PERFORMANCE-BASED SAFETY EVALUATION OF REQUESTS FOR NEW ACCESS OR MODIFICATIONS TO EXISTING ACCESS ON FREEWAYS

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Abstract
Freeway access management activities have traditionally taken a nominal approach to safety. Acceptable safety performance is presumed to result from attaining some desired interchange or ramp spacing. This approach oversimplifies driver behavior and complex interactions between roadway geometrics, traffic operations, and safety. The objective of this paper is to quantify the relationship between ramp spacing and freeway safety, with safety defined as number of accidents, or accident consequences, by kind and severity, expected to occur during a specified time period. Data for this study include freeway geometric features, traffic characteristics, and crash counts collected from over 1,600 directional miles of freeways in California and Washington State. The relationship between ramp spacing and safety was explored using a negative binomial regression modeling approach. Results indicate that expected crash frequency increased as ramp spacing decreased. The expected proportion of crashes resulting in a fatality or injury appears to decrease as ramp spacing decreases. The presence of an auxiliary lane is associated with lower crash frequencies for any given ramp spacing. The safety benefit derived from the presence of an auxiliary lane diminishes as ramp spacing increases. The model results related to ramp spacing and auxiliary lane presence were transformed into crash modification factors and validated through comparisons with an independent research study on weaving areas in Texas. The ability to quantify the potential safety impacts of a new or modified interchange on the freeway mainline will assist transportation agencies in making well-informed assessments of the overall benefits, impacts, and costs of freeway access decisions.

Introduction
Evaluating requests for new access or modifications to existing access on freeways is a frequent activity of state departments of transportation in the United States. Newly constructed or reconstructed interchanges increase access to nearby destinations and may improve operations and safety on the surrounding network surface streets. Transportation agency concerns regarding new or modified freeway access include ramp spacing on the mainline and its impact to freeway operations and safety. Modifying access on the Interstate System is formally regulated in the United States. All new or modified points of access on an Interstate route must be approved by the United States Department of Transportation's (USDOT) Federal Highway Administration (FHWA). There is a significant amount of published knowledge on geometric considerations, traffic operations, and signing in the context of freeway ramp and interchange spacing. Very little information exists on the safety impacts of ramp and interchange spacing.

Freeway access management activities have traditionally taken a nominal approach to safety. Acceptable safety performance is presumed to result from attaining some desired interchange or ramp spacing. Access management policy is met and the freeway mainline presumed "safe" if the access point spacing is greater than minimum. New access point requests or modifications to existing access may be denied if the result will be an interchange or ramp spacing smaller than the established minimum. These generalizations oversimplify driver behavior and complex interactions between roadway geometrics, traffic operations, and safety (*1*). They also oversimplify the decision-making framework and tend to promote a "one size fits all" approach to managing freeway access. Benefits, costs, and impacts need to be quantified and evaluated on a case-by-case basis. This paper focuses on one aspect of freeway access management: quantifying the safety effects of changes in ramp spacing expected to result from adding new access points or modifying existing access points on freeways.

Literature Review

A number of previous studies on this topic have explored the effect of ramp and interchange presence on safety, without considering a spacing effect (e.g., *2-7*). Others reported safety effects of a ramp or interchange count or density on a freeway segment through a multivariate regression model (*8-10*). The inverse of these types of variables represents an average interchange or ramp spacing. This technique is analogous to the interchange density speed adjustment factor in the freeway segment analysis methodology of the *Highway Capacity Manual* (*11*). It is relevant to a corridor-level safety analysis of interchange spacing. Only three studies took a direct look at the relationship between interchange or ramp spacing and safety (*12-14*). The findings reported in (*12*) are over 30 years old and included short mainline weaving areas between consecutive loop ramps of full cloverleaf interchanges, a scenario that modern interchange design practice tries to avoid. The study described in (*13*) used more modern analytical techniques and was an important first step on which to build an investigation of safety effects of interchange and ramp spacing. However, measures of exposure and spacing were combined in the model specifications, making interpretation difficult and potentially overestimating the elasticity between safety and interchange spacing. The study documented in (*14*) included safety performance functions for freeway segments and crash modification factors for a number of freeway features, including ramp spacing in freeway weaving areas. The safety findings from this paper will be compared to the findings from (*14*) later in the paper to test the potential transferability of the uncovered safety trends.

