AN INNOVATIVE APPROACH TO PROACTIVELY EVALUATE SAFETY PERFORMANCE OF FUTURE TRANSPORTATION PROJECTS

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ABSTRACT

The need to address traffic safety is gaining more attention as the frequency and severity of traffic incidents increase, therefore posing adverse economic impacts. Safety analyses of roadway facilities have typically been performed based on historic accident data or police reports for motor vehicle crashes. However, this traditional approach has limitations in its applications: it is a reactive rather than a proactive approach and has limited applications to assess safety of roadway designs that are yet to be built or traffic flow-control strategies that are yet to be applied in the field. On the other hand, most research on current predictive safety analysis methods is deterministic in its approach. There is a need for a methodology that would seamlessly integrate safety components with the dynamics of traffic operations.

The ability of microscopic simulation models to capture vehicle-to-vehicle interactions at every time step can be effectively used to predict the probability of vehicle conflicts. This paper formulates a methodology, based on a case study, to predict the number and spatial location of conflicts based on surrogate safety performance measures (time to collision and post-encroachment time) by integrating outputs of microscopic simulation models. This approach would draw a parallel between real-world accident data and the estimated number of conflicts from microscopic simulation model as baselines, which in turn can be used to predict safety performance measures for future alternatives. This procedure would aid engineers to better address safety concerns that will allow for preventive safety analysis as part of alternative development process.

1. INTRODUCTION

One of the key goals of this case study is to develop a methodology to proactively evaluate traffic safety for major freeway corridors and to incorporate safety needs in the planning phase of a project rather than using a reactive approach to safety issues after construction of a project. Across the globe, traffic safety is gaining much more attention than ever before due to a high incidence of crashes, increased severity of crashes, and subsequent economic loss as a result of these crashes.

Reviewing historic crash data and identifying crash hot-spots are important first steps toward mitigating the safety issues along major freeways. As part of conceptual development of a freeway project, it is important to ensure that the proposed concepts include design elements and roadway alignments that help minimize vehicular conflicts at these hot-spots. It is also important to consider safety beyond just the roadway design elements. The dynamic nature of traffic operations plays a vital role in determining the safety impacts of existing and new roadway design elements. An overall approach that encompasses the impact of these variables seamlessly is critical to improving traffic safety.

A detailed literature review of available safety evaluation tools, such as the Interchange Safety Analysis Tool (ISAT), the Interactive Highway Safety Design Model (IHSDM), and the Surrogate Safety Assessment Model (SSAM), was conducted to understand the advantages, limitations, and applicability of each analysis tool in evaluating major freeway projects. ISAT has been used to evaluate the safety impacts of interchange improvements. However, it is limited to evaluating interchanges as isolated entities and does not capture the impact of traffic operations at adjacent freeway sections/interchanges. Crashes are random events and are very dynamic in nature. ISAT captures the impact of roadway design elements on safety but does not capture the impact of the stochastic nature of traffic operations, the vehicle-to-vehicle interactions that could result in crashes. IHSDM is limited to evaluating two-lane roadways, and similar to ISAT, is very deterministic in approach. In summary, ISAT and IHSDM are limited in their applications and do not fit the needs of a complex freeway project where congestion-related issues are not isolated but rather are interrelated.

SSAM, developed by the Federal Highway Administration (FHWA), utilizes the outputs of microsimulation models such as VISSIM to predict the number of conflicts on any roadway facility. These conflicts could then be correlated to the probability of accidents based on certain surrogate safety performance measures as discussed below. This methodology allows for an overall approach that captures the interaction of roadway design elements and traffic operations. Therefore, SSAM was selected for conducting the predictive safety analysis.

The case study location is Interstate 285 (I-285) between Interstate 75 (I-75) and Interstate 85 (I-85), in Atlanta, Georgia, United States. This section of freeway is approximately 12 miles long and is one of the most congested freeway corridors in the U.S. according to the U.S. Department of Transportation. One of the key concerns for this corridor is related to traffic safety due to a high incidence of crashes; crash rates are significantly higher than the state-wide average rates for a similar facility. Roadway alternatives were developed and evaluated for safety performance based on the methodology discussed in the following section.

