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Impacts of freeway exit ramp configurations on traffic operations and safety

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Abstract
The main purpose of the paper is to evaluate the impacts of freeway exit ramp configurations on traffic operations and safety. Results summarized in the paper are based on a research project sponsored by China Department of Transportation to develop guidelines for safety design of freeway exit ramps in China. The main elements to be considered in freeway exit ramp configuration classification are geometric conditions (such as number of lanes in the upstream and downstream segments of exit ramps), geometrics of deceleration lanes, exit ramp lane configurations, etc. Google Earth was searched to identify many freeway ramp sites in USA, Japan, Europe countries, and China. The exit ramp configurations surveyed through these sites were summarized and categorized into four types. Based on such exit ramp lane configuration classifications, traffic operational and safety performances were analyzed. The main measures of effectiveness for traffic operations and safety are operational speed and traffic crash characteristics, respectively. Thus, for design purposes, adequate exit ramp configurations can be proposed in order to satisfy the operational and safety requirements under different conditions.

Keywords – freeway exit ramp, ramp configuration, traffic operations, safety, operational speed

1. Introduction
Freeway exit ramps are the places with significant vehicle maneuvers and traffic conflicts, which could potentially result in higher traffic crash frequency as compared with other basic freeway segments. For example, the freeway mileage in China has reached 60,000 kilometers and is ranked the second in the world in terms of total freeway miles. During 2003 and 2007, there were average 21,137 crashes per year on China freeways, which, on average, resulted in 6,118 fatalities, 15,501 injuries, and 52-million RMB ($7.6 million US dollars) direct costs per year. As an important special freeway segment, inadequate exit ramp design could result in significant reduction in capacity both on the main lane segments and on ramp segments. In addition, inadequate design may result in high crash frequency in the impacting areas of exit ramps. Statistical data have shown that freeway exit ramps could double the number of crashes as compared to freeway entrance ramps [1].
In past years, technical standards and specifications for freeway ramp planning and design have been published. These standards and specifications have covered ramp classification, ramp location determination, spacing between ramps, and traffic control at the ramp terminals [2-6]. In China, researches related to freeway ramps have focused on ramp capacity analysis, characteristics of merging and diverging traffic on ramps, and spacing between ramps [7,8]. Some research studies have been performed in USA to classify freeway exit ramps [9]. The way to classify exit ramps is mainly based on ramp geometric characteristics, including the way how traffic diverges from main traffic stream to enter exit ramps, number and length of deceleration lanes, number of exit ramp lanes, characteristics of merging and diverging paths on exit ramps, and other factors. Empirical methods based on regression analysis and traffic simulation have been widely applied to analyze traffic capacity of different exit ramp types [10-12]. The main study methods for traffic safety evaluation of exit ramps are generally based on statistical analysis of historical crash data and field survey data analysis [13-16].

Currently, there are some urgent technical issues related to traffic operations and safety on freeway exit ramps in China. One of the urgent issues is that there is no specific exit ramp configuration specification that could be adopted in freeway design in China. Without a technical guideline for exit ramp configuration design, it is difficulty to select adequate exit ramp types for given conditions. This paper presents a part of a research project sponsored by China Department of Transportation. The project aimed to developing safety design procedures for freeway exit ramps. More specifically, results presented in the paper focus on freeway exit ramp configurations. Impacts of freeway exit ramp configurations on traffic operations and safety are evaluated and presented in the paper. The results presented in the paper can be used in freeway exit ramp design in some developing countries such as in China.

2. Classification of exit ramp configurations

One of the main purposes for configuration classification is to develop design procedures so that adequate exit ramp configurations could be selected with the assumption that operational and safety performances at exit ramp sites can be improved under given conditions.

2.1. Impact areas of an exit ramp

Impact areas need to be identified for exit ramp configuration classification, operational analysis, and safety analysis. Impact areas mainly refer to upstream and downstream parts of main traveling lanes and the ramp midstream part as shown in Figure 1. The upstream part has a length of 1500 feet from the painted nose and the downstream part has a length of 1000 feet from the painted nose. The ramp midstream part covers the area from the painted nose to the ramp terminal area which has a direct access to a surface street.

