Crashes and Effective Safety Factors within Interchanges and Ramps on Urban Freeways and Highways

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Abstract: The aim of this study is to analyze effective factors crash in safety that occurs in influence areas of freeway ramps. The data for this research has been collected from freeway interchanges in central of an ABC highway (to protect the actual company name). The collected data of five crashes which had occurred in black spot interchange ramps was analyzed using SPSS statistical package version 18.0 (USA) and Microsoft office Excel 2007. According to AASHTO, ramp design speeds should approximate the low volume running speeds on intersecting highways. Where this design speed is not practical, ramps should not be designed at less than 50 percent of the design guideline for freeway and expressway ramps, where only those values of highway design speed above 80 km/h apply. Chi-Square Test was used to statically analyze the distribution of crashes according to their causes. However, chi square value of 135.75 (α<0.01) has indicated that a high percentage (79.17%) of crashes which were examined, were caused by over speeding followed by, loss of control, sleepy driver, bumper to bumper, loss of wheel, bad driving behaviour, hit and run with percentages, 8.33, 4.17, 4.17, 4.17, 2.08, 2.08 respectively. The result of the crash data analysis showed 50 types of accidents. A large percentage of crashes were caused by over speeding, in term 76% of severity with damage only, for type of collision 94% of crashes out of control. About 88.60% of crashes happened at daytime and 57.80% in fine weather conditions. It has been noticed that the distribution of crash among different condition of weather are equally shared, however, it was found out that weather, statistically, is not a strong factor in crashes. Ramps are scheduled for auditing based on descending road speed limits.

Key words: Factor crashes and Safety, Interchange and ramp design, Speed, Collision, Severity.

INTRODUCTION

Interchanges are essential components in freeway operations, because they control freeway access and handle the movement of traffic between roadways. In many cases, interchanges are inferior in design quality to the associated freeways and contribute to collisions, in part because of the likelihood of increased speed differentials between freeway main lines, ramp junction, and ramp. Many highways have controlled access. This means that vehicles can enter or leave the highway only where there are entrance or exit ramps. Interchanges have many different possible configurations. The configuration chosen for the design of any particular interchange must be appropriate for the volume of traffic making specific turning movements at the interchange, the alignments of the roadways being connected, the surrounding terrain, the adjacent development, and physical constraints such as existing Rivers, roadways, and railroad. The minor roadways that are provided within an interchange to allow traffic to move from one major roadway to another are known as ramps.

Ramps are usually part of grad-separated intersections, where they serve as interconnecting roadways for traffic streams at different levels. They are also sometimes constructed between two parallel highways to allow vehicles to change from one highway to the other. Ramps come in various configurations appropriate to the design of the interchange in which they are located. Many types are named after the interchange types in which they are most commonly used. Thus, the ramps of a diamond interchange are typically known as
diamond ramps, and the loop ramps within a partial cloverleaf interchange are typically known as parole loop ramps. Freeway ramps can be divided into two groups: A ramp that leaves a mainline freeway facility is known as an off-ramp or exit ramp. A ramp that joins a mainline freeway facility is known as an on-ramp or entrance ramp. This distinction is important because vehicles typically travel along off-ramps at higher speeds than along on-ramps, so that crashes are more likely to occur on off-ramps. Ramps that join mainline freeways at both ends serve as both off-ramps and on-ramps. And, in some cases, to arterials by speed change lanes that allow entering and exiting vehicle to speed up or slow down without conflicting with through traffic. The speed change lane for an off-ramp is known as a deceleration lane, while the speed change lane for an on-ramp is known as an acceleration lane. When it becomes necessary to control the number of vehicles entering or leaving a freeway at a particular location, access to the entrance or exit ramp is controlled in one of several ways such as closure, simple metering, traffic response metering, and integrated systems control. Ramp metering, or on-ramp control, which is designed to determine a metering rate for each controlled on-ramp based on traffic condition of part or whole of the corridor, has been considered a very important component of corridor traffic control. Ramp metering is designed to achieve one or more of the following none-mutually exclusive goals:

a) to alleviate or eliminate congestion,
b) to improve freeway flow, traffic safety and air quality by the regulation of input flow of a freeway,
c) to reduce total travel time and the number of peak-period accidents,
d) to regulate the input demand of the freeway system so that a truly operationally balanced corridor system is achieved (Jin and Zhang, 2001).

