Use of Freeway Conflict Rates as an Alternative to Crash Rates in Weaving Section Safety Analyses

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Traffic safety is an important concept in the evaluation of a transportation system and its impact on public health. Using reported crash rates as an indicator of safety of a freeway facility has many drawbacks, such as errors in the reporting and recording of crashes, inaccuracies in the way in which the exposure measure is derived, and the wait involved for a sufficient sample size to materialize. Conflict rates provide an alternative to crash rates as an indicator of safety. Benefits of their use include the ease and accuracy with which conflict rates at ramp weaves can be obtained and the high frequency at which they occur with no physical harm to the public. Computer subroutines were added to the Integrated Traffic Simulation (INTRAS) to count conflicts, and freeway traffic was simulated at 10 modeled ramp weaves on Interstate 294 (Interstate 294 serves as a quasi-beltway for the Chicago metropolitan area). The resulting conflict rates were then noted. Volume, geometric, and crash data for the 10 sites were provided by the Illinois State Toll Highway Authority and on-site visits. The conflict rates at the sites were applied in a test of their ability to identify the known hazardous ramp weaves, and the relationship between conflict and crash rates was examined.

Weaving is the crossing of traffic streams flowing in the same general direction. Freeway weaving sections have long been a problem area for highway engineers in terms of their design, traffic operations analysis, and safety. When a freeway driver performs a weaving maneuver in the weaving section, the driver interacts with entering and exiting drivers possibly in a conflicting manner. A traffic conflict is an event that has the potential of being a traffic crash.

Studies on freeway traffic conflicts are few in number. The main reason for this discrepancy is the high average crash rates observed on the nonfreeway system. The crash frequencies on freeways are far less than the crash frequencies on roadways with at-grade intersections. For instance, in 1988 Illinois urban Interstate highway crashes totaled 32,546, whereas urban non-Interstate highway crashes totaled 426,046 (*1*,p.11). Urban includes locations in or adjacent to a municipality or other urban area of more than 5,000 population (*1*). In Illinois rural areas, Interstate highway crashes totaled 6,298, and non-Interstate type crashes amounted to 509,514 (*1*).

This paper expands the traffic conflict concept in two principal ways: (*a*) freeway conflicts as opposed to intersection conflicts are examined and (*b*) freeway conflicts are counted from a microscopic freeway simulation program (which has been validated in its modeling of freeway traffic operations) rather than from direct empirical observations.

An overall goal of this work is to promote the safe movement of people and goods upon entering the freeway weaving section until they exit the weaving section. This goal can be expressed in two specific objectives: (*a*) to develop a tool that can be used to determine freeway conflict rates for an existing or proposed freeway facility and (*b*) to enhance the body of knowledge relating conflicts to crashes and the potential of using conflicts as an indicator of safety.

The first objective entailed the development of subroutines to be added to a freeway simulation program to assess the traffic conflicts that may occur in freeway weaving sections. The output of the revised program provides the user with a safety measure of the weaving section facility that is being modeled. In this way, highway engineers can examine the weaving traffic operations of a specific alternative as well as acquire an estimate of how safe the alternative will be if implemented.

METHODOLOGY

Definition of Terms

Simple Freeway Weaving Section

A simple freeway weaving section represents the physical space along a freeway where two traffic streams weave, as shown in Figure 1. The length of the weaving section is measured from a point where the entrance gore is 2 ft wide to a point where the exit gore is 12 ft wide, as shown in Figure 1 (*2*, pp. 4-1 to 4-19). This length represents the geometric distance in which weaving maneuvers must actually occur. In simple freeway weaving sections, there are four general movements: freeway to freeway, freeway to off-ramp, on-ramp to freeway, and on-ramp to off-ramp. Weaving traffic is composed of traffic from the second and third movements. The scope of this work is limited to ramp weaves because they are the most common type of freeway weaving sections.

Freeway Conflict

Two evident types of traffic conflicts occur on freeways. On the mainline, a driver is either following another vehicle or

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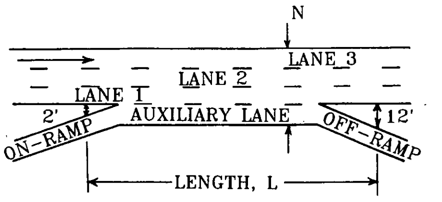

FIGURE 1 Layout of a ramp weave.

is in the process of changing lanes. Thus, the two most common types of freeway conflicts are rear-end conflicts and lane change conflicts. Some not so obvious conflicts are the head-on conflict, the object on lane of travel conflict, and the moving violation conflict. Their rare occurrence and lack of operational significance under normal driving conditions preclude any further discussion of their nature in this paper.

A freeway lane change conflict is a potential sideswipe or angle crash. It occurs when a vehicle changes lanes and the driver of the vehicle immediately following it in the target lane reacts to avoid a collision by applying the vehicle's brakes, as shown in Figure 2. If this maneuver is successful, the incident is a lane change conflict. Otherwise, a sideswipe or angle crash occurs.

