AN ANALYSIS OF VIOLATIONS ASSOCIATED WITH INTERSECTION-CROSSING-PATH CRASHES

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Paper Number 07-0284

ABSTRACT

This paper identifies and analyzes violations associated with intersection-crossing-path crashes for the purpose of providing support for development of effective collision avoidance countermeasure systems including the Cooperative Intersection Collision Avoidance System for Violation (CICAS-V) project. The methodology begins by addressing multi-vehicle crashes at intersection / intersection-related junctions subdivided by their respective traffic control devices. This is followed by translating crashes into subsets of two-vehicle crossing-path crashes and analyzing them in detail for their respective violations at various traffic control devices.

The analysis utilizes 2004 General Estimating System (GES) national crash data-files to arrive at the quantitative estimates. There were 1,035,000 two-vehicle-crossing-path crashes at intersections. A majority of the crashes involved vehicles at Straight crossing-paths followed by vehicles at Left turn across path / Opposite direction and Left turn across path / Lateral direction. The analysis provides adequate evidence of violators, the major contributors being *Failure to Yield*, which is due to the misjudgment of gap, and *Running a red light /Stop Sign*. Nearly half the crashes were at signalized intersections and the remaining at non-signalized intersections. For vehicles at Stop Signs, a majority of them were at a two-way Stop Sign.

The paper uses a novel approach by addressing pairs of vehicles and their interactions with each other at crossing-paths. The paper approaches violations by looking at the number of violating vehicles involved in each multi-vehicle crash situation. Pre-crash movement, critical event, and the type of traffic control device are utilized to identify the violating vehicle in each of these situations.

INTRODUCTION

The purpose of the paper is to determine the scope of violations at crossing-path intersection crashes using the National Automotive Sampling System (NASS)/ General Estimating System (GES) 2004 database of the National Highway Traffic Safety Administration (NHTSA). The paper addresses key areas of pre-crash behavior like critical event and vehicle maneuver combined with infrastructure components like traffic control device and junction type to estimate violations that produce crossing-path-intersection crashes.

Through the Cooperative Intersection Collision Avoidance Systems to avoid Violations at Stop Signs and Signals (CICAS-V) initiative, the USDOT is working in partnership with the Original Equipment Manufacturers(OEM) and State and local departments of transportation to pursue an optimized combination of autonomous-vehicle, autonomous-infrastructure and cooperative communication systems that potentially address the full set of intersection crash problems

The paper begins with the classification process and presents a general description of all crashes in the United States for their junction types. This leads to intersection-and intersection-related junctions and introduces multi-vehicle crashes at these junctions. This is followed by restricting the analysis to two-vehicle crashes and separating the data for their traffic control devices and their respective type of crossing-path.

The intermediate part of the paper presents the transformation process and describes the need for the transformation of data to address the crash situation. The paper progresses from crashes to vehicles and expands the available set of traffic control devices into appropriate combinations that address the crash situation. The paper introduces violations at this point and separates the vehicles into pairs of cited violations at intersections and identifies the violating vehicle among each pair.

The latter part of the paper presents a process for consolidation of uncited violations with cited violations so as to provide total estimates for all

violations at intersections. The process progresses through a series of steps by combining certain pre-crash scenarios like pre-event maneuver and critical event to arrive at conclusions about the unaccounted violations.

PREVIOUS WORK

Chovan et al. performed crossing-path crash studies using the Crashworthiness Data System (CDS) to device countermeasure concepts for the Intelligent Transportation System program. One part of the analysis dealt with straight crossing-path at signalized and un-signalized intersections [5, 6]. However, these studies did not distinguish crashes based on traffic control devices. Chovan et al. [7] also performed an analysis on vehicles turning left at intersections while the other vehicle was approaching from the opposite direction. This study did not differentiate between signalized and un-signalized intersections. Ragland and Zabyshny [4] developed taxonomy of Crossing-path crashes for the intersection decision support (IDS) project. The project would provide information to drivers through their Decision Support System builds on and previous work to provide possible IDS countermeasures at intersections with crossing-paths. However, the paper does not discuss the types of violations and their implications at these crossing-paths.

Wang et al. [8] produced a detailed report on the problem size assessment and statistical crash descriptions for intersection crossing-path-crashes using such measures as number of crashes, number and severity of injuries, number of fatalities, crash involvement rate, and crash involvement likelihood. In 2001, Najm et al. [1] performed a detailed analysis of the intersection problem by analyzing it for all types of junction; not just intersections. The paper deals with the understanding of the pre-crash scenario in order to evaluate proposed countermeasures for the intersection problem. The paper separates the intersection crashes by the pre-crash movement based on the type of crossing-path. Najm's paper serves as a model for the current paper. However, the current paper adds to the analysis by accounting for under-reported violations through a combination of critical event and pre-crash maneuvers to arrive at reasonable estimates.

ANALYSIS

The analyses of crossing-path intersection/ intersection-related crashes are broadly classified into the following three processes:

- Classification process
- Transformation process
- Consolidation process

1. Classification process

The process begins with a general description of the crash scenario and quantifies all crashes at intersection and intersection-related junctions. This is followed by restricting the analysis to two-vehicle crashes and separating the data into their respective crossing-path crashes. The activities involved in these processes are described below.

Type of Junction

The analysis begins by identifying the type of junction involved in crashes. Since 1992, junctions are broadly classified into *interchange* and *non-interchange areas*. The description of this is given below:

<u>Interchange/ Non-interchange-</u>The interchange area [3] is the area around a grade separation which involves at least two traffic ways. Included within its boundaries are: (1) all ramps which connect the roadways, and (2) each roadway entering or leaving the interchange to a point 30 meters beyond the gore or curb return at the outermost ramp connection for the roadway. One may find included within interchange area intersections, driveway accesses, and, of course, roadway sections which non-junctions are. This is illustrated in Figure 1[3].

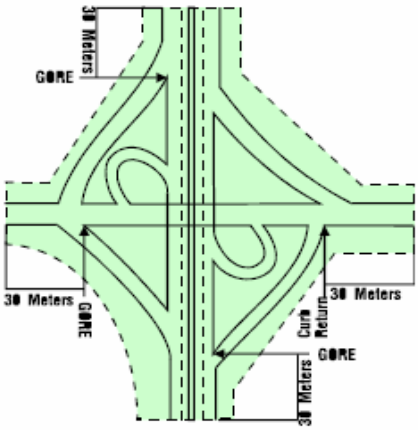

Figure1. Interchange and Non-interchange areas.

These areas are further classified into junction types as give below:

Non-Interchange
Code 0 Non-Junction
Code 1 Intersection
Code 2 Intersection Related
Code 3 Driveways, Alley Access, Etc
Code 4 Entrance/Exit Ramp
Code 5 Rail Grade Crossing
Code 6 On a Bridge
Code 7 Crossover Related
Code 8 Other, Non-Interchange
Code 9 Unknown, Non-Interchange

Interchange Area
Code 10 Non-Junction
Code 11 Intersection
Code 12 Intersection Related
Code 13 Driveways, Alley Access, Etc.
Code 14 Entrance/Exit Ramp
Code 16 On a Bridge
Code 17 Crossover Related
Code 18 Other Location in Interchange
Code 19 Unknown, Interchange Area

Combining interchange and non-interchange areas for all junctions, it is seen from Table 1 that there were 6,170,000 crashes in the United States in 2004. Among them, non-junctions account for 2,768,000(45%) of the crashes forming the biggest contributor followed by intersection and intersection-related junctions accounting for 1,304,000(21%) and 1,176,000(19%) of the crashes. Driveways and alley-access account for 568,000(9%) while enter/exit ramp account for 184,000(3%) of the crashes. Bridges, rail grade crossing, crossovers and others all together account for 170,000(3%) of the remaining crashes.

