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Freeway deceleration lane lengths effects on traffic safety and operation

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ABSTRACT

Until now, the findings of impacts of deceleration lane lengths on safety were not quite consistent or were even contradictory. A comprehensive study was needed to have a better understanding of the effects of different deceleration lane lengths on traffic safety and operations. This study has three objectives: (1) evaluate the safety performance of different deceleration lane lengths at freeway diverge areas; (2) examine the operational effects of deceleration lane lengths for two design types (one-lane exits with parallel/tapered designs and two-lane exits with parallel design); and (3) select optimal deceleration lane lengths by combining the results from safety and operation aspects. A total of 218 sites, categorized into nine groups, were selected for the crash analysis. Additionally, 360 simulation models were developed for different scenarios by the combination of the exit types (one-lane exits/two-lane exits), design speeds, exiting volumes, and number of through-lanes.

The safety and operational analysis results suggest that (1) for one-lane exits, a minimum deceleration length of 500 ft is essential for the design speed of 55 mph, 600 ft for the design speeds of 60 and 65 mph, and 700 ft for the design speed of 70 mph; (2) for two-lane exits, the minimum deceleration length of 500 ft is suggested for the design speeds of 55 mph and 60 mph, 600 ft for the design speeds of 65 and 70 mph; and (3) for both one-lane and two-lane exits, deceleration lane lengths longer than 700 ft are not recommended from a safety perspective. The results of this study could be used as a supplementary to the current design guideline.

1. Introduction

Although the deceleration lane contains less than 1% of total freeway mileages (FHWA, 2010; NCHRP, 2012), it was found to be more risky than the freeway mainline section. According to a recent National Cooperative Highway Research Program (NCHRP) study, the average crash rate at freeway deceleration lane sections was 0.68 crashes per million vehicles miles traveled (MVMT) in a three-year time frame (2004–2006) at 550 selected locations. The crash rate was 20% higher than that at freeway mainline section near exit ramps (0.58 MVMT), and three times higher than that at acceleration lane (0.18 MVMT) (NCHRP 2012).

The freeway ramp and its vicinity area are essential components in the highway system and the safety performance at these areas is critical to the overall system performance. When traffic approaches freeway diverge areas, exiting vehicles need to diverge to the deceleration lanes to exit freeway mainlines. To meet both traffic safety and operation requirements, it is important to select the appropriate deceleration lane length for exiting vehicles to complete sequential maneuvers.

Generally, exiting vehicles need a sufficient distance to gradually decrease speed and minimize the disruptions to through-traffic. If the length is not long enough, it is more likely that rapid speed changes or deceleration maneuvers would occur on the mainline thus affecting through traffic (El-Basha et al., 2007; Hunter et al., 2001). Additionally, a longer deceleration lane could increase the capacity so that congestion or spill-back from exit ramps can be relieved under peak traffic conditions. On the contrary, it is not safe, feasible and cost-effective in practice if the length is excessively long. Garcia and Romero's study (2006) found many vehicles do not initially decelerate and even in some cases, a vehicle surpasses other vehicles on the mainline sections if the deceleration lane is too long, which also increases the crash risk. A comprehensive study is needed to have a better understanding of the effects of various deceleration lane lengths on traffic safety and operations in highway system.

Thus, this study has three objectives: (1) evaluate the safety performance of different deceleration lane lengths at freeway diverge areas; (2) examine the operational effects of deceleration lane lengths for two design types (one-lane exits with

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parallel/tapered designs and two-lane exits with parallel design); and (3) select optimal deceleration lane lengths by combining the results from safety and operation aspects.

The rest of the paper is organized as follows: Literature review, Data Collection and Methodology, Data analysis, and Conclusion. A comprehensive literature review is presented followed by a detailed discussion of data collection efforts. The data analysis section lists the results from safety and operational perspectives respectively, and provides the guidelines. The conclusion summarizes the key findings and recommendations of this research.

2. Literature review

From the safety aspect, during the past decades, though several studies (Bared et al., 1999; FHWA, 2005; Garcia and Romero, 2006; Hunter et al., 2001; Lundy, 1967; McCartta et al., 2004) have focused on investigating the impacts of deceleration lane lengths on safety; the conclusions from these studies were quite inconsistent or even contradictory.

It was long believed that increasing the length of deceleration lanes would reduce crashes (Bared et al., 1998; Cirillo, 1970; Lundy, 1967; Wang et al., 2009). Lundy (1967) found that a higher percentage of crashes occurred on the deceleration lanes than the freeway mainline sections; thus, a longer deceleration lane length was recommended. Bared et al. (1999) estimated the impact of both the acceleration and deceleration lane lengths by using a negative binomial (NB) regression models. The results indicated that it is beneficial to provide longer speed-change lanes. Cirillo et al. (1970) concluded that a 900 ft or longer deceleration lane length would reduce traffic friction, and thus reduce accidents rates, although most deceleration lane lengths are less than 800 ft (Chen et al., 2009; Garcia and Romero, 2006) in practice.