Since the Integrated Traffic Simulation (INTRAS) program microscopically simulates traffic flow through its car-following and lane-changing algorithms, traffic conflicts occur in the simulations. However, in its original form, freeway conflicts were not counted in INTRAS, nor were they presented in its output reports. Thus, computer subroutines were developed, added to INTRAS, and microscopically validated so that freeway lane change and rear-end conflicts were accurately and precisely counted, their rates calculated, and conflict information reports generated as output. Moreover, the internal logic and validated car-following and lane-changing algorithms were not modified in any manner.

A lane change conflict was counted in the INTRAS simulation when the following two conditions were satisfied: the lane identification attribute of a freeway vehicle changed at a simulation time step (i.e., Vehicle A changed lanes in Figure 2) and the immediately following vehicle in the target lane (i.e., Vehicle B in Figure 2) had a deceleration greater than or equal to 0.61 m/sec^2 (2 ft/sec^2).

A freeway rear-end conflict is a potential rear-end crash. It occurs when a vehicle slows or stops on a freeway lane of travel, and the driver of the immediately following vehicle on the same freeway lane of travel reacts by applying the vehicle's brakes to avoid collision, as shown in Figure 3. If this maneuver is successful, the incident is a rear-end conflict. Otherwise, a rear-end collision occurs.

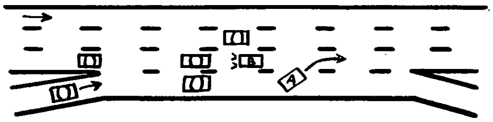

FIGURE 2 Lane change conflict: Vehicle A changes lane, and driver of Vehicle B brakes to avoid collision.

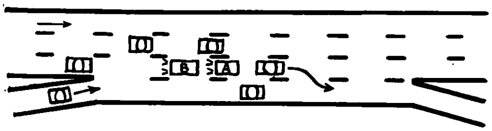

FIGURE 3 Rear-end conflict: Vehicle A slows or stops, and driver of Vehicle B brakes to avoid collision.

Counting rear-end conflicts in INTRAS was more difficult than counting lane change conflicts. In car-following, a vehicle in a given lane may decelerate through one or more simulation time steps (i.e., it experiences a deceleration cycle). A rear-end conflict was counted in the INTRAS simulation when the following two conditions were satisfied: (*a*) Vehicle A in Figure 3 experiences a deceleration cycle and (*b*) during the deceleration cycle of Vehicle A, the immediately following vehicle (i.e, Vehicle B in Figure 3) experiences a full or partial deceleration cycle that has a maximum amplitude of 0.61 m/sec^2 (2 ft/sec^2) or greater. In other words, Vehicle A is decelerating while Vehicle B has a braking deceleration.

In an ideal situation, individual lane changes caused by weaving traffic do not result in lane change conflicts or in upstream rear-end or lane change conflicts. However, this ideal scenario is never sustained in real-world freeway traffic flow. Even on basic freeway segments, there is always a certain "background" lane-changing frequency that often results in some lane change conflicts. The additional impact of conflicts caused by weaving adversely affects traffic and increases speed variation in the weaving section. This vehicular speed variation essentially describes turbulence (i.e., major speed differences among vehicles in a segment of freeway). One measure of turbulence for weaving sections has been the difference between weaving and nonweaving vehicular speeds. These speeds were produced as output in the simulation runs. Thus, conflicts cause drivers to change their speeds. Reducing turbulence should enhance the safety of the system as well as its operations.

In a ramp weave, one of the more common type of weaving sections, turbulence is mostly concentrated in the auxiliary and rightmost freeway lanes; this is where most of the drivers perform their weaving maneuvers (i.e., interact with other entering or exiting drivers to reach desired destinations). By definition, weaving involves a certain amount of lane changing. At the microscopic level, this "crossing" inside ramp weave involves lane changes by drivers who want to complete their weaving maneuvers. Some of these lane changes are lane change conflicts; these incidents, and the additional conflicts they propagate, are the cause of speed variations at the macroscopic level (i.e., turbulence) and hazardous freeway operations.

To examine the association between freeway weaving section crash rates and conflict rates, crash rate and conflict rate data were obtained from existing freeway weaving sections. Crash rate data were obtained from the Illinois State Toll Highway Authority (ISTHA). The conflict rate data were determined by simulation modeling of the weaving sections where crash rates were obtained.