Table 1.
Distribution of all crashes for their junction types based on GES 2004

Type of Junction	GES Code	Crashes	Pct %
Non-Junction	***0,10***	2,768,000	**45%**
Intersection	***1,11***	1,304,000	**21%**
Intersection Related	***2,12***	1,176,000	**19%**
Driveway, Alley access	***3,13***	568,000	**9%**
Enter/Exit ramp	***4,14***	184,000	**3%**
On a bridge	***6,16***	99,000	**2%**
Others	***8,18***	45,000	**1%**
Crossover Related	***7,17***	11,000	**0%**
Rail Grade crossing	***5,15***	15,000	**0%**
Grand Total		**6,170,000**	**100%**

For the purpose of this study, the analysis is restricted to intersection and intersection-related junctions which are defined as follows:

Intersection: An intersection [3] is a type of junction which: (1) contains a crossing or connection of two or more roadways not classified as a driveway access or alley access, and (2) is embraced within the prolongation of the lateral curb lines or, if none, the lateral boundary lines of the roadways. Where the distance along a roadway between two areas meeting these criteria is less than 10 meters, the two areas and the roadway connecting them are considered to be parts of a single intersection.

Intersection-related: Intersection-related [3] means that the first harmful event: (1) occurs on an approach to or exit from an intersection, and (2) results from an activity, behavior or control related to the movement of traffic units through the intersection. Among the many types of intersections, a 4-leg intersection is used to illustrate the areas of concern which is shown Figure 2[3].

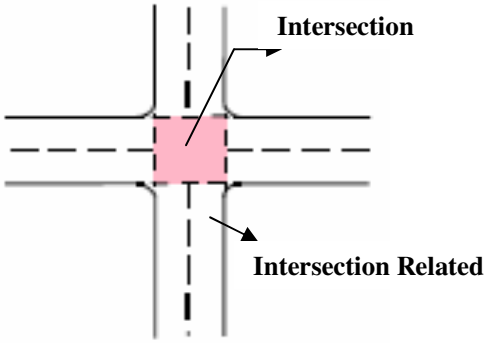

Figure 2. Intersection and intersection-related junctions.

It is seen from Table 2 that intersection and intersection-related crashes account for 2,480,000 of all crashes in the United States. Among them, intersections account for 1,304,000(53%) of the crashes and intersection-related crashes account for 1,176,000(47%) of the crashes. Also, 1,278,000 (52%) of them occur at a non-interchange/ intersection and 1,158,000 (46%) of them occur at a non-interchange / intersection-related junction. Also, Interchange / intersection and interchange / intersection-related junctions contribute to only around 1% each. It should be noted that intersection-related crashes were included to account for any intersection crash erroneously coded as intersection-related crashes.

Table 2.
Distribution of intersection / intersection -related crashes subdivided by the interchange and non-interchange areas.

Type of Junction	GES Code	Crashes	Pct %
Intersection		**1,304,000**	**53%**
Non-Interchange/ Intersection	*1*	1,278,000	52%
Interchange/ Intersection	*11*	26,000	1%
Intersection Related		**1,176,000**	**47%**
Non -Interchange/ Intersection-Related	*2*	1,158,000	46%
Interchange/ Intersection-Related	*12*	18,000	1%
Grand Total		**2,480,000**	**100%**

Table 2 summarizes the distribution of that Intersection/ Intersection-related crashes and leads to the distribution of vehicles involved in crashes.

Two-Vehicle-crashes

The data for intersection and intersection-related crashes from Table 2 are separated into single-and multi-vehicle crashes in Table 3. Multi-vehicle crashes are further separated into two-vehicle and greater-than-two-vehicle crashes. Table 3 also introduces traffic control devices associated with intersection / intersection-related crashes. The analysis utilizes three traffic control devices namely C*olors*, *Stop Sign* and *No Control*. The GES codes representing the traffic controls are as follows:

Code 00 No Controls
Code 01 Signal
Code 21 Stop Sign

According to the GES variable code manual, a vehicle is coded to be on *Colors* if the signal processes through the green, amber and red times [2]. A *Stop Sign* is coded in the police accident report if at least one vehicle involved in the accident was present at a Stop Sign. *No Control* is coded for vehicles if at the time of the crash, there is no intend to control (regulate or warn) vehicle traffic. This variable also applies when statutory warnings, deactivated or inactivated signs apply.

It is seen from Table 3 that two vehicle crashes account for 2,061,000(83%) of the intersection/ intersection-related crashes followed by single and more-than-two-vehicle crashes accounting for 241,000(10 %) and 177,000 (7 %) of the crashes. For the purpose of the current study, the analysis is restricted to two-vehicle crashes, since every vehicle is dynamically related to only one other vehicle. Also, this facilitates the process of separation. The single and the greater-than-two vehicle crashes, as seen by the shaded region in Table 3, are excluded in the subsequent analysis.

Among traffic control devices, *Signals* account for 1,214,000(49%) of the crashes followed by *Stop Signs* which account for 569,000(23%) of the crashes. *Uncontrolled intersections* account for 536,000(22%) of the crashes. All other types of controls like, y*ield signs*, *warnings signs* etc account for 160,000(6%) of the crashes as seen in Table 3.

Table 3.
Distribution of intersection / intersection-related single-, two-vehicle and greater-than-two-vehicle crashes against their traffic control devices.

Traffic control Device	Single vehicle	Two vehicles	Greater than two vehicles	Total
Colors	62,000	1,035,000	117,000	**1,214,000**
Stop Sign	54,000	498,000	17,000	**569,000**
No controls	104,000	399,000	33,000	**536,000**
Others	21,000	129,000	10,000	**160,000**
Total	241,000	**2,061,000**	177,000	**2,480,000**
Pct %	**10%**	**83%**	**7%**	**100%**

Thus, Table 3 summarizes two-vehicle intersection/ intersection related crashes for their respective traffic control devices and leads into their crossing-paths.

