

EMPIRICAL STUDY OF
FREEWAY INTERCHANGE CRASH CHARACTERISTICS
AND INFLUENCE AREAS

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by
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FREEWAY INTERCHANGE CRASH CHARACTERISTICS
AND INFLUENCE AREAS

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Abstract

Factors that affect drivers at interchanges are various and include changing lanes, changes in speed limits, and lengths of speed-change lanes. State Departments of Transportation (DOTs), local authorities, and transportation researchers use reported crash locations for analysis, neglecting the functionality of speed-change lanes. This may lead to the inaccurate prediction of the number of crashes and non-optimum geometric designs. This study used a newly proposed method for locating crashes by the functionality of speed-change lanes instead of exact crash location for safety analysis. Missouri crash reports were reviewed to determine how police officers located crashes. In addition, the functional and physical classification methods were compared. Crash distributions were presented for different types of facilities, such as freeway segments, speed-change lane segments, and ramp segments, in order to better understand the safety of different interchange-related facilities. In addition, on the basis of crash data, the safety influence areas were estimated using empirical data. By using functional classification, more crashes were assigned to speed-change lanes than ramps or freeways that had been assigned through the use of physical classification. Mainline freeway segments still generated the most crashes in interchanges under functional classification (62.09%), with speed-change lanes second (21.21%). The interchange influence area determined in this research was 2000 ft., which is longer than the 1500 ft. discussed in previous studies.

Keywords: functional classification; crash distribution; interchange facility type; interchange influence area.

I. Introduction

a. Research Problems

1. The accuracy of the existing crash locating methodology for freeway interchanges does not consider interchange function

State Departments of Transportation (DOTs), National Cooperative Highway Research Program studies, and other authorities use an existing crash location methodology that uses the exact reported location where harmful event occurred for locating crashes in relation to freeway interchanges. However, problems exist with using this physical classification methodology. First, there are factors that may have influenced the incident which are not due to the exact reported location where vehicles were present but instead are due to circumstances before or after the reported location. Second, crash reporting is also an issue because it has been difficult to establish a consistent crash reporting methodology. Some factors that make consistent crash reporting difficult include the experience level of the reporting officers, available reporting technologies, varying reporting protocols, departmental resources, necessary training, and the crash report processing.

The ANSI-07D16 (2007) definition of interchange accidents includes at-interchange accidents, interchange-related accidents, and driveway access accidents or non-junction accidents; these are accidents in which the first harmful events occur within the boundaries, including all ramps and roadway entering or leaving the interchange 100 feet (30 meters) beyond the gore point. Also, ANDI-07D16 (2007), suggests that an accident at an interchange be assigned to the highest class of trafficway even if it occurs at the interchange of several. Further,

ANDI-07D16 (2007) suggest that accidents in merge or diverge lanes should be assigned to the highest class trafficway as well.

2. Limited knowledge on the safety influence area of interchanges

In spatial analysis, an area of influence refers to an area polarized by a center for a set of relations (influence area of a city) or a category of relations (area of cultural or commercial influence, trading area). Some previous research used the term “interchange influence area” without defining the term influence area of interchanges or the distance from the center of interchange. The size of the safety influence area of interchanges depends on the interchange geometry design, operating features, and so forth (Wang, 2008). Some research has suggested that the interchange influence area include areas within 1,500 feet from the center of interchange (HCM, 2010). However, the literature on interchange influence areas is rather limited even though the concept is important for interchange crash data recording, maintenance, and safety analysis and prediction (Wang, 2008).

3. The proportion of crashes on different interchange facilities are not understood

Crash databases serve to document crash characteristics. The primary source for these data in the U.S. are records reported to statewide traffic crash records systems where available. Crash database typically includes important details such as crash severity, number of persons killed and injured, death and injury rates, crash circumstances, speed involvement, alcohol involvement, the age of drivers involved. However, few states database contain attributes that document whether or not a crash occurred at an interchange or more specifically, which road facilities are associated with particular crashes.

b. Significant and Original Contributions

The purpose of this research is to investigate how interchange attributes affect the interchange safety influence area. A statewide sample of 120 sites, including diamond interchange, partial cloverleaf interchange, and full cloverleaf interchange, within the state of Missouri was obtained. On the basis of crash reports, the research makes the following contributions:

1. Illustrates the functional crash locating procedure in contrast to the existing physical classification.
2. Applies empirical crash analysis of interchange influence areas in Missouri on different interchange configurations.
3. Documents general proportions of crashes on different interchange facilities.

II. Literature review

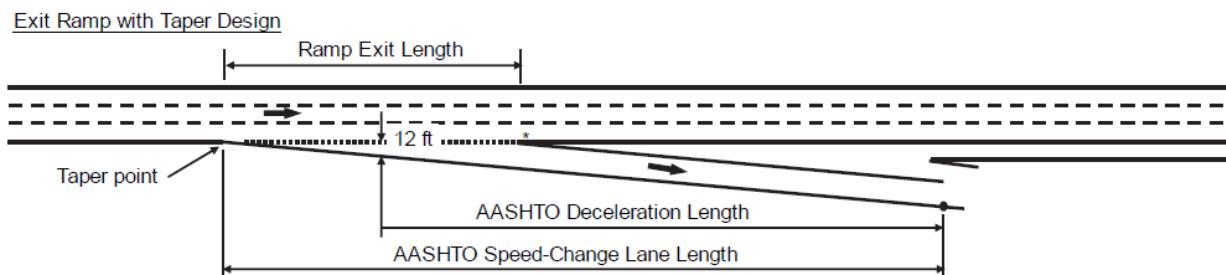
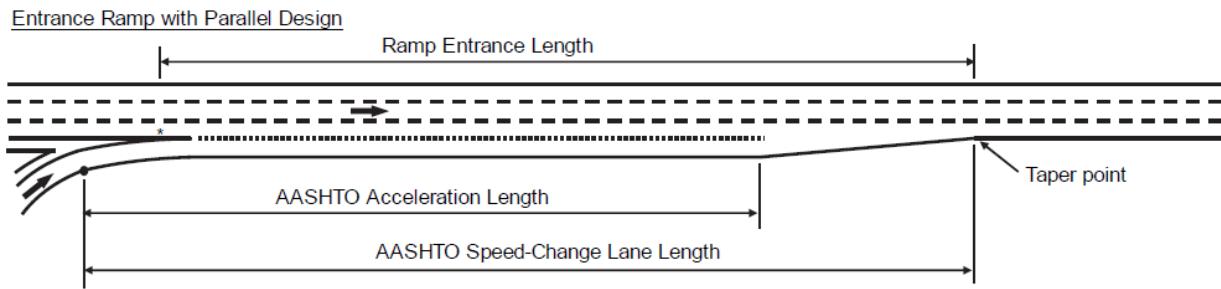
a. Existing Crash Locating Methodology, Physical Classification (e.g.

NCHRP/HSM)

A speed-change lane is defined as a “ramp entrance length” or a “ramp exit length” segment as shown in Figure1 (NCHRP 17-45, 2012). “A speed-change lane is an auxiliary lane, including tapered areas, primarily for the acceleration or deceleration of vehicles entering or leaving the through-traffic lanes” (AASHTO, 2004, pp 688). Speed-change lanes, including acceleration lanes and deceleration lanes, are added trafficways of highway that allow drivers to maneuver vehicles entering or leaving freeway segment necessarily (AASHTO, 2004). Speed-change lanes are designed as parts of interchanges but significant at the intersection of crossroads and freeway segments (AASHTO, 2004). In the existing crash locating methodology, the only criterion for assigning crashes is the exact location of the crashes. Crashes located between the gore point and the taper point of a speed-change lane related to an entrance ramp or speed-change lanes should be assigned to speed-change lanes as a definition of facility. Similarly, crashes occurred between the taper point and the gore point of a speed-change lane related to an exit ramp or speed-change lanes should be assigned to speed-change lanes in terms of physical classification.

i. Speed-Change Lanes and Freeway Crashes

The National Cooperative Highway Research Program (2012) guidelines suggest that the crashes located at the speed-change lane segment of freeway be attributed as speed-change lane related crashes (marked by milepost).



* Point where marked gore is 2 ft wide (gore point)
 • End of controlling curve on entrance ramp (start of curve on exit ramp)

Figure 1 Typical Speed-change Lanes (NCHRP 17-45, 2012)

All crashes documented as occurring between the gore point and the taper point of a speed-change lane related to an entrance should therefore be attributed to speed-change lanes. Similarly, all crashes that are located between the taper point and the gore point of a speed-change lane of a particular highway exit should be assigned to speed-change lanes. It is recommended that any freeway crashes that are not attributed to speed-change lanes should be simply attributed as freeway crashes (Sarasua, 2008). Figure 2 illustrates this method for attributing freeway crashes as due to either speed-change lanes or freeway lanes. In this example, all crashes that happen in Region A would be attributed as speed-change lane related. Crashes that happen outside of Region A (i.e., in Region B) would be attributed as freeway related.

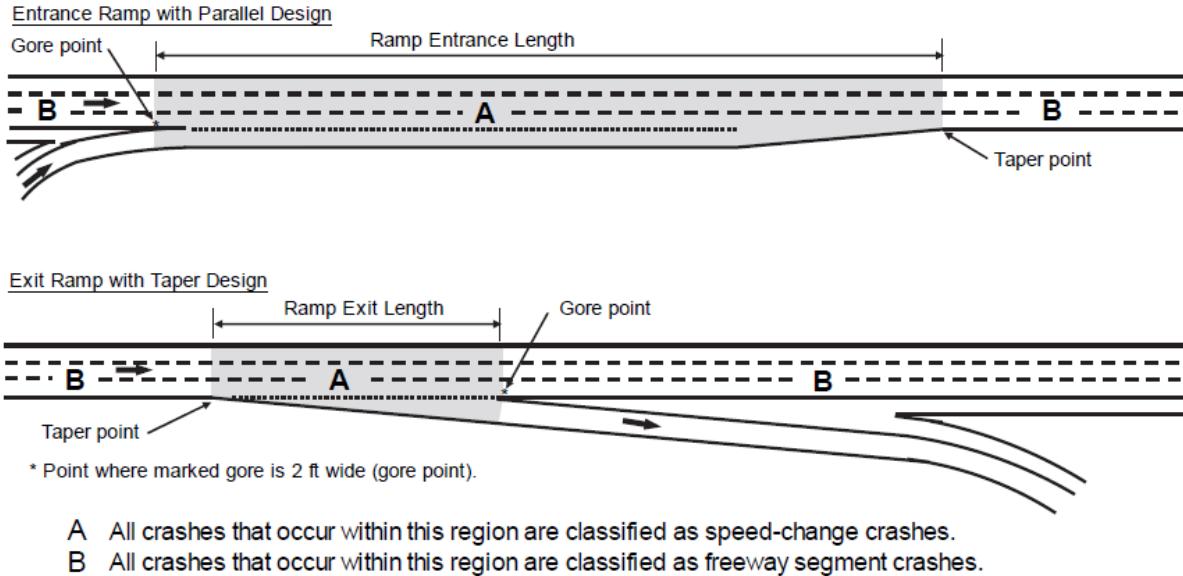


Figure 2 Definitions of Freeway Segments and Speed-Change Lanes (HSM, 2010)

ii. Ramp Segments

The most common crashes at exit ramps are those involving vehicles running off the roadway or colliding with objects or animals. Other types of crashes also occur, such as read end crashes (McCartt, 2003). At entrance/exit ramp sites, roadway curvature is a design factor thought to be responsible for the most crashes. Because of significant differences in speed, drivers might not be able to decelerate properly before reaching the exit ramp segment, resulting in a higher level of crashes. Similarly, at entrance ramps, drivers trying to find a gap on the freeway might collide before reaching the gore point. Figure 3 illustrates cases where vehicles run off the exit and entrance ramps.

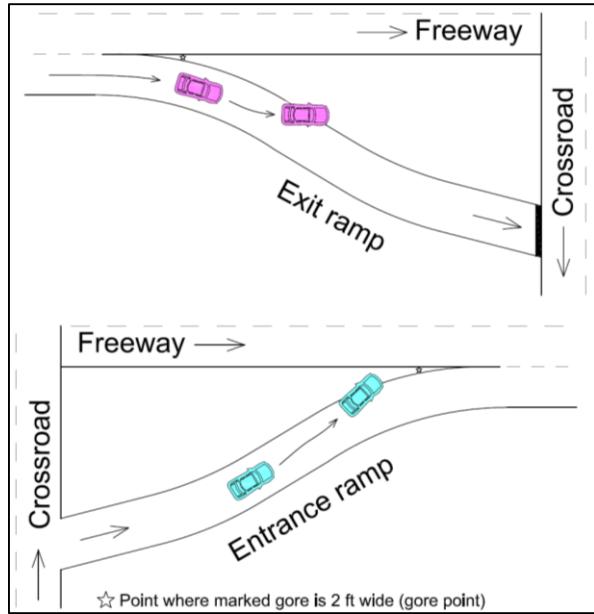


Figure 3 Run off the Road Crashes at Exit/Entrance Ramp Segments (Claros and Khezerzadeh, 2015)

Another common crash type at ramps is vehicle collisions with objects or animals along the road (Figure 4). In most cases, this type of crash would probably be attributed as ramp related.

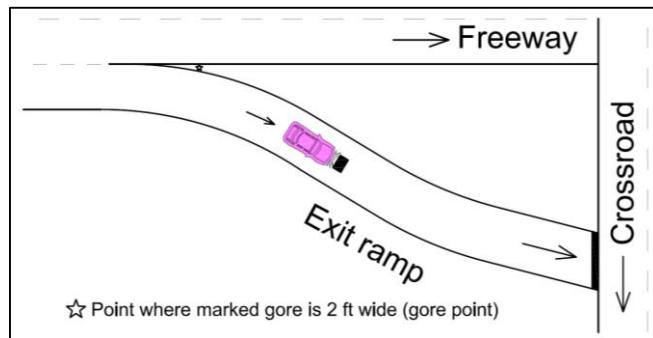


Figure 4 Collisions with Object or Wild Animal on Ramp Segment (Claros and Khezerzadeh, 2015)

b. Introduce Safety Influence Area

A sample of 1,150 crashes documented as occurring on heavily traveled urban interstate ramps in Northern Virginia included a large proportion of fatal crashes at highways interchanges: 11% in 2001 (McCartt, 2003). Figure 5 shows the areas surround an interchange within which

crashes would be considered interchange-related crashes. Crashes occurred 100 ft. after gore point of speed-change lane of on-ramp and crashes occurred 100 ft. after taper point of speed-change lane of off-ramp are interchange-related crashes as shown in Figure 5. However, at this point, a standard definition for interchange crash influence area does not exist.