2.2. Survey and analysis of current exit ramp configurations

Google Earth was used to survey more than 1000 freeway exit ramps in China, USA, Japan, and Europe. It is concluded from the survey that the main factors to be included in exit ramp configuration classifications are the geometrics of deceleration lanes on upstream part, changes in number of lanes on upstream and downstream parts, and lane configuration of exit ramps.

Through the survey from Google Earth, it was found that about 80% of freeway exit ramps in China have direct deceleration lanes which consist of tangent line and horizontal curves with changing radius from large to small so that exiting traffic can smoothly make turns and enter the exit ramp as shown in Figure 2.
The most popular configuration of exit lanes (outside lanes) on China freeways has the following characteristics: (1) The exit lane has a wider width when the lane approaches an exit ramp, (2) There is no change in number of lanes on the upstream and downstream parts near the exit ramp, and (3) There is only one exit ramp lane. About 55% of freeway exit ramps in China belong to such a category. Actually, this type of exit lane configurations may result in problems in traffic operations and safety as exiting vehicles may not have sufficient distance to decelerate their speeds and separate themselves from main line traffic, which could result in possible rear-end crashes or conflicts and reduction in speed of main line traffic.

Also, from Google Earth survey to exit ramps in USA, it is concluded that the deceleration lane configurations in impact areas of an exit ramp have better design characteristics. In order to improve freeway exit ramp design in some developing countries, there is a need to establish adequate lane configuration classifications in impact areas of exit ramps.

### 2.3. Exit ramp configuration classifications

As stated before, the exit ramps with direct deceleration lanes have some limitations which may result in possible operations and safety problems. Thus, exit ramps with direct deceleration lanes are generally not recommended.

From Google Earth survey, it was found that parallel deceleration lanes are widely used in USA. These parallel deceleration lanes are used only by the vehicles that enter exit ramps so that exiting traffic and main line traffic can be separated to minimize the conflicts. Exit ramps with parallel deceleration lanes should have better traffic operational and safety performances as compared to the exit ramps with direct deceleration lanes. For the reasons to improve traffic operational and safety performances, parallel deceleration lanes are generally recommended.

In the research, parallel deceleration lanes are recommended and freeway exit ramp configurations are classified into four types as shown in Figure 3. The following discusses the differences among the four types.
Fig. 3 - Classifications of exit ramp configurations

1) Type 1: Single-lane exit ramp without a taper design as shown in part (a) of Figure 3: In this type, the outer lane becomes a drop lane at the exit gore forming a lane reduction, and a paved and striped area beyond the theoretical gore to provide a maneuver and recovery area.

2) Type 2: Two-lane exit without an optional lane design as shown in part (b) of Figure 3: This type is used where one of the through lanes (the outer lane) is reduced and another full width parallel lane from tangent lane developed with a taper is forced to exit.

3) Type 3: Parallel from a tangent single-lane exit ramp design as shown in part (c) of Figure 3: This type has a full width parallel lane from tangent that leads to either a tangent or flat exiting curve which includes a decelerating taper. There are no direct drop lanes on the mainline sections beyond or after exits. The outer lane with a tangent would be a drop lane to the exits and become the though lane on the exit ramp section.

4) Type 4: Two-lane exit ramp with an optional lane design as shown in part (d) of Figure 3: This type includes two exit lanes while a large percentage of traffic volume on the freeway beyond the painted nose would leave at this particular exit. An auxiliary lane to develop the full capacity of the two lane exit is needed for a length of at least 1500 feet. The outer one of the two exit lanes directly drops to the exit ramps. But the inner lane of the two exit lanes, which is an optional lane, has two alternatives by continuing on the freeway or running off the freeway.