Sites

Site data were provided by ISTHA. Ten weaving section sites were selected as indicated in Table 1. The sites had histories

TABLE 1 Weaving Section Sites

Site	Location	Highway post marker	Length in kilometer (mile)
1.	Northbound I-294 (Tri-State Tollway) at Halsted Street (IL. 1)	2.77	1.1 (0.7)
2.	Southbound I-294 (Tri-State Tollway) at Halsted Street (IL. 1)	2.77	1.1 (0.7)
3.	Northbound I-294 (Tri-State Tollway) at Cicero Avenue (IL. 50)	12.08	0.6 (0.4)
4.	Northbound I-294 (Tri-State Tollway) at Ogden Avenue (U.S. 34)	27.63	1.1 (0.7)
5.	Southbound I-294 (Tri-State Tollway) at Ogden Avenue (U.S. 34)	27.63	1.1 (0.7)
6.	Northbound I-294 (Tri-State Tollway) from eastbound East-West Tollway (I-88) on-ramp to westbound Eisenhower Expressway (I-290) off-ramp	31.69	1.4 (0.9)
7.	Southbound I-294 (Tri-State Tollway) to eastbound Eisenhower Expressway (I-290) off-ramp from westbound East-West Tollway (I-88) on-ramp	31.69	1.4 (0.9)
8.	Northbound I-294 (Tri-State Tollway) from eastbound Kennedy (I-190) on-ramp to westbound Northwest Tollway (I-90) off-ramp	40.33	1.3 (0.8)
9.	Northbound I-294 (Tri-State Tollway) at Grand Avenue (IL. 132)	69.61	1.3 (0.8)
10.	Southbound I-294 (Tri-State Tollway) at Grand Avenue (IL. 132)	69.61	1.3 (0.8)

of high crash occurrence. All the sites are located on Interstate 294, the Tri-State Tollway. The Tri-State Tollway is a major cross-country freight route and also serves as a quasi-beltway for the Chicago metropolitan area.

Determination of Crash Rates

Crash counts by type (i.e., rear-end and angle/sideswipe) and by year were extracted from ISTHA computer printouts. The printouts contained only those crashes in or near the 10 weaving sections as indicated by the milepost of each crash record. The crash counts were tallied by year for the period 1985 through 1988. The crashes could have been disaggregated by a shorter interval of time, but such a strategy would increase crash count variability. Some of the crash counts at certain sites had to be aggregated with another site. This occurred when the sites had the same mileposts but opposite direction of traffic. The printouts did not distinguish whether the direction was northbound or southbound. Thus, the crash counts for the two Halsted Street sites, the two Ogden Avenue sites, the two I-88/I-290 sites, and the two Grand Avenue sites are combined.

To convert the crash counts to rates, the directional annual average daily traffic (AADT) through the weaving section and the length of the segment on which the crashes occurred must be determined. The directional AADT schematics of the 10 weaving sections for January 1, 1985, through July 31, 1988, were obtained from ISTHA. The AADT through the weaving section was known, and AADT for the on-ramp, off-ramp, freeway upstream, and freeway downstream of the section were also given. This additional information was used in determining origin and destination traffic movements when the weaving sections were modeled for simulation. Mainline AADTs and some ramp AADTs are determined from continuous counts throughout the year because of the mainline tollway plazas and ramp toll machines on the Tri-State. AADTs of ramps that had no collection devices were based on daily counts taken for a week and seasonally adjusted. Only one ramp had a toll collection device in the 10 sites examined—the on-ramp to Site 2. In general, AADT increases with each subsequent year except at Site 1 in 1988. In 1987 and 1988, this site was reconstructed into a collector-distributor weaving section.

The highway mainline lengths where the crashes occurred were determined from the upper and lower milepost values from the middle of the site. This milepost range is determined from the crash printouts. Once the distance of this range is known, 161 m (0.1 mi) are added [i.e., 80.5 m (0.05 mi) for each end] to adjust for round-off error in the crash reporting. Table 1 gives the length at each site where the crashes were counted.

Once the crash counts, AADT, and weaving section length were determined, the crash rates were calculated by crash type and year, as given in Table 2 and shown in Equations 1 and 2 for 1985 through 1987 and 1988, respectively:

$$\text{crash rate} = \text{crash count}/(\text{AADT} * \text{length} * 365) \tag{1}$$

$$\text{crash rate} = \text{crash count}/(\text{AADT} * \text{length} * 213) \tag{2}$$

TABLE 2 Weaving Section Crash Rates (Crashes per 100 Million Vehicle Kilometers)