2. METHODOLOGY

A conflict is defined as an observable situation in which two or more road users approach each other in time and space to such an extent that there is risk of collision if their movements remain unchanged. Figure 1 shows a snapshot of a conflict situation in VISSIM. The conflict frequency can be correlated with the risk of actual collision. To identify, classify, and evaluate a conflict, SSAM uses a technique that combines microscopic simulation and automated conflict analysis. This technique helps analyze the frequency and character of collisions in traffic in order to assess the safety performance of roadway facilities. The common surrogate safety measures include, but are not limited to, time-to-collision (TTC), post-encroachment time (PET), vehicle delay, travel time, number of lane changes, approach speed, speed distribution, deceleration distribution, and percentage of stopped vehicles. This approach can be used to determine the relative differences in the frequency of conflicts recorded between various alternatives; however, it should not be used to estimate the absolute crash rates.

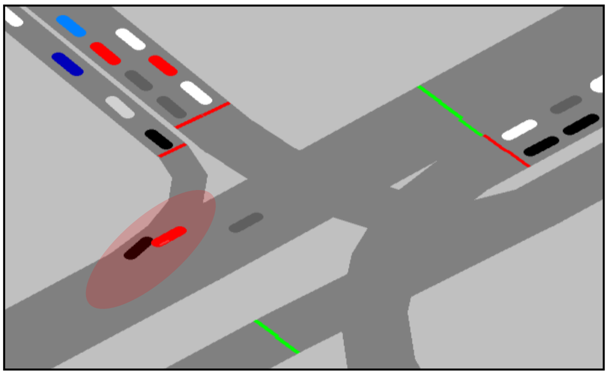

Figure 1: A Snapshot of a Conflict in VISSIM

The key input to SSAM is the trajectory data from the microscopic simulation model. The trajectory data records the position of each vehicle at every time step as the vehicle travels within the model. The VISSIM model, used to conduct operational analyses, has the ability to output the trajectory data that can be used to conduct conflict analyses using SSAM. The following section describes in detail the methodology adopted to establish a relationship between conflicts and crash rates and the application of this analysis in refining roadway designs.

2.1 DEFINING CONFLICT TO CRASH RELATIONSHIP

As discussed previously, the output from SSAM is in terms of number of conflicts. The goal is to evaluate and compare the crash rates between various alternatives based on the SSAM conflicts and thereby quantify the performance from a safety perspective. To correlate the conflict frequency to crash rates, it is important to understand the conflict to crash relationship. To formulate this relationship, the Georgia Department of Transportation's (GDOT's) existing conditions (2005) crash database for I-285 between I-75 and I-85 was screened, by freeway segments between interchanges, to extract only vehicle-to-vehicle-related crashes. This extraction process is critical in establishing the relationship between conflicts and crashes since SSAM cannot analyze non-vehicle-related crashes such as run-off-the-road crashes and weather-related crashes (wet pavement). This methodology would ensure that datasets within the crash database and the SSAM conflict database are of similar data type. Table 1 illustrates the crash rates and conflict rates for different freeway segments of I-285 between I-75 and I-85.

Table 1 shows that the average crash rate along I-285 is approximately 207 per 100 million vehicle miles traveled (MVMT). The average conflict rate based on SSAM is approximately 9.7 x 106 per 100 MVMT. The average value would not capture the spread within the dataset; however, standard deviation would show how the data points are distributed with regard to the average. The high standard deviation (11×10^6) around the average (9.7×10^6) indicates that the conflict rate values are highly scattered and indicates the presence of outliers. Another statistic that would help understand the relationship between two parameters is the correlation factor. Based on the data analysis, conflict rate and crash rate have a correlation factor of 0.70. This means that these two parameters are positively correlated. The positive correlation indicates that any increase in conflict rate would result in an increase in crash rate. Given the positive correlation between the two parameters, some simple regressions were analyzed.