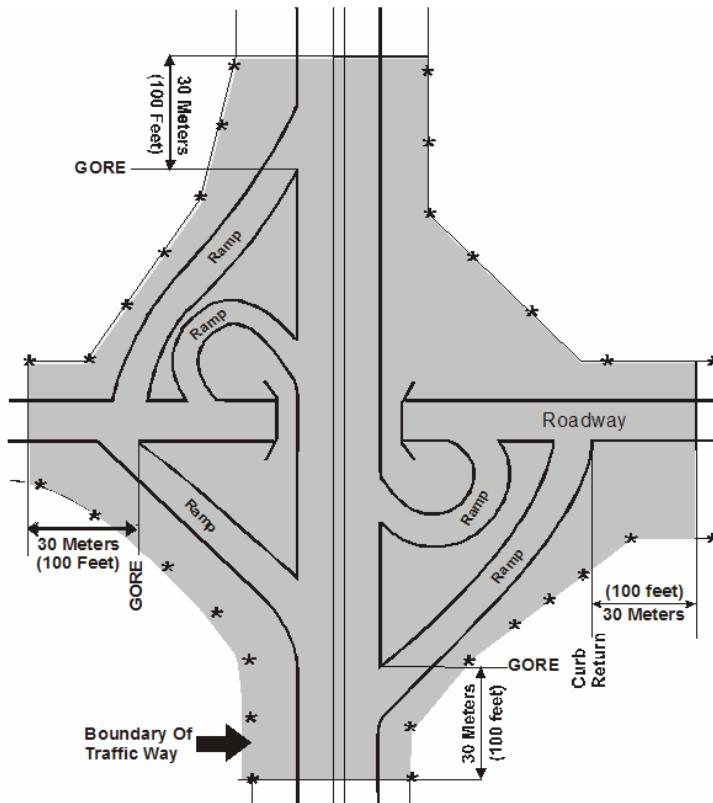


Figure 5 Interchange Accidents (accidents which occur within the shaded area are interchange accidents (ANSI-07D16)

Typically, all areas within 1,500 feet of an interchange are considered within the interchange's influence area (HCM, 2010; Lu et al. 2013) as shown in Figure 6 and Figure 7. Several factors affect the interchange influence area: like interchange types, merging and diverging area, speed-change lane length, and ramp safety. If the acceleration or deceleration

lane is not an adequate length, drivers would find it difficult to operate a vehicle, thus leading improper acceleration or deceleration operation and in turn an increase in crash rates.

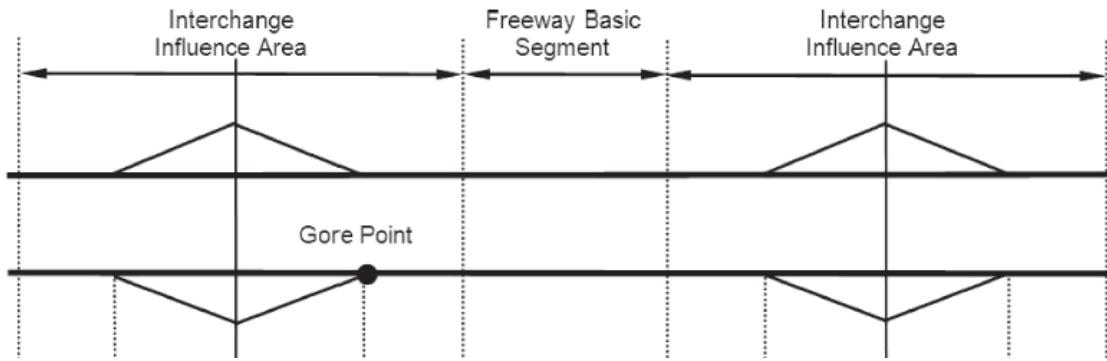


Figure 6 Interchange Influence Area (Lu et al. 2013)



Figure 7 Merge and Diverge Influence Area (HCM, 2010)

The following four factors are thought to affect interchange safety:

1. Interchange-related

The presence of a ramp entrance or exit creates a large number of lane changes on the freeway and a notable variation in lane volume (Kiattikomol et al. 2008). Kiattikomol et al. (2008) assess three years of urban freeway segment crash data in North Carolina and Tennessee. Segments located more than 1,500 feet from the center of the interchange were considered “non-interchange” segments. These crash rates were found to increase by about 200% on interchange

segments as compared to non-interchange segments. North Carolina and Tennessee data showed 42 and 82 crashes per 100 million vehicle-miles (100 mvm), respectively.

Torbic et al. (2007) consider segments located more than 0.3 mi (1580 ft) from the nearest ramp gore were considered to be “outside” interchange segments. The separate SPFs (safety performance function) they developed for freeway segments also indicated that “within” interchange segments have more crashes than “outside” interchange segments. Torbic et al. (2007) explained that the higher within crashes were likely due to weaving and lane-changing associated with interchange ramps.

2. Left versus right side entrances and exits

Moon and Hummer (2009) evaluated freeway crash data for 158 ramps (including 33 ramps with left-side entrance or exit) for gathering crash data on freeways in North Carolina. Information on crashes that occurred at speed-change lane segment and freeway segment up to 1,500 feet from the gore point were collected in the database. Their findings suggest that entrances or exits located on the left side have about 70 to 150% more crashes than entrances or exits located on the right-side.

In addition, Zhao and Zhou (2009) evaluate crash data from 19 ramps (with four left side exit) along Florida freeways. They also considered crashes in the speed-change lane but their data differed from Moon and Hummer (2009) in that they include crashes on freeway up to 1,000 feet from the start of the deceleration length instead of 1,500 feet from the gore point. Based on their analysis, they find that left side exits have 180% more crashes than right side crashes, which is slightly different from Moon and Hummer (2009).

3. Interchange spacing

Interchange spacing, the spacing between two interchange center (Figure 8), is also an important factor in interchange safety.

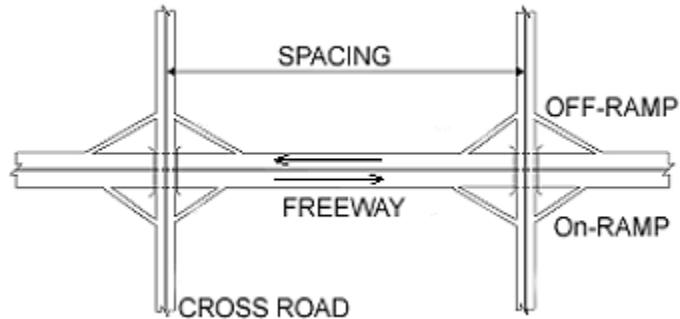


Figure 8 Interchange Spacing (Bared et al., 2007)

TRB (1999) provides guidelines for interchange area access spacing ranging from 230 m to 805 m (750 ft. to 2,640 ft.), depending upon the geometric characteristics of the interchange and crossroads and if the access is signalized (Gluck et al., 1999), as shown in Table 1.

Table 1 Suggested Minimum Access Spacing (Meter) Standards for Four-Lane Road at Interchanges

ACCESS TYPE	URBAN (55KM/H (35MI/H))	RURAL (85KM/H(55MI/H))
FIRST ACCESS FROM OFF-RAMP	230 (750)	400 (1320)
FIRST MEDIAN OPENING	300 (990)	400(1320)
FIRST ACCESS BEFORE ON-RAMP	300 (990)	400 (1320)
FIRST MAJOR SIGNALIZED INTERSECTION	805 (2640)	805 (2640)

Note: Gluck et al., 1999

As noted in NCHRP (1999), many states have established stricter policies than AASHTO (1991) to reflect the significance of providing a sufficient lengths of access control and/or separation distances along crossroads (arterials) at interchanges (Gluck et al., 1999). Table 2 and Figure 9 illustrate the recommended access separation guidelines of NCHRP (1999).

Table 2 Recommended Separation Distances from Interchange Exit Ramps (NCHRP 1999)

	DISTANCE
WEAVING-MOVING ACROSS THROUGH LANES	245m (800 ft.) on two lane arterials 365m (1200 ft.) on four lane arterials 490m (1600 ft.) on six lane arterials
TRANSITION-MOVING INTO LANE(S)	45-60m (150-200 ft.)
PERCEPTION-REACTION DISTANCE	30-45m (100-150 ft.)
STORAGE	Adequate for volume without overflow into through lane (typically 60-90m (200-300 ft.) depending on demand)
DISTANCE TO CENTERLINE OF INTERSECTION	12-15m (40-50 ft.)

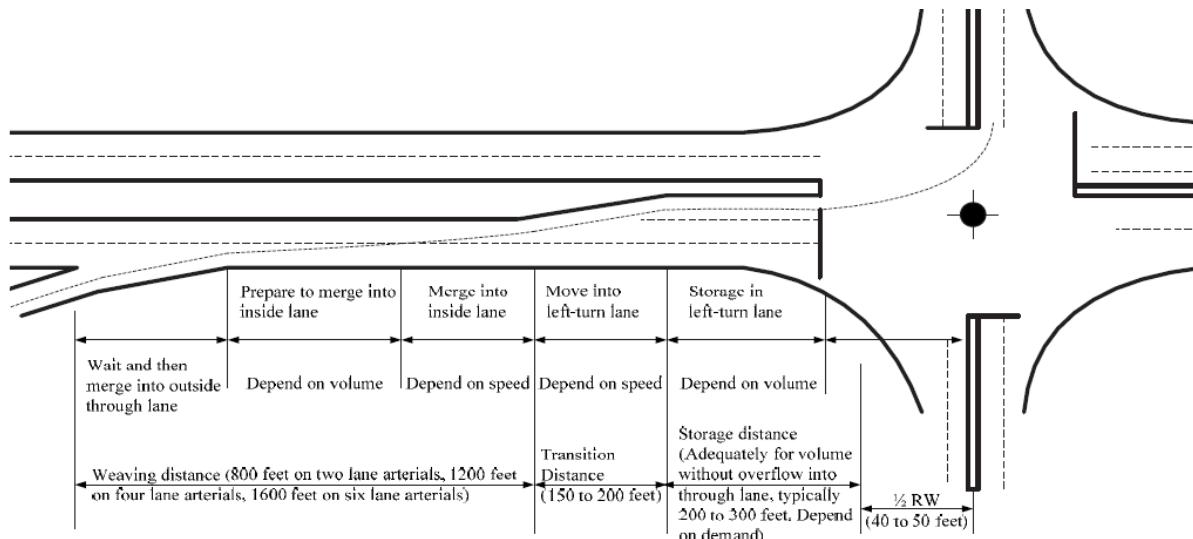


Figure 9 Recommended Access Separation Distances (NCHRP Report 420 Figure 50, 1999)

Given the study (NCHRP, 1999) assumptions (the free right-turn lane was removed from the network; the links not affected by the length of limited access right-of-way were removed, as was the off-ramp interaction with an adjacent downstream traffic signal) including a 3% growth rate in traffic volume, the increase of access spacing from 60–180 m (200–600 ft) would postpone interchange failure for approximately 8 years. Acquiring 400 m (1,320 ft) of limited

access right-of-way could potentially extend the operational life of the interchange for approximately 10 years.

The benefit of acquiring additional limited access right-of-way around interchanges is the potential reduction of crashes on the freeway due to traffic backups causing lane blockage. The safety analysis examined crash rates in the vicinity of exit ramps at several interchanges. The freeway segment was believed to most likely have safety problems due to insufficient access for controlled right-of-way.

4. Speed-change lane length

Previous research has indicated that freeway segment crash rates related to interchanges can be considerably higher than those that are located away from interchanges (Kiattikomol et al., 2008). Interchanges related crashes were reported to a greater extent despite involving less mileage occupancy, especially on ramps for entering or exiting freeways (McCartt et al., 2004). Several factors are thought to influence the impact of interchanges: interchange type, merging and diverging length, length of speed-change lane, whether ramp is for entering or exiting, speed limit, and the number of lanes.

For stable traffic flow, the merging influence area begins 150 meters (about 500 feet) upstream to 450 meters (about 1500 feet) from the gore point; the diverging influence area begins 450 meters (about 1500 feet) upstream to 150 meters (about 500 feet) downstream. These are shown in Figure 10 (Zhong et al., 2009).

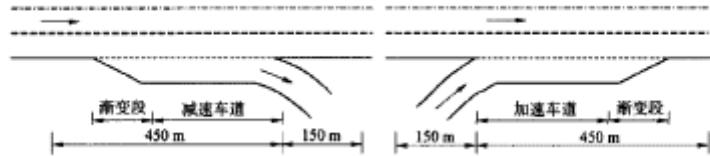


Figure 10 Diverging and merging influencing area (Zhong et al., 2009)

Speed-change lane designation is another area to consider, for if an acceleration lane or deceleration lane is not at a proper length, drivers would find it difficult to operate a vehicle, leading to improper acceleration or deceleration operation and therefore an increase in crash rates. Table 3 shows accelerated and decelerated lane length in different countries.

Table 3 Accelerated and Decelerated Lane Length in Different Countries

Country	Deceleration lane (meter)		Acceleration lane (meter)		Gradation zone (meter)	
	one lane	two lanes	one lane	two lanes	Acceleration	Deceleration
America	164 (538ft.)	164 (538ft.)	430 (1410ft.)	430 (1410ft.)	91.5 (300ft.)	76.3 (250ft.)
Japan	100 (328ft.)	150 (492ft.)	200 (656ft.)	300 (984ft.)	70 (230ft.)	70 (230ft.)
Germany	120 (393ft.)	120 (393ft.)	120 (393ft.)	120 (393ft.)	80 (262ft.)	80 (262ft.)
China	100 (328ft.)	150 (492ft.)	200 (656ft.)	300 (984ft.)	70 (230ft.)	70 (230ft.)

Note: Table from Zhong et al., 2009

5. Ramp safety

Traveling on a ramp at interchanges can lead to information overload for a driver.

Different information load levels vary, such as the area type, entrance or exit, or ramp side. The change of speed and directions and those complex circumstances increase the potential for crashes at interchanges.

Previous studies indicate that urban areas are more likely to have crashes than rural areas based on a regression model examined by Bauer and Harwood (1998); however, Torbic and other researchers found that the SPFs in ISAT (Interchange Safety Analysis Tool) are no different for both areas.

Lundy (1965), Khorashadi (1998), and Bauer and Harwood (1998) analyzed data from different states and find that exit ramps have more crashes than entrance ramps, given the same traffic volume and configuration type. According to Garber and Fontaine (1999, page 22), “Off ramps have the highest accident rates, since vehicles enter curves at high speeds and the capacity at ramp terminals is frequently deficient.”

Because of a low percentage of left-hand ramps, drivers on freeways develop high expectations for right-hand ramps. Hence, left-hand ramps increase speed and lane changing, which ends up increasing the rate of crashes. Not surprisingly, all left-hand entrances and exits were also found to have poor accident records (Fisher, 1961).

In terms of ramp configuration, despite of area type, SPF crash rates from low to high are free-flow loop, diamond, parclo loop based on Bauer and Harwood (1998); diamond, free-flow loop and parclo loop from Khorashadi (1998); and diamond, free-flow loop, and parclo loop are of same trend in ISAT. Ramps with diamond interchanges tend to have the lowest accident rates (Twomey, Heckman, Hayward, Zuk, 1993).

Another factor that influences the crash rate is the number of lanes on the ramp. Bauer and Harwood (1998) indicate that more than two times the number of crashes happened on ramps with one lane when compared with ramps with two lanes. In addition, they suggest that if the ramp length increases, the crash frequency rates will increase as well.

c. Introduce Different Interchange Types

i. Diamond Interchange Description

Diamond interchanges are the simplest and most common type of interchanges that are located on the freeways, commonly used in both rural and urban settings. A diamond interchange consists of four one-way diagonal ramps placed in every quadrant (Garber and Fontaine, 1999). The diamond interchange typically consists of two terminal configurations. Figure 11 shows the conventional diamond interchange. Both advantages and disadvantages exist with diamond interchanges. The advantages are as follows:

- All vehicles can enter and leave freeway with a relatively high speed.
- Diamond interchanges take a moderate amount of right of way and have a moderate capacity.
- Diamonds interchanges allow for high operating speeds and direct movements.