Site	Year	Crash Type				
		Rear-end	Sideswipe + Angle	Overturn	Other	Total
1. and 2.	1985	63.4 (102)[b]	79.5 (128)	0 (0)	43.2 (69.5)	186.4 (300)
	1986	26.6 (42.8)	35.5 (57.1)	0 (0)	20.7 (33.3)	82.6 (133)
	1987	16.2 (26.0)	48.5 (78.1)	0 (0)	18.9 (30.4)	83.9 (135)
	1988[a]	36.2 (58.3)	65.2 (105)	0 (0)	65.2 (105)	166.5 (268)
3.	1985	114.3 (184)	157.2 (253)	0 (0)	142.9 (230)	413.8 (666)
	1986	73.9 (119)	98.8 (159)	0 (0)	61.8 (99.4)	234.9 (378)
	1987	33.6 (54.0)	22.4 (36.0)	0 (0)	11.2 (18.0)	67.1 (108)
	1988[a]	0 (0)	17.1 (27.5)	0 (0)	17.1 (27.5)	34.2 (55.0)
4. and 5.	1985	22.9 (36.8)	16.0 (25.8)	0 (0)	9.1 (14.7)	48.0 (77.3)
	1986	27.3 (43.9)	25.2 (40.5)	0 (0)	6.3 (10.1)	58.8 (94.6)
	1987	17.6 (28.4)	25.5 (41.0)	0 (0)	9.8 (15.8)	52.9 (85.1)
	1988[a]	40.6 (65.3)	0 (0)	0 (0)	12.5 (20.1)	53.1 (85.4)
6. and 7.	1985	57.6 (86.2)	60.3 (97.0)	0 (0)	21.7 (35.0)	135.5 (218)
	1986	72.7 (117)	56.4 (90.8)	0 (0)	6.5 (10.4)	135.5 (218)
	1987	111.2 (179)	63.4 (102)	0 (0)	15.0 (24.2)	189.5 (305)
	1988[a]	149.1 (240)	81.4 (131)	0 (0)	12.0 (19.3)	242.3 (390)
8.	1985	94.4 (152)	113.1 (182)	9.5 (15.2)	51.8 (83.4)	268.4 (432)
	1986	131.1 (211)	103.8 (167)	4.5 (7.26)	40.6 (65.4)	279.6 (450)
	1987	119.3 (192)	80.8 (130)	0 (0)	51.2 (82.4)	251.7 (405)
	1988[a]	154.7 (249)	60.5 (97.3)	0 (0)	26.8 (43.2)	241.7 (389)
9. and 10.	1985	16.2 (26.1)	10.8 (17.4)	0 (0)	16.2 (26.1)	43.2 (69.6)
	1986	15.3 (24.6)	15.3 (24.6)	0 (0)	10.2 (16.4)	40.7 (65.5)
	1987	30.4 (49.0)	25.4 (40.8)	0 (0)	45.7 (73.5)	101.3 (163)
	1988[a]	76.4 (123)	15.3 (24.7)	0 (0)	69.0 (111)	160.9 (259)

[a] From January 1, 1988 to July 31, 1988, i.e., 213 days

[b] Crashes per 100 million vehicle-miles

Determination of Conflict Rates

The INTRAS program, which is distributed by FHWA under its technology transfer program, was implemented to model the 10 existing ramp weaves. Certain subroutines were added to the INTRAS program to allow the extraction of conflict data in the ramp weaves. The accuracy of the conflict counts from the simulations was established by examining vehicle trajectory dumps and the "flags" that mark the time step when a conflict was counted. In this way, the simulation conflict counting algorithms were debugged until they precisely and accurately matched the definitions of the rear-end and lane change conflict previously mentioned. Once the conflict counts were determined for a specific time period, they were divided by the vehicle-kilometers (vehicle-miles) of travel in the weaving section.

There are several reasons why INTRAS was selected for adaptation in this paper. First, to count individual vehicle conflicts, a microscopic simulation program is needed; INTRAS is microscopic. The fact that INTRAS has been rigorously validated at weaving sections gives credibility to its results (*3,4*). The capability of INTRAS to control for geometric and volume variables important to weaving sections (e.g., configuration, freeway volume, ramp volumes, length, and number of lanes) is another reason for selection. Next is an economic consideration: using INTRAS to generate and collect weaving section data is much less costly than collecting and processing data from the field. Finally, and most important, INTRAS uses highly detailed lane change and car-following logic. Such an elaborate simulation provided much needed insight and understanding of the complex turbulence relationships in a weaving section.

Once the 10 sites were modeled into INTRAS, traffic flow through each site was simulated for 15 min after equilibrium was obtained. Two hundred computer runs were performed (10 sites × 4 years × 5 random number seeds). In each computer run, total lane change conflict rates, mandatory lane change conflict rates, and rear-end conflict rates were recorded. The rates were determined by examining the appropriate INTRAS output reports and freeway link. One of the drawbacks of conflict rates, like crash rates, is that they can be highly variable. Yet, the variations in conflict occurrences by changing the random number seed in the simulation should not be large, that is, coefficient of variation (CV) ≤ 1, given all else held constant because of the stochastic nature of vehicle generation. By varying the random number seed five times, the mean, standard deviation, and CV for each group of five resulting conflict rates were also calculated. The CV values were quite low in all three conflict rate categories; most values were less than 1. The only exceptions occurred when the conflict counts were very low; this was expected.

Statistical Analyses

The Spearman rank correlation procedure was used to test the correlation between total lane change conflict rates and angle/sideswipe crash rates and the correlation between rear-end conflict rates and reported rear-end crash rates. The rank correlation coefficient of Spearman (r_S) is used in general when a population does not have an approximate bivariate normal distribution; the test is exact for small sample sizes and nonnormal data, and the effects of outliers are weakened (*5*).

