Development of a Conflict Analysis Methodology Using SSAM

Final Report
August 2012

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16. Abstract

The ultimate goal of this research was to provide improved design guidance for J-turn intersections by learning more about the safety and operational consequences of including or excluding certain geometric design features under various traffic volume conditions.

The proposed methodology to accomplish this research objective was to use the VisSim micro-simulation software package in conjunction with Federal Highway Administration (FHWA) Surrogate Safety Assessment Model (SSAM).

Three alternative high-speed rural expressway intersection designs were modeled previously in VisSim and used to accomplish this analysis. This report examines the use of SSAM for performing a conflict analysis, comparing the safety consequences of alternative designs, and developing conflict and/or crash modification factors. A conflict analysis methodology using the SSAM software was developed and refined. The refined conflict analysis methodology is included in this report.

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DEVELOPMENT OF A CONFLICT ANALYSIS METHODOLOGY USING SSAM

Final Report
August 2012

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OBJECTIVE

The research goals are to model high-speed rural expressway J-turn intersection (JTI) design alternatives with VisSim, use the Surrogate Safety Assessment Model (SSAM) to evaluate and compare the safety consequences of those alternative designs, and develop conflict modification factors (CfMFs) for individual JTI design components and their combinations.

The objective of the analysis described in this report is to experiment with the SSAM software to demonstrate its capabilities while evaluating a proposed conflict analysis methodology. Three alternative high-speed rural expressway intersection designs were modeled previously in VisSim and used to accomplish this analysis. While these designs are not JTIs, the intersection site characteristics (rural high-speed divided highway intersections) and volumes are similar to locations where a JTI would be considered.

The Iowa Department of Transportation (DOT) was interested in examining the operational effects of proposed offset left turn lanes at the intersection of US 18/US 218/T-44 on the south edge of Floyd, Iowa. Three VisSim models were developed to evaluate the operational performance of the existing conditions (a traditional 65 mph two-way stop-controlled rural expressway intersection) and two proposed intersection design alternatives: proposed replacement of traditional left turn lanes with offset left turn lanes and proposed offset left turn lanes combined with the addition of a proposed right turn acceleration lane for traffic turning northwest onto US 18 from southwest-bound US 218.

The three designs were each modeled in VisSim and examined with SSAM. The VisSim geometrics for these three simulation models are shown in Figures 1, 2, and 3.

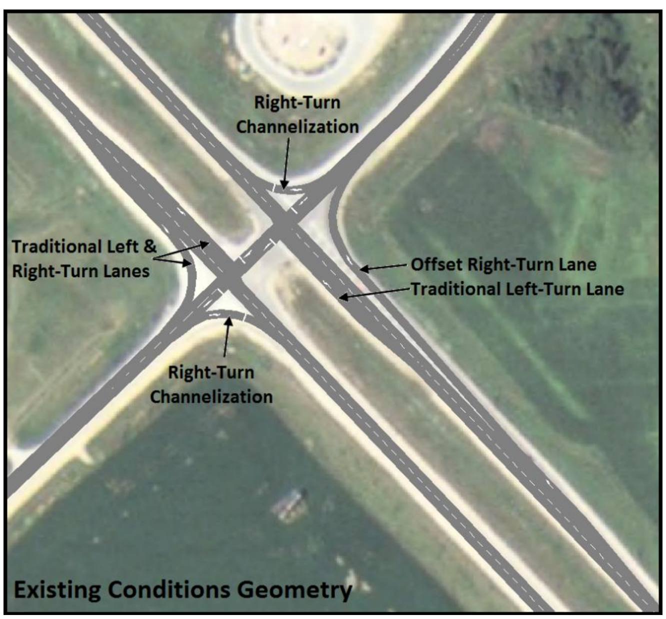

Figure 1. Existing conditions geometry

Figure 2. Offset left turn lanes geometry

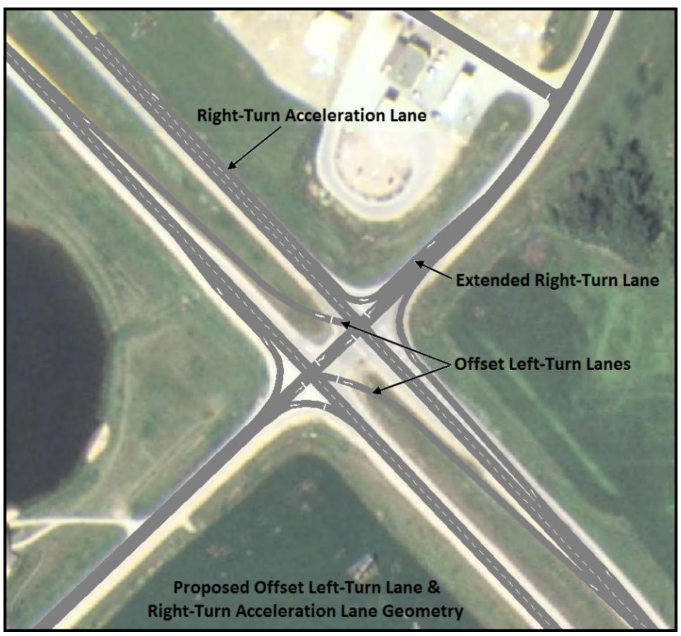

Figure 3. Offset left turn lanes and right turn acceleration lane geometry

In VisSim, each model was simulated over a period of two hours, with the first hour serving as the initialization or warm-up period in which traffic is loaded onto the network and the system is given a chance to reach equilibrium. Each alternative model was run 25 times with 25 different random seeds. Simulation runs with identical input files and random seeds generate identical results. Using a different random seed changes the profile of the arriving traffic (stochastic variation of input flow arrival times) and will vary the results (*1*). The results of each run will usually be close to the average of all runs; however, each run will be slightly different from the other. Dowling et al. (*1*) presented an example in which mean vehicle speed varied by up to 25 percent over six simulation runs with six unique random seeds. In our study, the same 25 random seeds were used to model each alternative so that each alternative was modeled with the same traffic arrival profiles/patterns and direct comparison could be made between alternatives.

METHODOLOGY

A proposed methodology for conflict analysis using SSAM was developed based on a comprehensive literature review. The methodology is as follows:

1. Use maximum time-to-collision (TTC) and maximum post-encroachment time (PET) thresholds to identify critical vehicle-vehicle interactions (i.e., conflicts) with SSAM. Initially, the maximum TTC threshold will be set to 5.00 seconds and the maximum PET threshold will be set to 9.95 seconds (the maximum possible PET threshold value).
2. Initially, use the default conflict angle threshold values in SSAM (30 and 80 degrees) to classify conflicts as rear-end, lane-change, or crossing. A sensitivity analysis will be performed to examine the most-ideal values for these thresholds.
3. After running the SSAM analysis, conflicts will be filtered out by location and time. Only conflicts occurring near the intersection of interest and after the simulation's initialization period will be included in the conflict analysis and analyzed further.
4. Each identified conflict will be assigned three scores: a TTC score as an indicator of collision propensity, a risk-of-collision (ROC) score as an indicator of potential collision severity based on a conflict's Max ΔV, and an overall conflict severity score (TTC + ROC) used to rate conflicts as potential, slight, or serious.
5. Locations of conflicts can be mapped to visually examine where the most severe conflicts are occurring, to examine patterns of conflicts by type (rear-end, lane-change, or crossing), or to compare the location of conflicts between intersection design alternatives.
6. Conflict modification factors (CfMFs) may be calculated for individual geometric design components and their combinations.
7. An intersection conflict index (ICI) will be established to compare the overall safety of each simulated intersection design alternative.

This conflict analysis methodology for using SSAM will be explored and refined as necessary as a result of this study. There are a number of remaining questions this study will attempt to answer:

- Will the selected TTC and PET threshold values generate a large enough sample size for an adequate conflict analysis?
- How many conflicts are selected based on TTC, PET, or both?
- What range of TTC values should be assigned to each TTC score?
- What range of Max ΔV values should be assigned to each ROC score?
- Is summing the TTC and ROC scores the best way to rate individual conflicts as potential, slight, or serious?
- What is the sensitivity of the conflict angle thresholds for classifying conflicts as rear-end, lane-change, or crossing?
- Which Sayed (*2*, *3*) ICI is a better method for comparing the safety of simulated intersection design alternatives?

TTC versus PET

TTC is defined as "The projected time until two road users would collide if they continue on their collision course with unchanged speeds and direction (*4*)." Whereas, PET is defined as "The elapsed time between the departure of an encroaching vehicle and the actual arrival of a trailing vehicle at the same location (*5*)." TTC and PET are both indicators of collision propensity with smaller minimum values during a conflict event indicating a higher probability of or nearness to a collision as shown in Figure 4 (*6*).

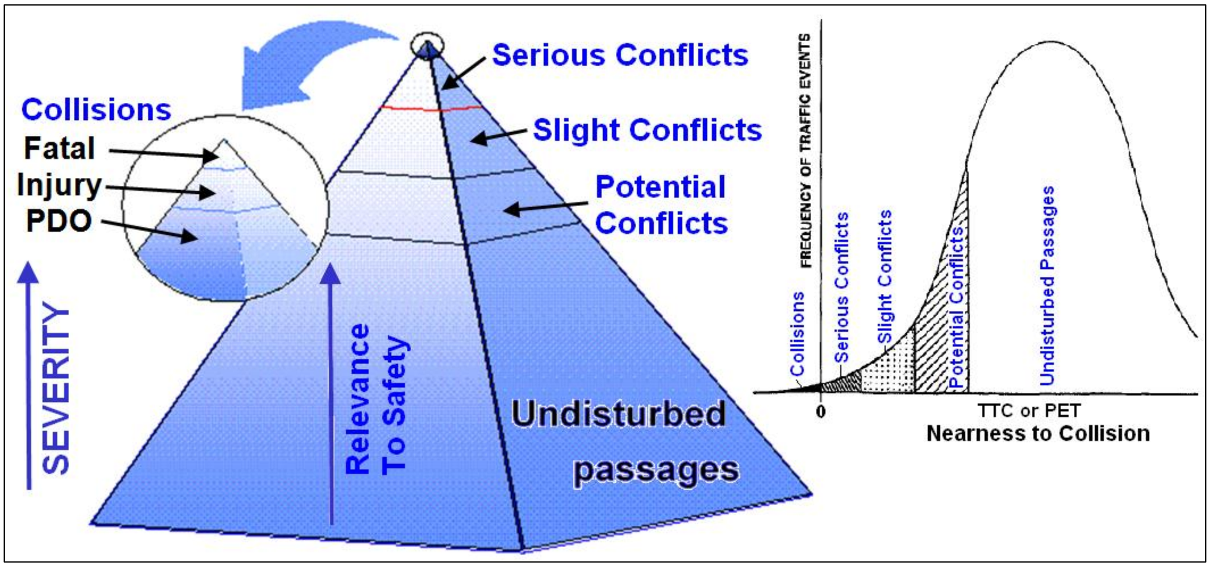

Figure 4. Pyramid of traffic events (adapted from (*6*))

While the different levels of conflicts (potential, slight, and serious) are not clearly defined or distinguished by a specific TTC or PET value, the 25 vehicle trajectory (.trj) files for each intersection design alternative (one file for each simulation run) from VisSim were uploaded to SSAM and processed using a maximum TTC threshold of 5.00 seconds and a maximum PET threshold of 9.95 seconds to identify potential conflicts. SSAM analysis will only yield conflict data and surrogate safety measures for those vehicle-vehicle interactions with minimum TTC and PET values less than these user-defined maximum thresholds. The default maximum TTC threshold value in SSAM is 1.50 seconds and the default maximum PET threshold value is 5.00 seconds; however, the user may override these with preferred alternate values ranging up to 9.95 seconds.

For TTC, the 1.50 second default value was derived from previous research at urban low-speed (25 to 30 mph) signalized intersections. Based on the conflict speed, time-to-accident, and conflict severity relationship developed by Hyden (*4*), as shown in Figure 5, the TTC threshold value for identifying serious conflicts could be estimated as 4.50 seconds for a rural expressway with a speed limit of 65 mph (105 kmph).

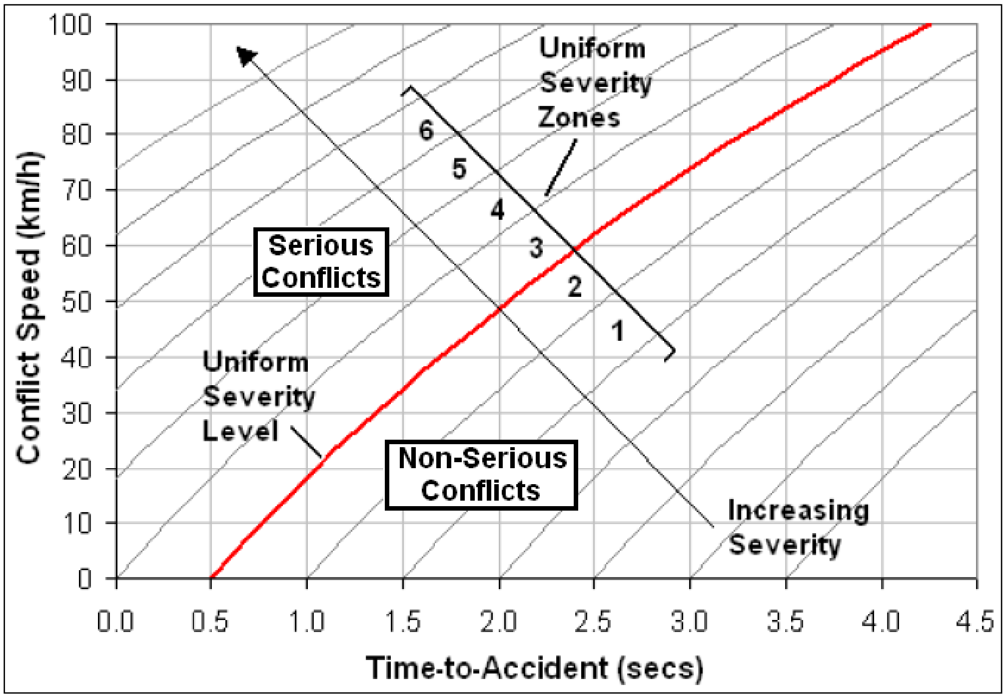

Figure 5. Uniform severity level and severity zones developed by Hyden (*4*)

Based on this estimated value, a maximum TTC threshold of 5.00 seconds was selected for our SSAM analysis. The value was rounded up to 5.00 seconds in an attempt to increase the sample size of "potential conflicts" identified by the SSAM software.

For PET, it is unclear how the 5.00 second default value for the maximum threshold in SSAM was originally selected or derived. Based on minimum time gaps for determining intersection sight distance given in the American Association of State Highway and Transportation Officials (AASHTO" "Green Book" (*7*) (summarized in Table 1), the PET threshold value could be estimated between 5.5 and 12.0 seconds, depending on the intersection traffic control, the minor road design vehicle, and the desired maneuver of the minor road vehicle.

Table 1. Time gaps for intersection sight distance cases (*7*)

<table>
<tr><th rowspan="2">Traffic Control Case</th><th colspan="3">Time Gap for Design Vehicles (sec)</th></tr>
<tr><th>Passenger Car (PC)</th><th>Single-Unit Truck (SU)</th><th>Combination Truck (CU)</th></tr>
<tr><td>B1 – Left turn from stop-controlled minor</td><td>7.5</td><td>9.5</td><td>11.5</td></tr>
<tr><td>B2 – Right turn from stop-controlled minor</td><td rowspan="2">6.5</td><td rowspan="2">8.5</td><td rowspan="2">10.5</td></tr>
<tr><td>B3 – Crossing from stop-controlled minor</td></tr>
<tr><td>C1 – Crossing from yield-controlled minor</td><td>$6.5 \leq 8.0$</td><td>$8.5 \leq 10.0$</td><td>$10.5 \leq 12.0$</td></tr>
<tr><td>C2 – Left/Right turn from yield-controlled minor</td><td>8.0</td><td>10.0</td><td>12.0</td></tr>
<tr><td>F – Left turn from major</td><td>5.5</td><td>6.5</td><td>7.5</td></tr>
<tr><td colspan="4">Note: The time gaps shown are for a two-lane major road with no median and grades of 3% or less. In the case of multilane highways, 0.5 seconds for passenger cars or 0.7 seconds for trucks should be added for each additional lane from the left, in excess of one, to be crossed and for narrow medians that cannot store the design vehicle.</td></tr>
</table>

The US 18/US 218/T-44 intersection is stop-controlled on both minor roads and in the median. To cover all movements by all vehicle types, it was decided to select a maximum PET threshold of 11.50 seconds; however, the range of the maximum PET threshold is limited by SSAM with a maximum allowed value of 9.95 seconds. Therefore, the maximum PET threshold was set to 9.95 seconds.

The VisSim models of the US 18/US 218/T-44 intersection included approximately 5 miles of the rural expressway corridor and included a total of four at-grade expressway intersections. SSAM identified 2,523 total conflicts for the 25 simulation runs of the existing conditions model over the entire network (≈ 101 conflicts/2 hr simulation run) with 1,508 rear-end conflicts, 805 lane-change conflicts, and 210 crossing conflicts.

In SSAM, the user can filter conflicts by area using the filter tab to specify the x and y coordinates of the lower left and upper right corners of a rectangular region or by using the map tab to drag a box around the area/intersection of interest as shown in Figure 6.