Crossing-path Crashes

The two-vehicle intersection/ intersection-related crashes (2,061,000 crashes) from Table 3 are separated into their respective crossing-path crashes in Table 4. By definition, crossing-path-intersection-crashes are defined as the type of crashes where one moving vehicle cuts across the path of another, while they were approaching each other from either perpendicular directions, and collide at or near a junction. GES codes these attributes for each vehicle in the *Vehicle file*. However, Table 4 represents the traffic control device at the crash level which need not necessarily be the same at the vehicle level. These issues are addressed in the forthcoming chapters. The codes used in GES for the different crossing-path crash situations are given below:

1: Code 68-69 Left turn across path/Opposite direction (LTAP/OD)

2: Code 82-83 Left turn across path/Lateral direction (LTAP/LD)
3: Code 76-77 Left turn into path (LTIP)
4: Code 78-79 Right turn into path (RTIP)
5: Code 86-89 Straight crossing path (SCP)
6: Code 74,75,80,81,84,85,90,91 Other Crossing Path

A pictorial representation of the graph is shown in Figure 3 [1]:

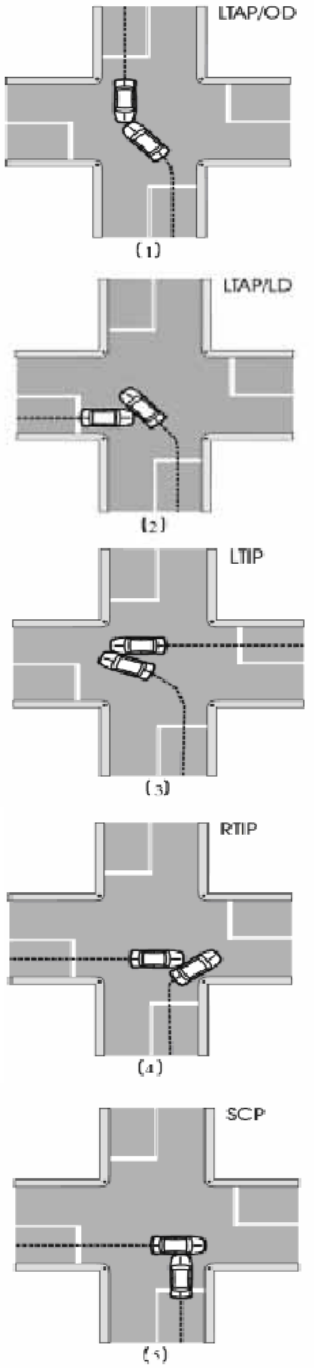

Figure 3. Descriptive diagram depicting the five crossing-paths: 1) LTAP/OD 2) LTAP/LD 3) LTIP 4) RTIP 5) SCP.

Table 4 summarizes the two-vehicle-intersection / intersection-related crashes and separates them between crossing-paths and non-crossing-path-crashes at intersections. It is seen that 1,114,000 (54%) of the two-vehicle intersection crashes are crossing-path crashes while 947,000(46%) involve non-crossing-path crashes like rear-end, lane-departure, side-wipe, backing etc., depicted by the shaded region. Also, other traffic control devices like yield signs, warning signs etc, are combined together as *Others*. This is shown in Table 4.

Table 4.
Distribution of two vehicle intersection/intersection - related crossing-path crashes for their traffic control devices including 'others/unknown'.

Two-vehicle intersection crashes	Colors	Stop sign	No Control	Others	Total
Crossing-path intersection crashes					
LTAP/OD	207,000	10,000	72,000	16,000	305,000
LTIP	14,000	28,000	14,000	3,000	59,000
RTIP	20,000	27,000	6,000	4,000	57,000
LTAP/LD	47,000	105,000	18,000	8,000	178,000
SCP	139,000	205,000	20,000	24,000	388,000
Other CP crashes	53,000	40,000	26,000	9,000	127,000
Total	**480,000**	**415,000**	**155,000**	**64,000**	**1,114,000**
Non-crossing-path two-vehicle intersection crashes					
Rear-end	447,000	55,000	155,000	48,000	705,000
Lane-change	45,000	2,000	28,000	6,000	82,000
Head-on	2,000	0	2,000	0	4,000
Side swipe/ Opp dir	2,000	1,000	4,000	0	7,000
Across path/ Same direction	27,000	4,000	36,000	3,000	70,000
Backing	14,000	11,000	5,000	3,000	33,000
Misc./ others	18,000	10,000	14,000	4,000	46,000
Total	**555,000**	**82,000**	**244,000**	**65,000**	**947,000**
Grand Total	**1,035,000**	**498,000**	**399,000**	**129,000**	**2,061,000**
	50%	24%	19%	6%	100%

Since the focus of this paper is on violations that lead to crossing-path crashes, two-vehicle non-crossing-path crashes are omitted from subsequent analysis. Also, crashes with *Other* type of traffic control devices are omitted as a means of simplifying the process. These are shown by the shaded regions in Table 4.

This leads to just two-vehicle intersection/ intersection-related crossing-path-crashes at traffic control devices of Signals, Stop Sign and No Controls as seen in Table 5. In Table 5, SCP crashes

are the biggest contributors with 364,000(35%) crashes followed by LTAP/OD and LTAP/LD with 289,000(28%) and 170,000(16%) crashes respectively. This is followed by LTIP and RTIP each contributing to 56,000(5%) and 53,000(5%) crashes respectively. The rest of the 119,000(11%) crashes are *other crossing-path crashes* like left turn/right turn combinations, lane-keeping etc. This is seen in Table 5 below.

Table 5.
Distribution of intersection/ intersection-related crossing-path crashes based on their traffic control devices excluding 'others/ unknown'.

Crossing path	Colors	Stop Sign	No Controls	Total
LTAP/OD	207,000	10,000	72,000	**289,000**
LTIP	14,000	28,000	14,000	**56,000**
RTIP	20,000	27,000	6,000	**53,000**
LTAP/LD	47,000	105,000	18,000	**170,000**
SCP	139,000	205,000	20,000	**364,000**
Other CP crashes	53,000	40,000	26,000	**119,000**
Total	**480,000**	**415,000**	**155,000**	**1,050,000**
Pct%	**46%**	**40%**	**14%**	**100%**

Table 5 summarizes the basic combination of all two-vehicle intersection/intersection-related-crossing-path crashes at traffic control devices of Signal, Stop Sign and No Controls.

2. Transformation Process

Table 5 presents the basic combination of the two-vehicle-crossing-path crashes at intersections. However, the challenges of identifying the violating vehicle, the appropriate traffic control device and the respective violation charged at the crash junction still prevails. These issues are addressed in detail in this section. The two key activities involved in the transformation processes are: 1) transformation of crashes to vehicles and 2) transformation of traffic control devices.

Transformation of crashes to vehicles: The key to an effective countermeasure system would be its ability to identify the violator or violating vehicle among a group of vehicles approaching each other at an intersection. Once identified, the system could warn or assist the violating driver of the impeding situation at the junction. This necessitates the inclusion of both vehicles in a two-vehicle crash. This is accomplished by moving the direction of the analysis for the two-vehicle-crossing-path crashes from the *Accident /Crash level* to the *Vehicle level*.

In order to better understand the situation, we examine the characteristics of the NASS/GES crash data files more closely. In GES, the *Accident file* contains information from 1988 to the current date on crash characteristics and environmental conditions at the time of the crash. There is one record per crash. The *Vehicle file* contains information describing the vehicles and drivers involved in the crash. There is one record per vehicle. The *Trafcon File* contains information of traffic control devices that govern each vehicle. It has one record for each traffic control device and, at least one record for every vehicle.