The Spearman rank-correlation procedure has been in use since 1904; its main advantages are simplicity and power. In addition, the method has been proven to be almost as powerful as its classical counterpart, the Pearson "product-moment" correlation method, under conditions favorable to the latter method and even more powerful than the parametric method when the Spearman method's assumptions are violated (*6*).

The Spearman rank-correlation procedure consists of five steps:

1. Replace the n values of the conflict rates by their ranks by giving the rank 1 to the "largest" and the rank n to the "smallest" (note: no ties were observed in the data).
2. Replace the n values of the crash rates by their ranks as in Step 1.
3. For each of the n rates, obtain a set of rank difference scores, that is,

$$D_i = \text{conflict rate rank}_i - \text{crash rate rank}_i$$

where $i = 1, 2, \ldots, n$.

4. Obtain the summation of squared rank difference scores, ΣD_i^2.
5. Obtain the Spearman rank-correlation coefficient (r_S), where

$$r_S = 1 - \{(6\Sigma D_i^2)/[n(n^2 - 1)]\} \qquad (3)$$

The r_S ranges from -1 to $+1$. When r_S is -1, a perfect negative relationship exists. The two variables are independent of each other when $r_S = 0$. When $r_S = +1$, a perfect positive relationship exists. After r_S has been determined, a hypothesis test can be performed using the proper test statistic (*5*).

RESULTS

Before any test could be performed, three cases had to be discarded. Two cases were dropped because the ramp weave was reconstructed into a collector-distributor weaving section. The crash rates of these two cases would be biased because of the construction activity. The third case was ignored because its high volume levels could not be maintained by the simulation program. Thus, in the revised data base, there was a total of 21 observations.

Hypothesis testing was conducted using a $p = 0.025$ level of significance. The null hypothesis is stated as

> H_o: Crash rates and conflict rates are independent.

The alternative hypothesis is

> H_A: Low crash rates and low conflict rates tend to occur together, as do high crash rates and high conflict rates. In summary, crash rates and conflict rates are positively correlated.

The decision rule for the one-sided test at a 0.025 level of significance is

Reject H_o if $|r_S| \geq$ critical value $r_{S,n,0.025}$

where $|r_S|$ is the absolute value of the Spearman's rho correlation coefficient,

$$|r_S| = |1 - \{[6 * \Sigma_1^n (\text{rank difference}_i)^2]/[n * (n^2 - 1)]\}| \qquad (4)$$

and $r_{S,n,0.025}$ is the test correlation coefficient obtained from an appropriate table (*5*).

The entire data set was disaggregated by three weaving section length ranges: long, moderate, and short. The long categories involved those three cases with lengths between 594.4 m (1,960 ft) and 624.8 m (2,050 ft). The eight cases with lengths between 259.1 m (850 ft) and 304.8 m (1,000 ft) were defined as having moderate length. The 10 cases with lengths between 152.4 m (500 ft) and 198.1 m (650 ft) were defined as short. Spearman tests were attempted for each length of the three categories for the lane change rates, as presented in Table 3, and similarly three Spearman tests were attempted for the rear-end rates, as presented in Table 4.

For the long length cases involving rear-end and lane change rates, valid Spearman's tests could not be conducted because of the small sample size of three cases. The minimum sample size required to obtain a test statistic is four (*5*). A desirable sample size would be greater than four in order to perform hypothesis tests on the significance of Spearman correlation coefficients. Although hypothesis tests could not be conducted on the long length cases, moderate Spearman correlation coefficients of +0.50 were calculated for the lane change and rear-end rates. The four CV values of the total lane change conflict rate, angle/sideswipe crash rate, rear-end conflict rate, and rear-end crash rate data were extremely low. The low values imply that the conflict rates and the crash rates did not vary widely in cases where the weaving sections had a long length.

For the eight moderate length cases, the results of the Spearman tests indicate that the null hypothesis is rejected at the $p = 0.025$ level of significance for the lane change rate test and for the rear-end test, and the null hypotheses were also rejected at $p = 0.050$. Thus, one can be 97.5 percent confident that there is a positive correlation between total lane change conflict rates and reported angle/sideswipe crash rates and between rear-end conflict rates and reported rear-end crash rates.

For the 10 short length cases, the two Spearman test results indicate that their null hypotheses could not be rejected at a level of significance of $p = 0.025$ for either the lane change rate test or the rear-end rate test, but at the $p = 0.050$ level they were rejected. Thus, at short weaving section lengths, no significant correlation existed between the conflict rates and crash rates at $p = 0.025$. The CV values were consistently equal or higher than their CV value counterparts in other length categories. Furthermore, the correlations were negative; this indicates an inverse relationship between conflict and crashes at the short length sites.