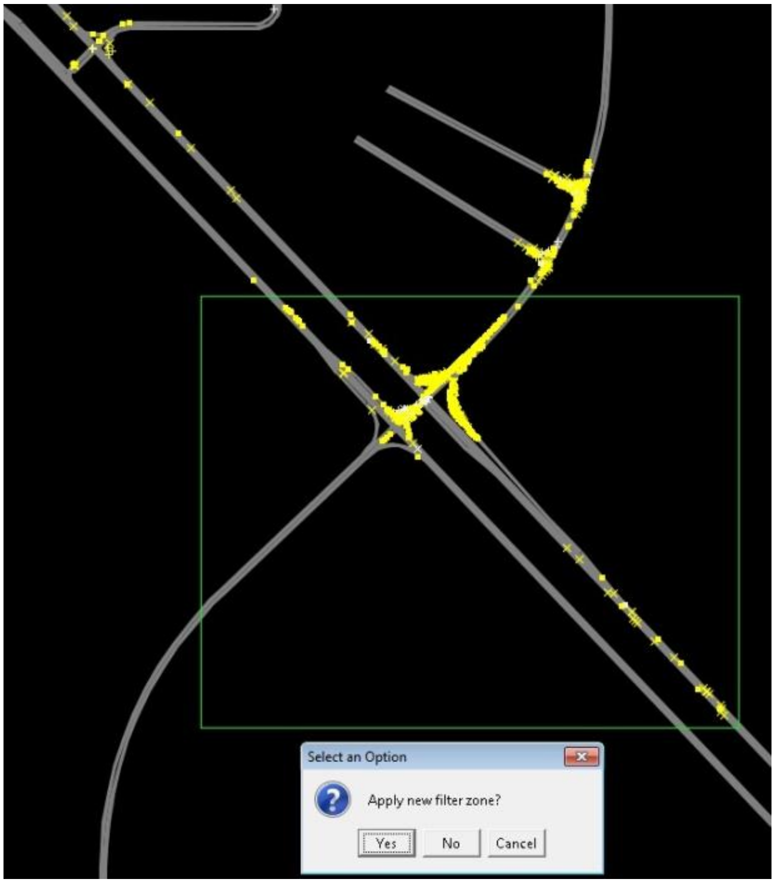

Figure 6. Filtering conflicts by area

The filter area (green box in Figure 6) was selected to include as many conflicts around the US 18/US 218/T-44 intersection as possible without selecting conflicts related to other intersections. There were 1,875 total conflicts (75 conflicts/2 hr simulation) within the filter area shown for the existing conditions model with 1,189 rear-end, 564 lane-change, and 122 crossing conflicts.

Because the first hour of each simulation run served as the initialization (warm-up) period, during which traffic was loaded onto the network, conflicts within that first hour were filtered out and the second hour was considered to be the analysis hour.

Amongst the data associated with each conflict is a tMinTTC variable which is the simulation time where the minimum TTC value for that conflict was observed. That variable was used to filter out all conflicts that occurred during the first hour (0 to 3,600 seconds). The total conflicts that occurred during the second hour within the filtered area of the existing conditions model was 1,004 (≈ 40 conflicts/simulation) with 654 rear-end, 291 lane-change, and 59 crossing conflicts occurring. Table 2 compares the total conflicts for each of the three alternative intersection designs at US 18/US 218/T-44.

Table 2. Conflict frequency comparison for US 18/US 218/T-44 design alternatives

	Existing Conditions Model	Offset Lefts Model	Offset Lefts + Right Turn Acceleration Lane Model
Total network conflicts	2,523 (101)	2,435 (97)	2,151 (86)
Total conflicts	1,875 (75)	1,806 (72)	1,499 (60)
2nd hour intersection conflicts	1,004 (40)	947 (38)	777 (31)
2nd hour rear-end	654 (26)	636 (25)	543 (22)
2nd hour lane-change	291 (12)	273 (11)	192 (8)
2nd hour crossing	59 (2)	38 (2)	42 (2)
Values in parenthesis are the average number of conflicts per simulation run			

Chin and Quek (*6*) suggest ascertaining suitable TTC and PET threshold values by establishing statistical distributions of vehicle-vehicle interactions so that the proportion of critical situations (i.e., conflicts) is not merely counted, but derived mathematically. Therefore, statistical frequency distributions were developed for both TTC and PET. Figure 7 shows the TTC frequency distribution for the existing conditions model at US 18/US 218/T-44 while Figure 8 compares the TTC frequency distributions of all three intersection design alternatives.

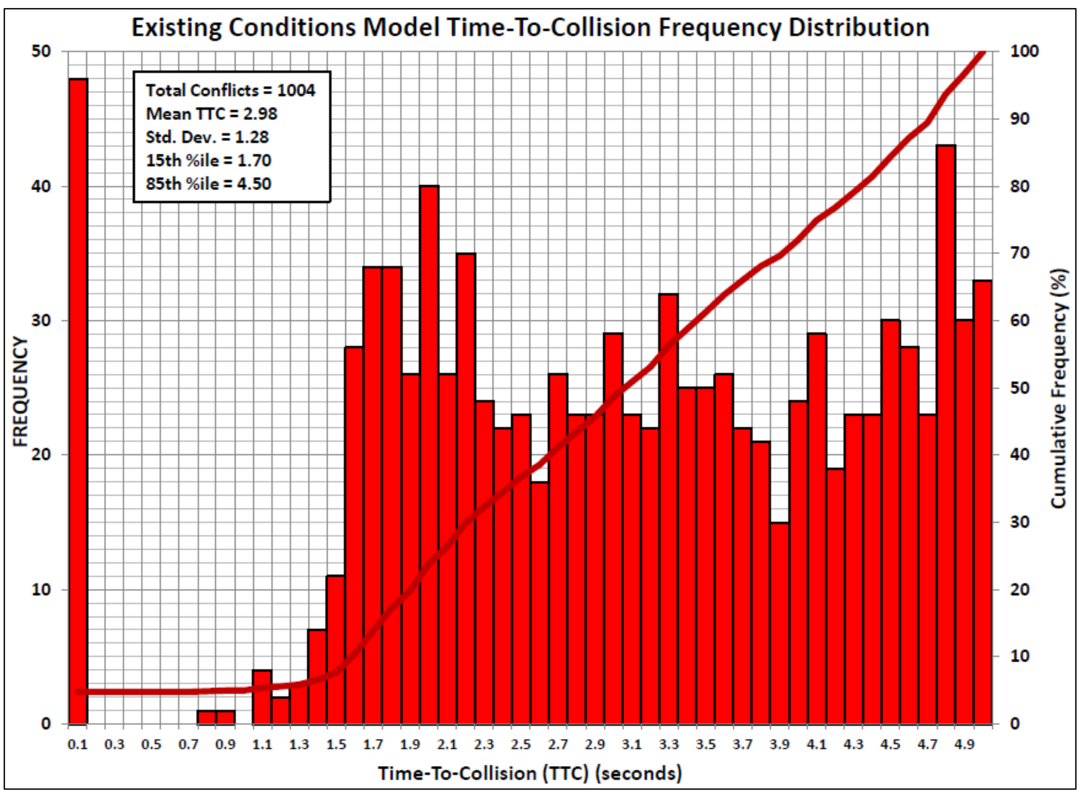

Figure 7. Existing conditions TTC frequency distribution

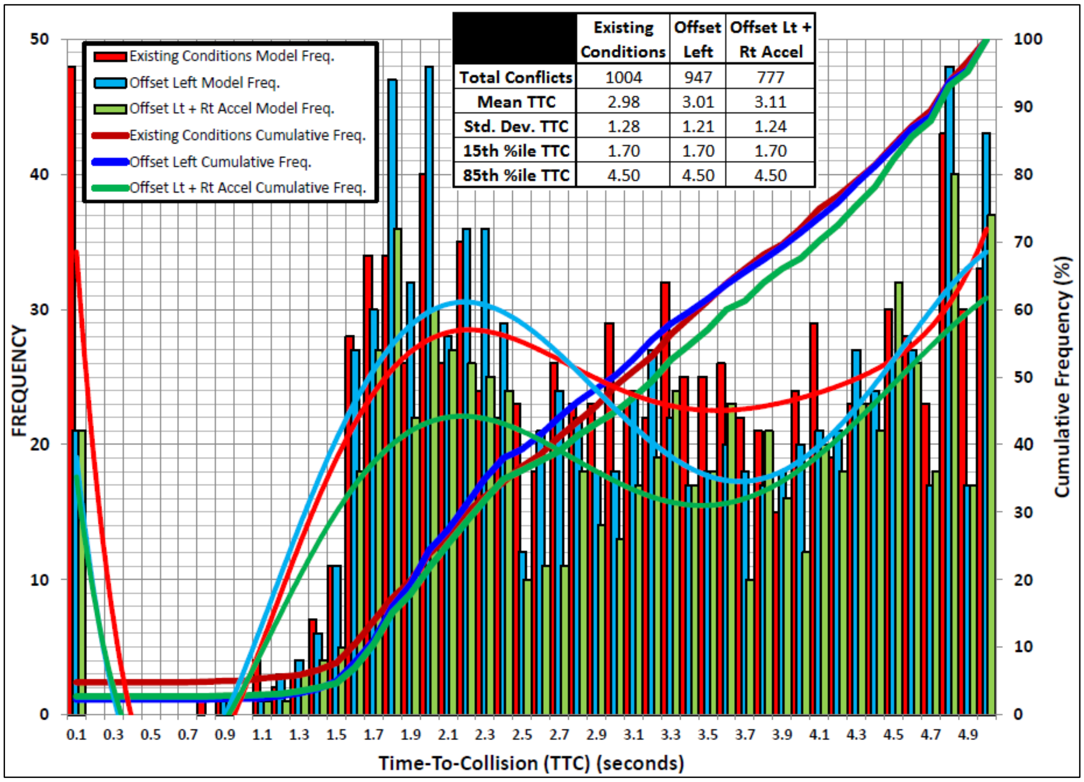

Figure 8. TTC frequency distribution comparison for all design alternatives

Figure 8 shows that the TTC distribution of all conflicts is very similar for all three design alternatives; however, the offset left-turn plus right-turn acceleration lane design alternative has the fewest conflicts and the highest mean TTC value, indicating that it is the safest design based on this comparison. Based on the cumulative frequency distributions, it appears that there are inflection points at approximately TTC = 1.50 and 2.40 seconds.

Figure 9 shows the PET frequency distribution for the existing conditions model at US 18/US 218/T-44 while Figure 10 compares the PET frequency distributions of all three intersection design alternatives.

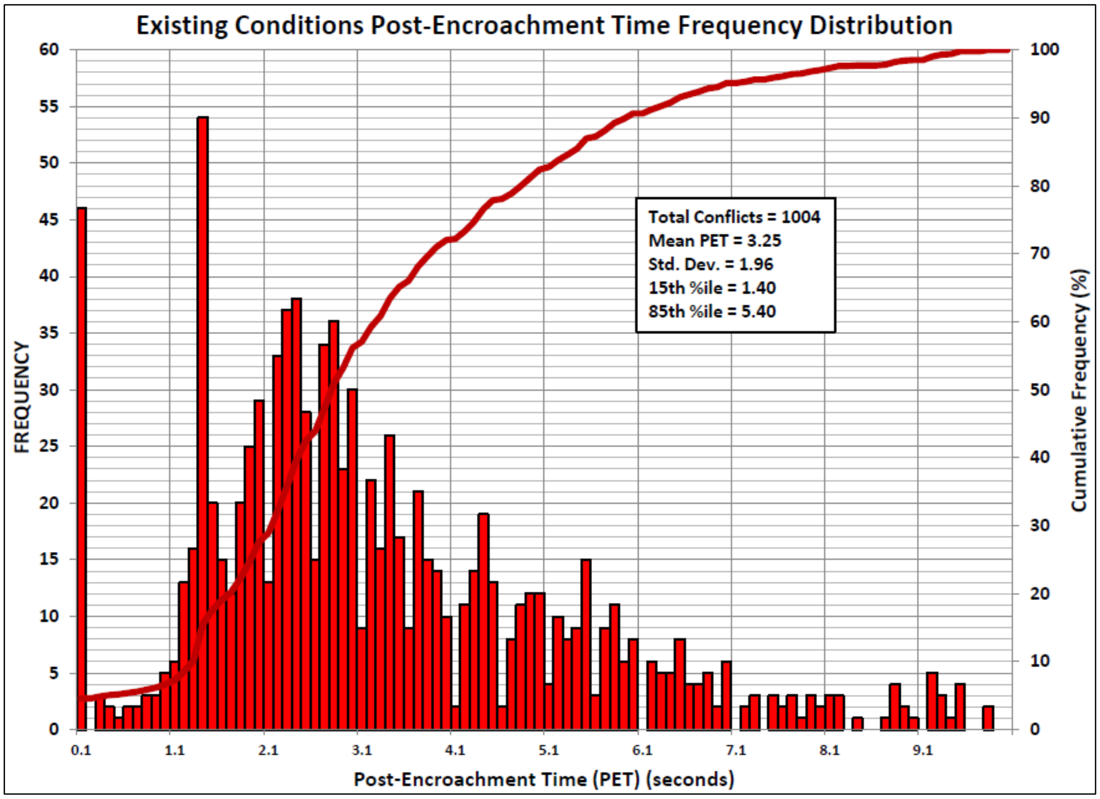

Figure 9. Existing conditions PET frequency distribution

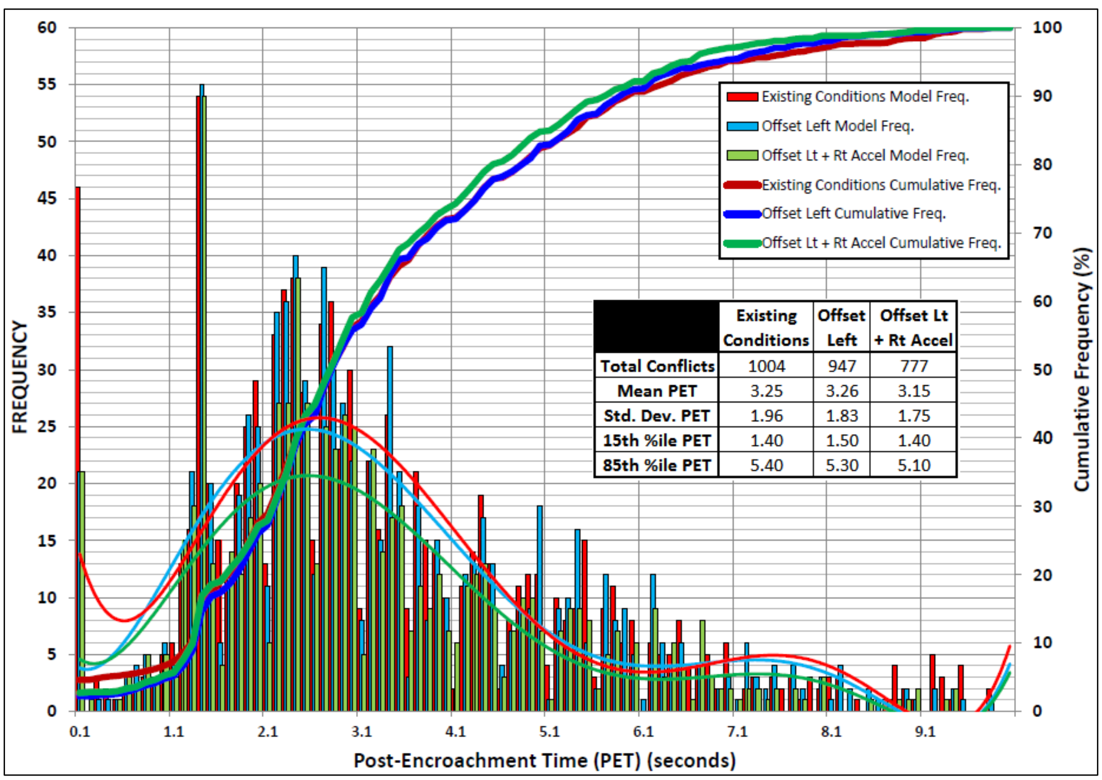

Figure 10. PET frequency distribution comparison for all design alternatives

Figure 10 shows the PET distribution of all conflicts is very similar for all three design alternatives, making it difficult to tell which alternative is the safest design based on PET alone. While the offset left-turn plus right-turn acceleration lane design alternative has the fewest conflicts, that alternative also has the lowest mean PET value. Based on the cumulative frequency distributions, it appears that there are inflection points at approximately PET = 1.10 and 4.25 seconds.

To investigate the relationship between TTC and PET, PET versus TTC was plotted in Figure 11 for the existing conditions model.

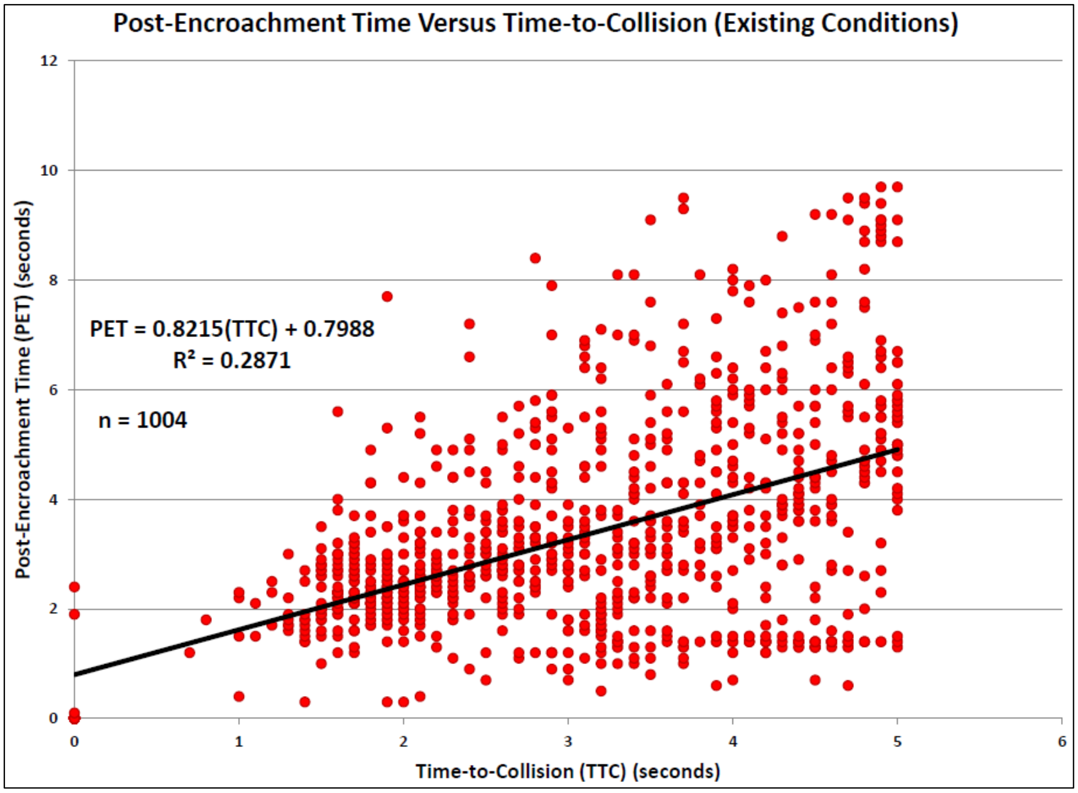

Figure 11. PET versus TTC for existing conditions model

The relationship between the two variables is not well correlated with a low R^2-value of 0.29. All 1,004 conflicts had both TTC ≤ 5.0 seconds and PET ≤ 9.95 seconds; therefore, it seems that conflicts must meet both threshold criteria to be identified by SSAM as conflicts.