According to AASHTO, ramp design speeds should approximate the low volume running speeds on intersecting highways. Where this design speed is not practical, ramps should not be designed at less than 50 percent of the design guideline for freeway and expressway ramps, but only for those values of highway design speed above 80 km/h apply (Hunter et al., 1997). And for gradients ramp the AASHTO, general criteria are as follows: it is desirable that ascending gradients on ramps with a design speed of 70 to 80 km/h be limited to 3 to 5 percent; those for 60 km/h speed, to 4 to 6 percent; and those for a 40 to 50 km/h speed, to 5 to 7 percent; and those for a 30 to 40 km/h speed, to 6 to 8 percent; and values taper entrance, parallel entrance, taper exit and parallel exit by AASHTO recommend. (AASHTO, 1994).

Freeway crashes throughout the United States Occurred 33% more after per vehicle-miles of travel (VTM) on freeway section with bridges or interchanges than on freeway section without them (Pigman et al., 1981). A study of police reported crashes on the Capital Beltway found that most crashes occurred in close proximity to interchanges (Solomon et al., 1996). Ramp design characteristics; have been identified as an important crash factor in crashes in some studies (Khorashdi, 1998). Motor vehicle crashes occur more frequently on curves and are more severe than crashes that occur on straight roadway sections. Analysis of the data collected from the fatality analysis reporting system and national automotive sampling system reported that more than twice as many occupants were involved in crashes per kilometre of curved roads than were on straight sections. Furthermore, crashes on curves resulted in nearly three times many fatalities per kilometre as those on straight sections (Troxel et al., 1994). Speed is a significant factor in crashes on curves, as well as in the severity of these crashes (Zegeer et al., 1990). Freeway exit ramps often are designed with horizontal curves, which can become crash-prone, when traffic speeds are excessive for ramp geometry. Design of horizontal alignment is based primarily on the laws of mechanics and driver capabilities. Design controls for curves are determined by establishing limits on the rate of super elevation (banking) and on the coefficient of side friction between tire and road (A Policy on Geometric Design of Highways and Streets. 1990). So, the high occurrence of exit ramp crashes can be attributed largely to high vehicle speeds entering ramp curves and sudden changes form straight alignments to sharp curves, which should be avoided (Twomey et al., 1992).

The speed at which a vehicle enters a curve is related more to the speed of its approach than to the sharpness of the curves (Puvanachandran, 1995). The primary method used to control the speeds of vehicles entering curves from tangent approaches is the posting of black and yellow advisory curve warning, or exit ramp speed signs (Manual on uniform Traffic Control Devices. 1998). Because drivers often exceed posted advisory speeds; some researchers have questioned the validity of the criteria used to set advisory speeds on curves (Chowdhury et al., 1998). At potentially hazardous locations such as sudden changes from straight alignment to sharp curves on freeways and other high speed roads, standard signage may not be enough. Although habituation to high freeway speeds may be hard to counteract, potential engineering countermeasures include geometric design changes to increase ramp design speed, increasing the length of deceleration lanes and increasing curve radii (Harwood and Graham 1983; Harwood and Mason, 1993, Twomey et al., 1992).
Analyses of crashes on urban and rural freeway ramps in California indicated that exit ramps were more crash-prone than entrance ramps in terms of both frequency of crashes and average crash rates. (Korashadi, 1998 and Lundy, 1965). Analyzed crash reports from 10 freeways in Texas during 1975 indicate that from 498 recorded ramps crashes, 82% were rear end impacts, 7% were side wipes collisions and 6% involved collisions with fixed objects. A study of police reported ramp-related crashes on two metropolitan Toronto freeways, (Janusz and Hauer, 1995) classified crashes into three categories (begin-ramp, mid ramp, and end-ramp). Half of the crashes were classified as end-ramp, 36% were mid-ramp, and 14% were begin-ramp (Mullins et al., 1961). Fifty six percent of end-ramp crashes on both on-ramp and off-ramp were read-end collision.