Thus, the *vehicle file*, in combination with the *trafcon file*, assigns the traffic control device to each individual vehicle instead of the crash. The number of crashes in Table 5 is transformed in Table 6 to the number of vehicles involved in the crash. Thus, situations for *Stop Sign /No Control* combinations where *This vehicle* was at a No Control while the *Other vehicle* was at a Stop Sign, were both assigned a *Stops Sign* at the crash level. However, the vehicle file assigns the respective traffic control device to each vehicle for such situations. This results in the re-arrangement in the estimates of crashes i.e. a decrease in crashes for Stop Signs (40% to 22%) in Table 5 and an increase in the number of vehicle for No control (14% to 32%) in the Table 6. Also, any combinations of known traffic controls (Signal, Stop Sign, No Control) for *This vehicle* with an *Unknown* traffic control for the other vehicle i.e. *Stop Sign-Unknown* or *No-Control-unknown* combinations were removed from further analysis. The result of these modifications is summarized in Table 6.

Table 6.
Distribution of vehicles involved in intersection/intersection-related crossing-path crashes based on their traffic control devices excluding 'other/unknowns'.

Crossing Path	Colors	Stop sign	No Control	Total
LTAP/OD	412,000	18,000	146,000	576,000
LTIP	29,000	29,000	52,000	110,000
RTIP	40,000	28,000	36,000	104,000
LTAP/LD	93,000	107,000	129,000	330,000
SCP	277,000	227,000	213,000	718,000
Other CP crashes	106,000	48,000	81,000	235,000
Total	**956,000**	**458,000**	**657,000**	**2,071,000**
Pct %	**46%**	**22%**	**32%**	**100%**

Transformation of Traffic control Devices: It is seen from Table 6 that intersections with signals account for 956,000(46%) of the vehicles in crashes and represent situations where both vehicles in either direction meet at a signal. Hence, the data for *Colors* represents both vehicles in that column and is consistent. However, the situation differs for *Stop Signs* and *No controls*. For situations with a *Stop Sign/ No Control* combination, i.e. situations where one vehicle is at a Stop Sign while the other vehicle is uncontrolled, the *Vehicle file* codes the traffic control of one vehicle to be at a *Stop Sign* while the other is coded to be at a *No control*. Thus one of the vehicles is represented by the 458,000(22%) vehicles at Stop Signs while the other vehicle is included in the 657,000(32%) vehicles at *No controls*. Also, situations where both vehicles are at a *Stop Sign* or *No controls* at an intersection are not separable from vehicles with *Stop Sign/ No Control* combinations in Table 6.

This necessitates the adjustment of the description of the traffic control devices at these junctions to adequately define the crash situation. The adjusted traffic control device for Signals, *Two-way Stop Sign*, Four-*way Stop Sign,* and *No control* is shown in Table 7. Thus, in the *Two-way Stop Sign* column, half of the 693,000 vehicles are at a *Stop Sign* while the other half are at a *No Control*. Both vehicles in the Four-*way Stop Sign* column are at a *Stop Sign*. Similarly, both vehicles in the No *Control* column are at an uncontrolled intersection.

From Table 7, it is seen that for vehicles at *Signals*, LTAP/OD and SCP were the major contributors for crossing-paths with 412,000(43%) and 277,000(29%) vehicles followed by (LTAP/LD) and (RTIP) with 93,000(10%) and 40,000(4%) vehicles. For vehicles at *Two-way-Stop Signs*, the major crossing-path types were SCP and LTAP/LD with 345,000(50%) and 187,000(27%) vehicles followed by contributions from LTIP and RTIP with 48,000 (7%) and 49,000 (7%) each. For vehicles at *Four-way Stop Signs* (except for LTAP/OD where the vehicles are in opposite directions), the biggest contributor was SCP with 55,000(50%) accounting for almost half of the crashes. This was followed by LTAP/OD and LTAP/LD with 16,000(14%) and 13,000(12%) vehicles. Small contributions were made from LTIP and RTIP with 6,000(3%) and 3,000(2%) vehicles. For vehicles at *No controls*, LTAP/OD is the biggest contributor with 144,000(46%) vehicles in crashes accounting for almost half of the crashes. This is followed by SCP and LTAP/LD with 40,000(13%) and 36,000(12%) vehicles. LTIP and RTIP contributed to 28,000(9%) and 12,000(4%) of the vehicles.

Table 7.
Adjusted distribution for traffic control devices for vehicles in two-vehicle intersection/ intersection-related crossing- path crashes

Crossing Path	Signals	Two way stop sign	Four way stop sign	No Control	Total
LTAP/OD	412,000	4,000	16,000	144,000	**576,000**
LTIP	28,000	48,000	6,000	28,000	**110,000**
RTIP	40,000	49,000	3,000	12,000	**104,000**
LTAP/LD	93,000	187,000	13,000	36,000	**329,000**
SCP	277,000	345,000	55,000	40,000	**717,000**
other CP crashes	106,000	60,000	18,000	51,000	**235,000**
Total	**956,000**	**693,000**	**111,000**	**311,000**	**2,071,000**

Table 7 summarizes the vehicles involved in two-vehicle intersection/ intersection-related crossing-path crashes. The remainder of the paper analyzes the role that violations play for the various types of crashes and types of traffic control devices.

Violations Charged

The NASS/GES data for violation is obtained either directly from an item on the Police Accident Report (PAR) or by interpreting the information provided in the report through reviewing the crash diagram, the officer's written summary of the crash, or combinations of variables on the PAR.
The variables used in GES to define the various violations are shown below:

Code 00: None
Code 01: Alcohol
Code 02: Drugs
Code 03: Speeding
Code 04: Reckless Driving
Code 05: Driving with a suspended or Revoked License
Code 06: Failure to Yield
Code 07: Running a Traffic Signal
Code 50: Hit and Run (No Information)
Code 97: Violation Charged- No details
Code 98: Other Violation

Table 8 introduces the types of violations that preceded these crashes at this point. The adjusted traffic control device and crossing-path from Table 7 are subdivided for their violations in Table 8.
For vehicles at *Signals*, 351,000 (37%) of the vehicles were cited for some kind of violation. Among them, *Failure to Yield* and *Red-light-running*

Table 8.
Distribution of vehicles involved in intersection/ intersection-related crossing-path crashes based on traffic control devices at the intersection subdivided by cited violations.