TTC, ROC, and Overall Severity Scores

Given Max ΔV is the surrogate measure for potential conflict severity, the frequency distribution of Max ΔV for all three intersection design alternatives was also examined and is shown in Figure 12.

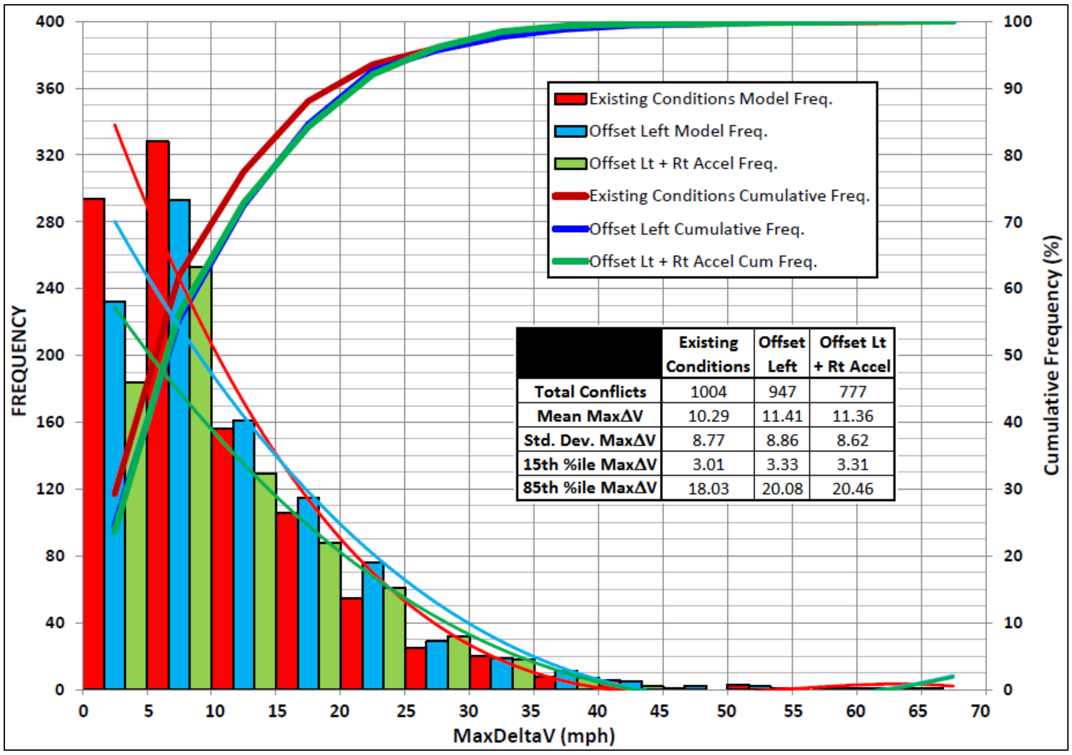

Figure 12. MaxΔV frequency distribution comparison for all design alternatives

Figure 12 shows the Max ΔV distribution of all conflicts is very similar for all three design alternatives and it is difficult to tell which alternative has the least severe conflicts based on Max ΔV alone. While the existing conditions model has the most conflicts, it also has the lowest mean Max ΔV value, indicating a lower overall potential collision severity level.

The Hyden (*4*) severity zones illustrated in Figure 5 were approximated by graphing MaxS (the maximum speed of either vehicle during the conflict event in kilometers per hour) versus minimum TTC, given conflict speed (the speed of the vehicle taking evasive action just before evasive action is initiated) and time-to-accident (the TTC value at the moment evasive action begins) are not directly available as SSAM output. All 1,004 second-hour intersection conflicts for the existing conditions model were plotted on the severity zone graph shown in Figure 13.

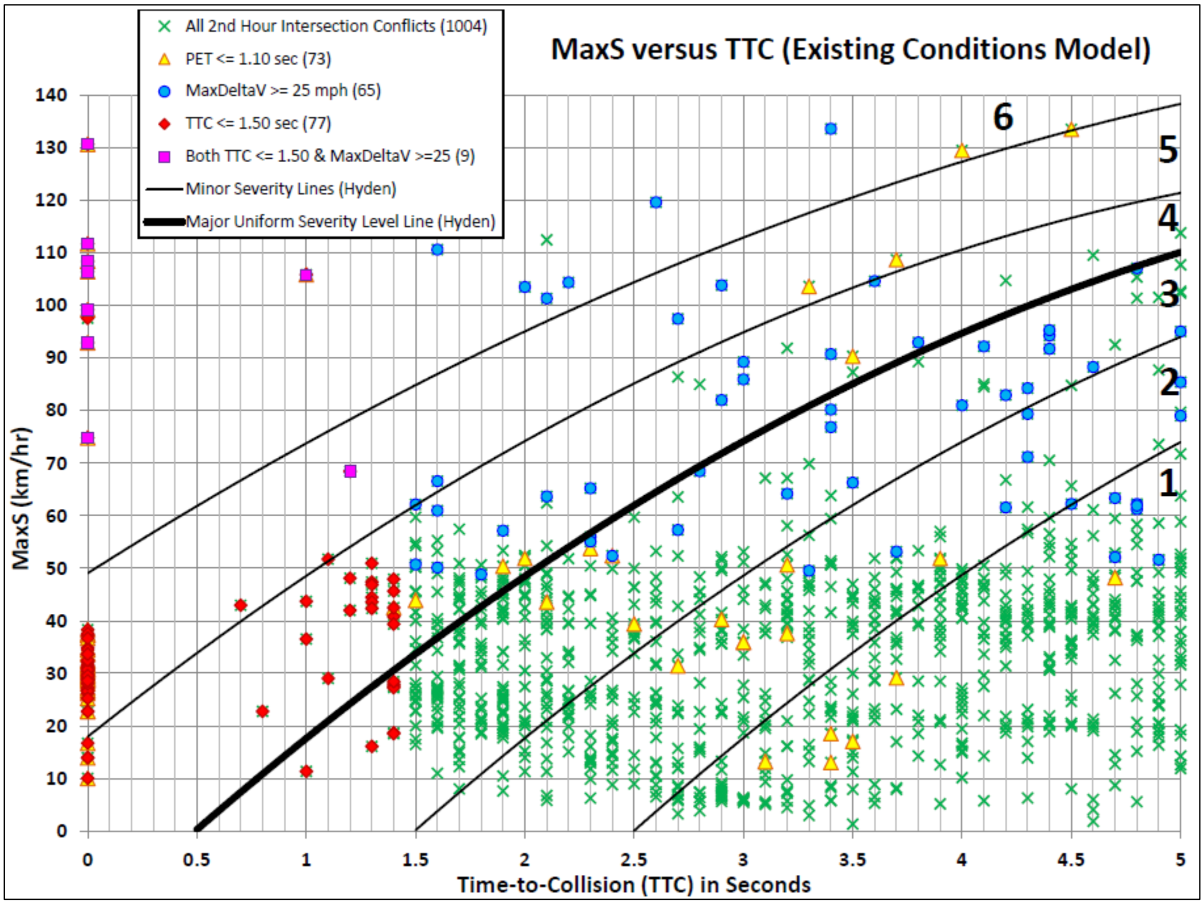

Figure 13. MaxS versus TTC conflict severity zones plot for existing conditions

All conflicts with TTC ≤ 1.50 seconds were selected and highlighted red in Figure 13. 1.50 seconds was selected as a critical TTC value due to the fact that it was an inflection point on the cumulative frequency distributions in Figures 7 and 8 and was also very near the 15th percentile value for TTC. Conflicts with TTC ≤ 1.50 seconds lie in severity zones 3 through 6 in Figure 13, with the majority falling above Hyden's (*4*) major uniform severity level line indicating most are serious conflicts.

All conflicts with Max ΔV ≥ 25 mph were selected and highlighted light blue in Figure 13. A critical Max ΔV value of 25 mph was selected in this case to have an equivalent sample size (65) to the number of critical conflicts selected based on TTC (77). Conflicts with Max ΔV ≥ 25 mph lie in all severity zones in Figure 13, with an approximate 50:50 split for those above and below Hyden's (*4*) major uniform severity line.

All conflicts with TTC ≤ 1.50 seconds and Max ΔV ≥ 25 mph are highlighted pink/purple in Figure 13. This combination seems to be a good indicator of potential collision severity with all nine of these conflicts falling in severity zones 5 and 6.

All conflicts with PET ≤ 1.10 seconds were selected and highlighted with a yellow triangle in Figure 13. The researchers selected 1.10 seconds as a critical PET value because it was an approximate inflection point on the cumulative frequency distributions in Figures 9 and 10 and because this value gave an equivalent sample size (73) to the number of critical conflicts selected based on TTC (77) and Max ΔV (65).

Conflicts with PET ≤ 1.10 seconds lie in all severity zones in Figure 13 and seem to be relatively scattered throughout the plot. As a result, TTC seems to be a better indicator of collision propensity than PET. This agrees with the findings of Gettman et al. (*8*) that, "While PET seems to be an important surrogate safety measure, it is evident that PET may be inappropriate for screening out conflict events."

To develop Sayed's (*2, 3*) intersection conflict index (ICI), a TTC score, risk-of-collision (ROC) score, and overall severity score need to be assigned to each conflict. The TTC score is assigned objectively to each conflict based on its minimum TTC value. Sayed used the TTC value ranges shown in Table 3 to assign the TTC score (*2, 3*).

Table 3. Sayed's TTC and ROC scores (*2, 3*)

TTC and ROC Score	TTC (sec)	ROC
1 (Potential)	1.5 < TTC ≤ 2.0	Low Risk
2 (Slight)	1.0 ≤ TTC ≤ 1.5	Moderate Risk
3 (Serious)	< 1.0 second	High Risk

In Sayed's method (*2, 3*), the ROC score was a subjective measure of the seriousness of the observed conflict as judged by trained field observers with 3 being assigned to a conflict perceived to be high risk as shown in Table 3.

The ROC score is independent from the TTC score. And, the sum of the TTC and ROC scores gives the overall severity score for each conflict, ranging from 2 to 6, with higher values indicating higher risk/more severe conflicts.

In the sample of 1,004 second-hour conflicts for the existing conditions model, only 24 percent of the data (239 conflicts) had TTC values less than or equal to 2.0 seconds. That's fewer than 10 conflicts per simulation run. Therefore, a decision was made to modify the TTC score ranges given in Table 3 based on the TTC sample data for the existing conditions model as shown in Table 4.

Table 4. Assigned TTC (collision propensity) scores

TTC Score	TTC Range (sec)	Sample Size (%)	Collision Propensity Level
0	4.00 < TTC	281 (27.99)	Low
1	2.50 < TTC ≤ 4.00	354 (35.26)	Moderate
2	1.50 < TTC ≤ 2.50	292 (29.08)	High
3	TTC ≤ 1.50	77 (7.67)	Extreme

The researchers selected 1.50 seconds as a critical TTC value due to the fact that it was an inflection point on the cumulative frequency distributions, as shown in Figures 7 and 8. Given approximately 10 percent of the data fell below this critical range, we selected the other TTC range values by attempting to split the data evenly with approximately 30 percent of the data in the other categories.

To make the ROC score more objective, a decision was made to assign a ROC score to each conflict based on its Max ΔV value. Equations based on Max ΔV for calculating the likelihood of injuries and fatalities occurring as the result of a collision were developed by Evans (*9*).

In our sample of 1,004 second-hour existing conditions model conflicts, the Max ΔV values ranged from 0 to 70 mph. Table 5 shows the Max ΔV cumulative frequency values in 5 mph increments and the probability of injury and fatality associated with each Max ΔV value assuming belted occupants.

Table 5. Selection of ROC score Max ΔV ranges

Max ΔV (mph)	Cumulative Frequency	Cumulative Percent	P(injury) Belted ≤ (*9*)	P(fatal) Belted ≤ (*9*)
≤ 5	294	29.28	0.0011	0.0000
≤ 10	622	61.95	0.0067	0.0001
≤ 15	778	77.49	0.0195	0.0009
≤ 20	884	88.05	0.0414	0.0034
≤ 25	939	93.53	0.0743	0.0095
≤ 30	964	96.02	0.1198	0.0220
≤ 35	984	98.01	0.1794	0.0444
≤ 40	992	98.80	0.2546	0.0818
≤ 45	998	99.40	0.3466	0.1401
≤ 50	999	99.50	0.4568	0.2268
≤ 55	1,002	99.80	0.5863	0.3505
≤ 60	1,002	99.80	0.7365	0.5217
≤ 65	1,003	99.90	0.9083	0.7521
≤ 70	1,004	100.00	1	1

The 85th percentile Max ΔV value was 18.0 mph; therefore, less than 15 percent of the conflicts had Max ΔV values above 20 mph, which is associated with relatively low probabilities of injuries and fatalities. Given this, the researchers selected critical values of Max ΔV based more upon the associated probabilities of injuries and fatalities rather than on the sample distribution. The researchers selected 20 and 40 mph as critical values of Max ΔV for assigning ROC scores as shown in Table 6.

Table 6. Assigned ROC (potential collision severity) scores based on Max ΔV

ROC Score	Max ΔV Range (mph)	P(injury)	P(fatal)	Sample Size (%)	Potential Collision Severity Level
1	MaxΔV < 20	< 0.0414	< 0.0034	884 (88.05)	Low ≈ PDO
2	20 ≤ MaxΔV ≤ 40	0.0414 to 0.2546	0.0034 to 0.0818	108 (10.76)	Moderate ≈ Injury
3	MaxΔV > 40	> 0.2546	> 0.0818	12 (1.19)	High ≈ Fatal

An initial overall conflict severity score was then assigned to each conflict as the sum of the TTC and the ROC scores. The overall severity scores ranged from 1 to 6 with a higher score indicating more serious conflicts. Overall severity scores of 1 and 2 represent potential conflicts on the pyramid of traffic events shown in Figure 4, 3 and 4 represent slight conflicts, and 5 and 6 represent serious conflicts. A graph of Max ΔV versus TTC for all 1,004 second-hour existing conditions model conflicts are shown in Figure 14 with each conflict classified by its initial overall severity score.

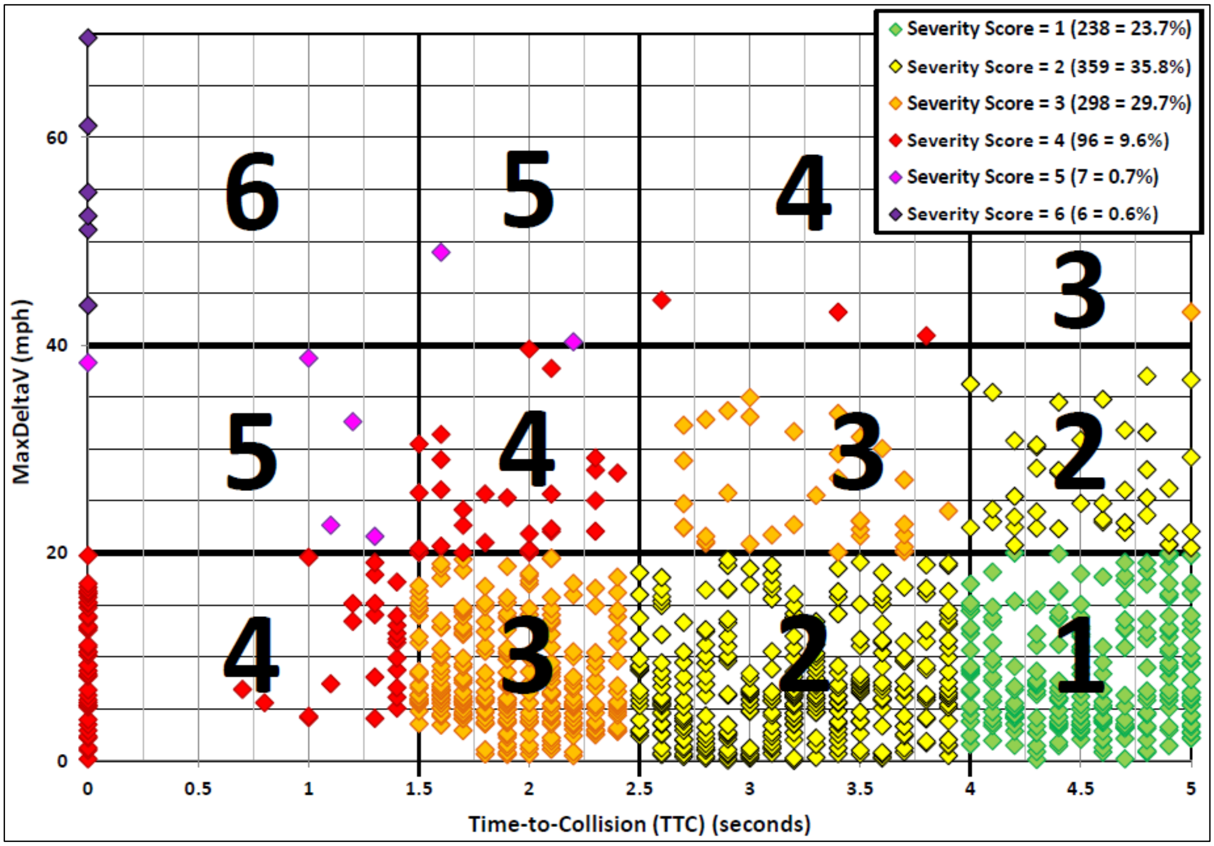

Figure 14. Max ΔV versus TTC plot by initial severity score for existing conditions

The severity score zones in Figure 14 are rather boxy looking and were smoothed out by creating five simple overall severity score contour lines shown in Figure 15.