There are many reasons for the high variations in the conflict rate and crash rate data especially when the weaving

TABLE 3 Spearman Test Results by Length for Lane Change Rates

Site Number	Number of Ranks	TOTAL LANE CHANGE CONFLICT RATE		SIDESWIPE AND ANGLE CRASH RATE		Spearman Correlation Coefficient
		Mean[d]	CV	Mean[e]	CV	
6 and 7[a]	3	0.1251 (0.2014)[i]	0.0557	60.0 (96.5)[j]	0.0562	+0.50[f]
8, 9 and 10[b]	8	0.0337 (0.0542)[i]	0.6004	53.1 (85.5)[j]	0.7927	+0.74[g]
1 and 2, 3, 4 and 5[c]	10	0.0747 (0.1202)[i]	0.5977	47.7 (76.8)[j]	1.0264	-0.61[h]

[a] Long Length Weaving Sections, 594.4 m (1,950 ft) to 624.8 m (2,050 ft)
[b] Moderate Length Weaving Sections, 259.1 m (850 ft) to 304.8 m (1,000 ft)
[c] Short Length Weaving Sections, 152.4 m (500 ft) to 198.1 m (650 ft)
[d] In conflicts per vehicle-kilometers (cpvkm)
[e] In crashes per 100 million vehicle-kilometer
[f] Insufficient sample size for hypothesis test
[g] Significant at 0.025 and 0.050
[h] Not significant at 0.025, significant at 0.050
[i] In conflicts per vehicle-mile
[j] In crashes per 100 million vehicle-mile

sections were of a short length. Errors in crash reporting, errors in determining AADT, errors between the lengths when the crashes were counted and weaving section length, and the stochastic nature of the simulation program probably contributed to data variation.

Two general conclusions were noted in all Spearman tests when the data were disaggregated regardless of whether the test involved lane change or rear-end rates. One is that when there is a decrease in the crash rate CV, there usually is a corresponding decrease in its conflict rate CV counterpart. Likewise, when the crash rate CV increases, usually so does the conflict rate CV. The second conclusion is that when the magnitude of the crash rate CV values are high, their conflict rate CV value counterparts tend to be high. When the crash rate CVs were low, the conflict rate CVs tend to be low. These two conclusions shed an important light on the freeway conflict-crash relationship: freeway weaving section conflict rate variations mimic the directional changes and magnitude of the freeway weaving section crash rate variations.

Another interesting finding is that the mean crash rates by length partially confirm previous research regarding crash rate versus weaving section length (*7*). Crash rates tend to stabilize for ramp weaves with lengths greater than 228.6 m (750 ft). When average rear-end and lane change crash rates are added together by long and moderate length categories that are greater than 228.6 m (750 ft), the average crash rates were 133.0 crashes per 100 million vehicle-kilometers (mvkm) [214 crashes per 100 million vehicle-miles (mvm)] for the moderate length category and 139.2 crashes per 100 mvkm (224 crashes per 100 mvm) for the long length category. The short length category had a crash rate of 89.5 crashes per 100 mvkm (144 crashes per 100 mvm). There was only a 4.7 percent difference between long and moderate length rates, whereas a 33.7 percent difference existed between short and moderate length rates.

TABLE 4 Spearman Test Results by Length for Rear-End Rates

Site Number	Number of Ranks	REAR-END CONFLICT RATE		REAR-END CRASH RATE		Spearman Correlation Coefficient
		Mean[d]	CV	Mean[e]	CV	
6 and 7[a]	3	2.7333 (4.3988)[i]	0.1944	78.9 (127)[j]	0.3715	+0.50[f]
8, 9 and 10[b]	8	0.5130 (0.8256)[i]	0.5291	79.5 (128)[j]	0.6810	+0.95[g]
1 and 2, 3, 4 and 5[c]	10	1.7009 (2.7373)[i]	0.7287	42.0 (67.6)[j]	0.7911	-0.48[h]

[a] Long Length Weaving Sections, 594.4 m (1,950 ft) to 624.8 m (2,050 ft)
[b] Moderate Length Weaving Sections, 259.1 m (850 ft) to 304.8 m (1,000 ft)
[c] Short Length Weaving Sections, 152.4 m (500 ft) to 198.1 m (650 ft)
[d] In conflicts per vehicle-kilometers (cpvkm)
[e] In crashes per 100 million vehicle-kilometer
[f] Insufficient sample size for hypothesis test
[g] Significant at 0.025 and 0.050
[h] Not significant at 0.025, significant at 0.050
[i] In conflicts per vehicle-mile
[j] In crashes per 100 million vehicle-mile

In summary, the results demonstrate a positive correlation between lane change conflict rates and reported sideswipe/angle crash rates and between rear-end conflict rates and reported rear-end crash rates at ramp weaves of moderate length. The conflict rate CV (i.e., standard deviation divided by the mean) is proportional to the crash rate CV; as the crash rate CV changes so does the conflict rate CV in the same direction. Furthermore, when the crash rate CV has a high value, the conflict rate CV tends to be high, and vice versa. The total rear-end plus lane change crash rate stabilizes when the weaving section length is greater than 259.1 m (850 ft).