The disadvantages are as follows:

- There must be adequate signage to prevent wrong-way entry onto the one-way ramps.
- Sufficient storage lanes must be provided.
- Left turns are forced to cross the path of opposing left turns at two points in the interchange.

With diamond interchanges, conflicts can occur at the terminals where ramps and crossroads meet. These conflicts can lead to backups that reduce the capacity and normal level of services (Garber and Fontaine, 1999).

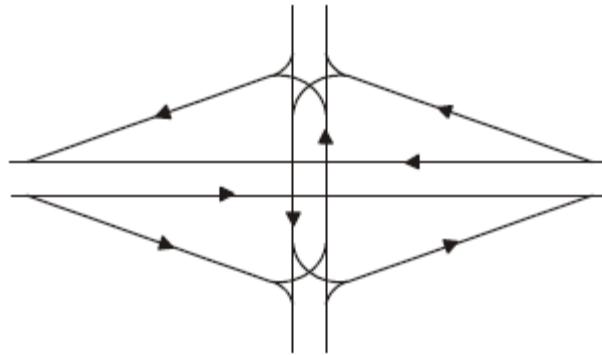


Figure 11 Diamond Interchange (Garber and Fontaine, 1999)

A conventional diamond interchange is a grade-separated intersection of a freeway and a crossroad composed of four facilities: freeway segments, speed-change lanes, ramp segments, and ramp terminals. Figure 12 shows the facilities of a conventional diamond interchange. The speed-change lanes are shown in magenta, the ramps in yellow, and the terminals in blue.

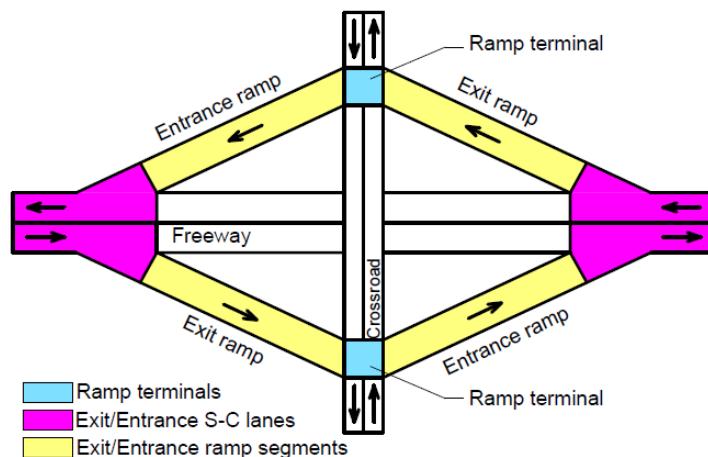


Figure 12 Facilities at a Conventional Diamond Interchange (Claros and Khezerzadeh, 2015)

ii. Full Cloverleaf Interchange Description

Full cloverleafs have several advantages which other forms of interchanges do not have:

- Full cloverleafs provide loop ramps for all left-turning movements, and these avoid safety problems that happen at diamond interchanges (Garber and Fontaine, 1999).

Figure 13 shows a typical full cloverleaf interchange.

- Full cloverleafs also allow for a free flow of traffic in all directions without traffic control (Holzman and Marek, 1993).
- The full cloverleaf interchange is the minimum design that can be used where two fully controlled access facilities cross: turns at grade are prohibited (Garber and Fontaine, 1999).

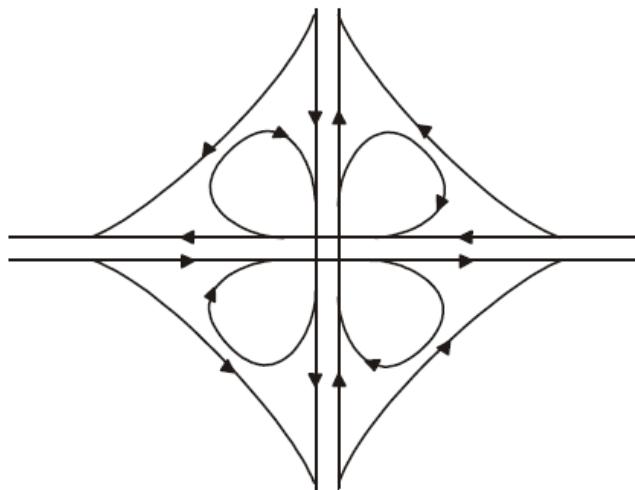


Figure 13 Typical Full Cloverleaf Interchange (Garber and Fontaine, 1999)

The full cloverleaf design has several disadvantages:

- Loop ramps use a great amount of the right of way.
- The amount of space required for the loop increases incredibly with the design speed of loop increases.

- Full cloverleafs generate weaving maneuvers that can cause safety concerns, especially for short distances.
- The level of service in weaving areas tends to be lower than of the other interchange components (Leisch, 1993).

These disadvantages tend to make full cloverleafs less desirable in an urban area than other interchange types. Large amounts of right of way are needed, which is usually not cost-effective at an urban area (Nueman, 1986). Because of this, cloverleafs have been found to be most appropriate in rural areas with lower turning movements than in urban areas (Leisch, 1962).

Figure 14 shows typical diamond interchange types.

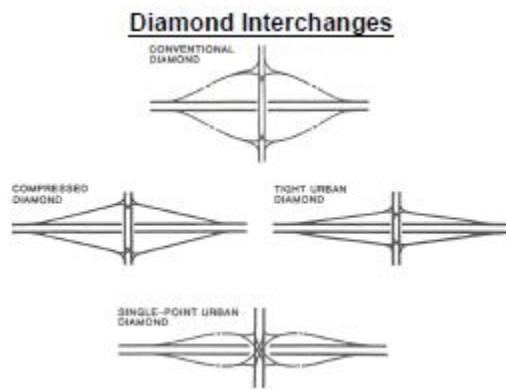


Figure 14 Typical Diamond Interchange Types (Garber and Fontaine, 1999)

iii. Partial Cloverleaf Interchange Description

The partial cloverleaf interchange is similar to a full cloverleaf, except that loop ramps are present in only three quadrants or fewer (Garber and Fontaine, 1999). The partial cloverleaf interchanges in this research are focused on two-quadrant partial cloverleafs as seen in Figure 15.

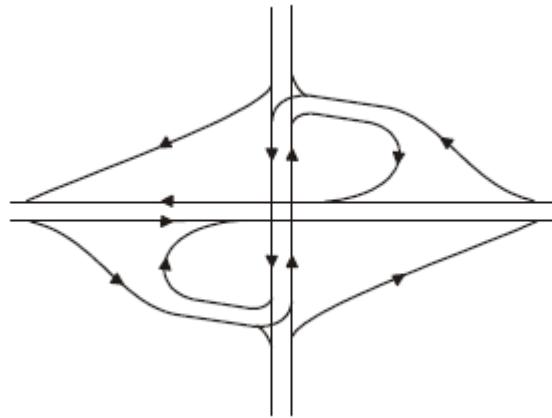


Figure 15 Partial Cloverleaf Interchange (Garber and Fontaine, 1999)

Partial cloverleaf interchanges are generally used where the right of way is not available in a quadrant or when the traffic volume making a particular movement possible is much lower compared to other movements (Garber and Fontaine, 1999). In the partial cloverleaf interchanges, the ramps should be laid out in the order that the entrances and exits would cause the least amount of disruption to the major road.

Partial cloverleaf (parclo) interchanges are primarily used where access needs, right of way, and street network configurations control the interchange configuration. However, partial cloverleaf interchanges suffer from many of the same drawbacks as the full cloverleaf interchanges concerning loop ramps and weaving sections (Garber and Fontaine, 1999). Figure 16 shows typical parclo interchange geometries.

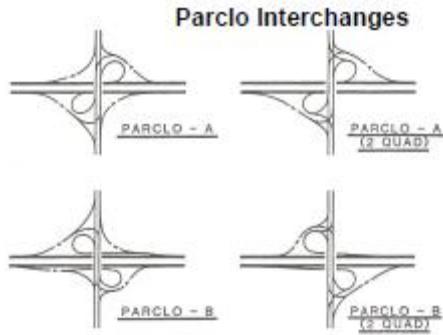


Figure 16 Typical Parclo Interchange Types (Garber and Fontaine, 1999)

Garber and Fontaine (1999) find that each type of interchanges has its own predominant collision locations, which are as follows:

- Diamond interchanges: Center of intersection; 54.8% of the total crashes occurred at diamond interchanges.
- Partial cloverleaf interchanges: Crossroad; 57.1% of the total collisions occurred at partial cloverleaf interchanges.
- Full cloverleaf interchanges: Weaving area; 38.9% of the total crashes occurred at full cloverleaf interchanges.

When the available right-of-way is restricted, the most appropriate interchange type is the diamond. In addition, some situations where the right-of-way is limited in one or more quadrants, the suitable interchange type will often be the partial cloverleaf interchange. In circumstances where the right of way is not limited, then full cloverleaf interchange may be considered for application, such in rural areas.

iv. Summary of Characteristics

Table 4 shows the summary characteristics of different interchange types.

Table 4 Summary of interchange characteristics

Interchange type	Right of way required	Capacity	Notes
Diamond	Low	Low	Simplest interchange
Partial Cloverleaf	Moderate	Moderate	Loops should be arranged to serve largest left turning movements.
Full Cloverleaf	High	Moderate	Weaving areas are safety and capacity concerns

Note: Garber and Fontaine, 1999

d. Introduce Different Facility Types

i. Freeway Description

A freeway segment of an interchange is the section of the freeway (in both directions) as shown in Figure 18 (Bonneson et.al, 2012). The gore points are used as the reference points to determine where the freeway segment begins and ends. The gore points are the locations where the ramp segments diverge or merge with freeway and are defined at the two feet wide points shown in Figure 17 (Bonneson et.al, 2012).

Within interchanges, there could be barriers on both sides of a freeway segment, bridge infrastructure, or grade differentials that could increase the risks of crashes. Hence, the crashes that occur on the freeway segment within an interchange might be different from non-interchange freeway segments that are not influenced by speed-change lane interaction, geometric design, and structural features.

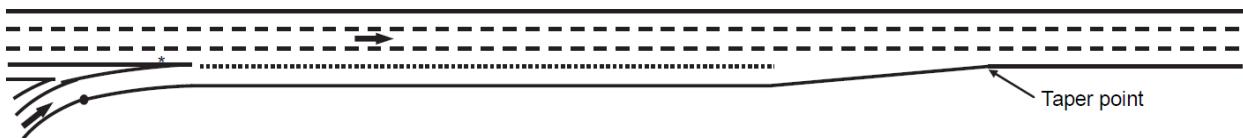
ii. Speed-change lane description

A speed-change lane is a unidirectional uncontrolled terminal between the freeway segments and ramp segments (Bonneson et.al, 2012). There are two types of speed-change lanes:

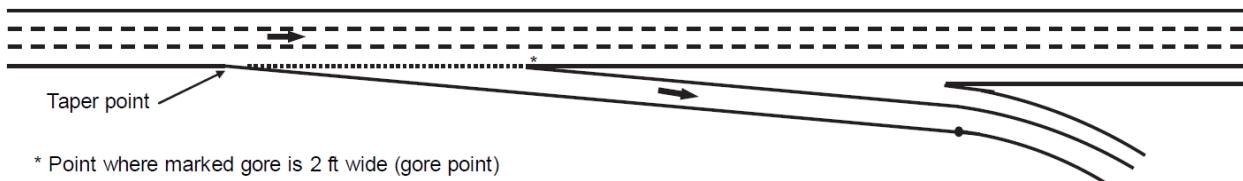
1. Exit speed-change lanes, which gradually add additional lanes to separate exiting traffic from through freeway traffic and connects with the exit ramp segment.
2. Entrance speed-change lanes, which merges the lanes from the ramp to the freeway by gradually dropping the ramp lanes, allowing vehicles to merge safely with the freeway through traffic.

Typically, an interchange has four speed-change lanes, two exit speed-change lanes, and two entrance speed-change lanes. The length of speed-change lanes is measured from the gore point to the beginning or end of the taper. Figure 5 shows a typical entrance ramp and an exit ramp with the associated speed-change lane, gore point, and taper point speed-change lane.

Entrance Ramp with Parallel Design



Exit Ramp with Taper Design

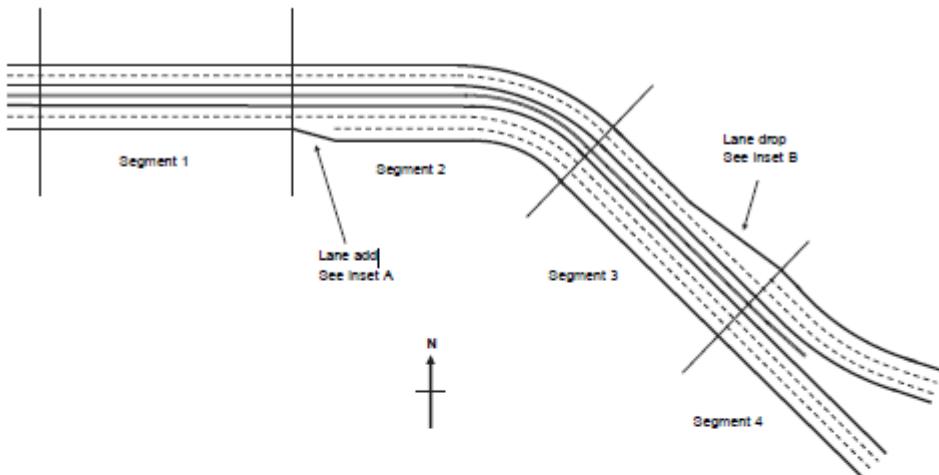


* Point where marked gore is 2 ft wide (gore point)

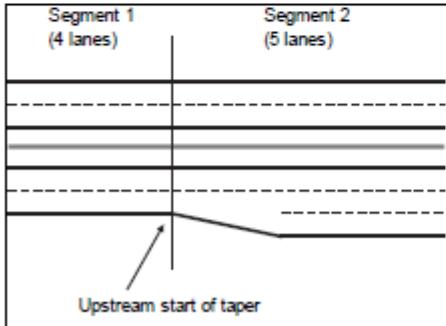
Figure 17 Freeway Speed-Change Lanes (ISATe User Manual)

Speed-change lanes differ from add or drop lanes. An add lane is a lane which is added to the main freeway lane without ending in a taper. Figure 18 shows a westbound add lane that continues and does not terminate at a taper. A drop lane, on the other hand, is a mainline lane

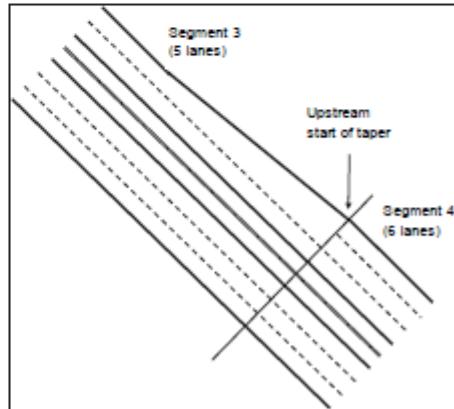
terminated via an off-ramp segment. Figure 18 also shows an eastbound drop lane where the drop lane did not begin with a taper.



a. Freeway Section Plan View



b. Inset A—Lane Add Start of Taper



c. Inset B—Lane Drop Start of Taper

Figure 18 Lane Add and Lane Drop (ISATe User Manual)



Figure 19 Example of Add and Drop Lanes

iii. Ramp Description

Ramp segments are unidirectional auxiliary roadways located between speed-change lanes and ramp terminals (Bonneson et.al, 2012). There are two types of ramp segments:

1. Exit ramp segments (off-ramp segments), which allow through traffic to leave the freeway and connect with the crossroad using the ramp terminal.
2. Entrance ramp segments (on-ramp segments), which provides the crossroad traffic access to the freeway through the ramp terminal.