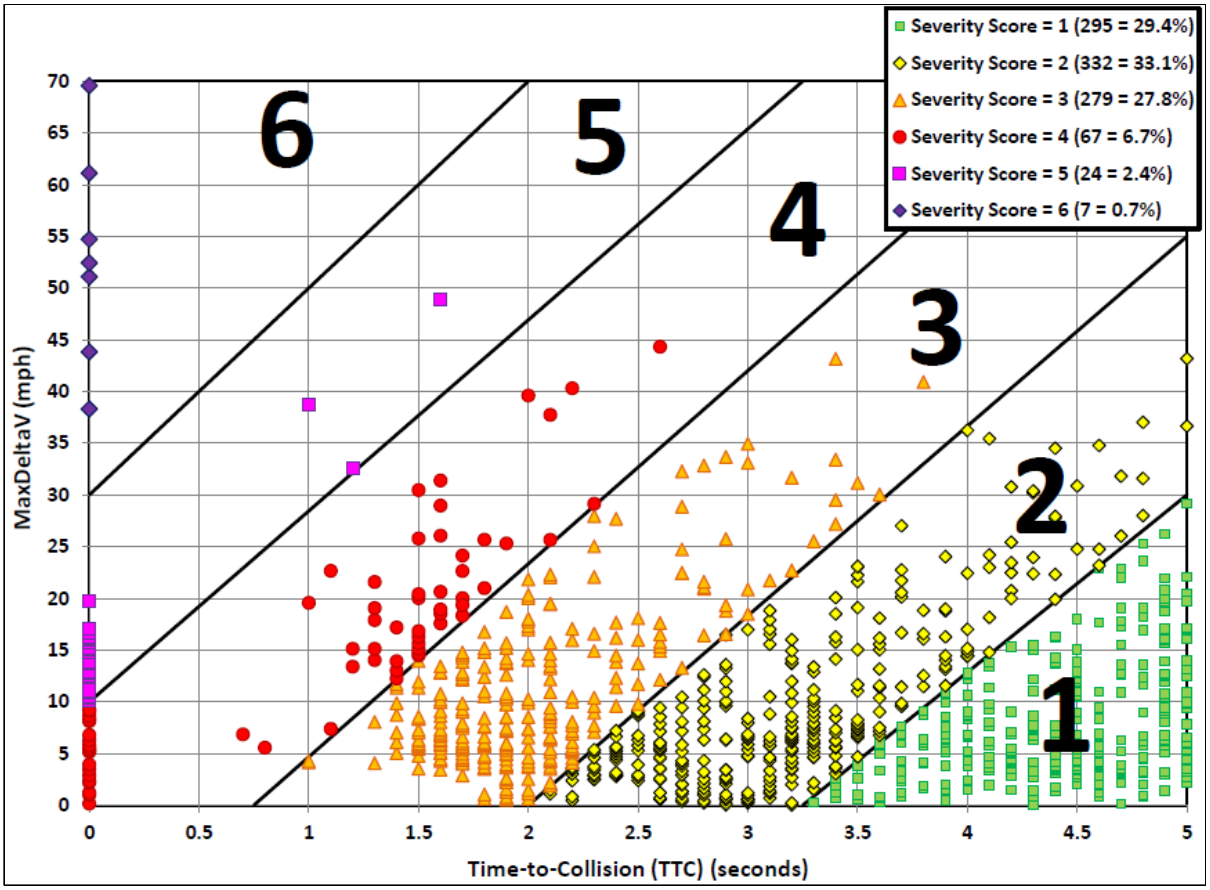

Figure 15. Max ΔV versus TTC versus modified severity score for existing conditions

The five contour line equations are given in Table 7 with Line #1 being the lower right-most contour line separating overall severity scores 1 and 2.

Table 7. Overall severity score contour line equations

Line Number	Equation (Max ΔV =)
1	(120/7)(*TTC*) – (390/7)
2	(55/3)(*TTC*) – (110/3)
3	(280/15)(*TTC*) – 14
4	(240/13)(*TTC*) + 10
5	20(*TTC*) + 30

The initial overall severity score was then modified. Each conflict was given an appropriate overall severity score based on the contour range in which it fell, as shown in Figure 15. The initial overall severity score changed for 199 of the 1,004 conflicts (19.8 percent). After the modifications, potential and serious conflicts increased by 3 and 2 percent, respectively, with a 5 percent decrease in slight conflicts as shown in Table 8.

Table 8. Changes from initial to modified overall severity score

Conflict Classification	Overall Severity Score	Initial Sample Size (%)		Modified Sample Size (%)	
Potential	1	238 (23.7%)	597 (59.5%)	295 (29.4%)	627 (62.5%)
	2	359 (35.8%)		332 (33.1%)	
Slight	3	298 (29.7%)	394 (39.2%)	279 (27.8%)	346 (34.5%)
	4	96 (9.6%)		67 (6.7%)	
Serious	5	7 (0.7%)	13 (1.3%)	24 (2.4%)	31 (3.1%)
	6	6 (0.6%)		7 (0.7%)	

As an exercise, all 1,004 second-hour existing conditions model conflicts were color-coded based on their modified overall severity scores and plotted on the approximated Hyden (*4*) uniform severity zone graph (Figure 5) shown here in Figure 16.

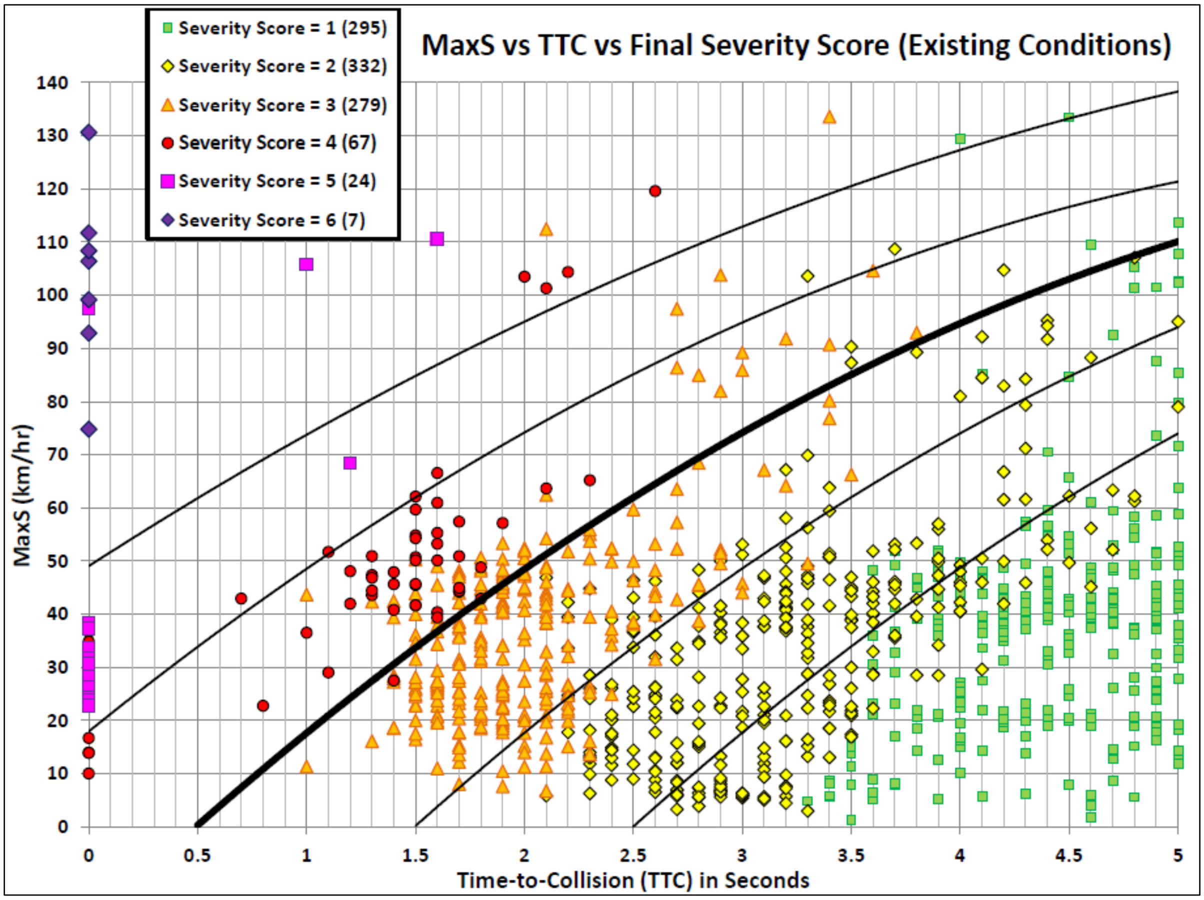

Figure 16. MaxS versus TTC by modified overall conflict severity scores

The modified overall severity scores seem to jive fairly well with Hyden's (*4*) uniform severity levels.

Conflict Angle Threshold Sensitivity Analysis

The conflict angle calculated by SSAM is "The approximate angle of the collision that would hypothetically occur between two conflicting vehicles based on the heading of each vehicle (*10*)."

The conflict angle ranges from -180 to +180 degrees with a negative angle indicating the second vehicle is approaching the first vehicle from the left and a positive angle indicating an approach from the right. An angle of ±180° indicates a direct head-on conflict and an angle of 0° indicates a direct rear-end conflict.

The conflict type describes whether a particular conflict is the result of rear-end, lane-change, or crossing vehicle movements. In SSAM, a combination of vehicle link/lane information and conflict angle are used to classify conflict type. When the conflict angle is used to determine conflict type, the conflict type is based on the absolute value of the conflict angle and user-defined conflict angle threshold boundaries. The ability to manually define these conflict angle thresholds was not possible until SSAM Version 2.1.4 was released in the spring of 2009 (*11*) and no prior research has indicated which threshold values would be the most ideal to use for a SSAM conflict analysis.

Default values for the rear-end and crossing angle thresholds are 30 and 80 degrees, respectively. This means if the absolute value of the conflict angle is less than or equal to 30 degrees, the conflict will be classified as a rear-end conflict, greater than 80 degrees, a crossing conflict, and as a lane-change, otherwise, as illustrated in the far right portion of Figure 17.

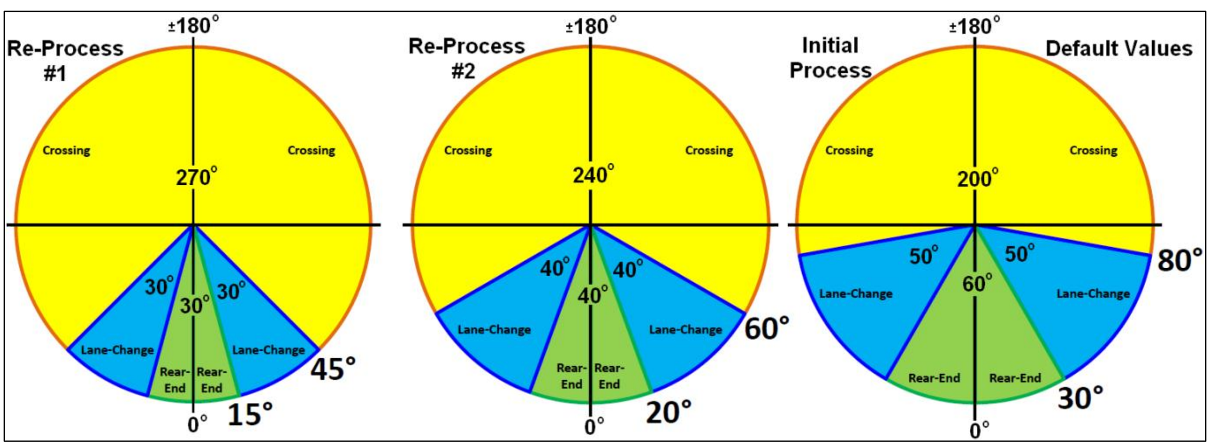

Figure 17. Conflict angle threshold sensitivity analysis trials

In 2008, Gettman et al. (*8*) found that SSAM (using the default conflict angle thresholds) recorded an inadequate number of crossing conflicts to perform a ranking comparison for crossing type incidents at urban signalized intersections and found significant differences between conflict type and actual crash type distributions as shown in Table 9.

Table 9. Comparison of conflict and crash type distributions (*8*)

	Incident Type			
	Rear-End	**Lane-Change**	**Crossing**	**All Types**
Average peak-hour conflicts	53.1	3.1	0.1	56.4
Percent conflicts by type	94.2%	5.6%	0.2%	100%
Average annual crashes	25.8	4.8	7.6	38.2
Percent crashes by type	67.5%	12.5%	19.9%	100%

As shown in Table 9, crossing and lane-change conflicts were under-represented, while rear-end conflicts were over-represented as compared to actual crash type distributions. Gettman et al. (*8*) recommended that, "This topic warrants further investigation into the appropriate angles or additional criteria/logic used for conflict type classification. It would also be useful to document the underlying value and motivation of classifying conflicts and perhaps more conflict types or subtypes (such as head-on) should be considered."

The 75 vehicle trajectory files from VisSim (25 .trj files for each intersection design alternative) were originally processed with SSAM using the default rear-end and crossing angle thresholds of 30 and 80 degrees. Figure 18 shows a frequency distribution of the absolute value of the conflict angle for the second-hour intersection conflicts of the existing conditions model.

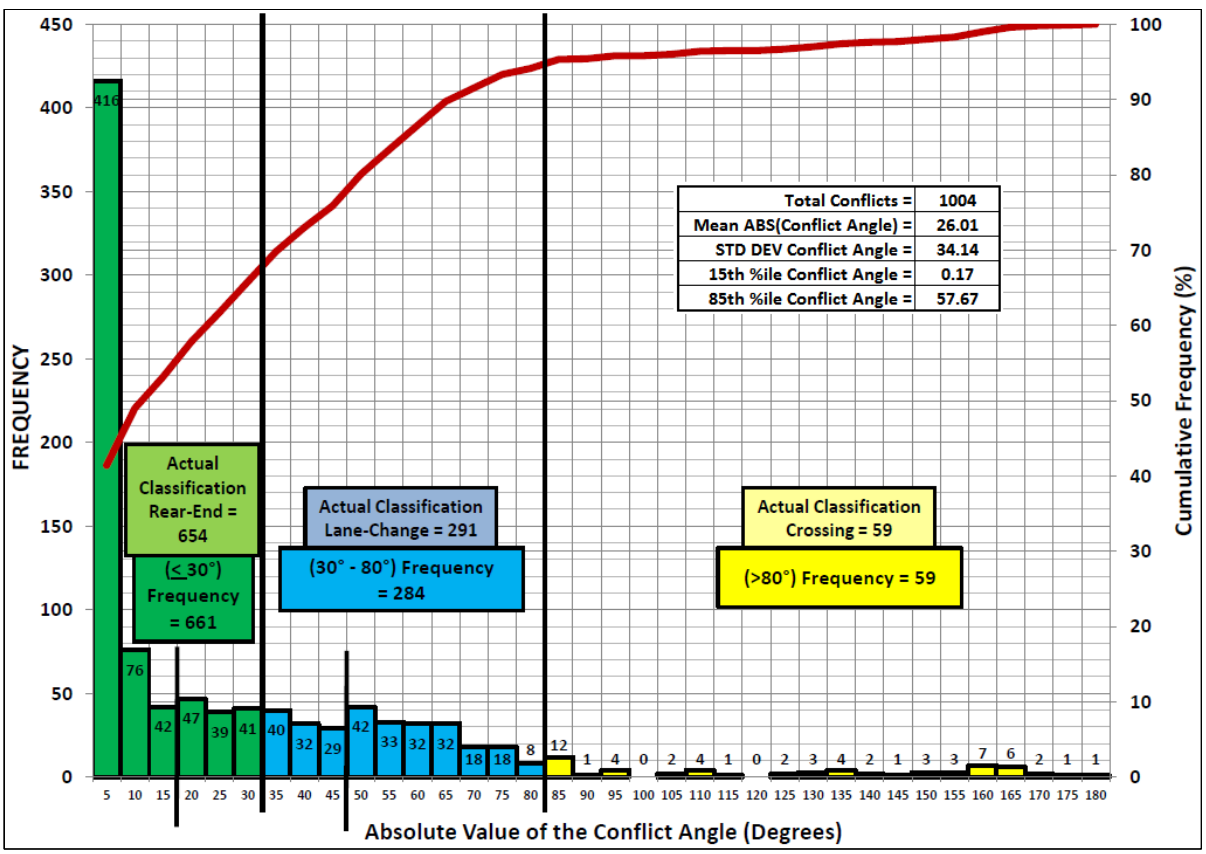

Figure 18. Conflict angle frequency distribution for existing conditions

The distribution shown in Figure 18 does not depend on the conflict angle threshold values, given the frequency of conflicts in each five-degree conflict angle increment will not change as the threshold values are changed. (Modifying the conflict angle threshold values only changes which columns/bars are summed to count the number of conflicts in each conflict type category.)

Using the default conflict angle threshold values, the frequency of conflicts by type shown in Figure 18 does not precisely match the actual classification of conflicts by type within SSAM because conflict type classification in SSAM is also based on vehicle link/lane information in some cases. These discrepancies will be discussed in more detail later in this report.

To conduct a sensitivity analysis on the conflict angle thresholds, the 25 vehicle trajectory files for the existing conditions model were re-processed twice in SSAM. First, they were re-processed using a rear-end angle threshold of 15 degrees and a crossing angle threshold of 45 degrees. Then, these threshold values were changed to 20 and 60 degrees, respectively, and the .trj files were re-processed once again.

All three of these conflict angle threshold scenarios are illustrated in Figure 17 and seem like realistic potential threshold value selections. The 15 and 45 degree threshold values were selected based on the frequency distribution given in Figure 18. In this distribution, there is a pattern in which the frequency values drop gradually, then suddenly rise back up. The 15 and 45 degree values were selected because these are two points where the frequency jumped back up (i.e., increased). The 20 and 60 degree threshold values were then selected as likely mid-points between the 15/45 degree values and the default values.

Table 10 shows the total frequency of conflicts (more than 25 simulation runs) for the existing conditions model classified as rear-end, lane-change, and crossing, under all three conflict angle threshold scenarios.

Table 10. Conflict angle threshold sensitivity analysis data for existing conditions

	5 Mile Network (2 hours)			US 18/US 218/T-44 Intersection (2 hours)			US 18/US 218/T-44 Intersection (2nd hour)		
Rear-End/ Crossing Thresholds	**15°/45°**	**20°/60°**	**30°/80°**	**15°/45°**	**20°/60°**	**30°/80°**	**15°/45°**	**20°/60°**	**30°/80°**
Rear-End	1,203 (47.7%)	1,315 (52.1%)	1,508 (59.8%)	959 (51.1%)	1,040 (55.5%)	1,189 (63.4%)	531 (52.9%)	578 (57.6%)	654 (65.1%)
Lane-Change	747 (29.6%)	832 (33.0%)	805 (31.9%)	469 (25.0%)	565 (30.1%)	564 (30.1%)	245 (24.4%)	291 (29.0%)	291 (29.0%)
Crossing	573 (22.7%)	376 (14.9%)	210 (8.3%)	447 (23.8%)	270 (14.4%)	122 (6.5%)	228 (22.7%)	135 (13.4%)	59 (5.9%)
Total Conflicts	**2,523**			**1,875**			**1,004**		

The data in Table 10 are examined separately for all conflicts within the entire five-mile network (50 simulated hours), all conflicts at the intersection of interest (50 simulated hours), and the analysis/second-hour conflicts at the intersection of interest (25 simulated hours).