3. Impacts of exit ramps configurations on traffic operations

The main purpose of the analysis was to analyze impacts of different exit ramp configuration types on operational performance. Thus, analysis approaches and measures of effectiveness should be determined before the analysis was performed. In this study, traffic simulation analysis was used for the analysis purpose, and average operational speeds in the upstream and downstream parts of main traveling lanes were used as the measure of effectiveness. Actually, simulation analysis approaches could be a useful way for such application.
One of the main reasons for that is that freeway simulation is relatively easy because the other effects (such as non-motorized users, bus stops, parking maneuvers, land use, etc.) do not exist.

3.1. Field site selection

Based on a field survey (through field observations and Google Earth survey), two exit ramps (the Tiexin Bridge Interchange and the Shuanglong Street Ramp) on Nanjing Expressway in Nanjing City suburban were selected for the purposes of field data collection and simulation calibration. Different traffic operations with exit ramp configurations were simulated and other field conditions at the two sites were kept for calibration purposes and as given conditions. Field traffic observations using video recording methods were performed to obtain traffic data in the upstream and downstream segments of the exit ramps. For this purpose, three video cameras were set up at the sites. The observed traffic characteristics include traffic volume, traffic composition, headway, speed distribution, exit traffic volume and composition, and other relevant field data. Traffic data reduction was performed in the lab by manual methods so that researchers could carefully review various traffic characteristics. These field data were very important for calibration, simulation, and operational analysis.

3.2. Calibration of the simulation software

Based on comparison of different traffic simulation packages, the simulation package TSIS was selected to simulate traffic movements at freeway ramp areas. The main reason for selecting TSIS was that TSIS has strong capabilities in simulating traffic movements in urban arterial and freeway network, especially, in the connecting areas of different roadways and facilities. TSIS meets the technical requirements for simulating traffic operations at freeway ramp areas. Actually, TSIS was successfully used in previous similar applications [9].

Field experiments were performed at the selected freeway ramp locations to calibrate TSIS so that the parameters to be used in TSIS could meet the practical situation in real freeway traffic operations. Video recordings and traffic detectors were used for data collection for some important parameter calibrations. Meanwhile, some simulation parameters used in previous simulation analyses for similar purposes were adopted.

With the calibrated TSIS for the particular applications, a four-lane freeway with different percentages of heavy vehicle composition was considered in the simulation. It needs to be stated that in the areas of east coast of China most freeways carry heavy percentage of heavy vehicles ranged from 30% to 80% as cargo transportation by cargo vehicles has become one of the most important cargo transportation modes. On the other hand, 20% to 50% turning ratios were used for simulation analyses. Turning ratios refer to the percent of main lane traffic that exit from freeway main lanes to an exit ramp. This turning ratio range is also normal in the area.

3.3. Measures of effectiveness

There are many parameters that can be used to evaluate traffic operational performance. However, in order to select adequate measures of effectiveness, the feasibility for obtaining reasonable data should be considered. In this research, traffic average operational speeds in the upstream segment, downstream segment, and exit ramp segment were used as measures of effectiveness to quantify the impacts of different exit ramp configuration types on traffic operations. An exit ramp segment is the area between upstream and downstream segments and it is the area close to the exit ramp.
3.4. Analysis of impacting factors

Based on preliminary analyses, the main impacting factors to exit ramp traffic operations are: exit ramp lane configurations, traffic volume and composition on the upstream segment, and turning volume or turning ratio from main traveling lanes to the exit ramp. For the analysis purpose, the impacts of traffic volume, heavy vehicle composition, and tuning ratio were first simulated and analyzed. With these results, reasonable ranges for traffic volume, heavy vehicle composition, and turning ratio could be determined. Then, finally, the impacts of exit ramp lane configurations could be evaluated.

The Part (a) of Figure 4 presents the impacts of freeway traffic volume on operational speeds (meaning average speeds) in the areas of upstream segment, exit ramp segment, and downstream segment. In this analysis, 20% turning ratio and 40% heavy vehicle composition were used. It is noted that there was no significance difference in operational speeds in the areas of upstream and downstream segments if traffic volume was less than 4000 vph.