country is also trying to pinpoint the location of blackspots on the National Highway. In this study, the authors visit the corresponding road segment in order to collect the required data. After that the authors used three methods to determine the location of the blackspot, namely, the Method of Ranking, the Accident Density Method, and the Weighted Severity Index Method. (Sorate, et al., 2015)

Road Geometric Condition

Based on the results of observations to accident site, there is work on the west side of the road at KM 91 therefore, the work may potentially disrupt the traffic flow. The observation also found several problems that could trigger the accidents such as limited signs and lack of traffic management. Even though there was a vehicle entered the work zone during the accident, there was no casualties from workers because the time of the accident coincided with the workers break time.

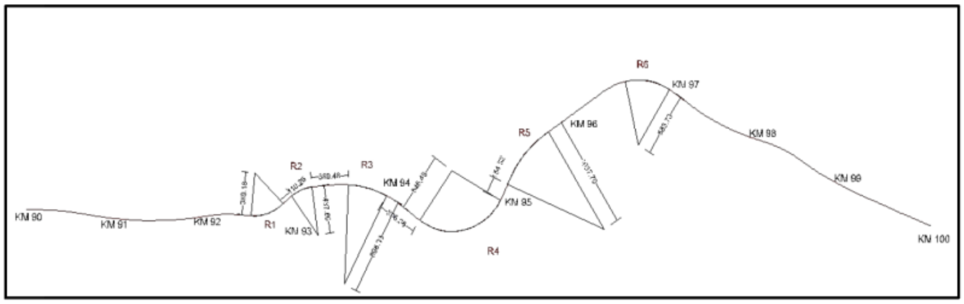

Figure 6. Horizontal Alignment of Cipularang Toll road Segment KM 90 - 100 (Pratama, Siregar, & Marino, 2017)

The KM 90 - 100 segment of the Cipularang Toll Road has more than 7% slope, which exceeds the maximum allowable slope limit of DGH standards (6%) for roads with a design speed of 80 km / h and a critical ramp of 500 meters. In terms of horizontal alignment, the Cipularang toll road segment has met Bina Marga standards. However, the coordination between vertical and horizontal alignment is not well-design, there are turn section with a large slope. which able to trigger a traffic accident (Pratama, Siregar, & Marino, 2017).

Vehicle Speed Data

The observation shown quite reasonable results since the light vehicles speed is higher than heavy vehicles on both uphill and downhill roads. In fact, at KM 93, heavy vehicle only has an average speed of 39.34 km/hr, much lower than other average values.

Table 1. Observed Vehicle Speed Data

Data	**KM 91**				**KM 93**			
	South (Bandung) Uphill		**North (Jakarta) Downhill**		**South (Bandung) Uphill**		**North (Jakarta) Downhill**	
	LV	**HV**	**LV**	**HV**	**LV**	**HV**	**LV**	**HV**
No. of obs. (n)	120	120	50	50	110	110	110	110
Mean	76,83	58,31	81,48	70,32	64,31	39,34	66,80	55,26
Std. Deviation	15,00	14,98	11,16	10,65	13,68	13,89	12,86	11,41
Minimum	32,00	22,00	57,00	45,00	26,60	13,70	25,40	24,80
Maximum	120,00	91,00	111,00	95,00	97,50	69,00	104,50	82,30
85%-ile	92,00	75,00	93,65	83,55	75,93	53,86	80,20	67,49

Data collection on KM 91 also found that the average speed of light vehicles was 81 km/h and 77 km/hour for downhill and uphill road respectively. This is interesting since the geometric conditions only affect 4 km/h speed differences. Therefore, it can be assumed that the vehicle starts to slow down on downhill road. Whereas the average heavy vehicles speed is 70 km/h and 58 km/h for downhill and uphill road respectively. In other words, there is a difference of 12 km/h speed between downhill and uphill.

The other important value is the minimum and maximum speed on the observation. In Table 1, the smallest value is 13 km / hour which is the speed of heavy vehicles when climbing at KM 93. This value is far below the minimum speed limit for toll roads. On the other hand, the highest speed during the observation occurred when a light vehicle drove at a speed of 120 km / hour passing the KM 91. With the uphill road conditions do not affect the driver as the vehicle continues to accelerate on a high speed.