For the analysis hour at the intersection of interest, the number of rear-end conflicts increased as the rear-end angle threshold increased. This relationship is illustrated by the rear-end conflict trend-line in Figure 19.

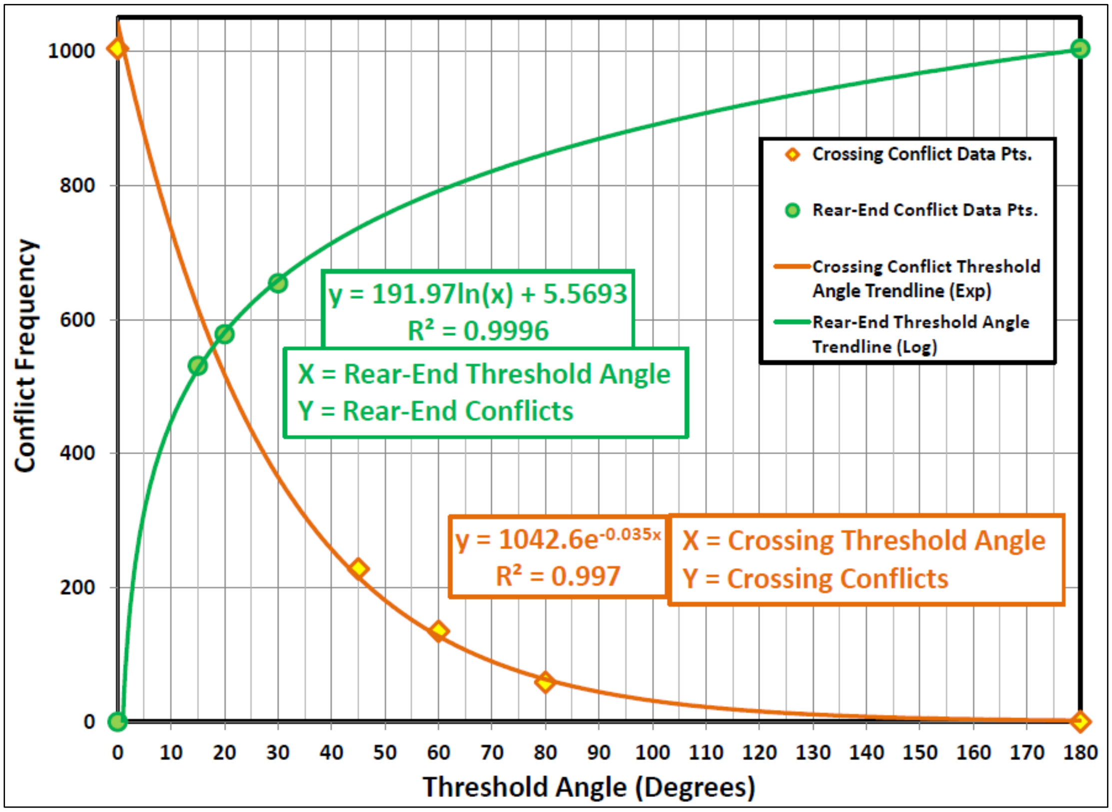

Figure 19. Conflict angle threshold sensitivity graph for analysis hour conflicts

As the crossing angle threshold increased, the number of crossing conflicts decreased as illustrated by the crossing conflict trend-line in Figure 19. The frequency of lane-change conflicts is equal to the total number of conflicts minus the total number of rear-end and crossing conflicts and would be a function of both the rear-end angle threshold and the crossing angle threshold values. However, as shown in Table 10, the frequency of lane-change conflicts remained relatively stable as the rear-end and crossing angle thresholds changed over the three scenarios, with the largest change in lane-change conflicts occurring between the 15/45 and the 20/60 scenarios.

As previously mentioned, SSAM uses a combination of vehicle link/lane information, conflict angle, and conflict angle threshold values to classify the conflict type of each conflict. As a result, the actual number of conflicts classified by type within SSAM and the frequency of conflicts within the three conflict type categories based on conflict angle and threshold values alone are very close, but not exactly the same. Table 11 shows the differences between the frequencies of rear-end, lane-change, and crossing conflicts as actually classified by SSAM versus the frequencies of those conflicts classified based only on conflict angle and threshold values.

Table 11. Differences in conflict classification for angle-based only versus SSAM

Conflict Type	15/45 Threshold	20/60 Threshold	30/80 Default Threshold
Rear-End	531 (534) [-3] [-14+7+4]	578 (581) [-3] [-14+7+4]	654 (661) [-7] [-14+7]
Lane-Change	245 (228) [+17] [+14-7-4+14]	291 (288) [+3] [+14-7-4]	291 (284) [+7] [+14-7]
Crossing	228 (242) [-14] [-14]	135 (135) [0]	59 (59) [0]
Total	**1,004**		

Note: The first value listed is the actual SSAM conflict type classification frequency. The value in parenthesis is the conflict type frequency based on conflict angle and thresholds only. The top row value in brackets is their difference. The second row values in brackets show how the difference was calculated from values given in Table 12.

As Table 11 shows, the 20 to 60 degree threshold values minimize the difference between the two classification schemes.

Table 12 lists 39 conflicts for which the type was classified differently by SSAM based on vehicle link/lane information versus how they would have been classified based on only their conflict angle under at least one conflict angle threshold scenario.

Table 12. Conflicts classified differently by type (angle-based only versus SSAM)

Number	Conflict Angle	Comment
1	0.29	Rear-end by angle in all threshold scenarios, but classified as lane-change based on vehicle link/lane information. (Represented by [-14] in Table 12 for all rear-end conflicts and [+14] for all lane-change conflicts.)
2	0.35	
3	0.46	
4	0.62	
5	1.04	
6	1.29	
7	1.48	
8	2.05	
9	2.16	
10	2.43	
11	2.44	
12	2.50	
13	2.72	
14	3.77	
15	20.75	Lane-change by angle in the 15/45 & 20/60 threshold scenarios, but classified as rear-end based on vehicle link/lane information. Rear-end by angle in the 30/80 threshold scenario. (Represented by [+4] in Table 12 for rear-end conflicts and [-4] for lane-change conflicts under the 15/45 and 20/60 threshold scenarios)
16	22.59	
17	27.56	
18	29.92	
19	30.08	Lane-change by angle in all threshold scenarios, but classified as rear-end based on vehicle link/lane information. (Represented by [+7] in Table 12 for all rear-end conflicts and [-7] for all lane-change conflicts.)
20	31.68	
21	32.46	
22	34.21	
23	35.51	
24	37.07	
25	43.81	
26	45.31	Crossing by angle in the 15/45 threshold scenario, but classified as lane-change based on vehicle link/lane information. Lane-change by angle in the 20/60 & 30/80 threshold scenarios. (Represented by [-14] in Table 12 for crossing conflicts and [+14] for lane-change conflicts under the 15/45 threshold scenario.)
27	45.84	
28	45.97	
29	46.87	
30	49.108	
31	49.109	
32	49.51	
33	49.70	
34	51.71	
35	53.97	
35	54.81	
37	55.50	
38	57.48	
39	57.64	

There were 14 conflicts (1 through 14 in Table 12) that would have been classified as rear-end based on their conflict angles and thresholds, but were actually classified as lane-change conflicts by SSAM. Each of these 14 conflicts had conflict angles less than four degrees.

There were another 11 conflicts (15 through 25 in Table 12) that would have been classified as lane-change based on their conflict angles under certain threshold scenarios, but were actually classified as rear-end conflicts by SSAM. These 11 conflicts had conflict angles ranging between 21 and 44 degrees.

Finally, there were 14 other conflicts (26 through 39 in Table 12) that would have been classified as crossing based on their conflict angles under the 15/45 threshold scenario, but were actually classified as lane-change conflicts by SSAM. These 14 conflicts had conflict angles ranging between 45 and 58 degrees.

Table 12 demonstrates that rear-end conflicts can range from 0 to at least 44 degrees and lane-change conflicts can range from 0 to at least 58 degrees. Realistically speaking, the crossing angle threshold value should be set somewhere between 45 and 85 degrees and should not be set much higher than the 80 degree default value.

Gettman et al. found that the default 80 degree value recorded an inadequate number of crossing conflicts to perform a ranking comparison for crossing type incidents and found that crossing conflicts were extremely under-represented as compared to actual crossing crash type distributions at signalized urban intersections (*8*). Lowering the crossing angle threshold value from the 80 degree default value to 45 degrees increased the frequency of conflicts classified as crossing and increased the overall percentage of crossing conflicts from 6 to 23 percent (see Table 10 and Figure 19).

Therefore, lowering the crossing angle threshold value from 80 degrees would hopefully generate a large enough sample size of each conflict type to conduct an adequate conflict type comparison analysis.

Based on the conflict angles in Table 12, 58 degrees appears to be near the upper limit for conflicts to be classified as lane-change based on vehicle link/lane information. In addition, the 85th percentile conflict angle was also 58 degrees. Therefore, 60 degrees would seem to be a better selection for the crossing-angle threshold value.

The rear-end angle threshold value should realistically be set somewhere between 5 and 45 degrees and shouldn't be set much higher than the 30 degree default value, given Gettman et al. (*8*) found that rear-end conflicts were extremely over-represented as compared to actual rear-end crash type distributions when using the 30 degree default value.

Lowering the rear-end angle threshold value from the 30 degree default value to 15 degrees decreased the frequency of conflicts classified as rear-end and decreased the overall percentage of rear-end conflicts from 65 to 53 percent (see Table 10 and Figure 19).

As Table 11 showed, the 20 degree rear-end angle threshold value helped minimize the difference between the frequency of conflicts actually classified by SSAM versus the frequency of conflicts classified based only on conflict angle and the threshold values. The reason for this is the 20 degree rear-end conflict threshold allowed the 14 conflicts (1 through 14 in Table 12) with small angles (0 to 4 degrees) classified by SSAM as lane-change, based on vehicle link/lane information, to be balanced out by the 11 conflicts (15 through 25 in Table 12) with angles ranging from 21 to 44 degrees classified by SSAM as rear-end, based on vehicle link/lane information. Therefore, 20 degrees would seem to be a better selection for the rear-end angle threshold value.

The center of Figure 17 illustrates the recommended 20 to 60 degree threshold values. The 20 to 60 threshold scenario results in 578 rear-end (57.6 percent), 291 lane-change (29.0 percent), and 135 crossing (13.4 percent) conflicts for the analysis/second-hour of the existing conditions model (25 simulation hours).

If actual crash data is available or a field conflict analysis has been performed at the existing intersection, those crash type or conflict type data could be used to help select the most appropriate conflict angle thresholds to adjust the conflict type distributions to match closely with the field data.

Conflict Location Mapping

SSAM has the capability of mapping the location of conflicts to help users visualize where conflicts are occurring. Users can specify which conflicts are displayed and change how different conflicts appear on the map. To specify which conflicts are displayed, users may filter conflicts within SSAM by simultaneously specifying a value range for up to seven different surrogate safety measures including TTC, PET, and Max ΔV. The user can then map any conflicts falling within the desired range(s). Conflicts can also be filtered and mapped by conflict type (rear-end, lane-change, or crossing).

When mapping conflicts, conflicts can be visualized with respect to conflict type and TTC. The user has the ability to choose the icon shape (circle, triangle, rectangle, diamond, etc.) and color to represent different conflict types (rear-end, lane-change, and crossing). The SSAM user may also color code conflict icons based on four preset levels of TTC ($TTC = 0$, $0 < TTC \leq 0.5$, $0.5 < TTC \leq 1.0$, and $1.0 < TTC \leq 1.5$).

For example, let's say you want to map the location of all intersection conflicts with an overall initial severity score of 6 (the most severe conflicts). This could be accomplished by filtering conflicts by intersection area using x-y coordinates, for $TTC \leq 1.50$ seconds, and for Max $\Delta V >$ 40 mph (17.882 m/s). This was done for both the existing conditions model and the offset left turn lane model with the maps for both shown in Figure 20.

Figure 20. Conflict map comparison for two intersection design alternatives

Unfortunately, the SSAM user cannot filter out conflicts by time, so the conflicts shown in Figure 20 are for all 25 simulation runs and all simulated hours (50 hours total), including the VisSim warm-up time.

In Figure 20, different conflict icon shapes represent different conflict types and each are color coded by TTC with red representing TTC ≤ 0.5 seconds and yellow representing a TTC between 0.5 and 1.0 second. In this way, the user can compare the location, type, frequency, and severity of conflicts visually between intersection design alternatives.

Figure 20 shows a majority of the conflicts occur in the northwest-bound expressway lanes. The offset left turn lane alternative seems to have helped address this issue somewhat and has also reduced conflicts occurring in the median.

Figure 21 shows a second example of a conflict map produced by SSAM for the existing conditions model illustrating the locations of all intersection conflicts (50 hours total) with a Max $\Delta V > 40$ mph.

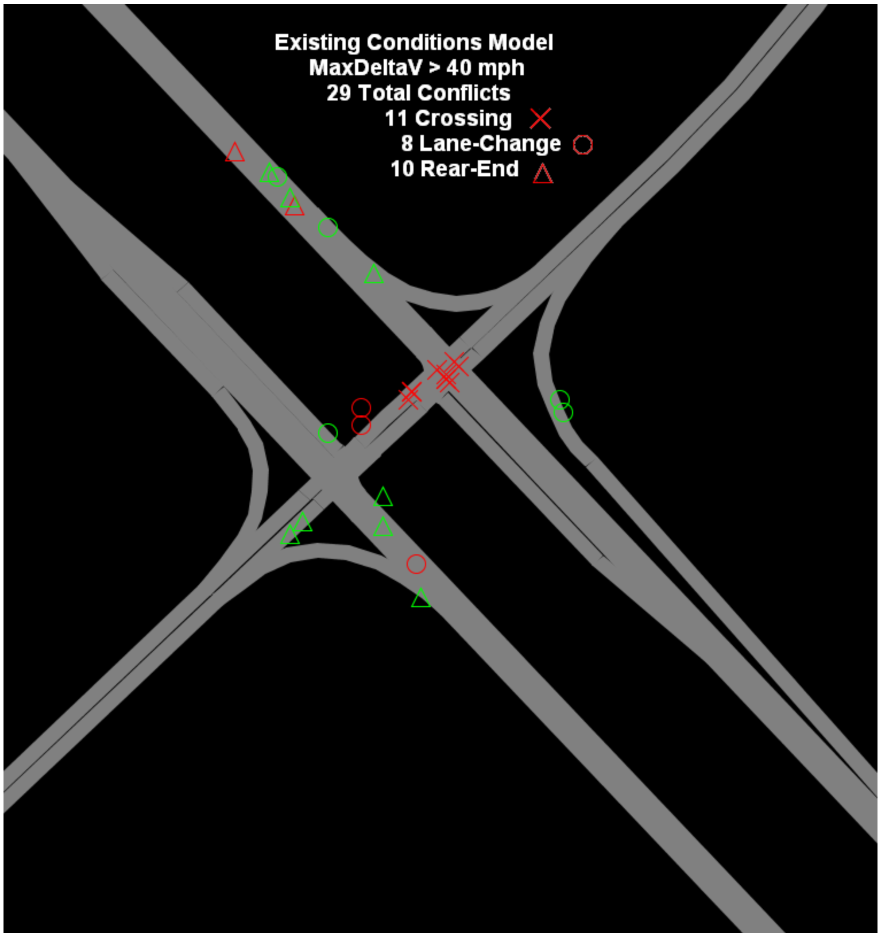

Figure 21. Conflict mapping by collision propensity

Again, the shape of the conflict icons represents different conflict types and the color-coding represents different levels of TTC. In this example, there were 29 conflicts with a Max ΔV > 40 mph, 16 with TTC ≤ 0.5 seconds, shown in red (the same 16 conflicts shown in Figure 20), and 13 with TTC > 1.5 seconds, shown in green. While all of the conflicts shown have relatively similar levels of potential collision severity based on their Max ΔV values, this map distinguishes the conflicts with regard to collision propensity.

The SSAM user can also obtain more detailed information for each individual conflict point shown on the map by clicking on the particular conflict of interest. Figure 22 shows an example in which three conflicts (one of each type) have been selected.