Research Objectives

The objective of this paper is to quantify the relationship between ramp spacing and freeway safety, with safety defined as number of accidents, or accident consequences, by kind and severity, expected to occur during a specified time period. The safety findings can be incorporated into a freeway access evaluation framework that includes geometric design, traffic operations, and signing considerations on the freeway as well as access, mobility, and safety impacts on the surrounding surface street network.

Interchange Spacing versus Ramp Spacing

Interchange spacing, defined from cross-street centerline to cross-street centerline, is not as meaningful as *ramp spacing*, defined from painted gore to painted gore, from a safety modeling and analysis standpoint. For a given interchange spacing, freeway segments between the cross streets may have different numbers, types, combinations, and spacings of interchange ramps. In addition, cross streets associated with some ramps are difficult to identify for atypical interchange types, and may not be centered between exit and entrance ramps. As a result, this research focused on developing relationships between *ramp spacing* and safety. The relationships can be aggregated to estimate interchange spacing effects for different interchange forms if desired.

Data Collection

Data for this study include freeway geometric features, traffic characteristics, and crash counts collected in California and Washington State. These two states were selected because both have comprehensive and accessible freeway, ramp, and crash databases. Data were collected using a combination of various tools and resources:

- Digital mapping and satellite imaging applications, primarily Google Earth and Google Maps;
- Online interchange database available through Washington State Department of Transportation's (WSDOT) Interchange Viewer;
- Online video logs available through WSDOT's SRweb and the California Department of Transportation's (Caltrans) Performance Measurement System-PeMS; and
- FHWA's Highway Safety Information System (HSIS) database.

More than 1,600 directional miles of freeways in Washington State and more than 2,000 directional miles of freeways in California were scanned using Google Maps and Google Earth to identify candidate freeway segments to study. The analysis described in this paper was focused only on segments with diamond interchanges, including typical diamonds as well as tight urban diamonds, half diamonds, and single point urban interchanges (SPUIs). A study segment (i.e., one row in the database) was defined from cross street to cross street. Ramp spacing was defined from painted gore to painted gore. These definitions are illustrated in Figure 1.

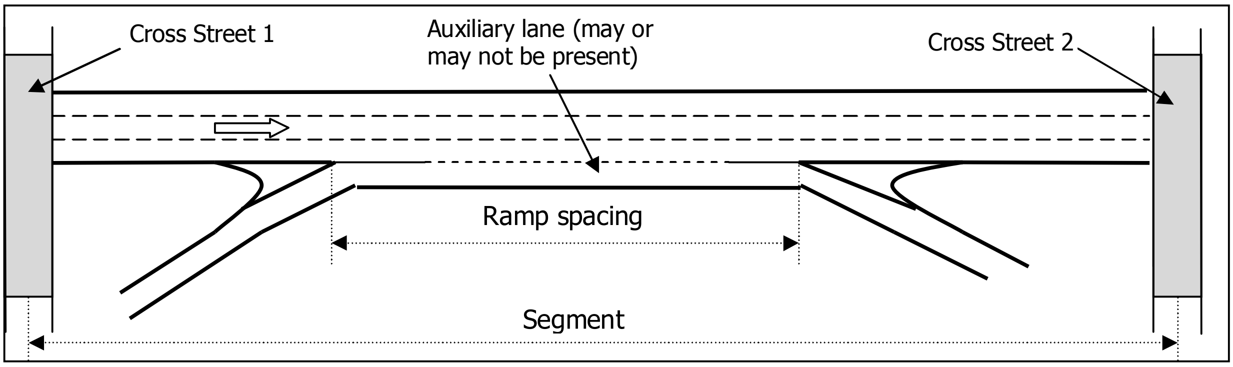

Figure 1 Illustration of Freeway Segment and Ramp Spacing Definitions (not to scale)