Table 1: Year 2005 I-285 Crash Rates and Conflict Rates Summary

Segment	Number Of Crashes			Percent Vehicle Only Crashes	Crash Rate Per 100 Million VMT			Conflict Rate Per 100 Million VMT
	All Crashes	Vehicle Only Crashes	Non-Vehicle Crashes		All Crashes	Vehicle Only Crashes	Non-Vehicle Crashes	
I-285 Eastbound from Cobb Pkwy to I-75	52	41	11	79%	259.41	204.54	54.88	904,145
I-285 Eastbound from I-75 to Northside Pkwy	127	101	26	80%	184.06	146.38	37.68	469,888
I-285 Eastbound from Northside Pkwy to Riverside Dr	77	64	13	83%	126.68	105.29	21.39	923,704
I-285 Eastbound from Riverside Dr to Roswell Rd	141	122	19	87%	243.42	210.62	32.80	346,041
I-285 Eastbound from Roswell Rd to SR 400	144	131	13	91%	307.43	279.68	27.75	38,610,350
I-285 Eastbound from SR 400 to Ashford Dunwoody Rd	129	114	15	88%	254.91	225.27	29.64	1,042,893
I-285 Eastbound from Ashford Dunwoody Rd to Chamblee Dunwoody Rd	109	100	9	92%	175.89	161.37	14.52	277,819
I-285 Eastbound from Chamblee Dunwoody Rd to Peachtree Industrial Blvd	267	251	16	94%	334.28	314.25	20.03	21,539,802
I-285 Eastbound from Peachtree Industrial Blvd to Buford Hwy	169	162	7	96%	401.36	384.73	16.62	26,811,549
I-285 Eastbound from Buford Hwy to I-85	188	171	17	91%	337.60	307.08	30.53	31,601,893
I-285 Eastbound from I-85 to Chamblee Tucker Rd	96	78	18	81%	202.61	164.62	37.99	203,426
I-285 Westbound from Cobb Pkwy to I-75	39	33	6	85%	194.56	164.63	29.93	1,289,302
I-285 Westbound from I-75 to Northside Pkwy	170	155	15	91%	246.38	224.64	21.74	16,032,053
I-285 Westbound from Northside Pkwy to Riverside Dr	138	125	13	91%	227.03	205.65	21.39	8,354,024
I-285 Westbound from Riverside Dr to Roswell Rd	87	74	13	85%	150.20	127.75	22.44	5,052,337
I-285 Westbound from Roswell Rd to SR 400	101	91	10	90%	215.63	194.28	21.35	2,715,847
I-285 Westbound from SR 400 to Ashford Dunwoody Rd	104	100	4	96%	205.51	197.60	7.90	2,083,453
I-285 Westbound from Ashford Dunwoody Rd to Chamblee Dunwoody Rd	96	82	14	85%	154.91	132.32	22.59	11,196,472
I-285 Westbound from Chamblee Dunwoody Rd to Peachtree Industrial Blvd	161	148	13	92%	201.57	185.29	16.28	19,266,335
I-285 Westbound from Peachtree Industrial Blvd to Buford Hwy	141	137	4	97%	334.86	325.36	9.50	12,803,070
I-285 Westbound from Buford Hwy to I-85	122	98	24	80%	219.08	175.98	43.10	7,237,808
I-285 Westbound from I-85 to Chamblee Tucker Rd	81	61	20	75%	170.95	128.74	42.21	5,988,265
Average	124	111	13	88%	233	207	26	9,761,385
Standard Deviation	47	47	5	6%	68	71	11	11,065,208
Minimum	39	33	4	75%	127	105	8	203,426
Maximum	267	251	26	97%	401	385	55	38,610,350
Correlation	0.70							

A regression analysis was conducted with and without outliers to establish a relationship that would best mimic the existing condition annual crash rates. Based on preliminary regression analysis, including the outliers resulted in estimated crash rates significantly (greater than 25 to 75 percent) different from the actual crash rates for approximately 35 percent of the data points. However, upon eliminating the outliers, the variation between the estimated and actual crash rates was in the range of 9 to 22 percent and a higher R-square value. In all regression analyses, conflict rate was considered the independent parameter and crash rate was considered the dependent parameter. The range of regression equations developed and the corresponding R-square values are shown in Table 2.