Traffic Control Device	Violation	LTAP/OD	LTIP	RTIP	LTAP/LD	SCP	Other CP crashes	Total
Signals	No Violation	256,000	19,000	25,000	57,000	175,000	74,000	606,000
	Alcohol and drugs	3,000	0	0	1,000	2,000	1,000	7,000
	Speeding	1,000	0	0	1,000	1,000	1,000	4,000
	Reckless driving	0	0	1000	0	0	0	1,000
	Failure to Yield Right of way	73,000	1,000	4,000	3,000	4,000	4,000	89,000
	Running a red-light/ Stop Sign	11,000	3,000	2,000	15,000	48,000	2,000	81,000
	Hit and run	8,000	2,000	1,000	3,000	9,000	7,000	31,000
	Others/unknown	60,000	3,000	7,000	13,000	38,000	17,000	138,000
	Total	**412,000**	**28,000**	**40,000**	**93,000**	**277,000**	**106,000**	**956,000**
Two way Stop Sign	No Violation	3,000	29,000	33,000	116,000	202,000	38,000	421,000
	Alcohol and drugs	0	0	0	1,000	2,000	1,000	4,000
	Speeding	0	0	0	0	1,000	1,000	2,000
	Reckless driving	0	0	0	1,000	1,000	0	2,000
	Failure to Yield Right of way	0	10,000	8,000	41,000	69,000	6,000	134,000
	Running a red-light/ Stop Sign	0	1,000	1,000	3,000	24,000	2,000	31,000
	Hit and run	0	3,000	2,000	4,000	9,000	3,000	21,000
	Others/unknown	1,000	5,000	5,000	21,000	37,000	9,000	78,000
	Total	**4,000**	**48,000**	**49,000**	**187,000**	**345,000**	**60,000**	**693,000**
Four way Stop Sign	No Violation	11,000	5,000	2,000	9,000	37,000	12,000	76,000
	Alcohol and drugs	0	0	0	0	1,000	1,000	2,000
	Speeding	0	0	0	0	0	0	0
	Reckless driving	0	0	0	0	0	0	0
	Failure to Yield Right of way	2,000	0	1,000	1,000	4,000	1,000	9,000
	Running a red-light/ Stop Sign	0	0	0	1,000	5,000	0	6,000
	Hit and run	1,000	0	0	0	2,000	1,000	4,000
	Others/unknown	2,000	1,000	0	2,000	6,000	3,000	14,000
	Total	**16,000**	**6,000**	**3,000**	**13,000**	**55,000**	**18,000**	**111,000**
No Controls	No Violation	94,000	19,000	9,000	26,000	26,000	35,000	209,000
	Alcohol and drugs	1,000	1,000	0	0	0	1,000	3,000
	Speeding	1,000	0	0	0	0	1,000	2,000
	Reckless driving	0	0	0	0	1,000	0	1,000
	Failure to Yield Right of way	23,000	3,000	1,000	4,000	7,000	1,000	39,000
	Hit and run	4,000	1,000	0	1,000	1,000	3,000	10,000
	Others/unknown	21,000	4,000	2,000	5,000	5,000	10,000	47,000
	Total	**144,000**	**28,000**	**12,000**	**36,000**	**40,000**	**51,000**	**311,000**
	Grand Total	**576,000**	**110,000**	**104,000**	**329,000**	**717,000**	**235,000**	**2,071,000**

were the major contributors with 89,000(9%) and 82,000(8%) vehicles followed by *Hit and run* with 30,000(3%) vehicles. Vehicles not cited for any violations accounted for 605,000(63%) vehicles

For vehicles at *Two-way-Stop Signs*, 272,000(39%) of the vehicles were cited for a violation. Among them, *Failure to Yield* was the major contributor for cited violations with 134,000(19%) vehicles in crashes accounting for almost half of the cited violation followed by *Running a Red-light* and *Hit and run* with 31,000(4%) and 21,000(3%). Among them, 421,000(61%) of the vehicles were not cited for any violation. For vehicles at *Four-way Stop*

Signs (except for LTAP/OD where the vehicles are in opposite directions), only 21,000(19%) were cited for a violation. *Failure to Yield* was the major contributor for cited violations with 9,000(9%) vehicles in crashes followed by *Red-light-running* and *Hit and run* with 6,000(8%) and 4,000(4%). Among them, 76,000(68%) of the vehicles were not cited for any violation.

For vehicles at *No controls*, 103,000 (33%) of the vehicles were cited for some kind of a violation. *Others /unknown* violations was the biggest contributor with 47,000(15%) accounting for almost half of the know violations. This was followed by *Failure to Yield* with 39,000(6%) vehicles constituting the remaining half of the known violations. *Hit and run* accounted for 10,000(3%) of the vehicles in crashes. Vehicles not cited for a violation accounted for 209,000(67%) of the crash vehicles. The details of violations are shown in Table 8.

It is seen from Table 8 that types of violations have not been documented for 13% of the crashes and 63% of the vehicles have not been cited for a violation. This is because NASS/GES data is obtained either directly from an item on the PAR or by interpreting the information provided in the report through reviewing the crash diagram, the officer's written summary of the crash, or combinations of variables on the PAR. Because of this interpretation, and because the police officer may not have entered some item of information or provided complete information, data can be missing. Table 8 summarizes violations using the adjusted traffic control devices.

In order to better understand this and other aspects of the data, it is classified into three groups of two-vehicle crashes: 1) vehicles with *violation by neither of the vehicles* 2) vehicles with *violation by only one of the vehicles* and 3) vehicles with *violation by both the vehicles*. This is seen in Table 9 below.

Table 9.
Distribution of vehicles involved in intersection/ intersection-related crossing-path crashes based on the number of vehicles cited by the GES codes for a violation.

Crossing Path Violation Charged		LTAP/OD	LTIP	RTIP	LTAP/LD	SCP	Other CP crashes	Total
Violation by none of the vehicles								
No Violation	Signals	142,000	12,000	15,000	30,000	98,000	49,000	346,000
	Two-way Stop Sign	2,000	13,000	20,000	59,000	89,000	19,000	202,000
	Four- way Stop Sign	7,000	4,000	2,000	6,000	22,000	8,000	49,000
	No Control	56,000	12,000	7,000	18,000	16,000	24,000	133,000
Total		**207,000**	**41,000**	**44,000**	**113,000**	**225,000**	**100,000**	**730,000**
Violation by one of the vehicles								
No Violation		156,000	32,000	26,000	95,000	215,000	58,000	582,000
Alcohol and drugs		4,000	0	0	2,000	4,000	3,000	13,000
Speeding		1,000	0	0	1,000	2,000	3,000	7,000
Reckless driving		0	1,000	0	1,000	1,000	0	3,000
Failure to Yield Right of way		88,000	13,000	12,000	44,000	77,000	11,000	245,000
Running a red-light/ Stop Sign		10,000	4,000	3,000	18,000	73,000	4,000	112,000
Hit and run		10,000	5,000	3,000	7,000	18,000	11,000	54,000
Others/unknown		43,000	7,000	7,000	22,000	39,000	27,000	145,000
Total		**312,000**	**62,000**	**51,000**	**190,000**	**429,000**	**117,000**	**1,161,000**
Violation by both the vehicles								
Alcohol and drugs		1,000	1,000	0	0	1,000	0	3,000
Speeding		0	0	0	1,000	0	1,000	2,000
Reckless driving		0	0	0	0	0	0	0
Failure to Yield Right of way		11,000	1,000	1,000	4,000	8,000	1,000	26,000
Running a Red-light/ Stop Sign		1,000	0	1,000	1,000	4,000	0	7,000
Hit and run		3,000	0	1,000	1,000	3,000	3,000	11,000
Others/unknown		41,000	5,000	6,000	20,000	47,000	12,000	131,000
Total		**57,000**	**7,000**	**9,000**	**27,000**	**63,000**	**17,000**	**180,000**
Grand Total		**576,000**	**110,000**	**104,000**	**330,000**	**717,000**	**234,000**	**2,071,000**

It is seen that there were 730,000(35%) vehicles in crashes where *neither of the vehicles* were cited for a violation, 1,161,000(56%) vehicles were in crashes where only *one of the vehicles* was cited for a violation and 180,000(9%) vehicles in crashes where *both vehicles* were cited for a violation. The group where neither of the vehicles was cited for a violation was further classified for their traffic control signals. Among the 730,000 vehicles, 346,000(47%) of the vehicles were at a Signal and 133,000(18%) were at uncontrolled intersections. Among *Stop Signs,* 202,000(28%) were at a *Two-way Stop Sign*, 49,000 (7%) were at a *Four-way Stop Sign*. This is seen in Table 9.