Segments were excluded from the dataset if construction activity was identified on or near the segment from 2006 through 2008 (the observation period for each segment). Temporary traffic control devices on the video logs or construction areas present on current and archived *Google Earth* photographs were used to identify these segments. Missing traffic volume counts (discussed below) for a segment also indicated possible construction activity; segments with missing volume counts were excluded. Additional resources (e.g., time to personally interview Caltrans or WSDOT personnel) were not spent to identify work zones from 2006-2008. Work zone presence is likely not correlated with traffic and geometric variables included in the safety models. Higher levels of unexplained variability in expected crash counts, a less serious flaw than omitted variable bias, is expected if some work zones were missed during the screening process.

Segments including rest-area ramps between entrance and exit ramps associated with two consecutive cross streets were excluded from the dataset. The final datasets used to estimate the safety models consisted of 404 segments, 154 from Washington State and 250 from California.

Traffic and Geometric Data for Defined Freeway Segments

Traffic and geometric data were collected for each defined freeway segment. Freeway mainline traffic volumes were collected from HSIS roadway files using route number and mainline milepost variables to identify the correct volume measurement. The mainline traffic volume assigned to each defined freeway segment represented the average daily traffic just upstream of the physical entrance ramp gore on the segment. The HSIS files included bidirectional traffic volumes. Directional traffic would be ideal since the segments were direction specific. The authors completed an analysis on a smaller scale using directional daily traffic for Washington segments, estimated using WSDOT's Automated Data Collection (ADS) stations. Data collected at ADS stations are summarized in the WSDOT's annual traffic reports and include directional mainline traffic volumes. The directional volume information was used to estimate a directional traffic volume ratio (D). The research team then assumed that the directional traffic volume ratio for each defined freeway segment was the same or very close to the volume ratio at the nearest ADS station. All defined freeway segments had an estimated directional traffic volume ratio falling between 0.49 and 0.51 using this approach. The assumption that directional volume equals approximately one half of the bidirectional volume was made based on these findings. Additional work is needed to verify this assumption for California data.

Entering and exiting traffic volumes were determined using ramp identification numbers and ramp milepost variables and represented the average daily traffic on the entrance and exit ramp-freeway terminals, respectively. The number of through lanes was determined using HSIS roadway files and confirmed with video logs, *Google Earth* satellite photography, and *Google Maps Street View*. The presence of an auxiliary lane between an entrance and exit ramp was determined from the interchange diagrams and also confirmed with video logs. The number of lanes on the entrance and exit ramps at the ramp-freeway terminal was determined from video logs and *Google Earth*. Data on the presence of high occupancy vehicle (HOV) lanes on the mainline or ramps as well as the presence of ramp meters were collected using satellite photography, video logs, and interchange diagrams. Descriptive statistics of the traffic and geometric features for the 404 segments are provided in Table 1.

Crash Frequencies and Severities
The number of crashes occurring on each freeway segment (i.e., between the cross streets) in the years 2006, 2007, and 2008 were counted using route number and milepost variables. The following crash counts were made:

- Number of crashes of all severities and types;
- Number of crashes resulting in at least one occupant fatality or injury;
- Number of crashes involving only one vehicle (i.e., single-vehicle crashes); and
- Number of crashes involving more than one vehicle (i.e., multiple-vehicle crashes).

Only the safety models for expected number of total crashes and fatal plus injury crashes are included in this paper due to space limitations.

