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**Intersection Decision Support Project:
Taxonomy of Crossing-Path Crashes at Intersections Using GES 2000 Data**

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ABSTRACT

The Intersection Decision Support (IDS) Project is designed to reduce crossing-path (CP) crashes at intersections by providing crucial information to drivers that would help them avoid such crashes. Over the past decade, researchers have used the General Estimates System (GES, a representative sample of police-reported crashes in the US) and other data sources to develop a taxonomy of CP crashes and pre-crash scenarios as groundwork for crash-prevention efforts. The current study builds on and extends prior work by constructing a taxonomy of CP crashes using data from the 2000 GES and identifying potential corresponding IDS countermeasures. Analyses differ from previously published analyses in that traffic control device data was available at the *vehicle* level, and not just at the *crash* level. This allowed more detailed study of crashes by traffic control device. Findings included documentation that crashes at intersections represent a very high percentage of all U.S. crashes, making intersections relatively high-risk areas compared to other roadway segments. Also, CP crashes constituted a substantial portion of total crashes in the US, including 25% of all crashes and about 45% of crashes at intersections. Patterns of CP crashes differed substantially by type of intersection (defined by traffic control device), and these differences in crash patterns reflected varied underlying causal factors that required tailored IDS countermeasures. In addition, CP collisions at intersections took place at moderate speeds, which is important for algorithms for warning systems. Finally, older drivers were over-represented in crossing-path collisions at intersections. IDS countermeasures will need to account for findings on intersections here and elsewhere that address driver behavior and vehicle movement and conflict.

INTRODUCTION

The Intersection Decision Support (IDS) Project was developed by the Infrastructure Consortium to use emerging Intelligent Transportation Systems (ITS) technologies to reduce crossing-path (CP) crashes at intersections. The Infrastructure Consortium included the US Department of Transportation (DOT), California DOT, Minnesota DOT and Virginia DOT. In support of the IDS Project, this paper presents a detailed analysis of patterns of CP collisions at intersections and identifies potential ITS countermeasures for each pattern.

Since the early 1990s, several researchers have investigated the various types of CP crashes at intersections. Chovan and colleagues investigated CP crashes using sets of collisions drawn from the Crashworthiness Data System (CDS) [1, 2, 3]. Wang and Knipling [4] used the General Estimates System (GES, a nationally representative sample of police-reported crashes) to generate national estimates of CP crashes at intersections. Najm and colleagues used a set of collisions from the CDS to study causal factors for various types of crashes, including CP crashes [5]. Recent studies have extended earlier work. In particular, Najm and colleagues have developed a systematic taxonomy of CP crashes based on the GES coding system, and they have used the GES to develop national estimates and to study potential causal factors [6-8].

This paper uses data from the Year 2000 GES to build on these studies. Specifically, this paper will:

- Clarify the definition of CP crashes at intersections using terminology of the GES;
- Describe types of crashes at intersections by traffic control configuration, providing a discussion of possible causal factors, traditional engineering countermeasures, and possible ITS countermeasures.

METHODS

Findings in this paper are based on the crash database from the Year 2000 *National Automotive Sampling System (NASS) General Estimates System (GES)* [9, 10]. The GES is a nationally representative sample of police-reported crashes that includes vehicle types as well as crash severity. The record includes about 50,000 sample cases each year and includes variables recorded in standard police accident reports (PARs).

The GES uses sampling weights to generate national estimates of the number of different types of crashes. Although the GES is accessible and well documented, it has several drawbacks. *First*, since it relies solely on PARs data, it is limited by the range and quality of information recorded by police officers. For example, variables such as alcohol involvement [11] and driver distraction are almost certainly underreported. *Second*, since not all crashes are reported to the police, the GES record substantially underestimates the number of crashes nationally, with the degree of underestimation roughly inverse to the severity of the collision (i.e., underestimation is greatest for least serious crashes) [11]. *Finally*, the GES includes no “exposure” data; i.e., using GES data alone, it is impossible to calculate rates per unit of exposure (e.g., per number of vehicles on the highway, per vehicle mile) for different types of crashes or injuries. Any identification of causal factors in crashes based on GES data alone should be interpreted cautiously.

The GES includes variables at three levels: the accident, vehicle occupants, and the vehicle itself. This paper analyzes data on the type of junction, crash type, traffic control device, posted speed limit, and age and gender of driver.

RELATION OF CRASHES TO JUNCTION TYPES

Description of the Variables

A *junction* is the area formed by the connection of two roadways. An *intersection* is a type of junction that (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 the lateral boundary lines of the roadways.[9, 10].

In the GES, a crash is assigned an “intersection” code “when the first harmful event occurs within the area formed by the prolongation of curb or edge lines of the approach legs of the intersection. An “intersection-related” code is assigned when the first harmful event occurs outside but near an intersection and involves a vehicle which was engaged or should have been engaged in making an intersection-related maneuver such as a turn [9, 10].

Distribution of Crashes

Table 1 shows the distribution of crashes by type of junction. Most crashes (59.7%) take place at junctions, and most of these (43.9% of all crashes) occur at intersections (23.8%) and near intersections (20.2%). Consistent with previous studies, the “intersection” variable used here will include both “intersection” crashes and “intersection-related” crashes.

Crash Types

This paper’s “crash type” variable was derived from the “crash type” variable in the GES data (V23). When crashes are coded, they are mapped onto a diagram by accident type, and a number is assigned to each vehicle based on the type of crash and role of the vehicle in the crash. For example, a vehicle that runs into the back of another vehicle that is stopped but poised to turn left is defined by crash types “20”, while the other is coded “22” (vehicle stopped to turn left).