Table 9 summarizes the separation of crashes based on the number of violations cited for pairs of vehicles. Independent of police citations, the logical assumption would be that there exists at least one violator in each of these intersection crash situations. This is illustrated with an example from the group *violation by neither of the vehicles* consisting of 730,000 crash vehicles. Among them, 346,000 of the vehicles were at signals. In actuality, at least one vehicle among the 346,000 vehicles in every one of these crashes should have been cited for a violation. Yet, none of them were cited for a violation. Similarly, for a SCP scenario at a *Two-way Stop Sign*, a two-vehicle-crash situation is the result of a violation by at least one of the vehicles. However, from Table 8, out of the 89,000 vehicles (45,000 crashes), neither of the vehicles were cited for any violation.

Table 8 and 9 establish the foundation for the classification and analysis of violations. The tables throw light on the apparent inconsistencies among violations and provide a basis for their consolidation.

3. Consolidation Process

The process developed in this paper to overcome the inconsistency is similar to the imputation process used by *National Center for Statistics and Analysis (NCSA)* where the data from the *other/unknown* categories are randomly distributed among the known data based on the percentage distribution of the unknown with respect to the known population.

The process accounts for violations by looking at combinations of pre-crash factors associated with vehicle pre-crash maneuvers and critical events and arrive at a conclusion about the crash dynamics. This provides more reasonable estimates of crash situations that could be addressed by appropriate countermeasure systems.

The process of assigning violations to crash vehicles uses some general guidelines based on the logical dynamic of the crash situation. These guidelines would support the basis of the assumptions to arrive at conclusive estimates for violations. The guidelines include all crossing-path crash scenarios under investigation and combine them with their respective violations and traffic control devices. The consolidation eliminates the need for *Violation by neither of the vehicles* group thereby providing a consistent set of violations by at least one vehicle. The details of the guidelines used for *Red light running* and *Failure to Yield* are given in the Appendix.

The challenge that prevails in the imputation process is the identification of the violator. Each scenario displays a unique dynamic between vehicles and hence requires a detailed inspection of violations. The process becomes even more difficult when none of the vehicles are cited for a violation at an intersection. For this purpose, the c*ritical event* variable and the p*re-crash maneuver* variable are used to arrive at conclusions about the violator. The key elements of the imputation process are: 1) Consolidation of types of violations 2) Consolidation of violations with type of crossing-paths.

<u>Consolidation of types of violations:</u> For violations, *Red light running* and *Failure to Yield* were considered as primary events for the intersection crash criteria. *Alcohol and drugs*, *Speeding, Reckless driving* and *Hit and Run* were considered to be preceding or precipitating events to these two primary violations. Each vehicle with one of these events was examined for their pre-crash maneuver and critical event. These events were cross-referenced with their respective crossing-paths and traffic control devices to identify possible *Failure to yield* or a *Red light run* violation for consolidation with the primary event. Combinations that did not meet the criteria were consolidated with *Others*. *For e.g. Driving with a suspended license* was not considered to be a related violation and hence was combined with *Others*.

<u>Consolidation of violations with types of crossing -paths</u>: Crossing-paths were also examined while assigning violations. For *Straight paths*, the focus of violation is only on the vehicle that is assigned the critical event of *This vehicle crossing intersection*. This is consistent with GES coding practice of having the initial critical event reflect the point of view of the causal vehicle. For *Left turn paths*, the violation is assigned to the vehicle with pre-event maneuver of turning and the critical event assigned to the vehicle

as *This vehicle turning OR* pre-event maneuver of going straight and the critical event assigned to the vehicle as *This vehicle going straight.* For *Right-turn paths*, the turning vehicle is assigned the violation unless the critical event is assigned elsewhere.

Vehicle speeds were also used in cases where the available information was not sufficient to describe the scenario. Conclusions from a previous study [9] showed that more than half of the red light runners were at a speed of 30 mph or less and the average speed was about 31.6. Based on the above conclusions, and certain assumptions made on vehicle dynamics, vehicles with speeds of greater that 25 mph and turning were cited for violations.

The consolidation process is further supported by a secondary extraction/validation process. In this process, the data is inspected for irregularities and inconsistencies that might have escaped the logical steps of the guidelines. Such situations were fixed manually by observing each scenario individually and correcting them when required. The process was repeated for each step of the consolidation process. The final data set showing the adjusted distribution of vehicles involved in intersection and intersection-related crossing-path crashes for their respective traffic control devices at the intersection subdivided by their violations is seen in Table 10.

It is seen that there were 956,000(46%) vehicles involved in crashes at *Signals*, 693,000(34%) vehicles at a *Two-way Stop Sign*, 111,000(5%) vehicles at a *Four-way Stop Sign*, and 311,000(15%) vehicles with *No controls*. Among Crossing-path crashes, SCP was the biggest contributors with 718,000(35%) vehicles followed by LTAP/OD and LTAP/LD with 576,000(28%) and 329,000(16%) vehicles. This is followed by vehicles at LTIP and RTIP each contributing to 110,000(5%) and 104,000(5%) vehicles.

For vehicles at *Signals*, the major contributors were LTAP/OD and SCP with 412,000(43%) and 277,000(29%) vehicles involved in crashes followed by LTAP/LD and RTIP with 93,000(10%) and 40,000(4%) vehicles. Also, 423,000(44%) of the vehicles were not cited for a violation. The major contributor for violation was *Failure to yield* with 266,000(28%) vehicles in crashes followed by *Running a red light* violation with 194,000(20%) vehicles involved in crashes. *Other* violations contributed to 73,000(8%) of the vehicles in crashes

For vehicles at T*wo way Stop Signs*, SCP contributed to 345,000(50%) vehicles while LTAP/LD contributed to 187,000(27%) vehicles. RTIP and LTIP contributed to 49,000(7%) and 48,000(7%) vehicles. Among violations, 298,000 (43%) of the vehicles were cited for *Failure to yield*, which forms the majority of the violations. This is expected since a two way Stop Sign is a typical situation where one of the vehicle is controlled by a Stop Sign intending to go straight or turn (left/right) at the intersection while the other vehicle is on an uncontrolled roadway going straight. *Running a Stop Sign* contributes to only 31,000 (4%) of the crash vehicles. From previous studies [1] it is seen that people generally don't run Stop Sign and thus form a very small portion of the statistic. *Other* violations contributed to 39,000 (6%) of the vehicles.