The length of a segment is determined from the gore point to the stop line at the ramp terminal for exit ramp segment, and the length from the edge of the crossroad to the gore point with the freeway for the entrance ramp segment (Bonneson et.al, 2012). Figure 20 shows the locations and length of ramp segments at a diamond interchange.

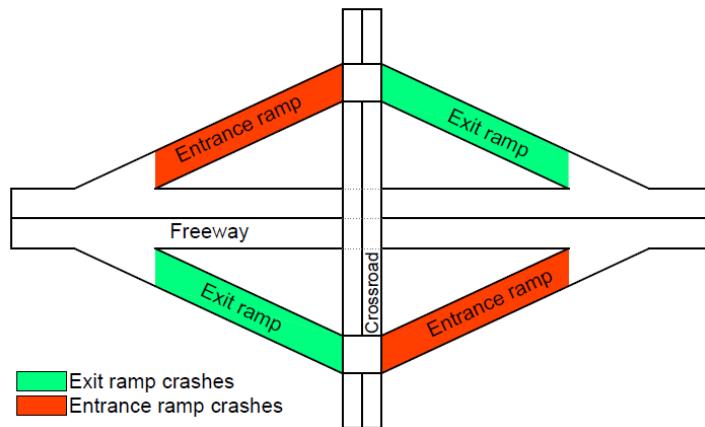


Figure 20 Ramp Segments Locations (Claros and Khezerzadeh, 2015)

e. Relevant Crash Frequency Modeling of Freeway Interchanges

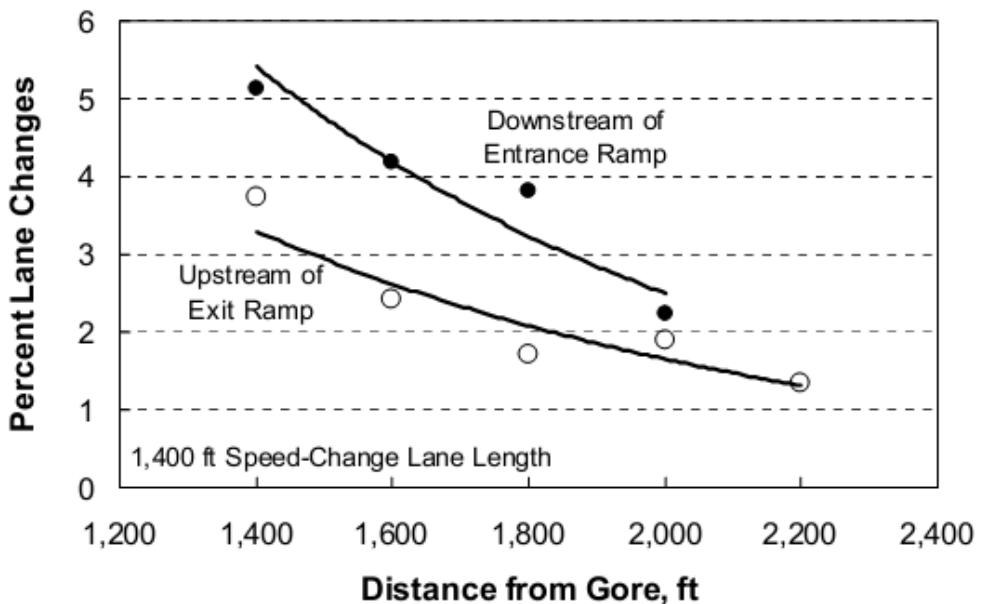


Figure 21 Percent of Lane Changes as a Function of Distance from Ramp Gore (Goswami and Bham, 2006)

Goswami and Bham (2006) examined the interchange terminal's vicinity to determine the range of lane-changing activity, using a segment of I-80 in California. In particular, they divided

a freeway segment into 200 ft. zones, and tabulate whole volume for one lane and lane-changing activities occurring within each zone. Figure 21 shows the frequency of entrance ramps and exit ramps. The lines shown in the figure represent regression models, which suggested that as the distance from ramp gore point increased, the lane-changing activity was reduced.

Cirillo (1968) examined total crash rates from the Interstate Highway System for segments that were in the vicinity of an interchange. Lane-changing activities, because of ramps, have a direct impact on the crash rates as shown in Figure 22. This impact is reflected as the following equation:

$$CMF_x = 1.0 + (0.001AADT_{ramp})^{b_0} e^{-b_1 x}$$

Where,

CMF_x =crash modification factor for lane changes at a distance x from the ramp gore;
 b_0 , b_1 =regression coefficients; and x =distance from ramp gore, mi.

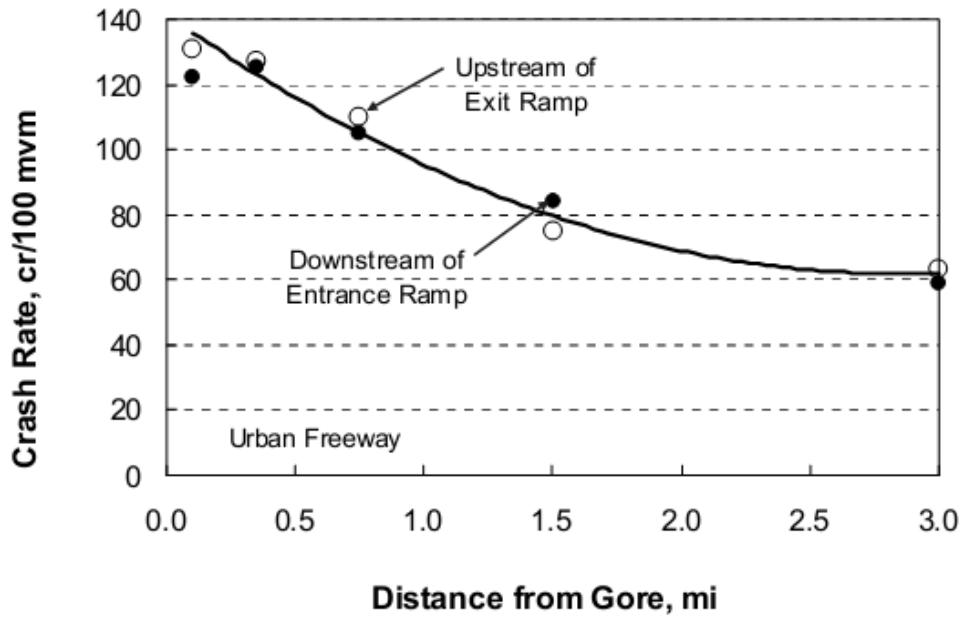


Figure 22 Total Crash Rate as a Function of Distance from Ramp Gore (Cirillo, 1968)

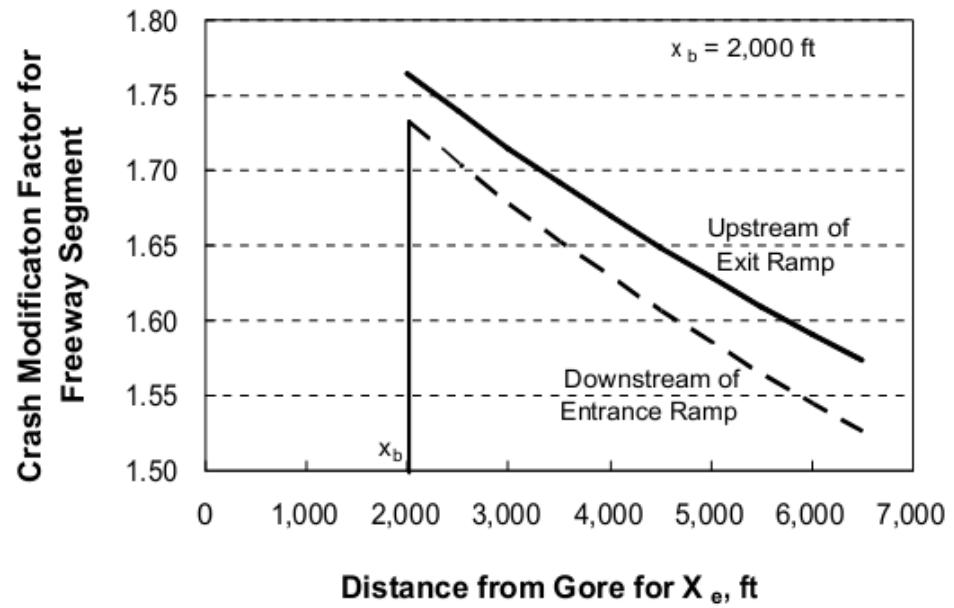


Figure 23 Relationship between CMF Value and Distance from Gore (Cirillo, 1968)

$$CMF_{lc} = \frac{\int_{x_b}^{x_c} CMF_x dx}{\int_{x_b}^{x_c} dx} = 1.0 + \frac{(0.001AADT_{ramp})^{b_0}}{b_1(x_c - x_b)} (e^{-b_1 x_b} - e^{-b_1 x_c})$$

Where,

CMF_{lc} =crash modification factor for ramp-related lane changes;

x_b =distance from ramp gore to start of segment, mi; and

x_c =distance from ramp gore to end of segment ($x_c > x_b$), mi.

Nonlinear regression was used to fit the equation above (using a simple SPF) to the data reported by Cirillo (1968). A factor was included in the SPF to account for differences between urban and rural segments. The b_1 regression coefficient was allowed to have a unique value for exits and for entrances (Bonneson et al. 2012). The calibrated CMF is shown in Figure 23 for a freeway segment that starts 2,000 ft from the ramp terminal. Other trend lines can be computed for other starting locations.

If the subject freeway segment starts 2,000 ft from the gore, then Figure 23 can be used to obtain a factor value for any specified segment length. For example, if the segment is 1,500 ft long and downstream of an entrance ramp, then the end of the segment is at 3,500 ft and the factor value is 1.65 (Bonneson et al. 2012). This value can also be obtained by inspection of the trends in Figure 22.

f. Research on First/Most Harmful Event

An accident is an unstabilized circumstance when a set of events are not under human control, including at least one harmful event (ANSI-07D16, 2007). In the Fatality Analysis Reporting System (FARS), the harmful event in a collection of fatal crashes in America was determined by trained analysts based on crash reports. Previous studies assessed risk based on the most harmful event. Using motorcycle collisions with a guardrail as an example, where the guardrail was designated the most harmful event, studies demonstrated a dramatically higher

fatality risk than passenger vehicle collisions with guardrail (Gabler, 2007). However, the concern has been raised about whether the guardrail actually was the most harmful event in these crashes (Daniello and Gabler, 2011). Figure 24 indicates a structure of a crash scenario that includes three major phases: pre-crash, impact, and injury as well as two minor phases: attempted avoidance and pro-impact stability (Eigen and Najm, 2009).

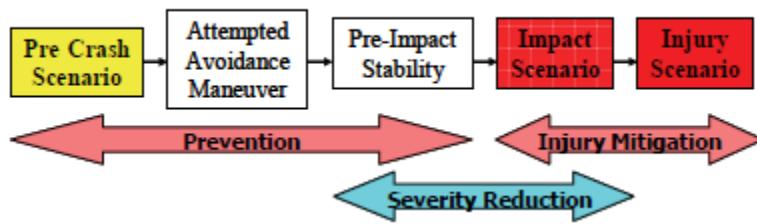


Figure 24 Crash Sequence (Eigen and Najm, 2009)

In terms of definition, a harmful event is an occurrence of injury or damage (Kar and Khasnabis, 2009) “crash impacts that result in injury or property damage are called harmful events in accident data files” (Viner, 1993), and can be categorized as either first harmful event (FHE) or most harmful event (MHE).

A first harmful event is reported in accident data files as an “accident level variable.” Each crash was assigned to a single FHE in spite of the number of the vehicles involved. The FHE in a crash may not be the cause that generated the greatest amount of property damage or injury. The most harmful event is reported in accident data files as a “vehicle level variable.” Separate MHEs were assigned to all vehicles present in a crash. (Viner, 1993)

The following example from Viner (1993) illustrates the major distinction between the two events:

“Consider for example a wet-pavement, two-vehicle collision injuring two occupants in the struck vehicle. Say the striking vehicle was then deflected into a utility pole, killing the driver. The FHE is the vehicle-vehicle collision, resulting in one fatality and two injuries. The MHE for the struck vehicle is the vehicle-vehicle collision, resulting in two injuries. The MHE for the striking vehicle is the utility pole collision, resulting in one fatality”. (Viner, 1993, pp. 139–145)

- Overtakes and fixed objects (particularly trees and utility poles) are disproportionately associated with a large number of crashes inflicting higher degrees of severities (MHE-dominant).
- Run-off-road crashes are disproportionately associated with crash causes (FHE-dominant).
- Nonfixed objects in general, and collisions with motor vehicles in particular, are equally associated with crash causes and severities (FHE-MHE indifferent).

There are three primary variables in the FARS database that are used to measure the type of crashes:

1. First harmful event (FHE): The first injury producing event or property damage.
2. Most harmful event (MHE): The major event for the vehicle involved in the crash that produced the most injury or property damage.
3. Sequence of events: Collision and non-collision events in sequence related to a motor vehicle crash irrespective of injury and/or property damage.

There are other similar definitions such as the initial point of impact and principal point of impact. Both of them indicate the angle at which vehicle was struck (Awadzia et.al 2008). In

MMUCC, the fourth edition, besides the definition of the FHE, there is needed for uniformity in reported motor vehicle crash statistics, understanding of crash causation, and identification of possible avoidance of countermeasures for the crash.

For the same purpose, in the accident classification of ANSI-07D16 (2007), the use of the FHE rather than the most severe or significant harmful event is specified for uniformity in reported road vehicle accident statistics. It may be desirable to collect and use information about subsequent harmful events. Motor vehicle accident categories from American National Standard are as follows.

Collision accident:

- Collision involving pedestrian
- Collision involving motor vehicle in-transport
- Collision involving parked motor vehicle
- Collision involving railway vehicle
- Collision involving pedal cycle
- Collision involving animal
- Collision involving fixed object
- Collision involving other object

Non-collision accident:

- Overturning accident
- Jackknife accident
- Other non-collision accident

Other road vehicle accident categories from American National Standard include the following:

Collision accident:

- Collision involving pedestrian
- Collision involving other road vehicle in-transport
- Collision involving parked motor vehicle
- Collision involving railway vehicle
- Collision involving animal
- Collision involving fixed object
- Collision involving other object

Non-collision accident:

- Overturning accident
- Jackknife accident
- Other non-collision accident

In addition, there is another definition called “location of first harmful event relative to the trafficway,” which is important to identify highway geometric deficiencies. It defines the location of the FHE as it relates to its position within or outside the trafficway.