Lastly, the observation of 85th percentile. The 85th percentile value describes the majority of the vehicles on the toll road. Based on table 1, the heavy vehicles speed on downhill road at KM 91 is reaching 83.5 km/h. Those value is quite high considering the downhill road geometry. If the driver is not able to brake properly, the probability of an accident will increase.

Table 2. Observed Speeding Vehicle Speed Data

Data	KM 91				KM 93			
	South (Bandung) Uphill		North (Jakarta) Downhill		South (Bandung) Uphill		North (Jakarta) Downhill	
	LV	HV	LV	HV	LV	HV	LV	HV
$n_{speeding}$	55	11	27	8	12	0	18	1
	45,83%	9,17%	54,00%	16,00%	10,91%	0,00%	16,36%	0,91%
$mean_{speeding}$	89,75	86,00	89,78	89,63	85,78	-	85,59	82,30
$Stdev_{speeding}$	8,24	3,71	7,09	2,56	4,66	-	5,94	-
85%-ile	96,90	90,00	96,00	90,00	89,26	-	88,75	82,30

Table 3. Observed Slowness Vehicle Speed Data

Data	KM 91				KM 93			
	South (Bandung) Uphill		North (Jakarta) Downhill		South (Bandung) Uphill		North (Jakarta) Downhill	
	LV	HV	LV	HV	LV	HV	LV	HV
$N_{slowness}$	14	68	1	7	38	102	34	71
	11,67%	56,67%	2,00%	14,00%	34,55%	92,73%	30,91%	64,55%
$mean_{slowness}$	51,57	48,09	57,00	56,29	49,60	37,42	52,20	48,74
$Stdev_{slowness}$	7,27	9,28	-	5,19	9,16	12,51	6,97	8,19
85%-ile	58,05	57,95	57,00	59,00	58,29	51,29	57,71	56,45

Tables 2 and 3 illustrate the speed data for vehicles that exceed the maximum speed limit and are below the minimum speed limit. At the uphill road, light vehicles tend to accelerate in order to maintenance the high speed. On the other hand, at the downhill road, the driver will tend to reduce speed to reduce the probability of accident. However, the significant differences between light vehicle and heavy vehicle speed on the uphill section may increase the probability of fatal accident if the driver does not behave properly.

At KM 93, There are about 92% of heavy vehicles passing KM 93 that are below the minimum speed limit with an average speed of 37 km/h. Meanwhile, on the same segment, 10% of light vehicles reach the speed of 85 km/h. This significant difference is considered quite dangerous if an accident occurs.

Figure 7 shows speed distribution which is assumed to be normal distribution. As expected, light vehicle speed distribution will always be higher than heavy vehicle. At KM 91, many light vehicles tend to exceed the maximum speed limit and only few heavy vehicles exceed the maximum speed limit. However, quite the opposite happened at KM 93. Only a small proportion of light vehicles passed the maximum limit. Moreover, almost no heavy vehicle that exceed the maximum speed limit.