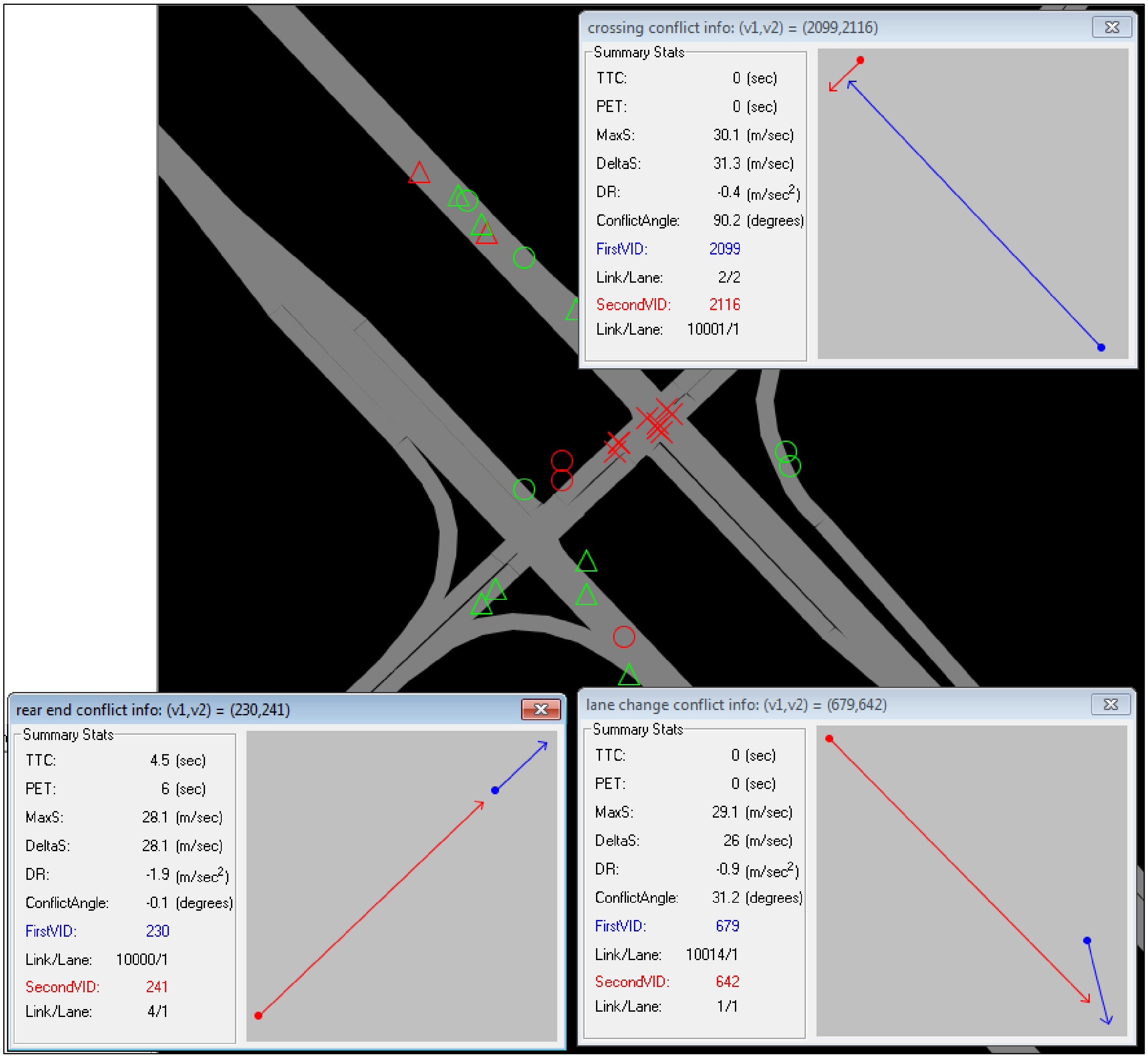

Figure 22. Displaying conflict lines and information

Surrogate safety measures and conflict lines corresponding to the selected conflicts are displayed. The blue and red conflict lines represent trajectories of the first and second vehicles, respectively. In the case of crossing conflicts, these conflict lines allow the user to determine if the conflict was a far-side or a near-side conflict. Viewing these conflict lines can also be a possible method of verifying the conflict type classification.

COMPARISON OF INTERSECTION DESIGN ALTERNATIVES

After running the SSAM analysis for each intersection design alternative and determining a severity score for each conflict, comparisons can be made between alternatives based on the overall frequency of conflicts, conflicts by type, and conflicts by severity. In addition, conflict modification factors (CfMFs) can be developed for those geometric design elements that were modified between design alternatives.

An intersection conflict index (ICI) can also be established for each intersection design alternative to facilitate more accurate safety comparison and better decision-making regarding alternative selection.

In this study, we examined each of these conflict comparison methods by comparing the existing conditions model conflicts with the offset left turn lane model conflicts at US 18/US 218/T-44.

Conflict Frequency Comparison

The 25 vehicle trajectory (.trj) files from VisSim for each intersection design alternative (one file for each 2 hour simulation run) were uploaded to SSAM and processed using a maximum TTC threshold of 5.00 seconds and a maximum PET threshold of 9.95 seconds to identify potential conflicts.

The rear-end and crossing conflict angle threshold values of 20 and 60 degrees were used to classify conflicts as rear-end, lane-change, or crossing. Next, the conflicts for both the existing conditions model and the offset left turn lane model were filtered by location and time. Only those conflicts occurring near the intersection of interest and after the simulation's initialization period (during the second simulation hour) were included in the conflict analysis. Finally, each identified conflict was assigned an overall severity score based on its TTC and Max ΔV values, in order to rate each conflict as potential, slight, or serious.

Conflict frequency data for total conflicts, conflicts by type, and conflicts by severity are given in Table 13 for each run of the existing conditions model.

Table 13. Existing conditions model conflict data for US 18/US 218/T-44

	Conflict Type (20°/60° Thresholds)				Conflict Severity		
Random Seed	**Total Conflicts**	**Crossing**	**Rear-End**	**Lane-Change**	**Potential (1-2)**	**Slight (3-4)**	**Serious (5-6)**
301	59	10	32	17	33	22	4
302	30	3	14	13	20	10	0
303	34	2	27	5	21	13	0
304	36	9	12	15	25	9	2
305	30	2	20	8	18	11	1
306	54	9	37	8	32	21	1
307	38	6	24	8	22	14	2
308	44	6	26	12	27	16	1
309	37	7	19	11	25	12	0
310	33	3	23	7	20	12	1
311	28	8	12	8	18	9	1
312	31	6	19	6	20	9	2
313	57	8	35	14	38	19	0
314	34	2	17	15	23	10	1
315	34	5	17	12	18	15	1
316	33	6	21	6	18	13	2
317	39	4	27	8	20	15	4
318	30	3	18	9	18	12	0
319	46	6	22	18	27	17	2
321	50	3	31	16	30	19	1
322	63	13	27	23	42	18	3
323	31	3	20	8	19	11	1
324	48	3	25	20	37	11	0
325	45	4	32	9	28	16	1
326	40	4	21	15	28	12	0
Total =	**1,004**	**135**	**578**	**291**	**627**	**346**	**31**
Average =	**40.16**	**5.40**	**23.12**	**11.64**	**25.08**	**13.84**	**1.24**
Std. Dev. =	**10.12**	**2.87**	**6.79**	**4.79**	**7.00**	**3.82**	**1.16**
Var. =	**102.39**	**8.25**	**46.11**	**22.99**	**48.99**	**14.56**	**1.36**
Min =	**28**	**2**	**12**	**5**	**18**	**9**	**0**
Max =	**63**	**13**	**37**	**23**	**42**	**22**	**4**

Conflict frequency data for the offset left turn lane model are given in Table 14.

Table 14. Offset left turn lane model conflict data for US 18/US 218/T-44

	Conflict Type (20°/60° Thresholds)				Conflict Severity		
Random Seed	**Total Conflicts**	**Crossing**	**Rear-End**	**Lane-Change**	**Potential (1-2)**	**Slight (3-4)**	**Serious (5-6)**
301	52	6	34	12	32	19	1
302	21	4	11	6	12	9	0
303	36	2	29	5	21	15	0
304	36	4	21	11	26	10	0
305	35	1	24	10	21	13	1
306	54	7	32	15	26	28	0
307	42	2	25	15	23	18	1
308	45	6	24	15	27	18	0
309	39	6	21	12	24	15	0
310	27	1	18	8	14	13	0
311	26	4	11	11	17	8	1
312	39	8	17	14	23	16	0
313	51	7	28	16	37	14	0
314	29	1	15	13	19	10	0
315	32	2	19	11	15	16	1
316	30	3	21	6	16	14	0
317	31	4	18	9	16	15	0
318	33	3	21	9	21	12	0
319	47	3	25	19	24	23	0
321	44	5	29	10	24	19	1
322	43	4	19	20	26	17	0
323	37	2	22	13	25	11	1
324	44	5	21	18	30	14	0
325	39	2	25	12	24	15	0
326	35	5	21	9	20	14	1
Total =	**947**	**97**	**551**	**299**	**563**	**376**	**8**
Average =	**37.88**	**3.88**	**22.04**	**11.96**	**22.52**	**15.04**	**0.32**
Std. Dev. =	**8.42**	**2.03**	**5.72**	**3.94**	**5.80**	**4.38**	**0.48**
Var. =	**70.94**	**4.11**	**32.71**	**15.54**	**33.68**	**19.21**	**0.23**
Min =	**21**	**1**	**11**	**5**	**12**	**8**	**0**
Max =	**54**	**8**	**34**	**20**	**37**	**28**	**1**

Raw differences and percent changes in conflicts between the two models are given in Tables 15 and 16, respectively.

Table 15. Conflict frequency differences for existing conditions versus offset left turn

	Conflict Type (20°/60° Thresholds)				Conflict Severity		
Random Seed	**Total Conflicts**	**Crossing**	**Rear-End**	**Lane-Change**	**Potential (1-2)**	**Slight (3-4)**	**Serious (5-6)**
301	-7	-4	2	-5	-1	-3	-3
302	-9	1	-3	-7	-8	-1	0
303	2	0	2	0	0	2	0
304	0	-5	9	-4	1	1	-2
305	5	-1	4	2	3	2	0
306	0	-2	-5	7	-6	7	-1
307	4	-4	1	7	1	4	-1
308	1	0	-2	3	0	2	-1
309	2	-1	2	1	-1	3	0
310	-6	-2	-5	1	-6	1	-1
311	-2	-4	-1	3	-1	-1	0
312	8	2	-2	8	3	7	-2
313	-6	-1	-7	2	-1	-5	0
314	-5	-1	-2	-2	-4	0	-1
315	-2	-3	2	-1	-3	1	0
316	-3	-3	0	0	-2	1	-2
317	-8	0	-9	1	-4	0	-4
318	3	0	3	0	3	0	0
319	1	-3	3	1	-3	6	-2
321	-6	2	-2	-6	-6	0	0
322	-20	-9	-8	-3	-16	-1	-3
323	6	-1	2	5	6	0	0
324	-4	2	-4	-2	-7	3	0
325	-6	-2	-7	3	-4	-1	-1
326	-5	1	0	-6	-8	2	1
Total =	**-57**	**-38**	**-27**	**8**	**-64**	**30**	**-23**
Average =	**-2.28**	**-1.52**	**-1.08**	**0.32**	**-2.56**	**1.20**	**-0.92**
Std. Dev. =	**5.95**	**2.54**	**4.29**	**4.10**	**4.64**	**2.81**	**1.22**
Var. =	**35.46**	**6.43**	**18.41**	**16.81**	**21.51**	**7.92**	**1.49**
Min =	**-20**	**-9**	**-9**	**-7**	**-16**	**-5**	**-4**
Max =	**8**	**2**	**9**	**8**	**6**	**7**	**1**
t* =	**-1.91**	**-3.00**	**-1.26**	**0.39**	**-2.76**	**2.13**	**-3.76**
Sig. @90%?	**Yes**	**Yes**	**No**	**No**	**Yes**	**Yes**	**Yes**
Sig. @95%?	**No**	**Yes**	**No**	**No**	**Yes**	**Yes**	**Yes**

Note: The table value is the raw difference in conflicts between alternatives [offset left-turn model conflicts minus existing conditions model conflicts]. t* is the test statistic for paired observations. t-critical for a two-tailed test = 1.711 and 2.064 for a 90% and 95% level of confidence, respectively.

Table 16. Conflict frequency percent change for existing conditions versus offset left turn

Random Seed	Conflict Type (20°/60° Thresholds) Total Conflicts	Crossing	Rear-End	Lane-Change	Conflict Severity Potential (1-2)	Slight (3-4)	Serious (5-6)
301	-11.86	-40.00	6.25	-29.41	-3.03	-13.64	-75.00
302	-30.00	33.33	-21.43	-53.85	-40.00	-10.00	(DIV/0)
303	5.88	0.00	7.41	0.00	0.00	15.38	(DIV/0)
304	0.00	-55.56	75.00	-26.67	4.00	11.11	-100.00
305	16.67	-50.00	20.00	25.00	16.67	18.18	0.00
306	0.00	-22.22	-13.51	87.50	-18.75	33.33	-100.00
307	10.53	-66.67	4.17	87.50	4.55	28.57	-50.00
308	2.27	0.00	-7.69	25.00	0.00	12.50	-100.00
309	5.41	-14.29	10.53	9.09	-4.00	25.00	(DIV/0)
310	-18.18	-66.67	-21.74	14.29	-30.00	8.33	-100.00
311	-7.14	-50.00	-8.33	37.50	-5.56	-11.11	0.00
312	25.81	33.33	-10.53	133.33	15.00	77.78	-100.00
313	-10.53	-12.50	-20.00	14.29	-2.63	-26.32	(DIV/0)
314	-14.71	-50.00	-11.76	-13.33	-17.39	0.00	-100.00
315	-5.88	-60.00	11.76	-8.33	-16.67	6.67	0.00
316	-9.09	-50.00	0.00	0.00	-11.11	7.69	-100.00
317	-20.51	0.00	-33.33	12.50	-20.00	0.00	-100.00
318	10.00	0.00	16.67	0.00	16.67	0.00	(DIV/0)
319	2.17	-50.00	13.64	5.56	-11.11	35.29	-100.00
321	-12.00	66.67	-6.45	-37.50	-20.00	0.00	0.00
322	-31.75	-69.23	-29.63	-13.04	-38.10	-5.56	-100.00
323	19.35	-33.33	10.00	62.50	31.58	0.00	0.00
324	-8.33	66.67	-16.00	-10.00	-18.92	27.27	(DIV/0)
325	-13.33	-50.00	-21.88	33.33	-14.29	-6.25	-100.00
326	-12.50	25.00	0.00	-40.00	-28.57	16.67	(DIV/0)
Total =	**-5.68**	**-28.15**	**-4.67**	**2.75**	**-10.21**	**8.67**	**-74.19**
Average =	**-4.31**	**-20.62**	**-1.87**	**12.61**	**-8.47**	**10.04**	
Std. Dev. =	**14.41**	**40.85**	**21.91**	**43.52**	**17.55**	**20.96**	
Var. =	**207.56**	**1668.40**	**479.95**	**1894.40**	**308.07**	**439.27**	
Min =	**-31.75**	**-69.23**	**-33.33**	**-53.85**	**-40.00**	**-26.32**	
Max =	**25.81**	**66.67**	**75.00**	**133.33**	**31.58**	**77.78**	

Note: The table value is the percent difference/change in conflicts between alternatives [(offset left-turn model conflicts minus existing conditions model conflicts)/(exiting conditions model conflicts)]. The highlighted (DIV/0) percentages could not be computed as the existing conditions model had zero conflicts.

As Table 15 shows, using a matched pairs experimental design with 95 percent level of confidence, the offset left turn lanes significantly reduced crossing, potential, and serious conflicts while significantly increasing slight conflicts. Total and rear-end conflicts were reduced while lane-change conflicts increased; however, these changes were not statistically significant.

As Table 16 shows, on average per simulation run, crossing conflicts were reduced by 21 percent, potential conflicts by 8 percent, total conflicts by 4 percent, and rear-end conflicts by 2 percent. An average percent reduction in serious conflicts per simulation run could not be computed; however, there was a 75 percent reduction in serious conflicts overall. On the other hand, lane-change conflicts increased by 13 percent and slight conflicts increased by 10 percent.

Overall, the total conflict sample size was large enough to perform an adequate conflict analysis. The 60 degree crossing conflict angle threshold produced at least one crossing conflict for each simulation run of the existing conditions model (see Table 13), which allowed percent changes in crossing conflicts to be computed for each simulation run (see Table 16). However, there were no serious conflicts for seven simulation runs of the existing conditions model (see Table 13), which did not allow percent changes in serious conflicts to be computed for those simulation runs (see Table 16) or overall descriptive statistics to be computed for percent change in serious conflicts per simulation run.

SSAM enables statistical comparison of conflict frequencies and surrogate safety measure values for two alternative cases using the Student t-distribution for hypothesis testing. This capability of SSAM was used to statistically compare the existing conditions model conflicts with the offset left turn lane model conflicts using a 95 percent level of confidence. However, SSAM is unable to filter conflicts by simulation time, so the comparison includes all conflicts occurring near the intersection of interest during the entire two-hour simulation. The results of the SSAM statistical comparison are shown in Table 17.

Table 17. SSAM statistical conflict analysis results for 95% confidence level

	Existing Conditions Model			Offset Left Turn Model			Statistical Analysis			
SSAM Measures	Mean	Variance	Samples	Mean	Variance	Samples	t-value	t-critical	SIG ?	Mean Difference
TTC (sec)	2.98	1.70	1875	2.99	1.52	1806	-0.24	1.66	No	-0.01
PET (sec)	3.20	3.68	1875	3.24	3.23	1806	-0.62	1.66	No	-0.038
MaxS (m/s)	10.46	37.80	1875	11.49	34.60	1806	-5.17	1.66	Yes	-1.025
DeltaS (m/s)	7.22	30.62	1875	7.92	32.24	1806	-3.82	1.66	Yes	-0.706
DR (m/s^2)	-1.09	1.45	1875	-1.16	1.43	1806	1.69	1.66	Yes	0.067
MaxD (m/s^2)	-2.47	1.06	1875	-2.55	1.02	1806	2.44	1.66	Yes	0.082
Max ΔV (m/s)	4.70	16.44	1875	5.15	16.79	1806	-3.33	1.66	Yes	-0.447
Total Conflicts	75.00	98.42	25	72.24	117.02	25	0.94	1.68	No	2.76
Crossing	10.80	13.50	25	8.32	8.89	25	2.62	1.68	Yes	2.48
Rear-End	41.60	81.75	25	41.56	67.01	25	0.02	1.68	No	0.04
Lane-Change	22.60	29.25	25	22.36	25.24	25	0.16	1.68	No	0.24

According to this analysis, the offset left turn lanes reduced total conflicts and all conflict types, but only the reduction in crossing conflicts was statistically significant. However, the analysis of surrogate safety measures indicates that the offset left turn lane model conflicts tend to be more severe with statistically-significant increases in Max ΔV (the maximum change in velocity of either vehicle assuming a hypothetical collision of the two conflicting vehicles), MaxS (the maximum speed of either vehicle throughout the conflict event), DeltaS (the magnitude of the difference between conflicting vehicle velocities observed at the instant minimum TTC occurs), DR (the initial deceleration rate of the second (trailing) vehicle as it initiates an evasive braking maneuver), and MaxD (the maximum deceleration rate of the second (trailing) vehicle during the conflict event).

Conflict Modification Factors (CfMFs)

The Highway Safety Manual (HSM) (*12*) defines a crash modification factor (CMF) as "An index of how much crash experience is expected to change following a specific modification in design or traffic control, while all other conditions and site characteristics remain constant." The CMF Clearinghouse (*13*) defines a CMF as "A multiplicative factor used to compute the expected number of crashes after implementing a given treatment."

All CMF values are estimates of the expected change in average crash frequency due to a change in one specific condition. A CMF less than 1.0 indicates safety is expected to improve, while a CMF greater than 1.0 indicates an expected decrease in safety. CMFs play a key role in predictive safety analysis and the alternative selection process as alternative designs and countermeasures can be evaluated economically and ranked based on their anticipated cost and safety impacts.