Typically, a higher R-square value indicates a strong correlation between the two parameters and potential for less error. However, R-square should not be the only parameter used to define the relationship between the parameters. Beyond R-square analysis, a fitted curve analysis was performed for each of the regression equations, as shown on Figure 2, to estimate crash rates based on conflict rates. The comparison of actual crash rates and estimated crash rates based on each of the regression equations is summarized in Table 3.

Table 2: Regression Analysis Summary

ID	Regression Equation	R Square
A	$\text{Crash rate} = 41.21(\text{Conflict rate})^{0.1116}$	0.55
B	$\text{Crash rate} = 180.67\ e^{(2E-8 \times \text{Conflict rate})}$	0.75
C	$\text{Crash rate} = 1.36E-5 \times \text{Conflict rate}$	0.63
D	$\text{Crash rate} = 5E-6 \times \text{Conflict rate} + 178.52$	0.758
E	$\text{Crash rate} = (\text{Conflict rate})^{0.3586}$	0.99
F	$\text{Crash rate} = 15.222 \times \ln(\text{Conflict rate})$	0.96

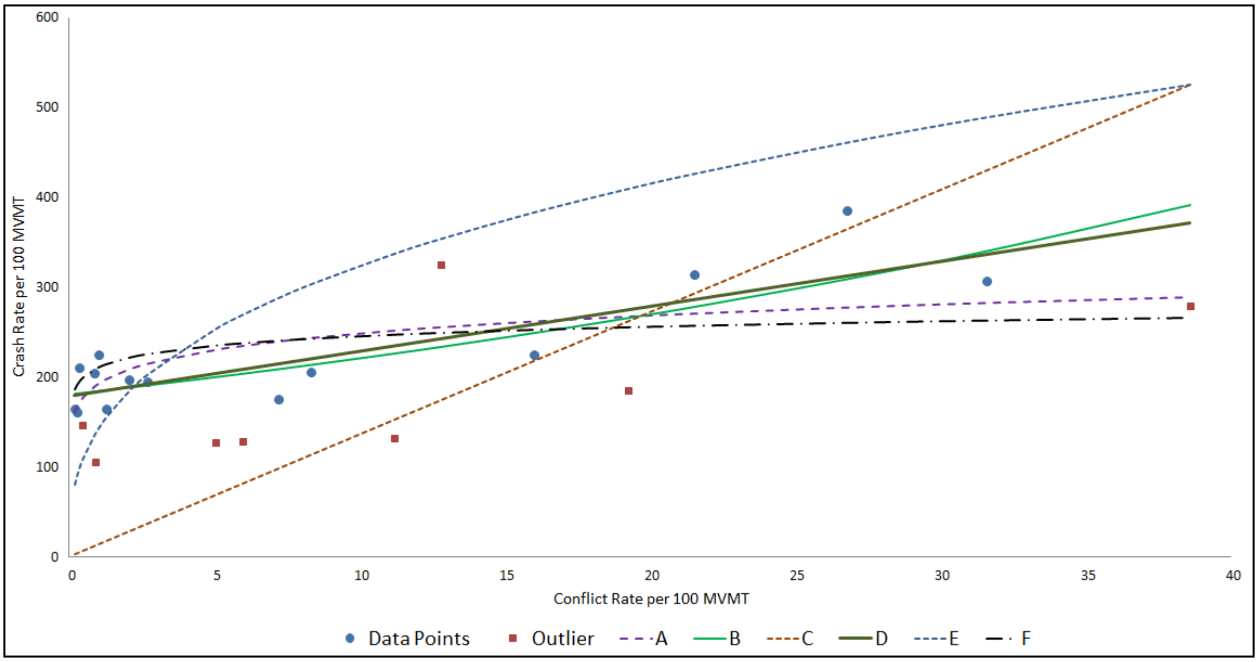

Figure 2: Fitted Curve Analysis Summary

Table 3: Actual Versus Estimated Crash Rates Summary, By Regression Equation

Segment	Year 2005 Actual Crash	Year 2005 Estimated Crash Rate					
		A	B	C	D	E	F
I-285 Eastbound from Cobb Pkwy to I-75	204.54	190	184	12	183	137	209
I-285 Eastbound from I-75 to Northside Pkwy	146.38	177	182	6	181	108	199
I-285 Eastbound from Northside Pkwy to Riverside Dr	105.29	191	184	13	183	138	209
I-285 Eastbound from Riverside Dr to Roswell Rd	210.62	171	182	5	180	97	194
I-285 Eastbound from Roswell Rd to SR 400	279.68	290	391	525	372	526	266
I-285 Eastbound from SR 400 to Ashford Dunwoody Rd	225.27	193	184	14	184	144	211
I-285 Eastbound from Ashford Dunwoody Rd to Chamblee Dunwoody Rd	161.37	167	182	4	180	90	191
I-285 Eastbound from Chamblee Dunwoody Rd to Peachtree Industrial Blvd	314.25	271	278	293	286	426	257
I-285 Eastbound from Peachtree Industrial Blvd to Buford Hwy	384.73	278	309	365	313	461	260
I-285 Eastbound from Buford Hwy to I-85	307.08	283	340	430	337	489	263
I-285 Eastbound from I-85 to Chamblee Tucker Rd	164.62	161	181	3	180	80	186
I-285 Westbound from Cobb Pkwy to I-75	164.63	198	185	18	185	155	214
I-285 Westbound from I-75 to Northside Pkwy	224.64	262	249	218	259	383	253
I-285 Westbound from Northside Pkwy to Riverside Dr	205.65	244	214	114	220	304	243