A sample of 1150 crashes that occurred on heavily travelled urban interstate ramp in Northern Virginia were also examined and analyzed. Based on a review of diagrams and narrative descriptions form police crash reports, the most common crash types were identified and examined for different roadway locations and ramp design and by whether at-fault drives were entering or exiting the freeway. Results: about half of all crashes occurred when at-fault drivers were in the process of exiting interstates, 36% occurred when drivers were entering, and 16% occurred at the midpoints of access roads or on ramps connecting two interstate freeways.

Three major crash types run-off-road, rear-end, and sideswipe cut-off accounted for 95% of crashes in the study. The crash type which was most frequently associated with the exiting analysis was run-off-road, and the most common types with entering drivers were rear-end or sideswipe cut off. Crashes which were observed to be most common on ramps were run-off-road crashes that frequently occurred when vehicles were exiting interstates at night, in bad weather, or on curved portions of ramps. Speed was often an important factor. Crashes occurring on ramp margins (where ramp or access roads enter or exit) were most commonly of the sideswipe cut-off type. The predominant crash type on access roads was read-end crash in which congestion was a critical factor. Alcohol was also a reported factor in a sizeable proportion of run-off-road crashes on ramp 14% and ramp margins 30%, (Anne and Mc Cartt et al., 2004).

**MATERIAL AND METHODS**

**Details of Accident Data:**

Five crash black-spot interchange ramps were selected from the collected data. (KM283.40: Location 1, KM289.00: Location 2, KM296.50: Location 3, KM302.80: Location 4, KM304.70: Location 5) The selected ramps were located in Kuala Lumpur, from Sungei Besi to Seremban at interchanges in section C5. The selection was based on accident frequency during 2007 which is liable of most Malaysian highways. The details of crash data were collected from traffic safety department in ABC expressway for ABC highway crash, and each black spot interchange ramp selected during 2007. Data included number of crashes, causes, time, weather, severity, types, and location in each crash during 2007. It is attached in Appendix A. These investigation involved a study of ramp geometric design, design speed, signing, pavement, marking and road safety features. That in on-ramp and off-ramp section C5 of the observations as follows. Number of ramp lanes 2 lanes, lane width 3.5 meter per lane, left and right clearance width 1.0 & 0.0 meter regularity, signing (include advance, warning, directional that are provided), road marking provided with deficiency, road condition as pavement surface in good condition with street lighting, observations as high travelling speed of vehicles over ramp more than 50km/hr.

**SPSS Software:**

According to review of the literature, data was collected about freeway interchange ramps in centre of ABC highway in Malaysia from the relevant authorities. Then data was entered to SPSS software statistical package version 18.0 (USA). Descriptive statistical analysis was conducted and used to study the relevant variables to accidents in interchange ramp areas. Figure 1 shows the flow chart under the stages of this study shows:

**RESULT AND DISCUSSION**

Data of these five accident black spot interchange ramps was analyzed using SPSS statistical package version 18.0 (USA) and Microsoft office Excel 2007. Descriptive analysis was performed by obtaining the corresponding percentages of the data of crashes which had occurred at five interchange ramps. Inferential statistical analysis was conducted using chi-squared test, because the data of this study was categorical count. This analysis produced the following results:
First, there were seven identified causes for crashes over the five black spot locations, including: over speeding, bad driving behaviour, lost control, sleepy driver, bumper to bumper, hit and run, and loss of wheel. The general over speed most of the share allocated to it (Figure 2.). Second, referring to detailed data and analysis, the severity of crashes (slight injury, serious injury, and damaged only) as occurred at each location, has been considered and the general damaged only type most of the share allocated to it. Third, due to various crash causes mentioned above, there were different related crash-types namely: rear-end, sideswipe, run-off-road and out of control. The predominant crash types on access freeway ramps were out of control and rear-end collision. Next, from weather condition we can find out road surface condition in Malaysia, due to rainy weather in Malaysia road surfaces have been affected and become considerable factor involved in vehicle accidents. Accidents which have been caused by road surface condition (wet or dry). With calculated the percentage of accident frequency occurred on both types of weather (rainy and fine) at each location, clear about 57.8% of accidents have happened in fine weather type. Finally, proportion of accidents happening according to the road timing condition (day and night) is about 88.6% of accident occurring during the day.

The chi-square test was utilized to find out if the number of accidents had almost equally occurred between day and night time at Location 1, Location 2, Location 3, Location 4 and Location 5 interchanges or not. Chi square value was generated by the statistical package SPPS. It is also known that, the higher value of chi squared means the statistical significance of the findings. Moreover the value of 42.04 is a good indicator of that significance. Based on analysis from five locations, it was found that KM 302.8 off-ramps and on-ramps had the highest frequency of accidents which was 17 crashes (Figure 3). The descriptive statistic showed that the highest number of accidents in term of severity of damage is only at 76%. The highest percentage of accidents is statistically different from those accidents occurring with serious injury of 18% and slight injury of 6%. These accident frequencies were found to have occurred at KM 283.4, KM 289.0, KM 296.5, KM302.8 and KM 304.7 in on-ramp and off-ramp (Figure 4.).

The Chi-Square Test procedure tabulates a variable into categories and computes a chi square statistic. This goodness-of-fit test compares the observed and expected frequencies in each category to test either all categories contain the same proportion of values or that each category uses a specified proportion of values. In this case, Chi-Square Test was used to analyze statically the distribution of accidents according to their
causes. However, chi square value of 135.75 (α<0.01) has indicated that there is a high percentage 79.17% of accidents were caused by over-speeding followed by, loss of control, sleepy driver, bumper to bumper, loss of wheel, bad driving behaviour, hit and run; with percentages 8.33, 4.17, 4.17, 2.08, 2.08 respectively (Figure 2.1). The result of such statistical technique has (Figure 5.) revealed clearly that the higher percent (94%) of accidents out of control is more than the rear-end collision (6%). (X2=38.72, α<0.001). The distribution of accidents according to the weather, based on chi-squared with value (α>0.05) for fine and rainy weather condition is 57.8 and 42.2 present respectively. Also according accident timing condition, the highest number of accident occurred at day time with a present of 88.6%, that is very different from accident occurred at night time with a percent of 11.4%. (X2=28.88, α<0.05).

Based on the detailed crash data analysis and its results, potential safety issues were identified at interchanges. Considering the need for high capacity and high travelling speeds, appropriate level of service and maximum safety, it is desirable to provide uniformity in application of pavement markings at exit and entrance areas. Crashes related to each of the potential safety issues were estimated through using a risk assessment framework.

Over speeding was found to be the major cause of crashes, so we have to force drivers to reduce their speed by providing groove at critical locations, to help decrease the number of crashes caused by over speeding at entrance and exit of ramps. Out of control collision were significantly related to over speed of drivers, but there are also some other factors such as wet surface of pavement, vehicle tire condition etc. It is recommended to select the appropriate type of pavement to be implemented for rainy weather and conduct periodic surveillance and inspection for vehicle tires. From the standpoint of driver expectancy and safety, it is essential that all interchange ramps be marked with wide lines. The intent of using wide lines is to provide emphasis so that drivers can easily recognize the geometry of exit or entrance areas in the high speed environment of an interchange. Ramps are scheduled for auditing based on descending road speed limits. In order for these result to be used best in speed reduction, it is recommend to employ speed reduction measure in groove schemes. Maybe after implementation, crash records can be better monitored to evaluate effectiveness. Road safety education is also important to inculcate the correct mindset and road behaviour in all road users.