For example, a given intersection is experiencing 15 angle crashes and 20 rear-end crashes per year. If a countermeasure with a CMF of 0.80 for angle crashes is applied, 12 angle crashes per year ($15 \times 0.80 = 12$) would be expected following implementation of the countermeasure. If the same countermeasure has a CMF of 1.10 for rear-end crashes, 22 rear-end crashes per year ($20 \times 1.10 = 22$) would be expected following implementation.

Table 18 summarizes the various methods available for developing CMFs and describes the strengths and weaknesses of each method.

Table 18. Summary of study designs for developing CMFs (*14*)

Study Design	General Applicability	Strengths	Weaknesses
Before-After with Comparison Group	Treatment is sufficiently similar among treatment sites Before and after data are available for both treated and untreated sites Untreated sites are used to account for non-treatment related crash trends	Simple Accounts for non-treatment related time trends and changes in traffic volume	Difficult to account for regression-to-the-mean
Before-After with Empirical Bayes	Treatment is sufficiently similar among treatment sites Before and after data are available for both treated sites and an untreated reference group A separate comparison group may be required where the treatment has an effect on the reference group	Employs SPFs to account for: Regression-to-the-mean Traffic volume changes over time Non-treatment related time trends	Relatively complex Cannot include prior knowledge of treatment Cannot consider spatial correlation Cannot specify complex model forms
Full Bayes	Useful for before-after or cross-section studies when: Complex model forms are required There is a need to consider spatial correlation among sites Previous model estimates or CMF estimates are to be introduced in the modeling	Reliable results with small sample sizes Can include prior knowledge, spatial correlation, and complex model forms in the evaluation process	Implementation requires a high degree of training
Cross-Sectional	Useful when limited before-after data are available Requires sufficient sites that are similar except for the treatment of interest	Possible to develop CMF functions Allows estimation of CMFs when conversions are rare Useful for predicting crashes	CMFs may be inaccurate for a number of reasons including: Inappropriate functional form Omitted variable bias Correlation among variables
Case-Control	Assess whether exposure to a potential treatment is disproportionately distributed between sites with and without the target crash Indicates the likelihood of an actual treatment through the odds ratio	Useful for studying rare events because the number of cases and controls is predetermined Can investigate multiple treatments per sample	Can only investigate one outcome per sample Does not differentiate between locations with one crash or multiple crashes Cannot demonstrate causality

Cohort	Used to estimate relative risk, which indicates the expected percent change in the probability of an outcome given a unit change in the treatment	Useful for studying rare treatments because the sample is selected based on treatment status Can demonstrate causality	Only analyzes the time to the first crash Large samples are often required
Meta-Analysis	Combines knowledge on CMFs from multiple previous studies while considering the study quality in a systematic and quantitative way	Can be used to develop CMFs when data are not available for recent installations and it is not feasible to install the strategy and collect data Can combine knowledge from several jurisdictions and studies	Requires the identification of previous studies for a particular strategy Requires a formal statistical process All studies included should be similar in terms of data used, outcome measure, and study methodology
Expert Panel	Expert panels are assembled to critically evaluate the findings of published and unpublished research A CMF recommendation is made based on agreement among panel members	Can be used to develop CMFs when data are not available for recent installations and it is not feasible to install the strategy and collect data Can combine knowledge from several jurisdictions and studies Does not require a formal statistical process	Traditional expert panels do not systematically derive precision estimates of a CMF Possible complications may arise from interactions and group dynamics Possible forecasting bias
Surrogate Measures	Surrogate measures may be used to derive a CMF where crash data are not available or insufficient (e.g., there is limited after period data or the treatment is rarely implemented)	Can be used to develop CMFs in the absence of crash-based data	Not a crash-based evaluation The approach to establish relationships between surrogates and crashes is relatively undeveloped

The most appropriate method depends on a number of factors including the type and availability of data. CMFs are developed typically through before-after effectiveness evaluations in which the frequency and/or severity of police-reported collisions at a location are compared during periods before and after implementation of a particular treatment. However, the collection of crash data for a safety analysis requires real world “experimentation” at a large number of study sites and lengthy evaluation/observation periods due to the random and sparse nature of crashes.

As a result, traffic conflicts have been used as a traffic safety surrogate (a quantifiable observation that can be used to replace or supplement crash records) for a less time-consuming measure to assess the safety effectiveness of a countermeasure. As highlighted in Table 18, surrogate measures (such as traffic conflicts) may be used to derive CMFs in the absence of crash-based data; however, the key to the application of this approach is the establishment of a relationship between surrogates and crashes.

Using VisSim in combination with SSAM is one potential method of developing CMFs from surrogate measures that has not been fully explored yet. VisSim can model designs that are rarely implemented or have yet to be applied in the field, or allow specific roadway geometrics to be changed quickly while holding all other site characteristics and traffic volumes constant.

SSAM can be used to assess changes in traffic conflicts between designs and conflict modification factors (CfMFs) can be computed. CMFs can then be estimated by using a model relating the observed change in conflicts before and after treatment to an expected change in crash frequency.

This method of developing CMFs should be viable as long as the VisSim models are calibrated and there is correlation between conflict counts and actual collisions, enabling meaningful inferences to be derived from the conflict analysis. However, the relationship between traffic conflicts and actual crashes remains relatively undeveloped and may be difficult to develop, particularly in the case of a treatment or countermeasure that is rarely implemented.

Part of the problem in establishing a correlation between conflicts and crashes lies in the nature of conflict and crash data, with both being subject to statistical variations and some amount of unreliable measurements (*6*).

In 2008, Gettman et al. assessed the correlation between conflicts recorded by SSAM and actual crash histories at 83 four-legged, urban, signalized intersections representing a wide range of traffic characteristics (*8*). Each intersection was simulated exclusively under morning peak-hour volumes. Regression was used to establish the following peak-hour conflict-based model to predict average annual intersection crash frequency:

$$\frac{Crashes}{Year} = 0.119\left(\frac{Conflicts}{Peak\ Hour}\right)^{1.419}$$

This equation exhibited a correlation (R-squared value) of 0.41, which is within the range of correlations reported for traditional crash prediction models in previous studies for urban signalized intersections (*8*).

In our case study of the US 18/US 218/T-44 intersection, this equation does not seem to fit very well. Between 2001 and 2008, this unsignalized high-speed rural expressway intersection experienced 23 total crashes (2.875 crashes/year) with 0 fatal, 8 injury (35 percent), and 15 PDO (65 percent) crashes, while crash type data were not readily available. In comparison, the existing conditions simulation model averaged 40 total conflicts during the peak hour with 1 serious (2.5 percent), 14 slight (35 percent), and 25 potential (62.5 percent) as shown in Table 13.

While the percentages of crash/conflict severity levels match up relatively well, 40 peak-hour conflicts equates to 22 crashes per year according to the Gettman et al. conflict to crash correlation equation (*8*), when this intersection experienced an average of only 3 crashes per year.

There are a couple possible reasons why the Gettman et al. correlation equation does not work well in this case study for US 18/US 218/T-44. First, the Gettman et al. equation was computed for urban signalized intersections, which would be expected to have more crashes than a rural unsignalized intersection. Second, the Gettman et al. definition of a conflict within SSAM was a vehicle-vehicle interaction with TTC and PET thresholds of 1.5 and 5.0 seconds, respectively, while the US 18/US 218/T-44 case study more loosely defined a conflict as a vehicle-vehicle interaction with TTC and PET thresholds of 5.0 and 9.95 seconds, respectively.

As a result, the US 18/US 218/T-44 simulation model produced more conflicts than the Gettman et al. definition of a conflict would have and thus predicted more crashes. However, using the Gettman et al. definition of a conflict for the US 18/US 218/T-44 existing conditions simulation model would have only resulted in a total of 77 conflicts being identified over the 25 simulation runs (see Table 4) or an average of only 3.08 total conflicts during the peak hour. This leads to a prediction of only 0.59 crashes per year.

Table 19 gives conflict modification factors (CfMFs) for offset left turn lanes developed from the case study at US 18/US 218/T-44.

Table 19. Offset left turn lane conflict modification factors for US 18/US 218/T-44

	Conflict Type (20°/60° Thresholds)				Conflict Severity		
Random Seed	**Total Conflicts**	**Crossing**	**Rear-End**	**Lane-Change**	**Potential (1-2)**	**Slight (3-4)**	**Serious (5-6)**
301	0.88	0.60	1.06	0.71	0.97	0.86	0.25
302	0.70	1.33	0.79	0.46	0.60	0.90	#DIV/0!
303	1.06	1.00	1.07	1.00	1.00	1.15	#DIV/0!
304	1.00	0.44	1.75	0.73	1.04	1.11	0.00
305	1.17	0.50	1.20	1.25	1.17	1.18	1.00
306	1.00	0.78	0.86	1.88	0.81	1.33	0.00
307	1.11	0.33	1.04	1.88	1.05	1.29	0.50
308	1.02	1.00	0.92	1.25	1.00	1.13	0.00
309	1.05	0.86	1.11	1.09	0.96	1.25	#DIV/0!
310	0.82	0.33	0.78	1.14	0.70	1.08	0.00
311	0.93	0.50	0.92	1.38	0.94	0.89	1.00
312	1.26	1.33	0.89	2.33	1.15	1.78	0.00
313	0.89	0.88	0.80	1.14	0.97	0.74	#DIV/0!
314	0.85	0.50	0.88	0.87	0.83	1.00	0.00
315	0.94	0.40	1.12	0.92	0.83	1.07	1.00
316	0.91	0.50	1.00	1.00	0.89	1.08	0.00
317	0.79	1.00	0.67	1.13	0.80	1.00	0.00
318	1.10	1.00	1.17	1.00	1.17	1.00	#DIV/0!
319	1.02	0.50	1.14	1.06	0.89	1.35	0.00
321	0.88	1.67	0.94	0.63	0.80	1.00	1.00
322	0.68	0.31	0.70	0.87	0.62	0.94	0.00
323	1.19	0.67	1.10	1.63	1.32	1.00	1.00
324	0.92	1.67	0.84	0.90	0.81	1.27	#DIV/0!
325	0.87	0.50	0.78	1.33	0.86	0.94	0.00
326	0.88	1.25	1.00	0.60	0.71	1.17	#DIV/0!
Total =	**0.94**	**0.72**	**0.95**	**1.03**	**0.90**	**1.09**	**0.26**
Average =	**0.96**	**0.79**	**0.98**	**1.13**	**0.92**	**1.10**	
Std. Dev. =	**0.14**	**0.41**	**0.22**	**0.44**	**0.18**	**0.21**	
Var. =	**0.02**	**0.17**	**0.05**	**0.19**	**0.03**	**0.04**	
Min =	**0.68**	**0.31**	**0.67**	**0.46**	**0.60**	**0.74**	
Max =	**1.26**	**1.67**	**1.75**	**2.33**	**1.32**	**1.78**	

Note: The highlighted (DIV/0) CfMF values could not be computed as the existing conditions model had zero conflicts.

These CfMFs were calculated as follows:

$$CfMf = \frac{Frequency\ of\ Conflicts\ in\ Table\ 14}{Frequency\ of\ Conflicts\ in\ Table\ 13} = \frac{100 + [\%\ Change\ from\ Table\ 16]}{100}$$

An average CfMF could not be computed for serious conflicts as several of the simulation runs of the existing conditions model experienced 0 serious conflicts. If a suitable model relating the frequency of conflicts to crash frequency can be established, CMFs could be developed potentially from the CfMF values given in Table 19.

While it has been shown otherwise, if we assume the Gettman et al. (*8*) conflict to crash correlation equation holds true for the US 18/US 218/T-44 intersection, that equation could be used to convert the conflict values in Tables 13 and 14 to crashes and CMFs could be computed as the quotient of the two. This was done as an exercise and the calculated offset left turn lane CMFs are given in Table 20.

Table 20. Calculated offset left turn lane CMFs for US 18/US 218/T-44

	Conflict Type (20°/60° Thresholds)				Conflict Severity		
Random Seed	**Total Conflicts**	**Crossing**	**Rear-End**	**Lane-Change**	**Potential (1-2)**	**Slight (3-4)**	**Serious (5-6)**
301	0.84	0.48	1.09	0.61	0.96	0.81	0.14
302	0.60	1.50	0.71	0.33	0.48	0.86	#DIV/0!
303	1.08	1.00	1.11	1.00	1.00	1.23	#DIV/0!
304	1.00	0.32	2.21	0.64	1.06	1.16	0.00
305	1.24	0.37	1.30	1.37	1.24	1.27	1.00
306	1.00	0.70	0.81	2.44	0.74	1.50	0.00
307	1.15	0.21	1.06	2.44	1.07	1.43	0.37
308	1.03	1.00	0.89	1.37	1.00	1.18	0.00
309	1.08	0.80	1.15	1.13	0.94	1.37	#DIV/0!
310	0.75	0.21	0.71	1.21	0.60	1.12	0.00
311	0.90	0.37	0.88	1.57	0.92	0.85	1.00
312	1.39	1.50	0.85	3.33	1.22	2.26	0.00
313	0.85	0.83	0.73	1.21	0.96	0.65	#DIV/0!
314	0.80	0.37	0.84	0.82	0.76	1.00	0.00
315	0.92	0.27	1.17	0.88	0.77	1.10	1.00
316	0.87	0.37	1.00	1.00	0.85	1.11	0.00
317	0.72	1.00	0.56	1.18	0.73	1.00	0.00
318	1.14	1.00	1.24	1.00	1.24	1.00	#DIV/0!
319	1.03	0.37	1.20	1.08	0.85	1.54	0.00
321	0.83	2.06	0.91	0.51	0.73	1.00	1.00
322	0.58	0.19	0.61	0.82	0.51	0.92	0.00
323	1.29	0.56	1.14	1.99	1.48	1.00	1.00
324	0.88	2.06	0.78	0.86	0.74	1.41	#DIV/0!
325	0.82	0.37	0.70	1.50	0.80	0.91	0.00
326	0.83	1.37	1.00	0.48	0.62	1.24	#DIV/0!
Total =	**0.92**	**0.63**	**0.93**	**1.04**	**0.86**	**1.13**	**0.15**
Average =	**0.95**	**0.77**	**0.99**	**1.23**	**0.89**	**1.16**	
Std. Dev. =	**0.20**	**0.56**	**0.33**	**0.69**	**0.24**	**0.32**	
Var. =	**0.04**	**0.31**	**0.11**	**0.48**	**0.06**	**0.10**	
Min =	**0.58**	**0.19**	**0.56**	**0.33**	**0.48**	**0.65**	
Max =	**1.39**	**2.06**	**2.21**	**3.33**	**1.48**	**2.26**	

Note: The crash modification factors given in this table were derived assuming the Gettman et al. (8) correlation equation is valid. The highlighted (DIV/0) CMF values could not be computed as the existing conditions model had zero conflicts.

Comparing Tables 19 and 20 shows only a slight difference between the CfMF and the CMF values, with the CfMF values being slightly more conservative in most cases. Therefore, the CfMF values could potentially serve as CMFs without any further adjustment necessary.

For comparison purposes, the CMFs Clearinghouse (*13*) was reviewed to gather existing CMF values for offset left turn lanes. The CMF Clearinghouse is a comprehensive web-based repository of all available CMFs that is updated on a regular basis via a periodic review of published research. Table 21 lists the roadway/area type, crash type, and crash severity for which each given CMF is applicable along with its star rating and standard error.

Table 21. Offset left turn lane CMFs from the CMF Clearinghouse (*13*)

Treatment	Roadway/ Area Type	Crash Type	Crash Severity	CMF	Quality Rating	Std. Error (Source)
Install Positively Offset Left turn lanes	Rural Principal Arterial Other (Freeways and Expressways)	All	All	0.5	2 Stars	0.19 (*15*)
				0.67	1 Star	0.2 (*15*)
			Fatal	0	1 Star	0 (*15*)
			Injury	0.16	2 Stars	0.11 (*15*)
				0.35	2 Stars	0.16 (*15*)
			PDO	1.57	1 Star	0.9 (*15*)
				1.65	1 Star	0.85 (*15*)
		Left-Turn	All	0	2 Stars	0 (*15*)
				0.15	2 Stars	0.12 (*15*)
		Left-Turn/ Rear-End	All	0.22	2 Stars	0.15 (*15*)
				0.24	2 Stars	0.15 (*15*)
		Angle	All	0.37	2 Stars	0.27 (*15*)
				1.24	1 Star	0.59 (*15*)

The star rating is a 1 to 5 scale with 5 indicating the most reliable study, judging the CMF according to its performance in five categories: study design, sample size, standard error, potential bias, and data source.

The standard error serves as a measure of reliability for a CMF and may be used to calculate a confidence interval for the predicted change in expected crash frequency after a countermeasure is applied. The smaller the standard error, the more reliable the estimate.

Unfortunately, all of the CMF values for offset left turn lanes given in Table 21 were derived from a single study that had a low star rating due to a limited number of study sites, a limited amount of before and after data, and a naïve before-after study design (*15*). Therefore, those results are not considered sufficiently reliable for inclusion in the HSM (*12*) and there are not universally-accepted CMFs for offset left turn lanes available for us to compare our results.

Intersection Conflict Index (ICI)

Sayed (*2, 3*) has proposed two different methods of calculating an intersection conflict index (ICI) for summarizing and comparing conflict risk at unsignalized intersections. The first method was established by Sayed (*2*) in 1998 as a scatter plot diagram of average conflict severity (ACS) on the y-axis versus the average hourly conflict rate per 1,000 entering vehicles (AHC/TEV) on the x-axis.

The ACS is defined as the sum of the conflict severity scores for all conflicts at an intersection divided by the total number of conflicts. The AHC rate is defined as the total number of observed conflicts at an intersection divided by the total number of observation hours. The ICI region boundaries are determined using one standard deviation from the calculated mean of the overall ACS and the AHC/TEV. In this 1998 method, the ICI ranges from A (low conflict frequency and severity) to E (high frequency and severity).

Figure 23 is a plot of the 1998 ICI method for 25 simulation runs of the existing conditions model and 25 simulation runs of the offset left turn lane model.