I-285 Westbound from Riverside Dr to Roswell Rd	127.75	231	200	69	204	253	235
I-285 Westbound from Roswell Rd to SR 400	194.28	215	191	37	192	203	226
I-285 Westbound from SR 400 to Ashford Dunwoody Rd	197.60	209	188	28	189	184	221
I-285 Westbound from Ashford Dunwoody Rd to Chamblee Dunwoody Rd	132.32	252	226	152	235	337	247
I-285 Westbound from Chamblee Dunwoody Rd to Peachtree Industrial Blvd	185.29	268	266	262	275	410	255
I-285 Westbound from Peachtree Industrial Blvd to Buford Hwy	325.36	256	233	174	243	354	249
I-285 Westbound from Buford Hwy to I-85	175.98	240	209	98	215	288	240
I-285 Westbound from I-85 to Chamblee Tucker Rd	128.74	235	204	81	208	269	238

Based on the statistical analyses, and in comparison with the existing condition (2005) crash rates, curve C was not used for crash predictions since it provides extreme values. Curve E, despite its high R-square value, has a tendency to predict extreme values. Curves A and F in most cases overestimate the crash rates and their fitted curve seems to suggest that crash rates are insensitive (indicated by flattened curves) to increase in conflict rates after a certain point. Curves B and D have similar R-square values and seem to predict acceptable values for crash rate. These curves do not predict extreme values like curves C and E nor are they insensitive to crash frequency like curves A and F. Therefore, picking either Curve B or Curve D was recommended for crash rate prediction for future year alternatives.

2.2 ESTIMATION OF OVERALL CRASH RATES

As discussed previously, SSAM can estimate only vehicle-to-vehicle conflicts and therefore the regression equation would yield vehicle-to-vehicle crash rates only. To estimate the overall crash rates, the percentage of non-vehicle-to-vehicle other crashes (e.g., run-off-the-road crashes and weather-related crashes) was estimated for each of the freeway segments based on Georgia DOT's 2005 crash database. For the purposes of predicting the future year overall crash rates, it was assumed that this percentage would remain the same and be applied to vehicle-to-vehicle crash rates. For example, I-285 eastbound between Roswell Road and State Route (SR) 400 had 91 percent vehicle-to-vehicle crashes and 9 percent non-vehicle-to-vehicle other crashes. The future year vehicle-to-vehicle crashes would be increased by 9 percent to estimate the overall crash rates along this freeway segment.