Crashes were counted only if they were coded as occurring in the roadway or roadside of the freeway mainline and in the same direction of travel served by the interchange ramps. Crashes coded as having occurred on the ramp proper or in the opposing direction of freeway travel were not assigned to the segment of interest. The HSIS *impact location* and travel direction variables were used to identify these appropriate crashes. One limitation of this approach is that it may not capture the complex interactions between ramp presence and cross-median, head on collisions found in (*6*). Descriptive statistics for the observed crash frequencies on the 404 segments are provided in Table 1.

Variable Definitions and Data Summary
The final dataset included the key variables listed below along with the notations and definitions used in this study:

- L=segment length, defined from the cross street associated with the entrance ramp to the cross street associated with the next downstream exit ramp (miles);
- Loglen=Natural logarithm of the segment length;
- DADT=One-way (directional) average daily traffic volume upstream of the entrance ramp (vehicles/day);
- LogDADT= Natural logarithm of the DADT;
- ADT_{en}=Average daily traffic volume on the entrance ramp (vehicles/day);
- $LogADT_{en}$= Natural logarithm of the ADT_{en};
- ADT_{ex}=Average daily traffic volume on the exit ramp (vehicles/day);
- $LogADT_{ex}$= Natural logarithm of the ADT_{ex};
- S =ramp spacing, defined from painted gore of the entrance ramp to painted gore of the exit ramp (feet);
- Invspa=inverse of ramp spacing, 1/S ($feet^{-1}$);
- Mainline1=indicator variable for the relative vertical position between the freeway mainline and the cross street associated with the entrance ramp (1=mainline over cross street, 0 otherwise);
- Mainline2=indicator variable for the relative vertical position between the freeway mainline and the cross street associated with the exit ramp (1=mainline over cross street, 0 otherwise);
- N_1=number of lanes on the freeway mainline upstream of the entrance ramp gore;
- HOV_{main}=indicator variable for the presence of an HOV lane on the freeway mainline (1=presence of an HOV lane, 0 otherwise);
- HOV_{en}=indicator variable for the presence of an HOV lane on the entrance ramp (1=presence of an HOV lane, 0 otherwise);
- Rmpmet=indicator variable for the presence of a ramp meter on the entrance ramp (1= ramp meter present, 0 otherwise);
- Auxln=indicator variable for the presence of an auxiliary lane connecting the entrance and exit ramps (1= auxiliary lane present, 0 otherwise);

- Invspa_aux=interaction variable for inverse spacing and the presence of an auxiliary lane (Invspa*Auxln);
- Total= total number of crashes (all severities and types);
- FI= number of severe crashes (at least one occupant fatality or injury);
- SV= number of single-vehicle crashes (involving only one vehicle); and
- MV= number of multi-vehicle crashes (involving two or more vehicles).

A summary of the dataset is provided in Table 1.

Table 1 Summary statistics of geometric, traffic and crash data for 404 segments

Variable	Mean	Standard Deviation	Minimum	Maximum
L (miles)	2.354	1.799	0.501	10.412
DADT (vehicles/day)	43,158	34,106	5,134	153,500
ADT_{en} (vehicles/day)	4,208	3,838	17	19,233
ADT_{ex} (vehicles/day)	4,228	3,913	25	19,400
S (feet)	9,677.19	9,508.98	316.80	52,219.20
HOV_{main}	0.067 [(a)]	0.250	0	1
HOV_{en}	0.057 [(a)]	0.232	0	1
Rmpmet	0.119 [(a)]	0.324	0	1
Auxln	0.119 [(a)]	0.324	0	1
N_1 (lanes)	2.832	0.941	2	6
Mainline1	0.433 [(a)]	0.496	0	1
Mainline2	0.433 [(a)]	0.496	0	1
Total (2006-2008 crashes)	46.99	48.79	1	493
FI (2006-2008 crashes)	15.78	15.53	0	113
SV (2006-2008 crashes)	14.11	9.61	0	55
MV (2006-2008 crashes)	32.88	44.38	0	456

Notes:
(a) the mean value of an indicator variable is interpreted as the proportion of segments with the indicator value equal to 1. HOVmain has a mean value of 0.067 means that 6.7 percent of the 404 segments have an HOV lane on the mainline.