Another observation from the results was that the average conflict rates for the weaving sections with short lengths are higher than the conflict rates of the moderate length sections. Average rear-end conflict rate for the short sections was 232 percent higher than the moderate sections. The lane change rate was 122 percent higher. Thus, weaving sections with short lengths have higher rear-end conflict rates and lane change conflict rates than sections of moderate length given similar four volume movements. These higher conflict rates translate into more traffic turbulence in those weaving sections.

The average conflicts rates in the long length category were abnormally high. The two sites in this category (northbound and southbound Tri-State near I-88) are well-known problem sites according to ISTHA officials. In fact, plans are being formulated for the reconstruction of these two sites. Besides length, they are different from most of the other sites in the data base because of their high nonweaving and weaving volumes and because their on- and off-ramps connect to other Interstate highways (I-88 and I-290), not to arterials like the moderate and short length sites. The higher volumes translated into a higher probability for a conflict to occur, despite the long length. The ability of the model to identify weaving sections with high conflict rates, as exemplified in the preceding two cases, confirms that the model can be used by the highway engineer to identify weaving sections that are hazardous to the motoring population. In other words, conflict rates of Interstate highway ramp weaves can be used as an indicator of traffic safety in Interstate highway ramp weaves.

Average rear-end and lane change crash rates were actually less in the weaving sections with short lengths than the rates in the other length categories. This observation does not confirm previous research indicating that crash rates in weaving sections increase significantly as weaving section length decreases after 228.6 m (750 ft), as indicated in Table 5 (*7*). This observation implies that either the average crash rates for moderate or long length sites were excessively high or the crash rate was abnormally low for the short length category, or both. At first, this discrepancy was thought to be directly due to difference between the length in which the crashes were counted and the measured weaving section length. However, a check on the differences in these lengths indicated that the difference was constant at approximately 914.4 m (3,000 ft) for 9 of the 10 sites. It was then thought that errors in the method by which AADT was determined might cause a bias in the crash rates. If there was a bias, there is no reason to believe that it would be more so for a specific length category (i.e., the bias would affect all sites equally). The only remaining explanation for the discrepancy lies in the process in which the crash locations were reported. Apparently, when the weaving section had a moderate to long length, more crashes tended to be reported in the segment that contained the weaving section. Similarly, fewer crashes tended to be attributed to the segments that contained weaving sections of short lengths.

An implicit assumption in the data base disaggregated by length category is that the yearly observations of crash rates for a specific site are independent of each other. To verify this assumption, an S_3 sign test of Cox and Stuart for the detection of a monotonic trend was performed using the total crash rate data in Table 2. The S_3 sign test was applied to determine whether the time series data (yearly crash rates) had no trend (H_o) (i.e., were random) or had a monotonic trend (H_A). The z-statistic equation used was one for small samples ($n < 30$): $z = [\mathrm{ABS}(S - n/6) - 0.5]/[\mathrm{SQRT}(n/12)]$, where n is the number of observations rounded to an appropriate multiple of 3 and S is the sum of the plus or minus signs (*5*). The results of the S_3 sign test indicated that an increasing or decreasing trend in the crash rates involving each

TABLE 5 Comparison of ISTHA Crash Rates with Past Research

n[a]	Length in meters (feet)	Mean VF[b] (vph)	Mean VRP[c] (vph)	Mean Crash Rate[d] Per 100 mvkm (Per 100 mvm)	Mean Crash Rate[e] Per 100 mvkm (Per 100 mvm)
3	594.4 to 624.8 (1950 to 2050)	3852	1674	139.2 [285.8][f] (224)	130.5 (210)
8	259.1 to 304.8 (850 to 1000)	2203	551	133.0 [54.7][f] (214)	130.5 (210)
10	152.4 to 198.1 (500 to 650)	3996	360	89.5 [177.7][f] (144)	273.4 to 155.3 (440 to 250)

[a] ISTHA site observations

[b] VF is the entering freeway volume to the ramp weave in vehicles per hour

[c] VRP is the entering ramp volume to the ramp weave in vehicles per hour

[d] ISTHA, Angle/sideswipe and rear-end crash rates

[e] Reference (*7*)

[f] Value in brackets indicates rear-end plus total lane change conflict rates in 0.01 conflicts per vehicle-kilometers

of the different sites or combination of sites could not be ascertained at the $p = 0.050$ level.

DISCUSSION OF RESULTS

Crash rates do provide the highway engineer with a measure by which to evaluate the level of safety of a facility. However, they are generally not applied in the determination of the quality of traffic flow through the highway facility. Implicitly, freeway conflicts have a disruptive operational effect on freeway traffic flow; they are a source of turbulence. Conflict rates can be used as a measure of the level of service (LOS) of traffic operations in ramp weaves because they quantify freeway turbulence, especially when the freeway facility has moderate to high service flows. Currently, average weaving and nonweaving speeds of vehicles through the ramp weave are applied in operational analysis procedures to determine the LOS of weaving and nonweaving traffic (*2*). In regard to freeway ramp weaves, conflict rates are minimized when the traffic through them operates at LOS C or better (*8*). Thus, when designing ramp weaves to handle forecast peak traffic flow rates, a geometry should be selected such that the weaving and nonweaving traffic operates at LOS C or better.