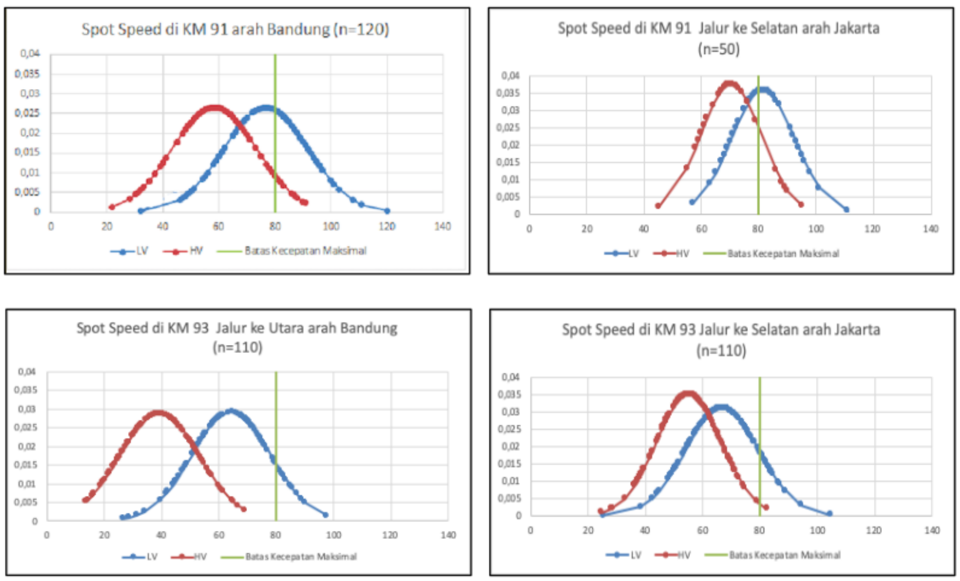

Figure 7. Observed speed distribution

ANALYSIS

In 1981, Göran Nilsson developed a model that describe the relationship between speed and the probability of accident. Based on the model, it is possible to approximate the probability of an accident regarding to the speed (Nilsson, 1981). Speed is still the most consistent factor on traffic accidents (Siregar, 2018). The speed limit threshold is 80 km / h. therefore the probability of accidents, especially fatal accidents, will indirectly decrease if the drivers are driving below 80 km / h. The slope of the model will get steeper as the accident severity increases. Fatal accidents have the steepest gradient, indicating a close association between speed and fatal accidents.

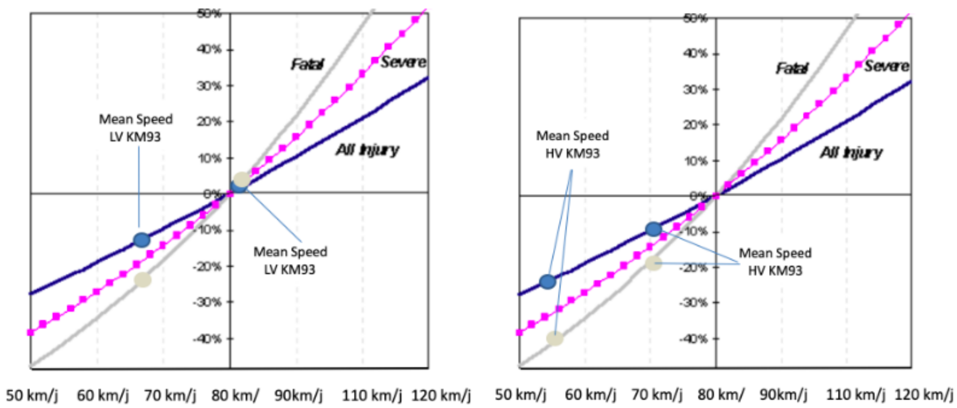

Figure 8. Nilsson Power Model

As stated before, the average speed at KM 91 tends to be higher than KM 93 for both light and heavy vehicles. An increasing average speed of light vehicles can increase the risk of accidents by 12% (all types of accidents) and 22% (fatal accidents). This is due to the significant relationship between high speed and fatal accidents. In terms of heavy vehicles, the increase in speed has an impact on an increase accident risk about 14% (all types of accidents) and 23% (fatal accidents). Therefore, speed limit or management will greatly affect the accident prevention efforts.

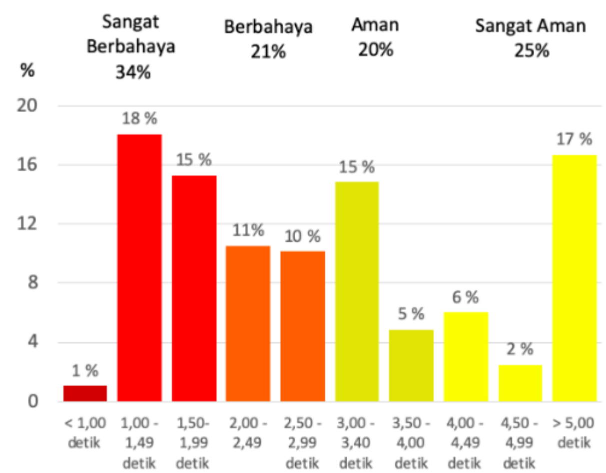

Figure 9. Vehicle Headway Distribution

Figure 9 shows the observed headway distribution. The level of danger classification based on the headway time, namely Very Dangerous (0-2 seconds), Dangerous (2-3 seconds), Safe (3-4 seconds), Very Safe (> 4 seconds). The classification based on PIEV time. PIEV stands for Perception, Intellection, Emotion, and Volition. In general, PIEV time is the time that driver need to react before braking. The average PIEV time was 2.5 seconds. Therefore, a headway that is below 2.5 s is a dangerous headway.