Table 5 shows the summary and comparison of crash information of Australasian, Europe Union, and U.S. databases. The comparison focused on general aspects at strategic level and operative level (New Zealand in Australasia; Italy in Europe; and Indiana in America).

Table 5 Summary and Comparison of Crash Information

Variable	EU Directive	EU CADaS	U.S. MMUCC	U.S. Indiana	Australia	New Zealand	Italy Highway Police	Italy ISTAT
Crash location	Precise as possible location	GPS coordinates	Highway name and linear referencing, GPS-GIS coordinates		Highway name, reference point, distance and direction from reference point	Highway name and GPS coordinates	Highway name, linear referencing system, address for urban roads	Highway name, linear referencing system, address for urban roads, GPS coordinates ^a
Crash narrative	No	No	No	Yes	Yes	Yes	Yes	No
Crash sketch	No	No	No	Yes, but access restricted	Yes, but access restricted	Yes	Yes ^b	No
Crash type	Yes	Yes	All the events are recorded in the traffic units section		Yes	Yes	Description ^c	No
Collision type	Yes	Yes	8-descriptors	8-descriptors	Yes	Yes	Description ^c	12-descriptors
First harmful event	No	Only the first event is recorded	Noncollision (8), collision (9), and collision with fixed object (21) descriptors		No	No	Description ^c	Only the first event is recorded
Contributing circumstances	No	No	Environmental circumstances (6 descriptors, 3 subfields), road circumstances (11 descriptors, 3 subfields)	Yes		A large number of cause factors is provided ^d	Description ^c	Yes
Weather conditions	Yes	7 descriptors	10 descriptors	8 descriptors	Yes	5 descriptors	Yes	CAdaS descriptors
Light conditions	Yes	6 descriptors	7 descriptors	7 descriptors	Yes	7 descriptors	Yes	No
Reported crashes	Not specified	Only injury crashes	All severities	All severities	All injury severities (only injury crashes in some jurisdictions)	All severities	All severities	Only injury crashes
PDO	Not specified	Not reported	Damages ≥ \$1,000	Damages ≥ \$1,000	Above threshold values (which vary across jurisdictions) or where the vehicle is towed away		Reported	Not reported
Number of non-fatal injury levels	2	2	3	3	2	2	1	1
Definition of nonfatal injury levels	Severe and nonsevere injuries	Serious: hospitalized for more than 24 h Slight: hospitalized for less than 24 h or not hospitalized	A: Suspected serious injury B: Suspected minor injury C: Possible injury	A: Incapacitating injury B: Nonincapacitating injury C: Possible injury	Injured, admitted to hospital (as inpatient) Injured, required medical treatment	Serious: requiring medical treatment Minor: other injuries	Injury description	Any injury reported by the police
Fatalities	Died within 30 days (refers to all countries in table)							
Link with hospital data	No	Yes ^e	No	Only for special studies	In Western Australia	No	In most cases	No

Note:

- GPS coordinates were introduced in the 2012 form but are not collected by police.
- The form has an area for a crash sketch, but it is completed only in few crashes.
- In most cases, this information can be retrieved from the crash narrative.
- Cause codes (e.g., “too fast for conditions” and “failing to give way”) and roadside hazards hit are extracted from crash diagram and witness reports.
- The link with hospital data takes place systematically in the Czech Republic, Germany, and the Netherlands. (Montella, et.al 2013)

III. Data

a. Data Collection Procedure

The data collection procedure included a series of tasks:

- Site identification for accident data collection
- Facility identification
- Merge crash reports with sample sites
 - i. Site Identification for Accident Data Collection

The selection of the study sites is a critical step in data collection for this research. The sites selected should represent a good cross section of interchange types in Missouri. Data were collected for 42 diamond, 2 full cloverleafs, and 16 partial cloverleafs, a total of 60 interchanges, 120 sites. These interchanges selected included those from both urban and rural environments.

The interchanges selected are as follows:

1. US 36 and RTO (C), Macon, Diamond
2. US 61 and RTP, Lewis, Diamond
3. IS 70 and RTM (O), Lafayette, Diamond
4. IS 70 and MO13, Lafayette, Diamond
5. IS 29 and RTK, Andrew, Partial Cloverleaf
6. US 67 and MO 110, Jefferson, Diamond
7. IS 44 and RTB, Webster, Diamond
8. IS 44 and RTK (PP), Greene, Diamond
9. US 24 and MO 168 (BUS 61), Marion, Partial Cloverleaf
10. US 24 and MO 13 (13th Street), Lafayette, Partial Cloverleaf

11. IS 55 and RTJ (U), Pemiscot, Diamond
12. US 24 and MO 13, Lafayette, Partial Cloverleaf
13. IS 44 and RTZ (O), Lawrence, Partial Cloverleaf
14. MO 13 and MO 52, Henry, Partial Cloverleaf
15. US 67 and MO 72, Madison, Diamond
16. IS 44 and MO 17 (RTC), Pulaski, Diamond
17. IS 44 and MO 30, Franklin, Diamond
18. IS 29 and MO 6 (Frederick Ave), Buchanan, Diamond
19. IS 70 and US 65, Saline, Full Cloverleaf
20. US 54 and MO 179 (RTB), Cole, Diamond
21. IS 72 and MO 79 (Harrison Hill Road), Marion, Diamond
22. IS 55 and US 67, Jefferson, Full Cloverleaf,
23. IS 49 and Civil War Road, Jasper, Diamond
24. IS 170 and Ladue Road, St. Louis, Partial Cloverleaf
25. IS 49 and MO 2 (South Commercial Street), Cass, Diamond
26. IS 49 and RTHH (West Fir Road), Jasper, Diamond
27. IS 55 and Main Street (Lasalle Ave), Cape Girardeau, Diamond
28. US 36 and South 22nd Street, Buchanan, Partial Cloverleaf
29. IS 70 and RTA (Freymuth Road), St. Charles, Diamond
30. US 36 and US 63, Macon, Diamond
31. IS 35 and RTN, Harrison, Diamond
32. US 24 and 13th Street, Lafayette, Partial Cloverleaf

33. US 61 and RTP, Lewis, Diamond
34. IS 35 and RTDD, Daviess, Diamond
35. MO 7 and Pier 31 Road, Camden, Diamond
36. IS 70 and MO 13, Lafayette, Diamond
37. IS 44 and RTZ (RTO), Lawrence, Partial Cloverleaf
38. MO 13 (MO 7) and MO 52, Henry, Partial Cloverleaf
39. IS 55 and US 61, Jefferson, Diamond
40. MO 21 and Old MO 21, Jefferson, Diamond
41. IS 44 and RTK (RTPP), Greene, Diamond
42. IS 29 and RTK, Andrew, Partial Cloverleaf
43. IS 55 and US 61, Cape Girardeau, Diamond
44. IS 55 and RTJ, Pemiscot, Diamond
45. US 67 and MO 72, Madison, Diamond
46. IS 29 and MO 6 (Frederick Ave), Buchanan, Diamond
47. US 36 and US 63, Macon, Diamond
48. IS 72 and MO 79, Marion, Diamond
49. IS 49 and East 163rd Street, Cass, Diamond
50. IS 435 and NE Cunningham Dr, Clay, Partial Cloverleaf
51. US 65 and US 76, Taney, Partial Cloverleaf
52. US 54 and MO 179 (RTB), Cole, Diamond
53. IS 44 and MO 17, Pulaski, Diamond
54. IS 64 and Lake St Louis Blvd, St. Charles, Partial Cloverleaf

55. US 61 and RTA, St. Charles, Diamond
56. US 36 and South 22nd Street, Buchanan, Partial Cloverleaf
57. IS 49 and Civil War Road, Jasper, Diamond
58. IS 49 and RTHH (West Fir Road), Jasper, Diamond
59. US 60 and US 61 (US 62), New Madrid, Diamond
60. IS 55 and RTHH (C538), Scott, Diamond

ii. Facility Identification

Next, a subset of critical facility types was determined, and based on previous description, each interchange was divided into freeway segments, ramp segments, speed-change lanes, and non-interested segments, using two methodologies that are physical methodology and functional methodology. In addition, both rural and urban models were considered.

iii. Merge Crash Reports with Sample Sites

This activity involved merging the crash data with the sample sites generated from step one. The crash data were obtained from crash reports from MoDOT (2010-2012). The objective was to assemble the highway safety database that included all the relevant crashes for analysis. Several separate safety databases were assembled for each comparison of roadway component.

b. Description of Crash Reports

Crash reports, which used for interchange facility assignment include image number, general crash information, location, damage to property, witness, pedestrian, collision diagram, drivers, codes, and narratives or statements of the crash. This research used the following:

- Image number: A unique number to identify a specific crash report assigned by the Missouri DOT, which is compatible with the electronic crash report.

- Location: Main road and crossroad, roadway direction, distance from the road, and so forth. The location information should be used in assistance with collision diagram and narratives or statements because people filing out the form have different perceptions of distance to interchange.
- Collision diagram: Shows the location and circumstances of the crash. If collision diagram is not applicable or limited, then location information and narratives need to be used to locate the crash.
- Narrative or statements: Includes a description of the crash reported by an officer and collected from drivers and/or witness involved in that crash. However, details in this part are also subjective due to officers' experience and expertise. (Missouri Uniform Crash Report Preparation Manual)

c. Database Summary

This part of the research summarizes the data assembled for the purpose of evaluating the crash influence area of interchange facilities. For each interchange, the crash reports are categorized as terminal-related and non-terminal-related. Based on the characteristics, some types generalized more terminal-related crashes while other types generalized more non-terminal-related crashes. This research considers only non-terminal-related crashes. Table 6 summarizes the crash data retained for analysis. For all of the 2,261 crashes occurring from 2010 to 2012, there were 1,473 crashes classified as non-terminal-related, which composed 65.1% of the total. For all of the 1,593 crashes associated with diamond interchanges, 925 crashes were classified as non-terminal-related, which composed 58.1% of the total. Conversely, 287 out of 368 crashes were non-terminal related crashes associated with parclo cloverleaf interchanges,

which composed 78.0% of the total. Full cloverleaf interchanges are symmetry types, so they are all non-terminal-related crashes.

Table 6 Crash data summary

Area type	No. of Interchanges	Ramp configuration	FI crashes (2010-2012)	PDO crashes (2010-2012)
Rural	20	Diamond	76	297
	10	Parclo	12	67
Urban	22	Diamond	71	244
	6	Parclo	65	145
	2	Full	71	190
Overall	60	-	295	943

Table 6 shows the distribution of crash severity. It illustrates that rural areas generate property damage only (PDO) crashes more in terms of diamond interchanges and less in terms of parclo cloverleaf interchanges. On the other hand, urban areas generate fatal and injury (FI) crashes less with regard to diamond interchanges and significantly more in parclo cloverleaf interchanges. At the same time, FI crashes occurred dramatically within full cloverleaf interchanges.

IV. Functional classification

a. Methodology

Several factors may distract drivers from operating vehicles. Crashes at exit ramp and freeway before or at speed change lane related to on ramp are usually caused by speed differential and lane changing, which can occur due to overloaded driver information. Drivers generally successfully handle exiting the freeway by reducing speed and changing lanes to exit the freeway to the ramp segment and continue to the crossroad. Conversely, crashes could occur at an entrance ramp where drivers might not be able to accelerate to the necessary speed to keep up with freeway traffic, or they might enter at a point with an improper gap between two vehicles whose speed on freeway is faster than theirs. These types of crashes are labeled as speed-change-lane crash even though those crashes happened beyond the speed change lane area (from the gore point to the taper point).

In the functional classification, the circumstances of each crash should be considered in addition to the exact crash location. There are three importance steps for assigning crashes under the functional classification: Step 1, crash location review; Step 2, crash circumstances review; and Step 3, crashes assignment.

In the first step, the specific location of the crash is determined by the provided information, such as the location field, collision diagram, and statement or narrative. The second step of the review including the analysis of the crash events with respect to the location. The narratives provided by the witnesses and people involved in the crash are carefully interpreted to modulate for personal biases. The following sections describe the crash assignment procedures for speed-change lane and freeway crashes. Characters are defined to specifically denote the type

of facility (freeway segments, ramp segments, or speed-change lanes), and entrance or exit (merging or diverging).

i. Speed-change Lanes

As mentioned before, crashes often happen at exits and entrances due to speed changes and distractions. However, failing acceleration or deceleration or changing lanes improperly might lead to crashes. Cases 1, 2, and 4 of Figure 25 are the types of crashes that are caused by failing changing lanes. In Case 3, the driver almost missed the exit and then makes a sudden turn that caused a collision at the gore point of speed-change lane. In Case 5, the driver lost control just before the gore point. All these types of crashes are assigned as speed-change lane crashes, which indicate that the crashes happened because of the geometric design of speed-change lane. Case 6 illustrates that the driver decided not to exit the freeway and returned improperly to the freeway, causing a collision.

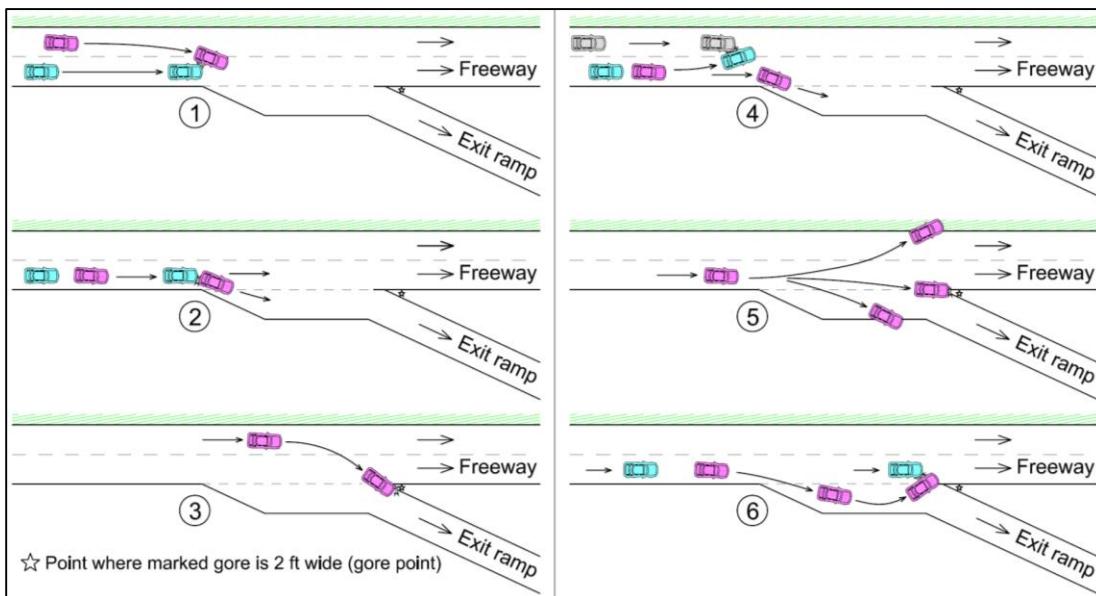


Figure 25 Common Crash Types at Exit Speed-change Lanes (Claros and Khezerzadeh, 2015)

Similar circumstances could occur at an entrance ramp. Cases 1 and 3 of Figure 26 illustrate these types of crashes where a driver might not be able to accelerate to keep up with freeway traffic. Case 2 shows a crash due to congestion on the freeway where ramp vehicles have difficulty finding a space to merge. Hence, a vehicle rear ends the front vehicle where a queue has been generated. Case 4 shows a crash caused by running off the road or loss of control. These crashes are considered speed-change related if the crash report information suggests that they were generated after the gore point. Figure 27 shows the thresholds for speed-change lane related crashes.