Four-way Stop Signs are similar to *Two-way Stop Sign*, since a majority of them are *Failure to yield* cases where one of the vehicles does not stop long enough for the other vehicle to pass. Almost all of these crashes fall in the SCP scenario, which involve 55,000(50%) vehicles and contribute to half of the crossing-path crashes. This is followed by LTAP/OD and LTAP/LD which contribute to 16,000(14%) and 13,000(12%) of the vehicles in crashes. Also, *Failure to yield* is the major contributing violation with 49,000(44%) vehicles, accounting for almost half the crashes followed by *Running a Stop Sign* with 6,000(5%) vehicles. *Other* violations contributed to 6,000(5%) of the vehicles

For vehicles at *No controls*, the LTAP/OD is the biggest contributor with 144,000(46%) vehicles in crashes accounting for almost half of the crashes. This is followed by SCP and LTAP/LD with 40,000(13%) and 36,000(12%) vehicles. Also, *Failure to Yield* seems to be the major contributor of violations with 140,000(45%) vehicles constituting half of the violations. *Other* violations contributed to 23,000(7%) of the vehicles

Similarly, Table 11 provides the adjusted distribution of violating vehicles involved in intersection/ intersection-related crossing-path crashes grouped by the number of vehicles cited for a violation. It is seen that there are 1,891,000(91%) vehicles in crashes with at least one of the vehicles involving a violation and 180,000(9%) vehicles where both vehicles involved a violation.

Among *violation by one of the vehicles*, 693,000(37%) of them have a *Failure to Yield* violation while 182,000(10%) have a *Running a red light* violation. *Also, 35,000(2%)* of the vehicles had a *Running a Stop Sign* violation while 946,000(50%) of the vehicles were not assigned any violation at all.

For *violation by both vehicles*, 62,000(34%) of the vehicles had a *Failure to Yield* while 12,000(7%) of the vehicles had a *Running a red light* violation. *Other* violations contributed to 103,000 (57%) of the vehicles.

Table 10.
Adjusted distribution of vehicles involved in intersection and intersection-related crossing-path crashes based on the traffic control devices at the intersection subdivided by violations.

Traffic control Device	Violation	LTAP/OD	LTIP	RTIP	LTAP/LD	SCP	Other CP crashes	Total
Signals	No Violation	185,000	13,000	18,000	42,000	126,000	39,000	423,000
	Running a Red light	14,000	11,000	2,000	36,000	121,000	10,000	194,000
	Failure to yield	193,000	0	15,000	5,000	1,000	52,000	266,000
	Others	20,000	4,000	5,000	10,000	29,000	5,000	73,000
	Total	**412,000**	**28,000**	**40,000**	**93,000**	**277,000**	**106,000**	**956,000**
Two-way Stop Sign	No Violation	2,000	23,000	23,000	87,000	159,000	31,000	325,000
	Running a Stop Sign	0	1,000	1,000	3,000	24,000	2,000	31,000
	Failure to yield	2,000	22,000	22,000	87,000	141,000	24,000	298,000
	Others	0	2,000	3,000	10,000	21,000	3,000	39,000
	Total	**4,000**	**48,000**	**49,000**	**187,000**	**345,000**	**60,000**	**693,000**
Four-way Stop Sign	No Violation	7,000	2,000	1,000	6,000	24,000	10,000	50,000
	Running a Stop Sign	0	0	0	1,000	5,000	0	6,000
	Failure to yield	8,000	3,000	2,000	5,000	24,000	7,000	49,000
	Others	1,000	1,000	0	1,000	2,000	1,000	6,000
	Total	**16,000**	**6,000**	**3,000**	**13,000**	**55,000**	**18,000**	**111,000**
No Controls	No Violation	66,000	13,000	6,000	17,000	18,000	29,000	149,000
	Failure to yield	72,000	12,000	4,000	17,000	19,000	15,000	139,000
	Others	6,000	3,000	2,000	2,000	3,000	7,000	23,000
	Total	**144,000**	**28,000**	**12,000**	**36,000**	**40,000**	**51,000**	**311,000**
Grand Total		**576,000**	**110,000**	**104,000**	**329,000**	**717,000**	**235,000**	**2,071,000**

Table 11.
Adjusted distribution of vehicles involved in intersection/ intersection-related crossing-path crashes based on the number of vehicles cited by the GES codes for a violation.

	Violation	LTAP/OD	LTIP	RTIP	LTAP/LD	SCP	Other CP crashes	Total
Violation by one of the vehicles	No Violation	260,000	50,000	48,000	152,000	328,000	108,000	946,000
	Running a red light	13,000	11,000	2,000	34,000	113,000	9,000	182,000
	Running a Stop Sign	0	1,000	1,000	4,000	27,000	2,000	35,000
	Failure to yield	247,000	36,000	40,000	107,000	168,000	95,000	693,000
	Others	0	4,000	4,000	5,000	19,000	3,000	35,000
	Total	**520,000**	**102,000**	**95,000**	**302,000**	**655,000**	**217,000**	**1,891,000**
Violation by both the vehicles	Running a red light	1,000	0	0	2,000	8,000	1,000	12,000
	Running a Stop Sign	0	0	0	0	2,000	0	2,000
	Failure to yield	30,000	1,000	3,000	8,000	17,000	3,000	62,000
	Others	26,000	6,000	6,000	17,000	36,000	13,000	103,000
	Total	**57,000**	**7,000**	**9,000**	**27,000**	**63,000**	**17,000**	**180,000**
	Grand Total	**576,000**	**110,000**	**104,000**	**329,000**	**717,000**	**235,000**	**2,071,000**

Table 10 and Table 11 summarize the adjusted violations for all vehicles involved in two-vehicle Intersection/ Intersection-related crossing-path crashes for their respective traffic control devices. The analysis provides a fundamental understating of crossing-path intersections and the violations associated with these junctions. Further analysis of driver factors like distraction and vision obstruction would help better understand the crash situation to provide adequate countermeasure systems at these junctions.

CONCLUSIONS

An analysis of violations associated with intersection crossing-path crashes was conducted using the 2004 GES data for the purpose of providing guidance for the CICAS-V project. The analysis was aimed at providing insight on the crossing-path problem. The results of the analysis may enable the authors and other interested parties with the ability to better ascertain and possibly devise appropriate collision avoidance countermeasures at such intersections. However, the recommendation of a particular countermeasure at this stage of research and analysis of crossing-path crashes would be premature. More statistical analysis including the all important Human Factors element must be incorporated into any potential countermeasure solution.

There were almost 1.1 million police reported two-vehicle intersection-crossing-path crashes for the year 2004 which constituted about 17% of all crashes in the United States. All crashes occurred at an intersection or were intersection-related. The analysis was restricted to traffic control devices of Signals, Stop Signs and No Control.

Underlying concept of the analysis is that most crossing-path crashes involve either a *Running a red light* or *Failure to yield* type of violation. The paper was successful in addressing under-reported violations for pairs of vehicles and their interactions with each other at crossing-paths using pre-crash movement, critical event, and the type of traffic control device to identify the violating vehicle in each of these situations. This has resulted in a two-fold increase in *Red light running* situations (81,000 to 194,000 vehicles) and a three-fold increase in *Failure to Yield* situations (271,000 to 755,000).

A summary of the findings of the analysis includes the following statements:
Vehicles at signalized intersections contributed the most number of crashes accounting for 956,000(46%) of the vehicles in crashes. Among them, *Failure to Yield* contributed to 267,000(28%) vehicles while *Running a red light* accounted for 194,000(20%) vehicles. This is followed by vehicles at *Stop Signs* with 803,000(39%).

Among *Stop Signs*, the crashes were distributed between *Two-way Stop Signs* and *Four way Stop Signs*. Two-way Stop Signs contributed to 693,000(86%) of the vehicles where the vehicles were at a *Stop Sign* /N*o Control* combination. Among them, Failure *to yield* accounted for 298,000(43%) violations while *Running a Stop Sign* accounted for 31,000(4%) violations.