2.3 ROADWAY DESIGN REFINEMENTS

In addition to predicting the crash rates along I-285, the results of the conflict analysis also provided spatial location and types of conflicts (e.g., rear-end, lane change). The conflict analysis, in combination with the results of the operational analysis, was used to refine the roadway designs, as a feedback process, to improve operational and safety performance along the I-285 corridor. Refinements include improving merge, diverge, and weave sections along the freeway.

This proactive approach would capture the impact of roadway design elements in relation to the dynamic nature of traffic operations. The conflict analysis would help refine the roadway design elements to facilitate safer and more efficient movement of people and goods along the interstate system.

3. RESULTS

To address mobility and safety needs along I-285, one No-Build/Do-Nothing and three Build alternatives were evaluated for traffic safety performance. The No-Build/Do-Nothing alternative shows the safety impacts in terms of crash rates, if nothing was done to improve I-285 operations. The three build alternatives evaluated are Alternative 1 (Operational Improvements), Alternative 2 (Operational Improvements and Additional Capacity via Managed/Toll Lanes), and Alternative 3 (Modified Version of Alternative 2 with one less free lane/general-purpose lane). The safety analysis was performed to evaluate and compare how these alternatives would perform during the design life (typically 20 years from project completion) of the project. The findings of the analysis are summarized below. Figure 3 shows the predicted crash rate comparison by alternative.

- The existing condition (2005) crash rates (based on GDOT crash data) are generally high along the I-285 corridor. With no major improvements to address the operational issues and thereby safety issues under the 2040 No-Build/Do-Nothing alternative, crash rates can only be expected to worsen. Most of the freeway segments under the design year No-Build/Do-Nothing alternative would operate higher than the statewide average crash rates.

- It is observed that the locations of the highest crash rates under the No-Build /Do-Nothing alternative would be the same freeway segments that would experience congestion during both morning and afternoon peak periods. For example, I-285 eastbound between Northside Drive and Glenridge Drive would experience operational issues during the design year morning and afternoon peak periods, indicating a longer duration of congestion over the day and therefore a higher probability of crashes.

- With the proposed roadway improvements under Alternative 1 and Alternative 2, major crossing / weaving movements would be eliminated; major bottleneck locations along I-285 were addressed by providing additional interchange capacity. These improvements would significantly reduce the extent of congestion during the morning peak periods. On the other hand, during the afternoon peak periods, the extent of the proposed operational and interchange capacity improvements would be restricted due to capacity constraints at ends of the study area especially towards I-85.

- As discussed above, the proposed improvements under Alternative 1 and Alternative 2 would result in overall reduction in extent of congestion. This in turn would have a safety benefit and is evident in reduction in estimated crash rates along I-285 general-purpose lanes being lower as compared to statewide average crash rates for a similar facility type. The crash rates would continue to be higher than statewide average crash rates along I-285 travelling eastbound towards I-85 due to capacity constraints that would exist unless there are major capacity improvements along I-85 freeway segment.

- Under Alternative 3, the crash rates may not result in significant improvement over the No-Build/Do-Nothing alternative. This is primarily due to the impact of the reduction in one-lane mainline capacity along I-285. This outcome is in line with the results of the operational analysis, which showed poor traffic operations.