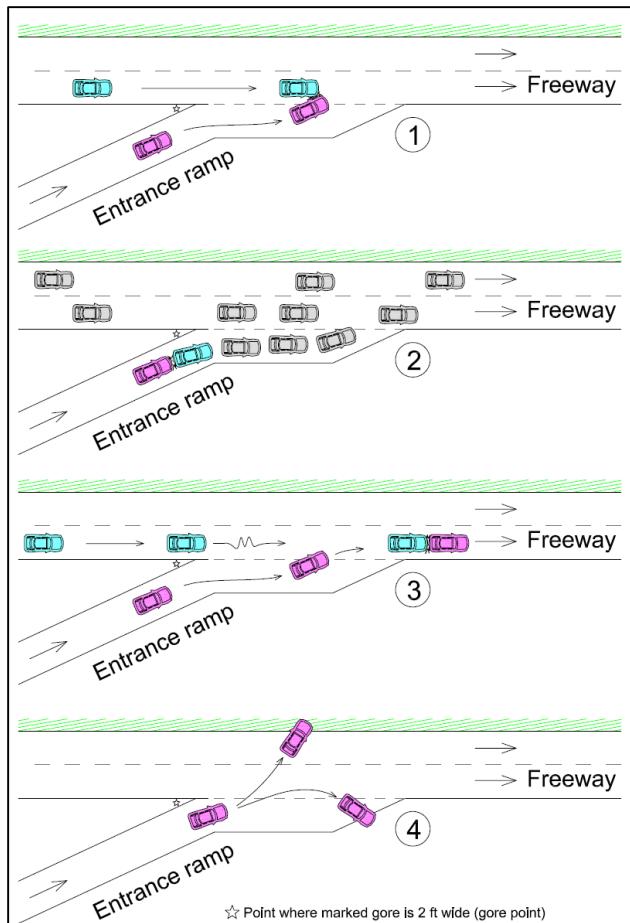


Figure 26 Common Crash Types at Entrance Speed-change Lanes (Claros and Khezerzadeh, 2015)

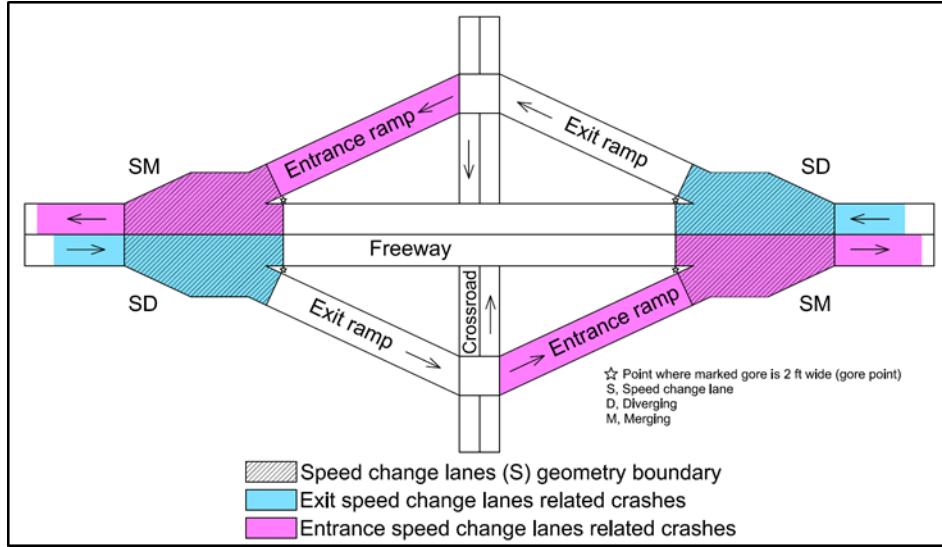


Figure 27 Speed-change Lanes Related Crashes and Boundaries (Claros and Khezerzadeh, 2015)

ii. Freeway Segment

Figure 28 shows cases on an interchange freeway segment. Case 1 shows a collision with an object or animal between the gore points. Case 2 shows a sideswipe crash because of a failure of lane changing in the limits between the gore points. Case 3 shows loss of control (overturning or overcorrecting) of a vehicle between the gore points. All types of freeway related crashes not impacted by the geometric design of speed-change lanes should be crashes should be assigned to speed-change lanes instead of freeways.

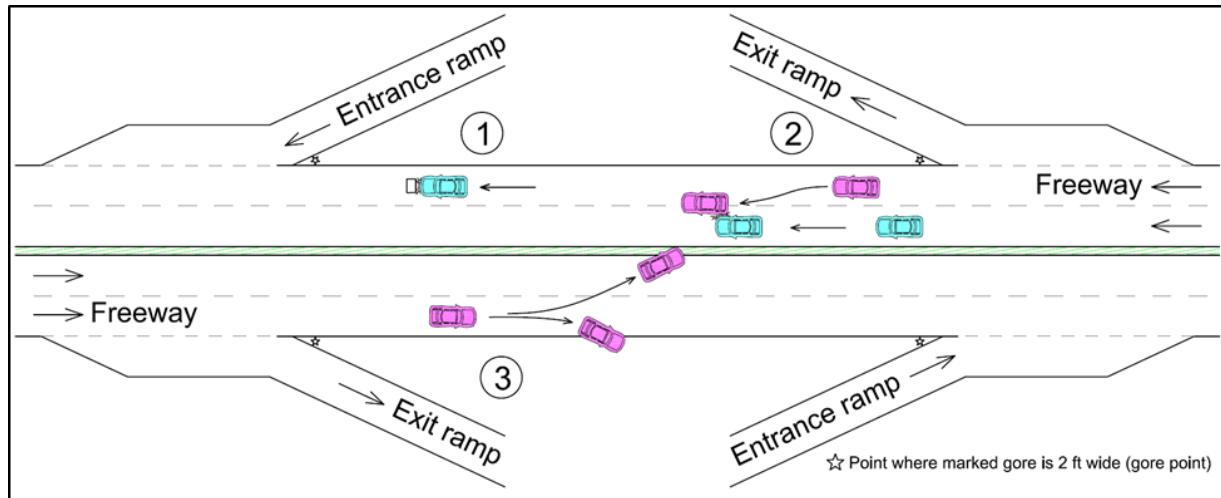


Figure 28 Crashes at Interchange Freeway Segment (Claros and Khezerzadeh, 2015)

b. Probable Contributing Circumstances

Some crashes should be excluded from review because they are unique they cannot be used as selected data. The Missouri Uniform Crash Report (MUCR, 2012) explains the difference between “motor vehicle traffic crashes” and “motor vehicle crashes”:

Motor Vehicle Traffic Crash: Any motor vehicle crash with an unstabilized circumstance or a harmful event generated on a trafficway is a “motor vehicle traffic crash.”

Motor Vehicle Crash: If any unstabilized circumstance or harmful event is generated off a trafficway, this kind of crash is a motor vehicle crash but not a motor vehicle traffic crash.

Both motor vehicle crashes and motor vehicle traffic crashes are included in STARS; however, STARS statistics only include motor vehicle traffic crashes. Hence, to have a “motor vehicle crash,” the following elements must be present:

- At least one motor vehicle involved.
- At least one harmful event.

- The harmful event must be the result of an unintentional act.
- The harmful event is not the direct result of a cataclysm.
- The crash was not initiated by an action of an aircraft or watercraft.
- The crash does not include any harmful event involving a railway vehicle in transport prior to involvement of a motor vehicle in transport. (MUCR, 2012 page 19)

The rare or unique circumstances in reviewing crash reports are as follows:

- Work zones moving or stationary: Work zones, either moving or stationary, fundamentally changing the nature of the road, and these crashes should be removed from the database. For example, if there is a work zone ahead, whether it contains stationary or moving vehicles, there could be lane drops that reduce capacity and add turbulence at the taper point especially when encountering moving working vehicles that move much slower than the designed speed limit or reduced lane width. Hence, these crashes should be considered as work zone crashes instead of interchange crashes.
- Mistaken assignments or cross street crashes: Crashes are excluded as they are not generated from the interchanges or interchange facilities of interest.
- Crash ahead: These types of crashes are similar to those of work zones. If there are primary crashes, other circumstances can occur, like lane closures, congestion, or emergency vehicles. Also, like work zone crashes, those circumstances lead to significant changes to the roadway.

- Vehicle defects: When a vehicle defect does not lead to a crash, it should not be classified as crash. For instance, a vehicle broken down and parked on the shoulder without a collision should be recorded as an incident instead of crash.

In addition to the unique circumstances above, based on crash reports reviewing, the probable contributing circumstances of crashes are as follows:

- Deer: Include for both physical and functional classification.
- Animal (for any animal other than deer): Include for both physical and functional classification.
- Object in roadway: Any kind of object or obstruction left in the roadway or dropped from other vehicle, like tires or mattresses. These should be included for both physical and functional classification.
- Work zone: As explained before, these should be exclude for both physical and functional classification.
- Physical impairment: As an example, a driver has a heart attack. Include for both physical and functional classification.
- Driver falling asleep: Include for both physical and functional classification.
- Drug: Include for both physical and functional classification.
- Alcohol: Include for both physical and functional classification.
- Hydroplane: Include for both physical and functional classification.
- Icy/snowy road condition: Include for both physical and functional classification.

- Vehicle defect: Include for both physical and functional classification. One exception is when a vehicle defect does not result in a crash, as it should be excluded for both classifications.
- Crash ahead: Include for physical but exclude for functional classification. Since a crash might block a lane or affect the roadway speed, it is recommended to exclude this kind of crash for functional classification.
- Congestion ahead: Include for both physical and functional classification.
- Construction vehicle ahead: Exclude for both physical and functional classification. These are similar to work zones, which should be treated as moving work zones.
- Tire blowout: Include for both physical and functional classification.
- Minor road: Crashes occurred in intersecting street; exclude for both physical and functional classification.
- Improper loading: In particular for trucks and trailers; include for both physical and functional classification.
- Mistake assignment: Not related to the interested interchanges; exclude for both physical and functional classification.
- Police pursuit: Include for physical classification but exclude for functional classification. In emergency situations, police and emergency vehicles do not necessarily follow the rules. They might drive over the speed limit, drive on trafficway shoulders, or pass the stop sign or red light directly without a stop. Hence, exclude these crashes from the functional samples.

- Emergency vehicle: Include for physical classification but exclude for functional classification as is the case for police pursuit.
- Any other kind of crash caused by distraction of drivers such as using cell phone, reading map, eating or drinking, or changing music; include for both classifications.

All in all, the difference between functional and physical classification in contributing circumstances are crash ahead, police pursuit, and emergency vehicle.

V. Results

a. Functional vs. Physical Classification

i. comparison

The major difference between functional classification and physical classification is the functionality of freeway and speed-change lane, which results in differences in assigning crashes to facilities. Table 7 and Table 8 show crash location distribution under two classifications.

Table 7 Crash Location Distribution under Physical Classification

Interchange type	Crash Location	Speed-Change Lane (Diverging)	Speed-Change Lane (Merging)	On-Ramps	Off-Ramps	Freeway	Total
Diamond	Count	50	62	30	46	476	664
	Total	112		76			
	Percentage (%)	7.53	9.34	4.52	6.93	71.69	100.00
		16.87		11.45			
Parclo	Count	16	26	8	21	130	201
	Total	42		29			
	Percentage (%)	7.96	12.94	3.98	10.45	64.68	100.00
		20.90		14.43			
Full	Count	0	0	29	28	31	88
	Total	0		57			
	Percentage (%)	0.00	0.00	32.95	31.82	35.23	100.00
		0.00		64.77			
Total	Count	154		162		637	953
	Percentage (%)	16.16		17.00		66.84	100.00

Table 8 Crash Location Distribution under Functional Classification

Interchange type	Crash Location	Speed-Change Lane (Diverging)	Speed-Change Lane (Merging)	On-Ramps	Off-Ramps	Freeway	Total
Diamond	Count	58	64	26	35	375	558
	Total	122		61			
	Percentage (%)	10.39	11.47	4.66	6.27	67.20	100.00
		21.86		10.93			
Parclo	Count	18	28	7	18	124	195
	Total	46		25			
	Percentage (%)	9.23	14.36	3.59	9.23	63.59	100.00
		23.59		12.82			
Full	Count	5	6	30	25	25	91
	Total	11		55			
	Percentage (%)	5.49	6.59	32.97	27.47	27.47	100.00
		12.09		60.44			
Total	Count	179		141		524	844
	Percentage (%)	21.21		16.71		62.09	100.00

In diamond interchanges, functional classification assigns more crashes to speed-change lane than physical classification, and this leads to fewer crashes on ramps and freeways. Due to rare events that might not result from geometric design, the total number of crashes from physical classification is more than those in the functional classification. For partial cloverleaf interchanges, because of their large angle curve, ramps generated more crashes than diamond interchanges. The same was true for partial cloverleaf interchanges, where functional classification generated more crashes on speed-change lane than that under physical classification. For full cloverleaf interchanges, more crashes are assigned to speed-change lane under functional classification than to physical classification.

Figure 29 shows a comparison between two types of classification in diamond interchanges. It illustrates that freeway has the largest portion of crashes and also the largest variance at an interchange, with more crashes assigned under the physical classification. Speed-change lanes rank the second, with more assigned crashes under functional classification. Ramps had more physical classified crashes than functional classified crashes.

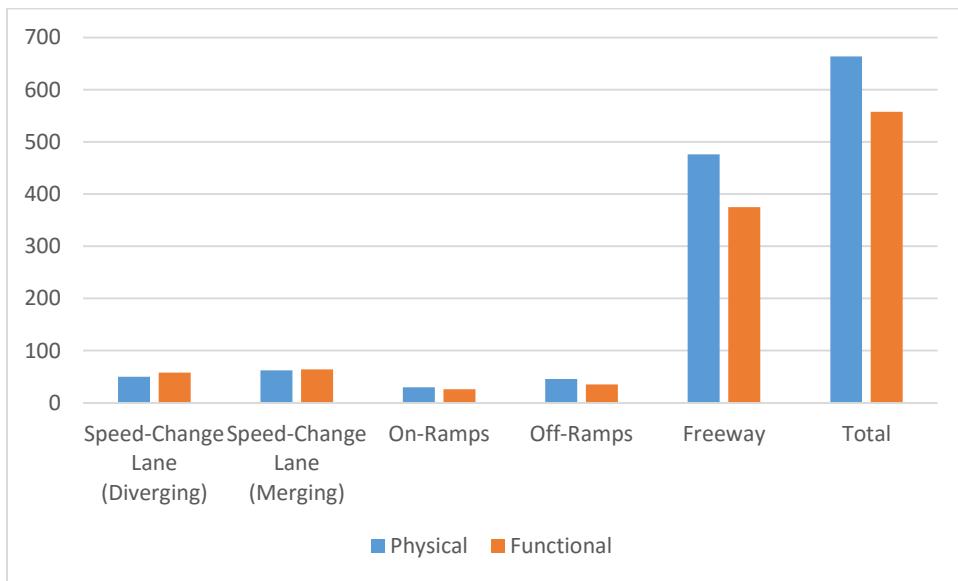


Figure 29 Comparison between Two Types of Classification in Diamond Interchange

Figure 30 shows comparison between two types of classification in partial cloverleaf interchanges. Figure 30 shows same trend as Figure 29 but with less variance between two types of classification.