Modeling Approach

The relationship between ramp spacing and safety was explored in this study using a negative binomial regression modeling approach. The use of Poisson regression to model the relationships between crash frequency, traffic volumes, and weather conditions was introduced in 1986 (*15*). Negative binomial regression, a more general form of Poisson regression, was later used to explore the relationship between crash frequencies, daily traffic, and highway geometric design variables (*16*). In the negative binomial model, the expected number of crashes of type *i* on segment *j* is expressed as:

$$\mu_{ij} = E(Y_{ij}) = \exp(X_j\beta + \ln L_j)$$

where:
$\mu_{ij} = E(Y_{ij})$ = the expected number of crashes of type *i* on segment *j*;
X_j = a set of traffic and geometric variables characterizing segment *j*;
β= regression coefficients estimated with maximum likelihood that quantify the relationship between $E(Y_{ij})$ and variables in X;
L_j = length of segment *j*; and,
ln L_j = the natural logarithm of segment length.

The mean-variance relationship of the negative binomial regression model is expressed as:

$VAR(Y_{ij}) = E(Y_{ij}) + \alpha[E(Y_{ij})]^2$

where:
$E(Y_{ij})$ = the expected number of crashes of type *i* on segment *j*;
$VAR(Y_{ij})$ = variance of of crashes of type *i* on segment *j*; and
α = overdispersion parameter.

The data are over-dispersed if α is greater than zero and under-dispersed if α is less than zero. The negative binomial model reduces to the Poisson model if α equals zero.

Ramp spacing was the primary variable of interest in the matrix of explanatory variables, X_j. However, a number of other traffic and geometric variables were included to decrease unexplained variation in expected crash frequency and to try and minimize *omitted variable bias*. Omitted variable bias would involve over- or under- estimating the safety effect of ramp spacing due to other variables that influence crash frequency and are correlated with ramp spacing, but are excluded from the model.

Segment length, L, was included in the models as an offset variable (i.e., the regression coefficient for the natural logarithm of segment length was constrained to 1.0), and captures the linear increase in expected crash frequency with an increase in segment length due to increased exposure. Model fit was evaluated using the McFadden Pseudo R-Squared. The McFadden Pseudo R-Squared (ρ^2) is analogous to the R-squared value used to express the goodness of fit of a standard, ordinary least squares regression model. It is expressed as:

$$\rho^2 = \frac{L(full)}{L(0)}$$

where:
ρ^2 = McFadden Pseudo R-Squared;
L(*full*) = log-likelihood of the model with explanatory variables; and,
L(0) = log-likelihood of the intercept-only model.

The McFadden Pseudo R-Squared may take a value between 0 and 1; the value moves closer to 1 as model fit improves.

Model Estimation Results

The coefficients of the safety models were estimated using the STATA software package. Estimation results for models with the response variable being all crashes (total) and severe crashes (FI) are summarized in Table 2 and Table 3, respectively. The models have the following form, which is consistent with the general modeling discussion in the "Modeling Approach" section:

$$E(Y_i) = \exp(constant + 1.0*\ln(L) + b_2*\ln(DADT) + b_3*\ln(ADT_{EN}) + b_4*\ln(ADT_{EX}) + b_5*S^{-1} + b_6*(Auxln/S) + b_7*N_1 + b_8*Mainline1 + b_9*Mainline2 + b_{10}*Rmpmet + b_{11}*HOV_{en} + b_{12}*HOV_{main})$$

with all variables defined above and b_i equal to estimated regression coefficients listed in Table 2 and Table 3. The models can also be expressed as:

$$E(Y_i) = L^{1.0}\, DADT^{b2}\, ADT_{EN}^{b3}\, ADT_{EX}^{b4} \exp(constant + (b_5/S) + b_6*(Auxln/S) + b_7*N_1 + b_8*Mainline1 + b_9*Mainline2 + b_{10}*Rmpmet + b_{11}*HOV_{en} + b_{12}*HOV_{main}).$$