Based on observations, about 34% of vehicles have a very dangerous headway. In fact, about 1% of vehicles have an unacceptable headway (1 second), which is equal to half of average PIEV time. Therefore, it is unlikely for the driver to response in time to prevent a crash. In addition, law enforcement needs to implement a demerit system to reduce the accident fatality rate. In the demerit system strategy, the driver with very dangerous headway cannot be tolerated and must get a progressive penalty. While, the other 33% driver will also receive penalties which may be lower but still provide a deterrent effect.

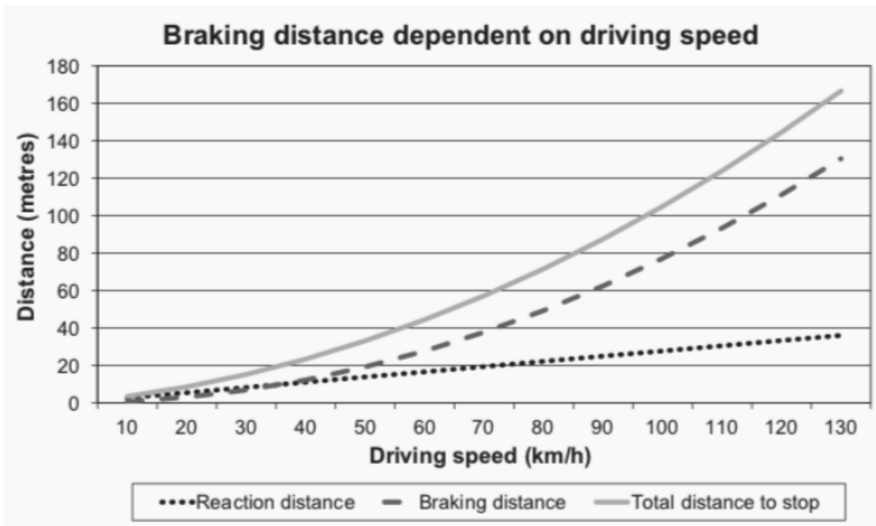

Figure 10 Braking distance dependent on driving speed

In Indonesia, the recommended headway value is 3 seconds (0.5 seconds greater than the average PIEV time). Figure 10 shows the relationship between speed and stopping distance of a vehicle. The line depicting the braking distance tends to move exponentially as speed increase, while the reaction distance tends to be linear. Reaction distance are affected by driver visibility. Faster vehicle will reduce the driver visibility scope. Therefore, drivers will tend to have longer reaction times and resulted in longer reaction distances. Meanwhile, the braking distance is very dependent on speed. The vehicle ability to decelerate has a quadratic function as the faster vehicle will have farther braking distance.

RECOMMENDATION

In order to prevent and reduce traffic accidents on toll roads, there are several recommendations and strategies that can be implemented:

1. Implementation of Toll Road Incident Detection and Automatic Signaling as a Smart Toll System. The main idea is the capability of the toll road on detecting incidents that occur and can automatically give a warning for other drivers regarding the incident. These systems include Overhead Variable Message Signs (OVMS) and cameras installed along the roads. In other words, this system may reduce the driver's smartphone usage.

(a) (b)

Figure 11. (a) *Chevron marking* and (b) *Escape Ramp*

2. Implementation of Chevron markings along the toll roads. The chevron marking aims to provide a visual representation of recommended distances between vehicles. Drivers can estimate the allowable distance according to chevron markings. In accordance with the recommended headway standard for toll roads in Indonesia of 3 seconds, the chevron marking position can be adjusted to the distance required by the vehicle at a certain speed (recommended speed of 80 km / hour) to stop perfectly in 3 seconds.
3. Construction of Runaway / Escape Ramp and Climbing Lane to anticipate the vehicle braking failure. The escape ramp can be made parallel to the shoulder of the road. Moreover, the recommended material for the escape ramp is to use a sand trap with loose aggregates. In addition, there should be a regular supervision to prevent the escape ramp to be crusted.

CONCLUSION

The Cipularang Toll Road is one of the toll roads with high accident rate in Indonesia. As a toll road that connects several activity centers, especially in Java, there are various vehicle accessing the road. The mountainous road geometric are prone to accidents on the Cipularang Toll Road. Several accidents at the Cipularang Toll Road were related to braking failure on heavy vehicles or the inability of drivers to control the vehicle at high speeds. Therefore, several strategies need to be taken to prevent and reduce the number of accidents. One of the strategies is the implementation of the Toll Road Incident Detection, Chevron markings, and the construction of escape / runaway ramps and climbing lanes.

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