Most published works and research emphasize on the importance of ramp design speed and truck performance. These measures can contribute to about 50 percent reduction in design speed from a freeway to a ramp and minimize hazards posed large and/or heavily loaded trucks. This reduction influences operating speeds as a vehicle moves from one facility to another. In order to guarantee high performance for the managed lane facilities, the chosen design speed for the ramps must consider the anticipated speeds of vehicles entering the ramp, the desired speed of the vehicles on the ramp, and also the speed of the vehicles when they are attempting to merge. The performance of the managed lane is influenced by a design speed less than the anticipated or desired operating speed. Wherever trucks are supposed to be a primary vehicle type for the facility, designers need to clearly consider this fact while they are trying to select the appropriate design features for the ramp and the managed lane as well as when they decide on the signing to be used.

Conclusion:

The findings of this research revealed the factors which were involved in crashes taking place at five selected crash black-spot interchange ramps. Identifying the problems, on ramp crash was the principal purpose of the analysis undertaken in this project. Looking at difference rates of involvement with respect to crash types and other crash characteristics, we have come up with some suggestion and conclusions that as follow:

- There are four major contributing factors for crashes caused or loss of control. They are: horizontal curves, speed, road condition, and weather condition. Reducing crash rates along the location is possible through checking the curves to current design standard and checking the road condition to improve the safety of interchange highway at these locations. We have access to information on geometric design features for ramps in different sources including the AASHTO Green Book and the Texas Roadway Design Manual. According to a review of state design manuals, Texas manual includes more discussion and examples on ramp design than most other state manuals which have been released so far.
- The crash data analysis results show that the crash ramp have highly associated causes of crash, collision type, weather and time. It has been noticed that the distribution of crash among different condition of weather are almost equally shared, however, the weather is not statistically a strong factor in crashes as implied.
Providing highlight gore areas with colour pavement (red, white and yellow) and reflective flexible posts can prevent sudden manoeuvre and assist vehicle drivers estimate the capability of their vehicles to react in sufficient time to avoid problems especially at night for using at freeway and highways exits. The comparison has proved a significant reduction in the erratic manoeuvre rates after taking a measure and the above treatment up to 60% in daytime and up to 65% at nighttime.

Although crashes at night are fewer than crashes during the day, the 11.4% share of crashes in the night need programming and safety arrangements, even though street lighting has been provided. It is recommended to create additional lighting, near by the black spot ramps to provide better visibility for drivers to avoid unexpected problems.

As a good solution, we can refer to “dual-dual” roadway which improves operations and safety by separating heavy vehicles from light vehicles and increases capacity through permitting only heavy vehicles on the outer roadway. This solution also increases flexibility for managing the incidents by means of directing the drivers to the roadways without any incident through the use of changeable message signs. Based on the review of the recent published reports and analyse, we find lower crash rates for the dual dual portion as compared to segments of the turnpike, where separate roadways are not available.

The recommendations for road safety goals and targets for improving road safety in the interchanges and ramps. It can be discussed when there is a better understanding of many road safety issues that are being encountered in each interchange and ramp on urban freeways.
Fig. 5: Effect type of Collision on the section C5 2007.

ACKNOWLEDGMENT

We would like to express our gratitude to the center of ABC highways Malaysia and also to Mr. Abdulla Ibrahim Mukhtar Ali for collection of our database. We are also thankful to Sustainable Urban Transport Research Centre (SUTRA) / Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM, for providing and supporting related study.