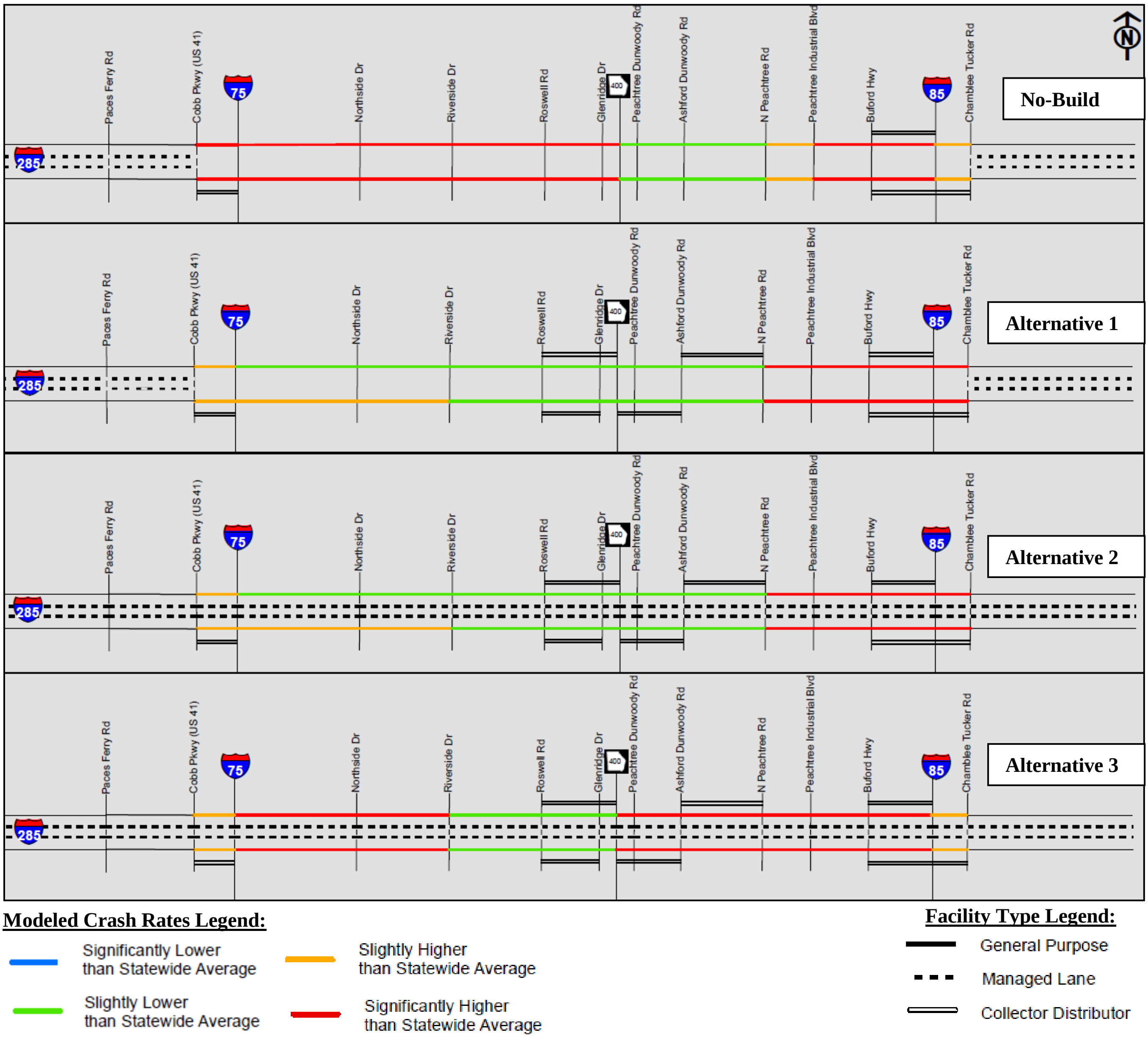

Figure 3: Predicted Crash Rates Summary, By Alternative

- The higher serviceability of I-285 managed/toll lanes under Alternative 2 and Alternative 3 would help reduce crashes along managed/toll lanes.

- Under the No-Build/Do-Nothing alternative, 81 percent of I-285 corridor miles would experience crash rates higher than the statewide average crash rates.

- Alternatives 1, 2, and 3 would have approximately 46 percent, 46 percent, and 78 percent, respectively, of I-285 corridor miles that would experience crash rates higher than the statewide average crash rates.

- In summary, Alternative 1 and Alternative 2 would have the greatest reduction in crash rates along the general-purpose lanes. With the additional capacity of the managed lanes under Alternative 2, one could expect a slightly higher reduction in crash rates under Alternative 2 as a system.

This predictive safety analysis clearly aids decision makers/stakeholders in making an informed decision in the selection of the preferred alternative. Incorporating this kind of safety information at the planning level is vital in improving the mobility and safety of freeway systems.

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