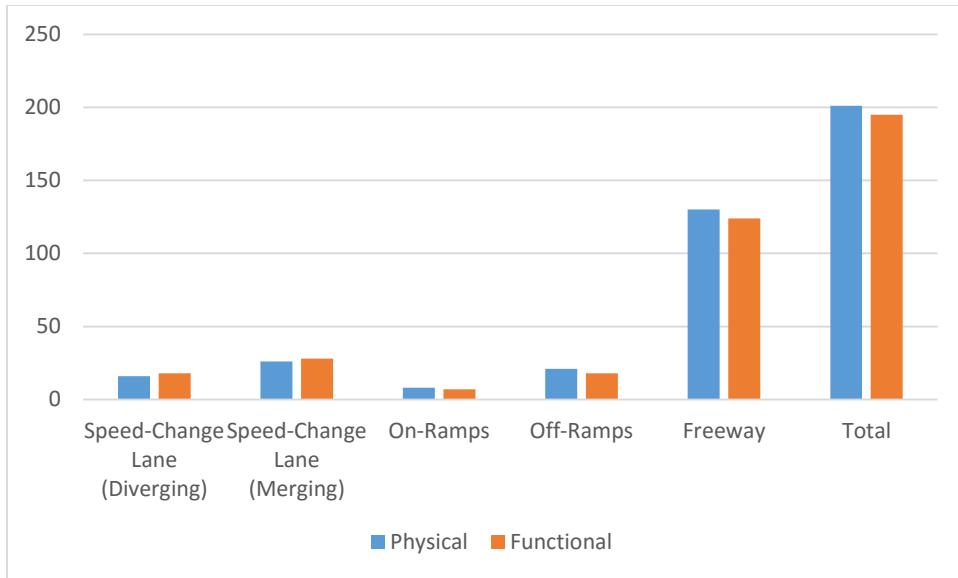


Figure 30 Comparison between Two Types of Classification in Partial Cloverleaf Interchange

As seen in Figure 29 and Figure 30, Figure 31 also shows the same trend, which is more crashes are assigned to speed-change lanes and less crashes are assigned to ramps and freeways under functional classifications than under physical classifications.

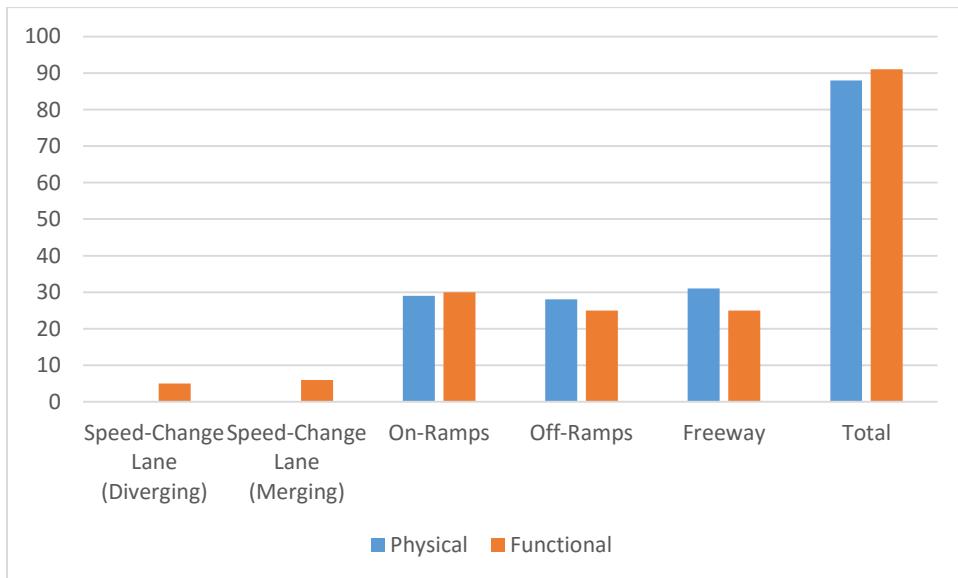


Figure 31 Comparison between Two Types of Classification in Full Cloverleaf Interchange

ii. First Significant Event

Geometric design of speed-change lanes might influence crashes. Characteristics that could have a significant impact include taper configuration, number of lanes, width of lanes, and horizontal and vertical curves. For example, multiple lanes or short tapers add more risk to speed-change lanes, because one leads to more interactions with other lanes and the other may lead to drivers' improper movement decisions.

Crashes should be assigned to speed-change lanes if the geometric design and vehicle operations influenced the crash; they should not be assigned to the exact crash location, such as freeways. The fact that a crash happened within the boundaries of a facility type does not guarantee that the crashes is related to that facility. At this point, safety problems might be addressed more efficiently by using the first significant event (FSE: is an operation characteristic that causes a driver to fail to properly change lanes or speed, thus leading to a crash) instead of first harmful event (FHE) or the most harmful event (MHE). However, by using FHE or MHE and physical classification, the true problem could be mistaken. Hence, a wrong countermeasure could be selected.

Figure 32 shows an example of the difference between two types of classification. The witness stated the vehicle attempted to pass the exit but instead quickly swerved right to exit the interstate. After that, the vehicle continued to veer right, ran off the road, and hit the sign. Therefore, the cause appeared to be a last minute exit that led to the collision with a ramp sign. Because the driver made a wrong decision in a speed change lane and lost control, a speed-change lane related crash would be a better answer for the functional classification. Based on the exact location of the crash, it is clearly a ramp related crash for physical classification.

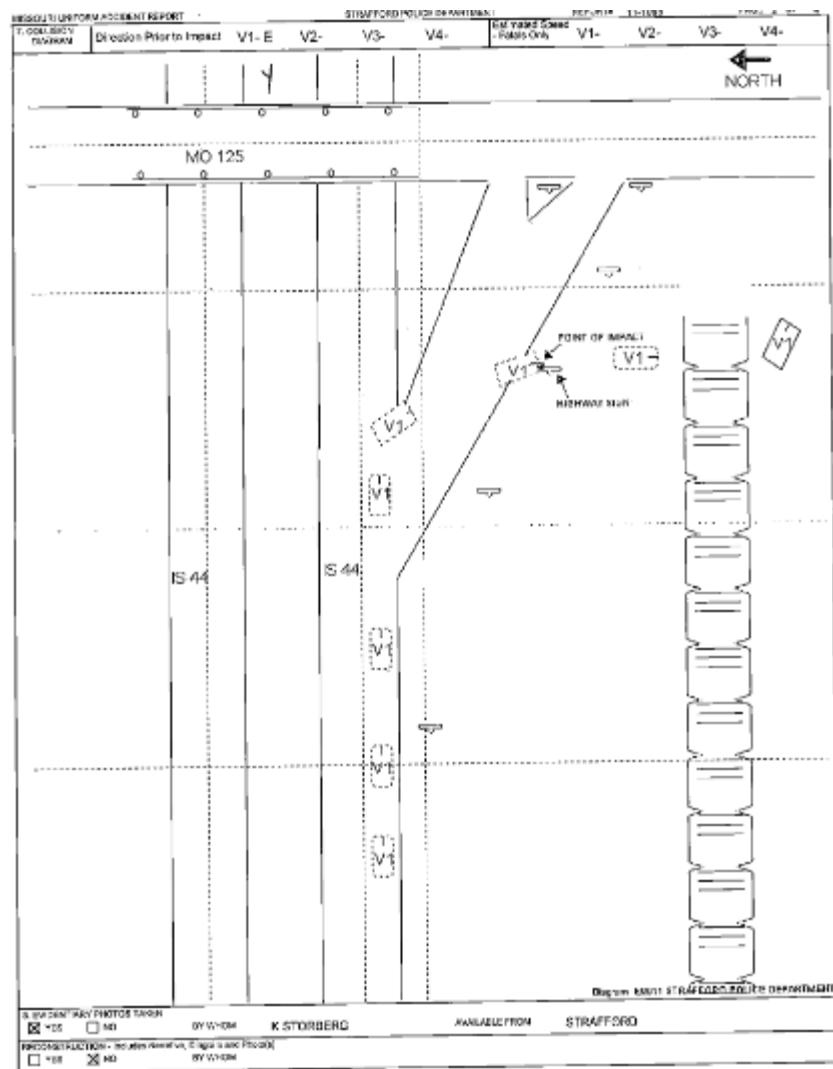


Figure 32 Diagram of Crash Report

Any countermeasures would be related to the ramp at this case, such as improving shoulders, pavement, or striping. However, the real cause of the crash was due to the speed change lane and not the ramp. Thus the functional classification and FSE method would produce the appropriate counter-measure, which might include better signage (more visible, larger font, earlier) regarding the upcoming speed-change lane.

b. Interchange Influence Area

Data used for analyzing interchange influence area is the same 120 sites discussed above. And for analysis, assumption here is that interchange segments generate more crashes than non-interchange segments.

For analyzing an interchange influence area, the crash distribution of interchanges is divided by 100 ft. sections, which is shown in Figure 33. The Y axis represents the number of crashes that occurred in the sample interchanges. The count of crashes from 100 to about 2000 ft. fluctuates significantly, and after that length, the count steadily decreased. This could also be seen more clearly in Figure 34, Figure 35 and Figure 36, where the crash distribution is divided in 500 ft. sections. Hence, for defining the “Interchange Influence Area”, it is better to use distribution in 500 ft. than 100 ft. sections.

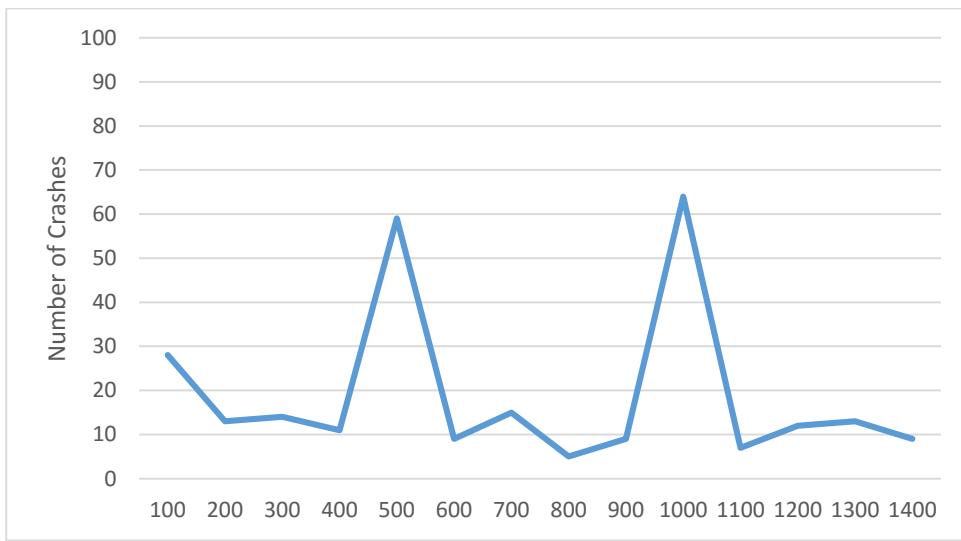


Figure 33 Crashes Distribution of Interchange by 100 ft. Sections of Diamond Interchange

Figure 34 shows the crash distribution of diamond interchanges; it indicates that the crashes drop dramatically between 1,500 ft. to 2,000 ft. After that, crashes rate tends to be

stationary. However, after 4,000 ft., the number of crashes tends to increase, which may be because of another interchange. For the diamond interchange, the influence area would be 2,000 ft.

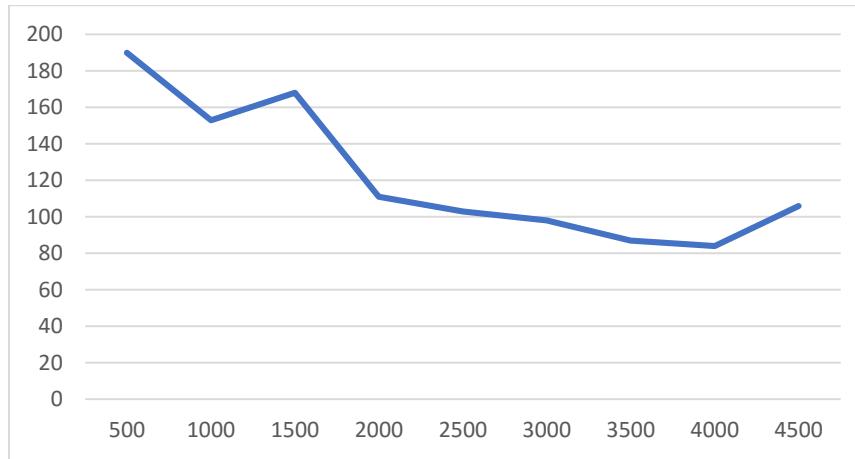


Figure 34 Crashes Distribution of Interchange by 500 ft. Sections of Diamond Interchange

Figure 35 shows crash distribution of partial cloverleaf interchange. The number of crashes decrease from 500 ft. to 2,000 ft., increase from 2,500 ft. to 3,000 ft., and then remain stationary. Thus, an appropriated influence area distance for partial cloverleaf interchanges might be 3,000 ft.

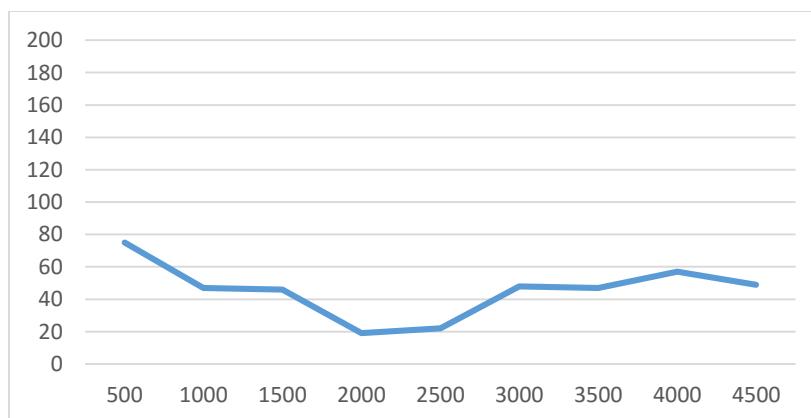


Figure 35 Crashes Distribution of Interchange by 500 ft. Sections of Partial Cloverleaf Interchange

For a full cloverleaf, the number of crashes was found to decrease up to 3,000 ft., as shown in Figure 36. Therefore, an appropriate interchange influence area distance threshold for full cloverleaf interchange might be 3,000 ft.