Crashes at *Four-way Stop Signs* contributed to 111,000(14%) vehicles where both vehicles were at a *Stop Sign*. Among them, *Failure to yield* accounted for 49,000(44%) violations while *Running a Stop Sign* accounted for 6,000(5%). Uncontrolled intersection contributed to 311,000(15%) vehicles. Among them, *Failure to Yield* accounted for 140,000(45%) of the violations.

Among crossing-paths, SCP crashes were the biggest contributors with 717,000(35%) vehicles followed by LTAP/OD and LTAP/LD with 576,000(28%) and 329,000(16%) vehicles. This is followed by vehicles at LTIP and RTIP each contributing to 110,000(5%) and 104,000(5%) vehicles. *Other* crossing-path crashes contributed to 235,000 (10%) of the vehicles.

Also, the analysis showed that among pairs of vehicles in crashes, 1,891,000(92%) of the vehicles had one vehicle cited for a violation. Among them, 693,000(37%) of the vehicles were cited for *Failure to Yield* while 182,000(10%) were cited for *Running a red light*. *Running a Stop Sign* contributed for 35,000(2%) of the vehicles. Also, 180,000(8%) of the vehicles were involved in crashes where both vehicles were cited for a violation. Among them *Failure to Yield* contributed to 62,000(34%) vehicles in crashes while *Running a Red light* contributed to 12,000(19%) vehicle.

ACRONYMS

PAR- Police Accident Report
NASS- National Automotive Sampling System
GES- General Estimating System
CDS- Crashworthiness data system
LTAP/OD- Left Turn across Path/ Opposite direction
LTAP/LD-Left Turn across Path / Lateral direction
LTIP-Left turn into path
RTIP-Right turn into path
SCP-Straight crossing-path

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APPENDIX

GUIDELINES FOR THE EXTRACTION PROCESS FOR VIOLATIONS

The guidelines provide details of the process used to consolidate violations at crossing-path by looking at combinations of vehicle pre-crash maneuvers and critical events for certain vehicle dynamics and arrive at a conclusion on the violator. The violations are classified between *Running a red light* and *Failure to yield* violations.

Running a Red Light

LTAP/OD

- If none of the vehicles were cited for a violation, then the onus of yielding falls on the turning vehicle since no information is available on the violating vehicle. Thus, if the vehicle was turning with a critical event of *this vehicle turning* and traveling at a speed greater that 25 mph at a signal, it was considered *Running a red light.*

Exception: the critical event could be due to the vehicle coming straight but is assigned to this vehicle.

- If at least one of the vehicles had a violation AND if a vehicle was cited for speeding or reckless driving or red light run, then cited for *Running a red light.*

LTIP

- If none of the vehicles were cited for a violation AND the critical event on *this vehicle* was turning or going straight at a signal, it was considered a red light run.
- If at least one of the vehicles had a violation AND if the vehicle was turning or going straight with a critical event on *this vehicle*, OR cited for red light run or hit and run, then cited for *Running a red light.*

RTIP

- If at least one of the vehicles had a violation AND cited for red light run, then cited for *Running a red light.*

LTAP/LD

- If none of the vehicles were cited for a violation AND a critical event on *this vehicle* was turning or going straight at a signal, it was considered a red light run.
- If at least one of the vehicles had a violation AND if the vehicle was turning or going straight with a critical event on *this vehicle*, and cited for speeding or reckless driving or hit and run or red light run, then cited for *Running a red light.*

SCP

- If none of the vehicles were cited for a violation AND a critical event on *this vehicle* was going straight at a signal, it was considered a *Red light run*.
- If at least one of the vehicles had a violation and a critical event on *this vehicle* was *going straight* at a signal, then cited for *Running a red light.*

Other crossing-paths

- If none of the vehicles were cited for a violation AND if the vehicle was turning or going straight with a critical event on *this vehicle* and speed greater than 25, it was cited for *Running a red light.*
- If at least one of the vehicles had a violation AND if the vehicle cited for running a red light or hit run or vehicle was speeding or reckless driving while turning, then cited for *Running a red light.*

Failure to Yield

LTAP/OD

- If none of the vehicles were cited for a violation and at a Signal or Stop Sign or No Control AND with a pre crash maneuver of turning and critical event of *this vehicle* turning or excessive speed or over the lane line OR critical event of *this vehicle* starting from a traffic lane , it was considered a *Failure to yield.*

Exception: the violation could be due to the vehicle coming straight but is still attributed to *this vehicle*, usually the turning vehicle.

- If at least one of the vehicles had a violation and at a Signal or Stop Sign or No Control AND with a critical event of *this vehicle turning* or *going straight* and some cited violation OR violation of Failure to Yield OR a critical event of *this vehicle* starting from a traffic lane , it was considered a *Failure to yield.*

LTIP

- If none of the vehicles were cited for a violation and at a Stop Sign or No Control AND vehicle with a critical event of *this vehicle turning* or *going straight*, it was considered *Failure to yield.*

- If at least one of the vehicles had a violation and at a Stop Sign or No Control AND vehicle with a critical event of *this vehicle turning* or *going straight* and cited for any violation, it was considered *Failure to yield.*

RTIP

- If none of the vehicles were cited for a violation and at a Signal or Stop Sign or No Control AND vehicle with a critical event of *this vehicle turning right*, it was considered *Failure to yield.*

- If at least one of the vehicles had a violation and at a Signal or Stop Sign or No Control AND vehicle with a critical event of *this vehicle turning right* or *going straight* and cited for any violation, it was considered *Failure to yield.*

LTAP/LD

- If none of the vehicles were cited for a violation and at a Signal or Stop Sign or No Control AND vehicle with a critical event of *this vehicle turning left* or *going straight* or *over the lane line* , it was considered *Failure to yield.*

- If at least one of the vehicles had a violation and at a Signal or Stop Sign AND vehicle with a critical event of *this vehicle turning left or going straight* AND a violation of speeding or reckless driving or failure to yield OR vehicle turning right and cited for violation of hit and run or other violations , it was considered *Failure to yield.*

SCP

- If none of the vehicles were cited for a violation and at a Stop Sign or No Control AND vehicle with a critical event of *this vehicle turning left or going straight*, it was considered *Failure to yield.*

- If at least one of the vehicles had a violation and at a Stop Sign or No Control AND vehicle with a critical event on *this vehicle going straight* and cited for some sort of violation , it was considered *Failure to yield.*

Other crossing-paths

- If none of the vehicles were cited for a violation and at a signal AND vehicle with critical event of *this vehicle turning or going straight* OR *critical event NOT the other vehicle over the lane line* OR crossing intersection OR Stop Sign or No Control OR vehicle with critical event of *this vehicle turning* OR poor road conditions or *excessive speed* OR pre crash maneuver was *starting from a traffic lane*, it was considered a *Failure to Yield.*
- If at least one of the vehicles had a violation and at a Signal- pre maneuver of turning left or a cited violation , it was considered *Failure to yield.*
- If at least one of the vehicles had a violation and at a Stop Sign or No Control AND critical event of over the lane line or starting from the lane OR pre-crash maneuver of turning left with other/unknown violations, it was considered *Failure to yield.*