For example, the model for the expected number of crashes of all types and severities [i.e., $E(Y_i)$ = E(Total)] is expressed as:

$E(Total) = L^{1.0}\ DADT^{0.9212}\ ADT_{EN}^{0.1209}\ ADT_{EX}^{0.0445}\ \exp(-8.492 + (513.59/S) - 300.89*(Auxln/S) + 0.1638*N_1 + 0.0465*Mainline1 - 0.0573*Mainline2 + 0.1354*Rmpmet - 0.1553*HOV_{en} + 0.1854*HOV_{main})$

Discussion and Conclusions

The models in Table 2 and Table 3 contain a number of variables that influence safety on freeway mainlines. The discussion here will focus on ramp spacing as this is the variable applicable to access management (*17*). The parameter for ramp spacing associated with the expected number of total crashes (i.e., all severities and types) was statistically significant and positive. The result indicates that expected crash frequency increased as ramp spacing decreased. The parameter for ramp spacing associated with the expected number of crashes resulting in a fatality or injury was also positive and statistically significant, but smaller than the ramp spacing parameter for crashes of all severities and types. While the results suggest an increase in the frequency of severe crashes with decreasing ramp spacing, the expected proportion of crashes resulting in a fatality or injury appears to decrease as ramp spacing decreases. The result is consistent with published findings reported by (*9*). Both models show that the presence of an auxiliary lane is associated with lower crash frequencies for any given ramp spacing. The safety benefit derived from the presence of an auxiliary lane diminishes as ramp spacing increases.

The model results related to ramp spacing and auxiliary lane presence were transformed into crash modification factors. A crash modification factor (CMF) "represent[s] the relative change in crash frequency due to a change in one specific condition (when all other conditions and site characteristics remain constant)" (*18*). A CMF is the predicted ratio of expected crash frequency at a location under two different conditions as shown below:

$$CMF = \frac{Expected\ Crash\ Frequency\ with\ Site\ Condition\ b}{Expected\ Crash\ Frequency\ with\ Site\ Condition\ a}$$

Condition 'a' often represents a base condition, with the CMF value quantifying the effect of a deviation from the base conditions at a location. The base condition in this paper (i.e., condition 'a') is a basic freeway segments with no ramps. The ramp spacing-auxiliary lane CMFs for total crashes and fatal plus injury crashes, created using the model results in Table 2 and Table 3, are provided below:

$$CMF_{Total} = \exp\left(\frac{513.59 - 300.89 \times Aux\ln}{S}\right) \qquad CMF_{FI} = \exp\left(\frac{421.51 - 229.84 \times Aux\ln}{S}\right)$$

where:

CMF_{Total} = crash modification factor for total crashes (all types and severities);
CMF_{FI} = crash modification factor for severe crashes (at least one occupant fatality or injury);
S = ramp spacing (feet)
Auxln = indicator variable for presence of an auxiliary lane between the entrance and exit ramp (1 = auxiliary lane present; 0 = not present)

Table 2 Model estimation results for total crashes

			Number of obs		404	
			LR chi2 (11)		847.39	
			Log likelihood		-1656.24	
			Pseudo R2		0.2037	
Total	**Coef.**	**Std. Err.**	**z**	**P>|z|**	**[95% Conf. Interval]**	
LogDADT	0.9212	0.0687	13.40	0.000	0.7865	1.056
$LogADT_{en}$	0.1209	0.0244	4.95	0.000	0.0731	0.1687
$LogADT_{ex}$	0.0445	0.0270	1.65	0.099	-0.0084	0.0974
Invspa	513.59	166.41	3.09	0.002	187.43	839.76
Invspa_aux	-300.89	148.77	-2.02	0.043	-592.48	-9.302
N_1	0.1638	0.0458	3.58	0.000	0.0741	0.2535
Mainline1	0.0465	0.0497	0.94	0.350	-0.0509	0.1439
Mainline2	-0.0573	0.0508	-1.13	0.260	-0.1568	0.0423
Rmpmet	0.1354	0.1023	1.32	0.186	-0.0652	0.3360
HOV_{en}	-0.1553	0.1196	-1.30	0.194	-0.3897	0.0790
HOV_{main}	0.1854	0.1087	1.71	0.088	-0.0276	0.3984
constant	-8.4921	0.5033	-16.87	0.000	-9.479	-7.506
Loglen	1.0000					
Overdispersion parameter	0.1630	0.0137			0.1382	0.1923