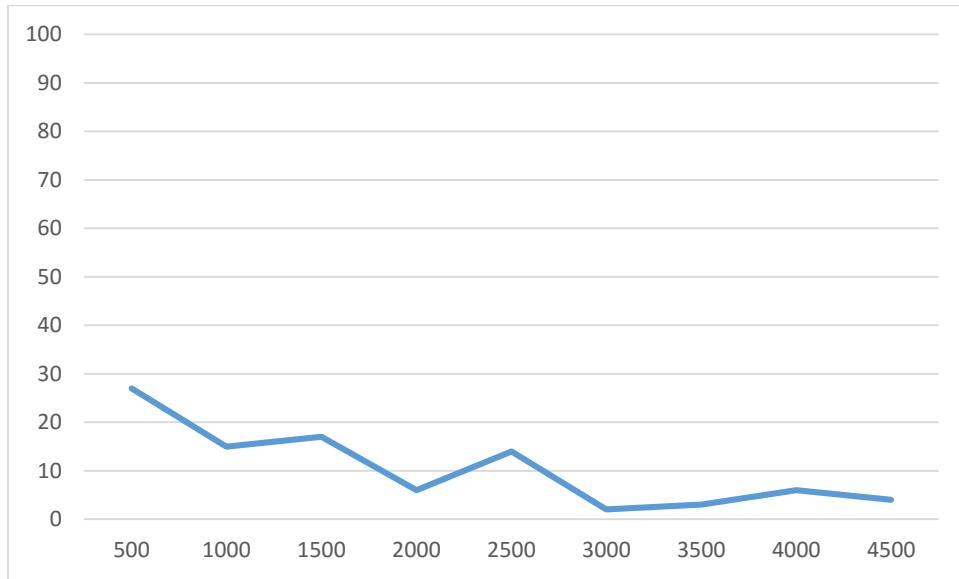


Figure 36 Crashes Distribution of Interchange by 500 ft. Sections of Full Cloverleaf Interchange

Figure 37 shows all types of interchanges studied. The figure illustrates the decreasing frequency of crashes up to 2,000 ft. This indicates that a good general interchange influence area distance for interchanges in Missouri might be 2000 ft. based on the studied samples.

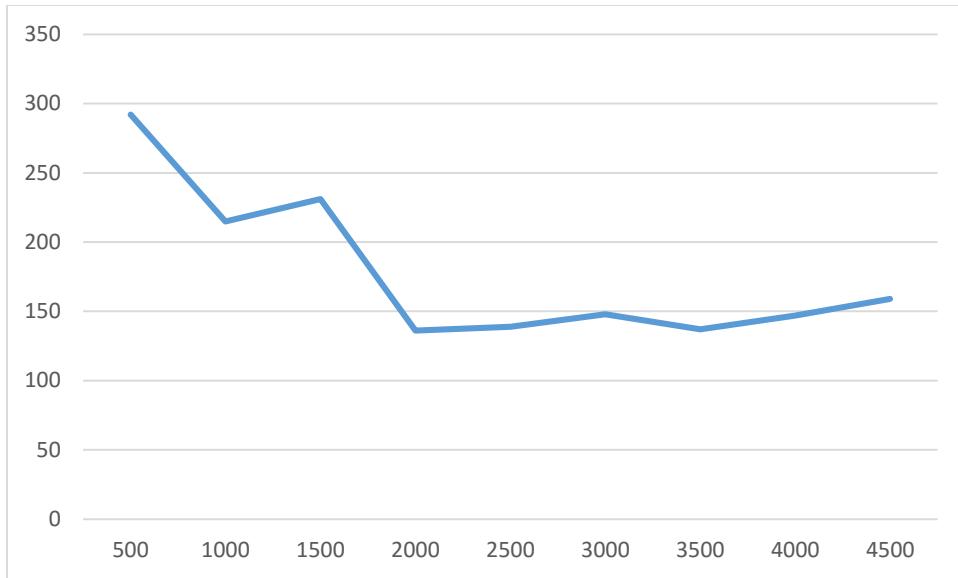


Figure 37 Crashes Distribution of Interchange by 500 Ft. Sections of All types of Interchanges

c. Empirical Safety of Interchange Facilities

For the non-terminal-related crashes, the counted ones are excluded rare or unique circumstances and the ones that were generated from other interchanges but assigned to the sample interchanges by mistake. Table 8 shows the results for crash location based on facility types.

For diamond interchange type, 67.20 % of crashes occurred in the freeway segment, which occupied the largest portion of non-terminal-related crashes. The second largest portion of non-terminal-related crashes occurred in the speed-change lanes, at 21.86 %. Specifically, the diverging area generated about 1 % less crashes than the merging area. Crashes that occurred on ramps were 10.93 %. Also, off-ramp segments generated more crashes than on-ramp segments as shown in Table 8.

For partial cloverleaf interchanges, crashes happened most on freeway segments, which is similar to diamond interchanges, 63.59 % of all non-terminal-related crashes. Speed-change lane segments were again in second at 23.59%, and ramp segments are the area with the least crashes at 12.82 %. Like diamond interchanges, merging areas generated more crashes than diverging areas (14.36% and 9.23%), and off-ramp segments generated more crashes than on-ramp segments (9.23% and 3.59%, respectively).

Full cloverleaf interchanges have different crashed rates because of their different geometric structure. In full cloverleaf interchanges, the location where crashes occurred the most is ramps, freeway segments are second, and third are speed-change lanes, at 60.44%, 27.47%, and 12.09%, respectively. Crash severity is also counted for different types of facilities for different types of interchanges, which are shown in Figure 38 to Figure 40.

Figure 38 shows severity distribution in diamond interchanges. The figure indicates that PDO crashes are much more than FI crashes in all the facilities. Ramps and freeway segments have more PDO crashes under physical classification than under functional classification. Conversely, speed-change lane segments generated less PDO crashes under physical classification than under functional classification. FI crashes shows the same trend as PDO crashes in diamond interchanges.

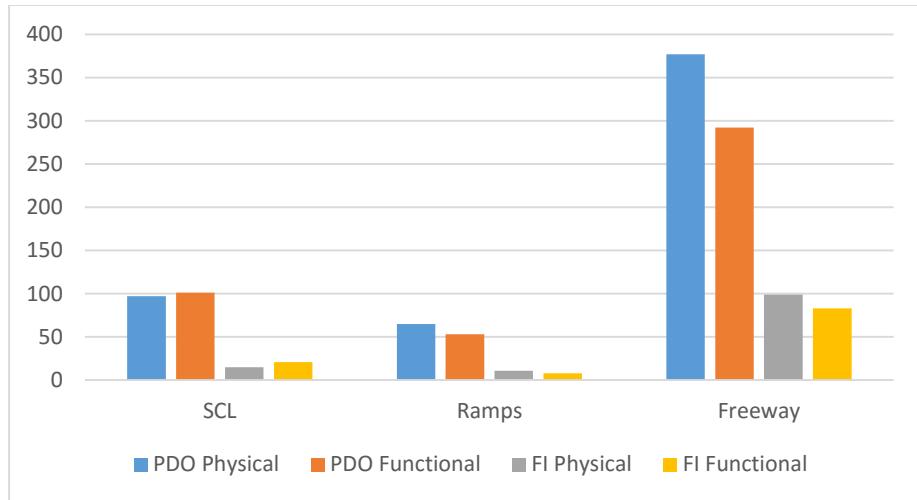


Figure 38 Severity Distribution on Diamond Interchanges

Figure 39 shows severity distribution for partial cloverleaf interchanges. The same situations are shown here as in Figure 38.

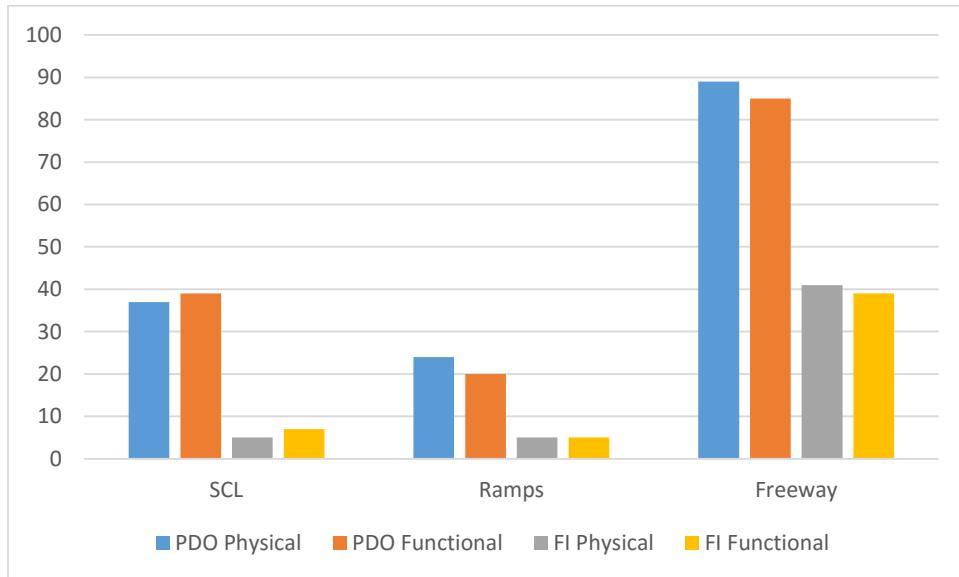


Figure 39 Severity Distribution on Partial Cloverleaf Interchanges

Figure 40 shows severity distribution on full cloverleaf interchanges. Unlike diamond and partial cloverleaf, the full cloverleaf reveals a different pattern. Ramps occupy the largest portion

and freeway comes next. PDO crashes happen more in ramps and freeway and less in speed-change under physical classification. FI crashes show the same trends as PDO crashes.

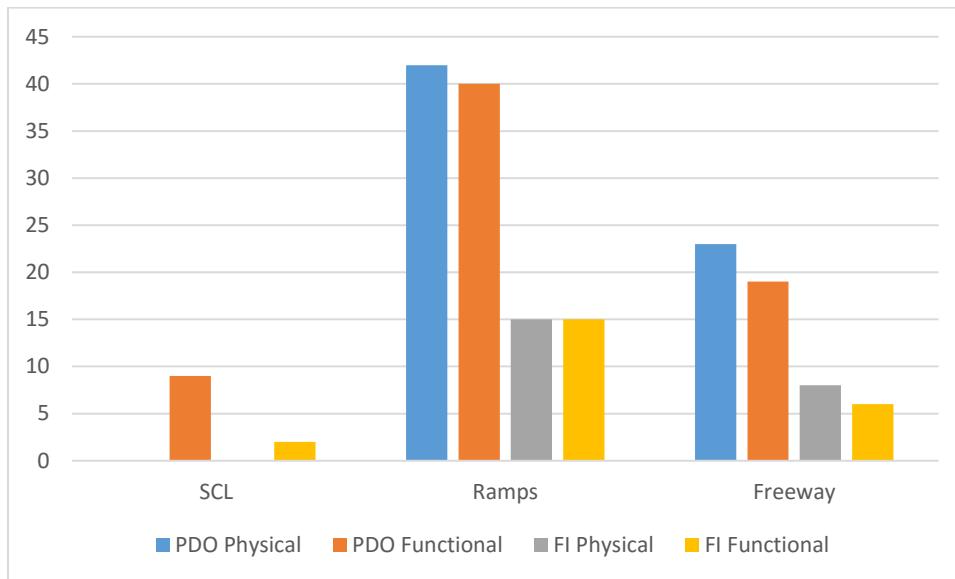


Figure 40 Severity Distribution on Full Cloverleaf Interchanges

VI. Conclusion

a. Functional Classification

i. Comparison between functional and physical classification

Under functional classification, circumstances of each crash would be considered in addition to the exact crash location. Vehicles entering or exiting freeway segments change lanes and speeds. Crashes due to speed-change lanes' geometric design or operations should be assigned to speed-change lanes instead of ramps or freeways. In addition, geometric design characteristics of speed-change lanes, like taper points, gore points, and curves may also influence crashes; these types of crashes should also be assigned to speed-change lanes instead of others.

In diamond interchanges, functional classification assigns more crashes to speed-change lanes than physical classification, which are 122 crashes and 112 crashes. Due to rare events that might not result from geometric design, the total number of crashes from physical classification is more than those in the functional classification, with 953 crashes and 844 crashes respectively. For partial cloverleaf interchanges, because of their large angle curve, ramps generated more crashes than diamond interchanges, with the proportions being 12.82% versus 10.93%. For partial cloverleaf interchanges, where functional classification generated more crashes on speed-change lane than physical classification, the percentages are 23.59% under functional classification and 20.90% under physical classification. For full cloverleaf interchanges, more crashes are assigned to speed-change lanes under functional classification than to physical classification. However, unlike the other two types of interchanges, ramps generated many more crashes than the other facility types, with 60.44% of the total.

For the whole sample sites selected, about 5% more crashes are assigned to speed-change lane related under functional classification than that under physical classification.

ii. First Significant Event

The first significant event (FSE) is an operation characteristic that causes a driver to fail to properly change lanes or speed, thus leading to a crash. Safety problem might be addressed more efficiently by using FSE instead of FHE or MHE. However, by using FHE or MHE and physical classification, the exact problem might not be identified. Hence, a wrong countermeasure could be selected. This indicates that using both the functional classification and FSE method would produce the most useful countermeasure.

iii. How DOTs can apply functional classification

Guide the police officer how to determine the functional classified interchange facilities, and ask them to notify the first significant event on the collision figure. In addition, create a field on crash report that specify where the crash occurred, such as freeway, speed-change lane, ramp or terminal.

b. Interchange Influence Area

Based on counting the number of crashes using different foot sections (100 ft. and 500 ft.), 500 foot sections were found to have less fluctuations.

For diamond interchange types, curves had fewer crashes beyond 2,000 ft. For partial cloverleaf interchange types and full cloverleaf interchange types, curves were not an issue beyond 3,000 ft. Hence, an interchange influence area distance in Missouri of 2,000 feet is recommended instead of the 1,500 foot standard recommended by Highway Safety Manual.

c. Crash Distribution

Accident data for 42 diamond interchanges, 16 partial cloverleaf interchanges, and 2 full cloverleaf interchanges were obtained and analyzed. Accidents were classified according to severity and facility type. The trend of accidents at each severity level was similar for diamond interchanges and partial cloverleaf interchanges. Because of its different geometric design, full cloverleaf interchanges have different trends of crashes and severity levels.

Each accident was also classified according to facility type: freeway segments, ramp segments, and speed-change lanes. Consistently, diamond interchanges and partial cloverleaf interchanges show similar trends, with freeways generating the most crashes, speed-change lanes generating the second most crashes, and ramps the fewest. On the other hand, ramps generated the most crashes, with freeways ranking second, and speed-change lanes generated the fewest for full cloverleaf interchanges.

Future studies could include the following areas:

- Modeling crash frequency in terms of distance from the interchange center. At this point, the sample selected are all typical types of interchanges, the interchange center is easy to use. Also, if the interchange is extreme complex, other distance, like distance from ramp gore point, can be used for modeling.
- Larger sample size for analyzing interchange influence areas. Since the sample here only including two full cloverleaf interchanges, there may be bias for that type of interchange.
- Samples across the nation for analyzing interchange influence areas.

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