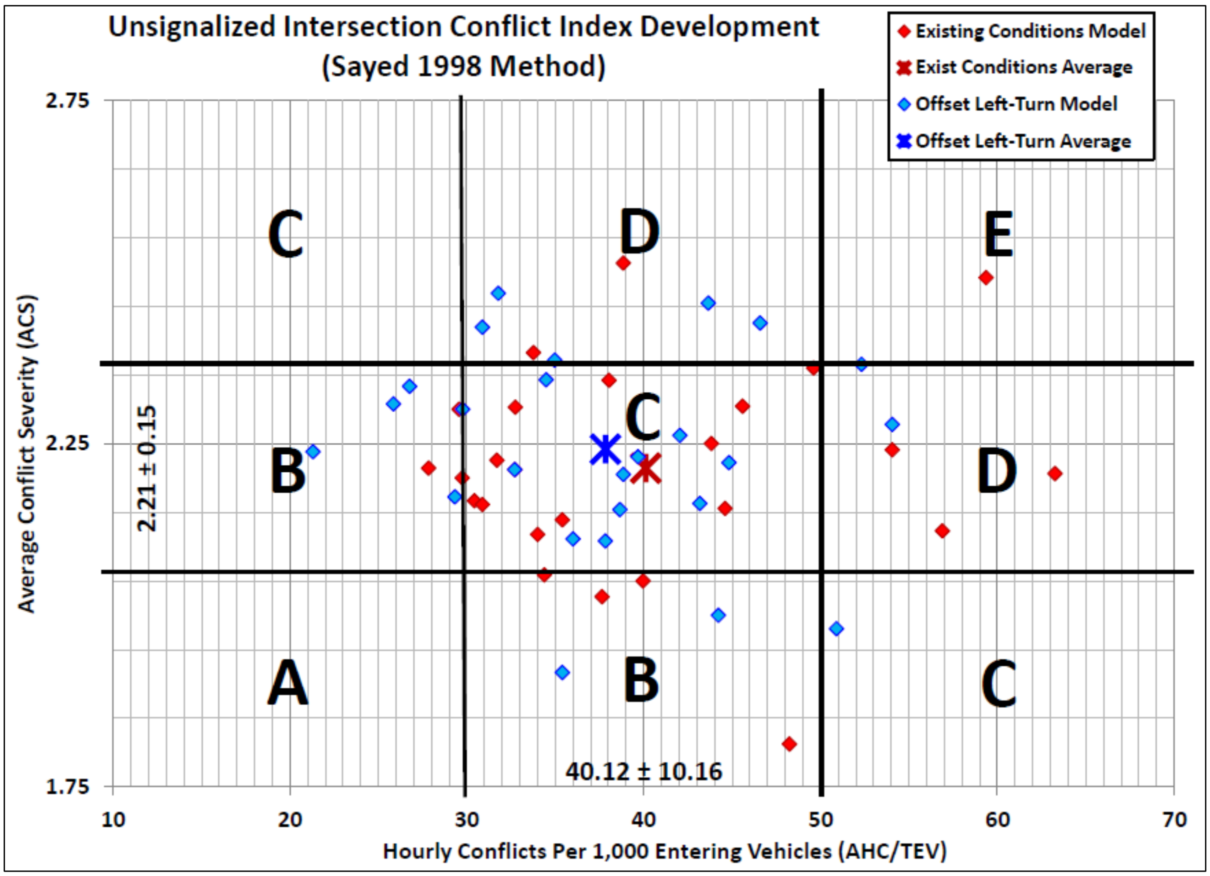

Figure 23. 1998 ICI method for existing conditions versus offsest left turn lane

The average ICI is also plotted for each model. The ICI region boundaries were determined using one standard deviation from the calculated mean of the ACS and the AHC/TEV for the existing conditions model, which is why the existing conditions model average is in the center of the scatter plot.

Both models have an average ICI grade of C. According to the plot, the offset left turn lane model has a lower average conflict rate, but a higher average conflict severity than the existing conditions model. This finding is consistent with the SSAM statistical analysis shown in Table 17, but makes it difficult to select the safest design alternative.

The second ICI method was established by Sayed (*3*) in 1999 as a scatter plot diagram of the average hourly conflict rate per the square root of the product of the hourly entering volume in thousands (AHC/PEV) on the y-axis versus the average hourly severe conflict rate per the square root of the product of the hourly entering volume in thousands (AHC4+/PEV) on the x-axis.

The AHC rate is defined as in the 1998 ICI method. The AHC4+ rate is defined as the total number of observed severe conflicts (conflicts with a total severity score of 4 or greater) at an intersection divided by the total number of observation hours. PEV is the square root of the product of the hourly entering volume in thousands.

For example, if the average hourly volumes entering an intersection from the major and minor roads are 500 and 800 vehicles per hour, respectively, $PEV = \sqrt{0.5 \times 0.8} = 0.63$. As in the 1998 ICI method, the ICI region boundaries are determined using one standard deviation from the calculated mean of the overall AHC/PEV and the AHC4+/PEV. However, in this 1999 method, the ICI ranges from A (low frequency and severity) through F (very high frequency and severity).

Figure 24 is a plot of the 1999 ICI method for 25 simulation runs of the existing conditions model and 25 simulation runs of the offset left turn lane model.

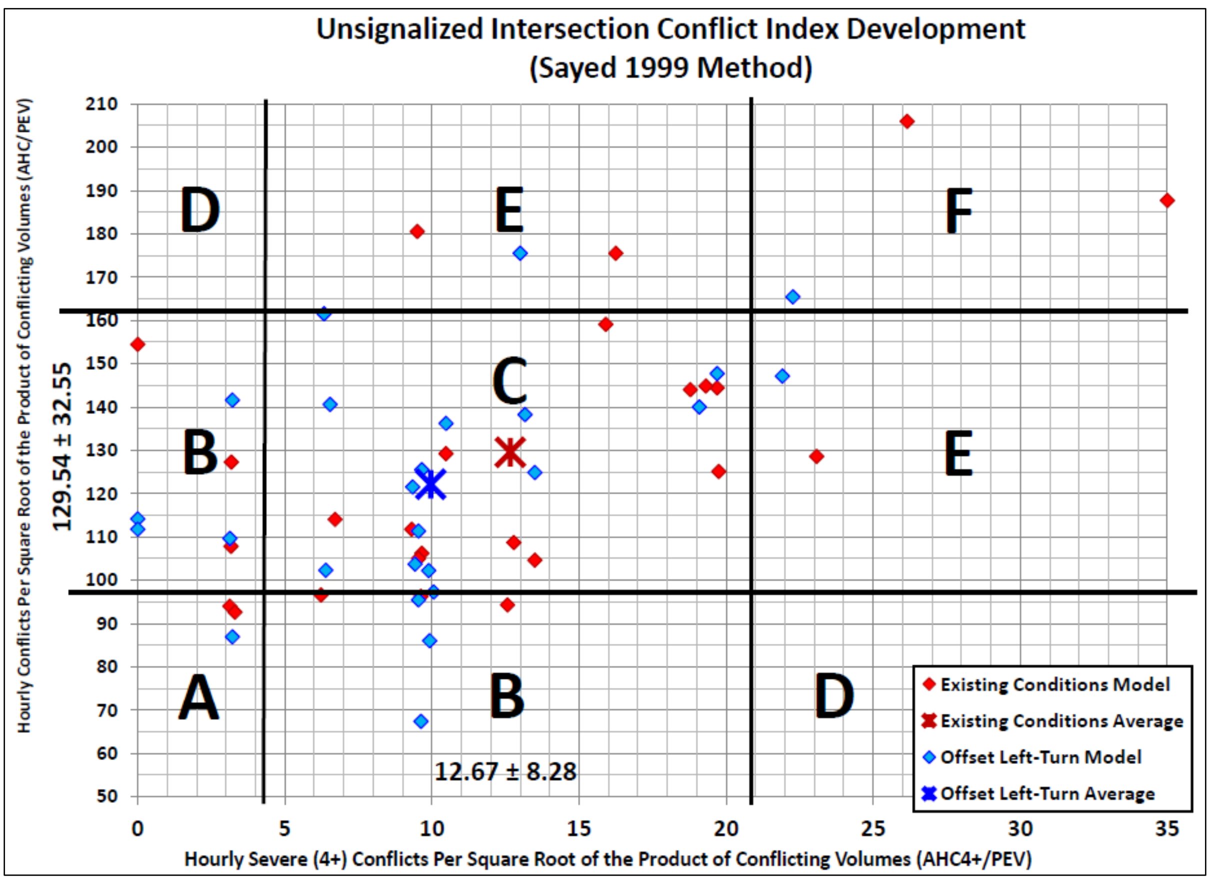

Figure 24. 1999 ICI method for existing conditions versus offset left turn lane

The average ICI is also plotted for each model. Similar to the 1998 method, the ICI region boundaries were determined using one standard deviation from the calculated mean of the AHC/PEV and the AHC4+/PEV for the existing conditions model, which is why the existing conditions model average is in the center of the scatter plot.

In this method, both models still have an average ICI grade of C. According to the plot, the offset left turn lane model has a lower average conflict rate and a lower average severe conflict rate, making it the safer design alternative. This finding is consistent with the conflict frequency comparisons made in Figures 15 and 16.

While both of Sayed's methods are adequate, they are both arbitrary in terms of probabilistic risk assessment. Probabilistic risk assessment is a methodology used to evaluate the risk associated with an activity. Risk can be characterized by the probability (rate) of occurrence and the magnitude (severity) of the outcome. Expressed numerically, risk is the product of probability and consequence. This is implied in both of Sayed's methods (more so with the 1998 method) given the ICI gets worse as you get further from the lower left, but is not clearly evident.

Therefore, an adaptation of Sayed's 1998 method was developed to include curves of equal risk with risk defined as conflict rate (AHC/TEV) multiplied by conflict severity (ACS). Figure 25 is a plot of this modified ICI method.

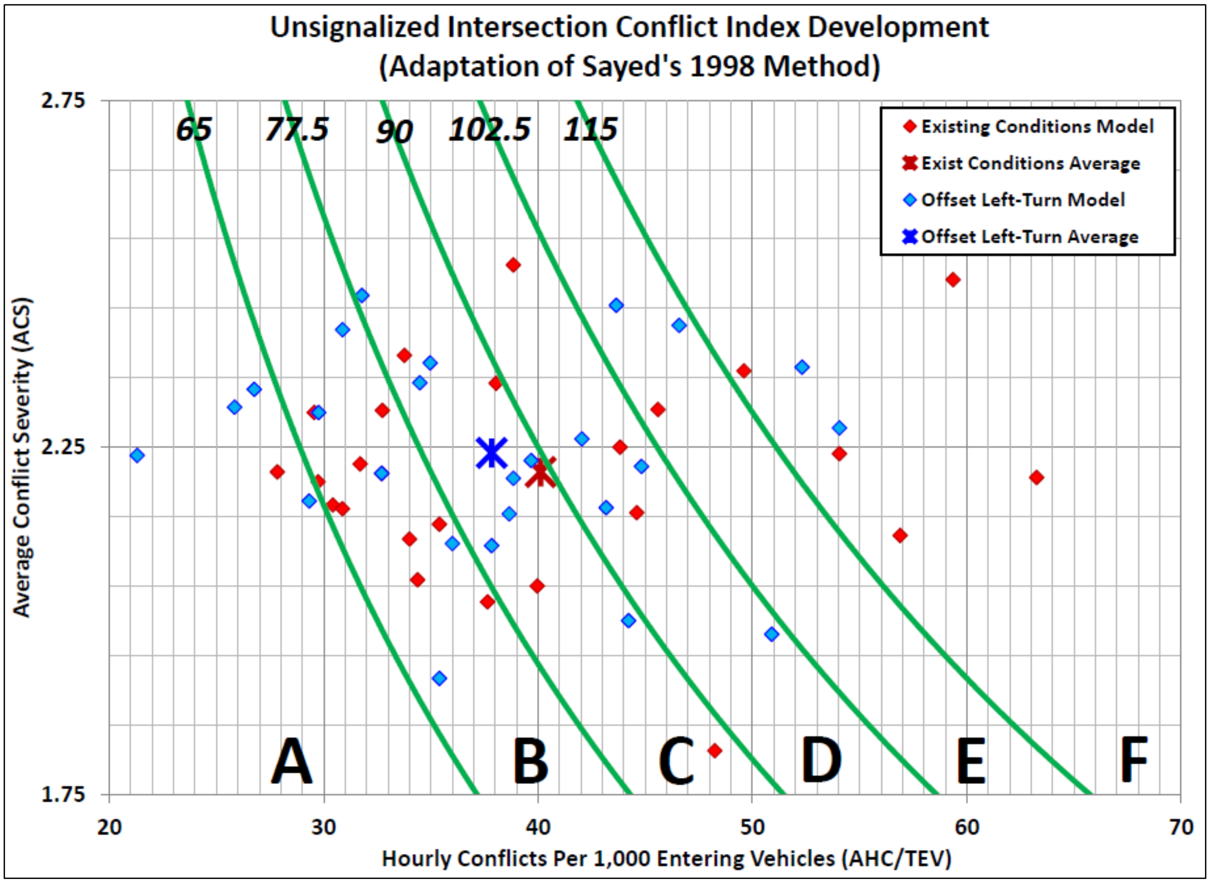

Figure 25. ICI with risk assessment for existing conditions versus offset left turn lane

Figure 25 illustrates the same data shown in Figure 23 with 25 simulation runs and the average of the existing conditions model and 25 simulation runs and the average of the offset left turn lane model. The ICI region boundaries were determined using one standard deviation from the calculated mean risk of the existing conditions model. For the existing conditions model, the mean risk was equal to 88.94 with a standard deviation of 24.14. Therefore, a risk value of 90 was selected as the C/D ICI boundary, with 65 for the A/B boundary and 115 for the E/F boundary. The B/C and D/E boundaries were selected using the midpoints of 77.5 and 102.5.

Based on these risk-based ICI boundaries, both models have an average ICI grade of C. According to the plot, the offset left turn lane model has a lower average conflict rate, but a higher average conflict severity than the existing conditions model; however, it is more evident now that the offset left turn lane model is the safer alternative as it has moved further from the C/D ICI boundary and is less risky than the existing conditions.

The risk-based ICI boundaries shown in Figure 25 were solely based on this case study for demonstration and comparison purposes and do not have any true meaning that is extended to the real world.

For instance, the ICI boundaries in Figure 25 were constructed to give the existing conditions model an average ICI of C; however, the risk associated with the existing conditions model may be extremely high as this intersection is in the top 5 percent of the most dangerous rural expressway intersections in the state of Iowa.

For future research, it would be ideal to develop risk-based ICI boundaries that have true meaning (i.e., what level of risk is acceptable/unacceptable?). The risk associated with these ICI boundaries should be defined based on the functional class of the intersection and some economic level. For example, the safest 5 percent of rural expressway intersections could be defined with an ICI grade of A, the next 10 percent B, the next 35 percent C, the next 35 percent D, the next 10 percent E, and the most dangerous 5 percent F.

CONCLUSIONS

This report examined the use of SSAM for performing a conflict analysis, comparing the safety consequences of alternative designs, and developing conflict and/or crash modification factors. A conflict analysis methodology using the SSAM software was developed and refined. The refined conflict analysis methodology is as follows:

1. Use the following threshold values to identify conflicts and classify conflicts by type within SSAM: Maximum TTC = 5.00 seconds, Maximum PET = 9.95 seconds, Rear-End Angle = 20 degrees, Crossing Angle = 60 degrees. These values seem adequate for rural high-speed two-way stop-controlled expressway intersections, but may vary for other intersection types.

2. Use the filter mechanism within SSAM to filter the identified conflicts by area. Extract the filtered conflict data into a database format and filter conflicts by time using the tMinTTC variable. Only conflicts occurring near the intersection of interest and after the simulation initialization period should be included in the conflict analysis and analyzed further.

3. Calculate the overall conflict severity score for each individual conflict using the equations given in Table 7 or some variation based on a conflict's TTC and Max ΔV values to rate conflicts as potential, slight, or serious.

4. Compare conflict frequencies statistically between design alternatives. SSAM enables statistical comparison of conflict frequencies and surrogate safety measure values between two design alternatives using the Student t-distribution for hypothesis testing. However, SSAM is currently unable to filter conflicts by simulation time or classify conflicts by severity, so this statistical analysis will need to be performed by another means.

5. Calculate CfMFs for individual geometric design components or their combination.

6. Compare the overall safety/risk of each simulated design alternative using the developed ICI with probabilistic risk assessment (an adaptation of Sayed's 1998 method).

7. Map the locations of conflicts to examine patterns of conflicts visually by type or severity, or to compare the locations of conflicts between design alternatives.

It is our recommendation that the SSAM software be modified so that this entire conflict analysis process may be automated within SSAM. To do so, the following additions to the SSAM software are recommended:

- Add the ability to filter conflicts by simulation time (tMinTTC)
- Add a conflict severity classification scheme based on TTC and Max ΔV to rate each individual conflict as potential, slight, or serious
- Add the ability to statistically compare conflicts between two design alternatives by conflict severity classification (potential, slight, or serious)
- Add the ability to map conflicts by conflict severity classification (potential, slight, or serious)
- Add the ability to compute and report CfMFs between two design alternatives for total conflicts, conflicts by type, and conflicts by severity
- Add the ability to extract traffic volume information for each simulation run from VisSim and automatically calculate, report, and plot ICI values and curves of equal risk
- Add the ability to select specific individual conflicts for mapping similar to the user interface in ArcMap GIS

This study also found that conflicts must meet both TTC and PET threshold criteria to be identified by SSAM as conflicts; however, TTC seems to be a better indicator of collision propensity and PET may not be as appropriate for screening out conflict events. The TTC scores shown in Figure 4 assigned a value of 0 to any conflict with a TTC greater than 4.00 seconds; therefore, the maximum TTC threshold value may be reduced to 4.00 seconds.

From the conflict angle threshold sensitivity analysis, 20 and 60 degrees are the recommended values for the rear-end and crossing angle thresholds, respectively. However, if actual crash data is available or a conflict analysis has been conducted in the field for that particular intersection, the conflict angle thresholds could be adjusted in an attempt to match the SSAM conflict type distributions to those observed in the field.

Offset left turn lanes significantly reduced crossing and serious conflicts as compared to the existing intersection geometry. CMFs could not be developed for serious conflicts, but the offset left turn lane CMF for crossing conflicts was 0.79. By plotting curves of equal risk on the ICI graph, it became evident that the offset left turn lane model was the safer/less risky alternative.

For future research, it would be ideal to develop risk-based ICI boundaries that have true meaning so the ICI can be used as a realistic indicator of intersection safety.

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