Table 3 Model estimation results for fatal and injury crashes

			Number of obs		404	
			LR chi2 (11)		730.09	
			Log likelihood		-1273.92	
			Pseudo R2		0.2227	
FI	**Coef.**	**Std. Err.**	**z**	**P>|z|**	**[95% Conf. Interval]**	
LogDADT	1.0494	0.0845	12.42	0.000	0.8838	1.2150
$LogADT_{en}$	0.1207	0.0291	4.15	0.000	0.0637	0.1776
$LogADT_{ex}$	0.0270	0.0321	0.84	0.400	-0.0358	0.0899
Invspa	421.51	195.25	2.16	0.031	38.837	804.18
Invspa_aux	-229.84	174.06	-1.32	0.187	-570.98	111.31
N_1	0.0825	0.0531	1.55	0.120	-0.0216	0.1866
Mainline1	0.1028	0.0585	1.76	0.079	-0.0118	0.2174
Mainline2	-0.0584	0.0596	-0.98	0.327	-0.1754	0.0585
Rmpmet	0.1373	0.1157	1.19	0.235	-0.0894	0.3640
HOV_{en}	-0.1115	0.1314	-0.85	0.396	-0.3692	0.1461
HOV_{main}	0.0875	0.1212	0.72	0.470	-0.1500	0.3249
constant	-10.546	0.6285	-16.78	0.000	-11.778	-9.3139
Loglen	1.0000					
Overdispersion parameter	0.1743	0.0179			0.1425	0.2133

The transferability of results to other states and geographic regions is generally the primary concern with focused, single-state, or dual-state data collection efforts such as the one undertaken to-date. A study conducted at the Texas Transportation Institute (TTI) included safety performance functions for freeway segments and crash modification factors for a number of freeway features, including ramp spacing in freeway weaving areas (*14*). The safety findings from the analysis of Washington and California data presented in this paper were compared to related safety findings from Texas. Similar underlying safety trends in states as different in location, climate, and topography as California, Washington, and Texas would build confidence in the general transferability of both sets of results.

The weaving CMF for Texas freeways reported in (*14*) took the form:

$$CMF_{wev,FI,TX} = e^{152.9/L^*_{wev}} \text{ for } L^*_{wev} \geq 800 \text{ feet}$$

where:
$CMF_{wev,FI,TX}$ = crash modification factor for fatal and injury crashes in weaving areas developed using Texas freeway data; and,
L^*_{wev} = weaving section length (feet).

The Texas CMF takes the value of 1.0 as the weaving length approaches infinity (i.e., a basic freeway segment) and allows for direct comparisons to the fatal plus injury CMFs reported in this paper. These findings are illustrated in Figure 2. The CMFs show very similar safety relationships and increase confidence that the general safety trends uncovered by both sets of authors are transferable to areas with other geographic characteristics.