Conflicts may also be analyzed to determine the level of safety of a freeway facility. Conflicts do not have to be associated with crashes to be a good indicator of safety. However, it is desirable to examine conflict/crash associations to strengthen the argument that conflicts may be used as a surrogate for crashes in lieu of crash data. A good indicator of traffic safety is characterized by the completeness of the counts on which the indicator is dependent, the frequency of occurrence (sufficient sample size), and its ability to identify hazardous facilities and prevent or minimize hazardous events and situations.

In comparing the advantages and disadvantages of using either conflict rates or crash rates as an indicator of safety, crash rates have some major disadvantages. First, not all crashes are reported, especially the very minor ones. A crash rate based on such counts may not be representative of the crash population. Second, crashes are usually reported by law enforcement officials and transcribed into a data base by a data entry operator. This process of reporting and recording crashes could lead to ambiguities relative to the exact location and time of crash occurrence and transcription errors. Both may result in misleading crash statistics for a given facility. This could have been why negative correlations between conflicts and crashes were observed for the short length sites; reporting personnel may have underreported crashes in short weaving sections by using mileposts numbers outside the ramp weaves. Third, most crash rates use vehicle-kilometers (vehicle-miles) of travel as an indicator of risk. Using vehicle-kilometers (vehicle-miles) as an exposure measure is better than using raw crash counts, but it has serious drawbacks. This exposure measure does not consider the total number of passengers in the vehicle, speed (i.e., a time element is not involved), or the accuracy of the procedures from which the number of vehicles is obtained (e.g., AADT and gasoline mileage).

Conflict rates should be a good indicator of traffic safety because they are predictors of the probability of crash occurrence. Thus, one would not need to wait for crash occurrence to assess the level of safety of a traffic facility. Conflict rates are easily measured from the field over a short time and distance interval. For a ramp weave, conflict rate determination using empirical methods involves counting vehicular brake light indications over a peak 15-min interval along the weaving section length and the total number of vehicles that entered the ramp weave. The counts can be electronically stored at the time of collection and directly uploaded into a computer for data processing. These counts would not have the ambiguities and errors associated with crash reporting and processing. The only major source of error would be malfunction of vehicular brake lights. Given that newer vehicles have three brake lights (right, left, and center rear window), the probability of all three being simultaneously inoperable is low. Finally, the work reported here indicates that conflict rates should mimic crash rates in terms of variation (i.e., when crash rate variation increases, conflict rate variation also increases, and vice versa).

The factors that contribute to crash occurrence on the freeway mainline also contribute to conflict occurrence. Such factors are the driver, freeway geometry, the vehicle, and the environment. For drivers, items such as reaction time, vision, age, experience, and blood alcohol level may contribute to crash/conflict occurrence. Vehicle characteristics such as type and condition (brake malfunctioning, excessive tire wear, etc.) may be contributing factors. Freeway geometries such as sharp horizontal curves, steep grades, short weaving section length, and short speed change lanes are items that may affect crash/conflict occurrence. Environmental factors that may be important are day-to-day weather and road surface conditions, for example, fog, glare, and ice on the roadway. If crashes are aggregated over a yearly basis, the temporary effect of the weather will average out over the years.

CONCLUDING REMARKS

A Spearman's correlation coefficient of +0.74 occurred between lane change conflict rates and reported angle/sideswipe crash rates, and a coefficient of +0.95 occurred between rear-end conflict rates and rear-end crash rates, for the eight ramp weaves that had moderate lengths between 260 m (850 ft) and 305 m (1,000 ft). Both these correlations were significant at $p = 0.025$ and $p = 0.050$. For the 10 weaving sections with short lengths between 152 m (500 ft) and 198 m (650 ft), the lane change and rear-end hypothesis tests indicated no significant correlations between the conflict and crash rates at $p = 0.025$, but significance at $p = 0.050$. The two long sites with lengths of 610 m (2,000 ft) had moderate Spearman's correlation coefficients of +0.50 between lane change conflict rates–angle/sideswipe crash rates and between rear-end conflict rates and rear-end crash rates; an insufficient sample size prevented hypothesis tests from being conducted.

With the developed conflict extracting subroutines that were added to FHWA's freeway simulation program (INTRAS, soon to be renamed FRESIM), conflict output reports are produced to enable the highway engineer to obtain not only operational performance measures of a freeway facility but also a measure of safety. Properly using the program, the engineer may model proposed freeway facility alternatives to determine which design would be less hazardous. In this paper, only weaving section facilities were examined. Moreover, conflict output reports are also produced for basic freeway segments and freeway ramp junctions. Further conflict/crash studies involving those two freeway components are recommended.

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