However, another study conducted by Garcia and Romero (2006) found that a long deceleration lane would encourage drivers accelerate before they exit the deceleration lanes. As a result, if the distance is too long, an acceleration maneuver often appears before drivers start braking on the deceleration lanes. In addition, they also found the percentage of return vehicles is higher while the deceleration lane length increases. Consequently, it would increase crash risks at freeway diverge areas. These results are also consistent with two of the most recent studies on this topic (Chen et al., 2009, 2011). The crash predictive models indicated that crash counts increase with the increase of the deceleration lane length. Some aggressive drivers would use it as a general purpose lane (GPL) instead of a deceleration lane for passing or lane changing purpose. Thus, using a longer deceleration lane would create more weaving maneuvers. Further investigation is needed to discover the effects of deceleration lane lengths on traffic safety.

From the operational perspective, exiting vehicles need an optimaldistance to gradually decrease speed and minimize the disruptions to through-traffic. El-Basha et al. (2007) examined driver behaviors at 13 freeway diverge areas in the city of Ottawa, Canada. The regression model indicated that a longer deceleration lane length would allow higher diverge speeds and thus reduce the differential speeds between those vehicles traveling through and those diverging to deceleration lanes. But the model did not include the exiting volume which is highly related to the deceleration lane lengths. The exiting volume is an essential consideration to determine the deceleration length. If the exiting volume is high and the deceleration distance is insufficient, the early decelerating will occur far beyond the beginning of the taper, resulting in a delay for the freeway mainline flow. If few vehicles exit with a long distance, besides the cost-effectiveness consideration, a large speed differential between those exiting vehicles entering the deceleration lanes and those approaching exits can be observed. Some through-vehicles may even take it as a GPL for aggressive driving maneuvers.

The American Association of State Highway and Transportation Officials (AASHTO, 2011) Green Book presents the minimum deceleration distances measuring from the point of the added lane attaining 12 ft for a parallel design or a 12 ft right wedge for a tapered design to the point where alignment of ramp roadways begins, as shown in Fig. 1. Past studies (El-Basha et al., 2007; Hunter et al., 2001) have led to some recommendations on the AASHTO acceleration lane length measurement based on traffic operational effects. Hunter and Machemehl (2001) evaluated six entrance ramps by videotaping the operational features, including traffic speeds on freeways and ramps, acceleration rates, accepted gaps, and headways for different acceleration lane types at the merging areas. However, the results do not apply to the diverging areas. According to Garcia and Romero's study (2006), a balance between operational and safety effects should be used to determine the optimal deceleration lane lengths at freeway diverge areas.

For one-lane exits, the minimum lengths defined by the AASHTO Green Book (2011) are based on design speeds of freeway mainlines and exit ramps. For two-lane exits, AASHTO only provides the minimum distance from the beginning of taper to the forming of the deceleration lane with a 12 ft width for a parallel type (Fig. 1). A supplementary design guideline should be developed to assist decision-makers to select the optimal length of deceleration lanes under various traffic and geometric conditions.

In practice, it is hard to control and measure the beginning of the alignment of each exit ramp. Due to various curvatures and horizontal alignments of ramps, this study will focus on the freeway diverge areas to minimize these unrelated factors and increase the accuracy of the resource data. For example, the extraction of crash data is determined by the milepost range at that site. If the location of the end of the deceleration lane defined by AASHTO (indicated in Fig. 1) is estimated by milepost, some unrelated crash data might be included in the final crash database. So the definition of the deceleration lane in this study differs from the AASHTO definition for one-lane exits. The study area measures from the same starting point defined by AASHTO to the point of the painted nose, shown in Fig. 1. AASHTO (2011) presents the same minimum deceleration lengths for one-lane exits with a parallel design and one-lane exits with a tapered design. For two-lane exits with parallel designs, Fig. 1 shows the study area which is the same as the one-lane exits with a parallel design. As a result, this study would combine these three types together to determine the optimal deceleration lane length for the safety performance evaluation.

3. Data collection and methodology

3.1. Site selection

As crash occurrence is a very complicated process, involving factors related to road geometrics, human behaviors, environments, and vehicles. In order to minimize the impacts other than the interested variable (deceleration lane length), it is critical to control the site selection procedures and ensure the selected sites have similar geometric features, traffic characteristics and environments. The criteria to identify the sites are also important to mitigate the unstable and unrelated factors. The freeway segments were selected from major Florida Highway System including right-side off-ramps only. There should be no large vertical or horizontal curves at the selected sites. The distances from the upstream ramp to the beginning of deceleration lane should be long enough (larger than 0.5 mile) so that no traffic disturbances to exiting vehicles or through vehicles are minimal. Similar, the