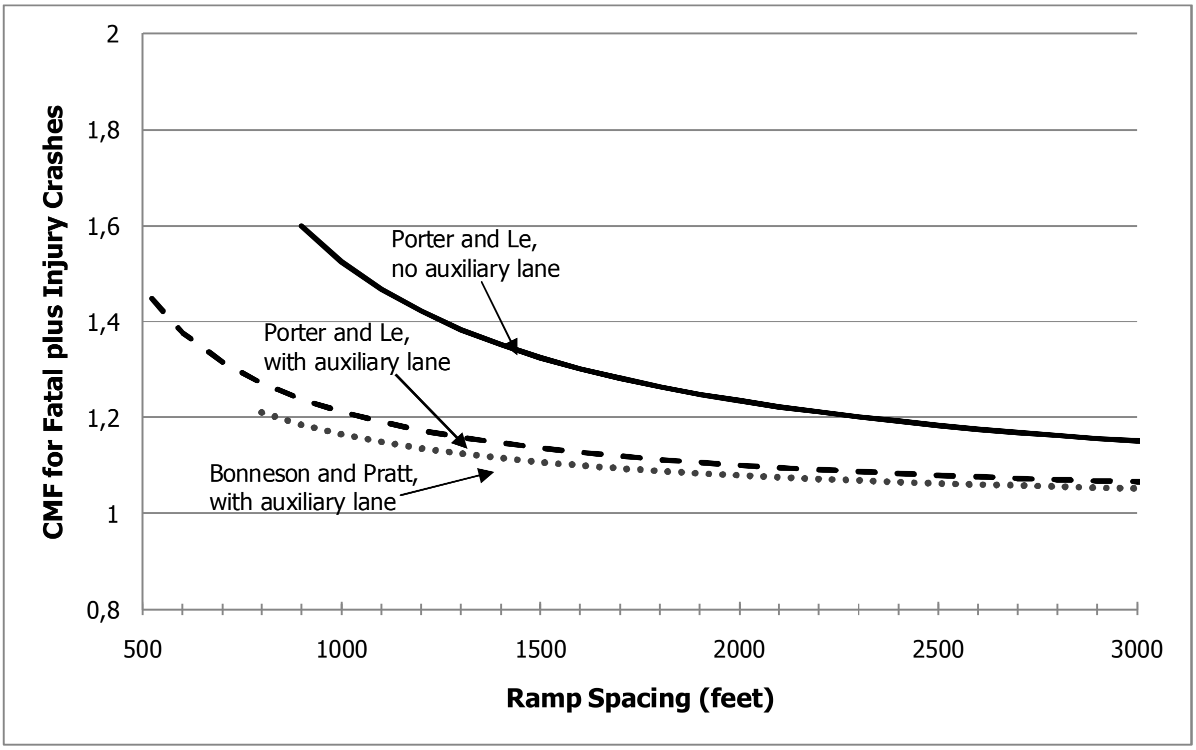

Figure 2 Comparison of Crash Modification Factors from this Study to Related Texas Findings

The tools reported in this paper can be used to quantify the freeway mainline safety effects of ramp spacing. This capability is directly relevant to access management on freeways, specifically in evaluating requests for new access or modifications to existing access. The ability to quantify the potential safety impacts of a new interchange on the freeway mainline will assist transportation agencies in making well-informed assessments of the overall benefits, impacts, and costs of freeway access decisions. A comprehensive safety evaluation of new freeway access should consider safety impacts on the freeway mainline (addressed with this paper), safety associated with speed-change lane presence and design, safety along the ramp proper, safety at ramp terminal intersections, and safety on the surrounding highways and streets.

The authors of this paper continue to build datasets to improve the predictive scope and accuracy of the freeway safety models presented in this paper. Data on cross section, horizontal alignment, and vertical alignment elements are currently being collected. Speed change lane dimensions will also be added to the dataset in an attempt to study potential safety trade-offs between the length of speed change lanes and ramp spacing. The dataset is also being expanded to include other interchange and ramp types as the current paper was focused only on spacing between different types of diamond interchanges. A separate sponsored research effort is just underway at the University of Utah to intertwine travel demand modeling and safety prediction. Such capabilities will assist transportation agencies in quantifying the trade-offs between freeway mainline safety effects and effects on the surrounding network roads as a result of new freeway access.

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