Appendix A: Database Accident at Interchanges in Section C5 in Year 2007

<table>
<thead>
<tr>
<th>Interchange No of KM</th>
<th>Interchange No of Acc.</th>
<th>Causes of Accident:</th>
<th>Time of accident:</th>
<th>Weather:</th>
<th>Accident Severity:</th>
<th>Types of collision:</th>
</tr>
</thead>
<tbody>
<tr>
<td>KM283.4: Nilai</td>
<td>7</td>
<td>Causes of Accident:</td>
<td>Day Time</td>
<td>Rainy</td>
<td>Accident Severity:</td>
<td>Types of collision:</td>
</tr>
<tr>
<td>KM289.0: Putrajaya</td>
<td>5</td>
<td>Causes of Accident:</td>
<td>Night Time</td>
<td>Rainy</td>
<td>Accident Severity:</td>
<td>Types of collision:</td>
</tr>
<tr>
<td>KM302.8: Kajang</td>
<td>12</td>
<td>Causes of Accident:</td>
<td>Day Time</td>
<td>Fine</td>
<td>Accident Severity:</td>
<td>Types of collision:</td>
</tr>
<tr>
<td>KM304.7: UPM</td>
<td>9</td>
<td>Causes of Accident:</td>
<td>Night Time</td>
<td>Rainy</td>
<td>Accident Severity:</td>
<td>Types of collision:</td>
</tr>
</tbody>
</table>

Types of collision:
1. Out of Control 2
2. Out of Control 4
3. Damaged only 14
4. Damaged only 6
5. Damaged only 12
6. Damaged only 9
7. Damaged only 6
8. Damaged only 12
9. Damaged only 9
10. Damaged only 6
11. Damaged only 9
12. Damaged only 6
13. Damaged only 9
14. Damaged only 6
15. Damaged only 9
16. Damaged only 6

Types of accident:
1. Damaged only 7
2. Damaged only 2
3. Damaged only 1
4. Damaged only 3
5. Damaged only 5
6. Damaged only 1
7. Damaged only 3
8. Damaged only 1
9. Damaged only 3
10. Damaged only 1
11. Damaged only 3
12. Damaged only 1
13. Damaged only 3
14. Damaged only 1
15. Damaged only 3
16. Damaged only 1

Types of collision:
1. Out of Control 4
2. Out of Control 11
3. Damaged only 14
4. Damaged only 6
5. Damaged only 12
6. Damaged only 9
7. Damaged only 6
8. Damaged only 12
9. Damaged only 9
10. Damaged only 6
11. Damaged only 9
12. Damaged only 6
13. Damaged only 9
14. Damaged only 6
15. Damaged only 9
16. Damaged only 6

Appendix A: Database Accident at Interchanges in Section C5 in Year 2007

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</tr>
</tbody>
</table>

Types of collision:
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3. Damaged only 14
4. Damaged only 6
5. Damaged only 12
6. Damaged only 9
7. Damaged only 6
8. Damaged only 12
9. Damaged only 9
10. Damaged only 6
11. Damaged only 9
12. Damaged only 6
13. Damaged only 9
14. Damaged only 6
15. Damaged only 9
16. Damaged only 6

Types of accident:
1. Damaged only 7
2. Damaged only 2
3. Damaged only 1
4. Damaged only 3
5. Damaged only 5
6. Damaged only 1
7. Damaged only 3
8. Damaged only 1
9. Damaged only 3
10. Damaged only 1
11. Damaged only 3
12. Damaged only 1
13. Damaged only 3
14. Damaged only 1
15. Damaged only 3
16. Damaged only 1

Types of collision:
1. Out of Control 4
2. Out of Control 11
3. Damaged only 14
4. Damaged only 6
5. Damaged only 12
6. Damaged only 9
7. Damaged only 6
8. Damaged only 12
9. Damaged only 9
10. Damaged only 6
11. Damaged only 9
12. Damaged only 6
13. Damaged only 9
14. Damaged only 6
15. Damaged only 9
16. Damaged only 6

Source: Traffic Safety Department ABC Expressway 2007

REFERENCES