To reconstruct a particular crash event in the GES data, it is necessary to view the pattern of crash types for all vehicles involved in the event. In the example above, the vehicle-level code for each of a pair of vehicles would be “20” and “22,” and the combination of these two would define the type of crash as a “rear end” crash. Most often, when there are more than two vehicles in a crash and any particular pair of vehicles defines a crash type, then most other vehicles in the crash event will have a code indicating “unknown” or “other.”

The GES includes a fixed number of pre-coded crash types, and CP crashes are identified by pre-defined combinations. Najm and colleagues [6] used the GES categories to focus on five types of CP crashes. For example, straight CP (SCP) crashes are defined if a pair of vehicles is assigned the numbers 86 and 87 or 88 and 89, respectively. Najm and colleagues’ taxonomy [6] follows, with corresponding GES codes in parentheses:

1. Left Turn Across path - Opposite Direction Conflict (LTAP/OD) (68/69)
2. Left Turn Across path - Lateral Direction Conflict (LTAP/LD) (82/83)
3. Left Turn Into Path - Merge Conflict (LTIP) (76/77)
4. Right Turn Into Path - Merge Conflict (RTIP) (78/79)
5. Straight CP (SCP) Crashes (86/87 or 88/89)
6. Other crashes

Additional crashes have been categorized within GES as “Other crossing-path crashes” [13]. For example, if a vehicle is entering an intersection and turning left, it might experience a collision with another vehicle proceeding from the:

1. opposite direction and turning left;
2. opposite direction and turning right;

3. lateral direction (left) and turning left; or the
4. lateral direction (right) and turning left.

Because we were interested in comparing CP crashes at intersections with non-CP crashes at intersections, we aggregated all “other” GES crashes into four categories: rear end crashes, crashes involving pedestrians and bicyclists, single-vehicle crashes, and (iv) other non-CP crashes.

Table 1 shows the frequency and distribution of crash types. One-quarter of all GES crashes were CP crashes.

	GES Codes	Number of Crashes	Percent
Location of Crash			
Non-Junction	0,10	2,572,747	40.3
Junction			
Intersection	1,11	1,518,102	23.8
Intersection Related	2,12	1,289,460	20.2
Driveway, Alley Access, Etc.	3,13	676,824	10.6
Entrance/Exit Ramp	4,14	163,990	2.6
Rail Grade Crossing	15	56,686	0.9
On A Bridge	6/16	15,329	0.2
Other, Non-Interchange	7/17, 8/18	96,173	1.5
Total Crashes		6,389,310	100.0
Type of Crash			
<i>Crossing-Path Crashes (total)</i>		1,595,879	25.0
LTAP-OD	68/69	427,054	6.7
LTAP-LD	82/83	306,813	4.8
RTIP	78/79	94,306	1.5
LTIP	76/77	93,178	1.5
SCP	86/87 88/89	546,941	8.6
Other Crossing-Path Crashes	70/71 72/73 74/74 75/75 80/81 84/84 85/85 90/90 91/91*	127,587	2.0
<i>Non Crossing-Path Crashes (total)</i>		4,793,431	75.0
Rear End	20/33**	1,797,934	28.1
Pedestrian/Bike	13	385,471	6.0
Single Vehicle		1,319,798	20.7
Other Crashes***	All other types	1,290,228	20.2
Total Crashes		6,389,310	100.0

*When “other” is coded, each of a pair of vehicles has the same number.

**All rear end-crashes are defined by combinations of codes between 20 and 33.

***Other crashes include single driver, head on, and sideswipe.

CRASHES AT JUNCTIONS

Table 2 shows the distribution of crashes for intersections, non-intersection junctions, and non-junctions. CP crashes are about 25% of all crashes, but they constitute more than 44% of intersection crashes and about 36% of non-intersection junction crashes. Only a small number of CP crashes are reported for non-junctions. A substantial proportion of all three types of junctions are rear end crashes.

There are some similarities in the pattern of crashes at intersections and non-intersection junctions. Both LTAP-OD and LTAP-LD are among the top three in both cases. The major exception is SCP, which is most frequently reported in intersections and among the least frequently reported for non-intersection junction crashes.

Crash Type	Junction Type						Total	
	Non-Junction		Intersection		Non-Intersection		Number	Percent
Crashes	Number	Percent	Number	Percent	Number	Percent	Number	Percent
LTAP-OD	2,602	0.1	340,739	12.1	83,713	8.3	427,054	6.7
LTAP-LD	1,008	0.0	193,439	6.9	112,366	11.1	306,813	4.8
RTIP	791	0.0	58,885	2.1	34,630	3.4	94,306	1.5
LTIP	592	0.0	54,782	2.0	37,804	3.7	93,178	1.5
SCP	3,036	0.1	499,568	17.8	44,336	4.4	546,941	8.6
OTHER CP	1,792	0.1	99,903	3.6	25,891	2.6	127,587	2.0
Total Crossing path Crashes	9,821	0.4	1,247,316	44.4	338,740	33.6	1,595,879	25.0
Non-crossing-path crashes								
REAR END	627,465	24.4	904,749	32.2	265,720	26.3	1,797,934	28.1
PED/BIKE	280,968	10.9	83,547	3.0	20,955	2.1	385,471	6.0
SINGLE VEHICLE	1,015,613	39.5	189,387	6.7	114,799	11.4	1,319,798	20.7
OTHER CRASHES	638,877	24.8	382,562	13.6	268,788	26.6	1,290,228	20.2
Total Non-Crossing path Crashes	2,562,923	99.6	1,560,245	55.6	670,262	66.4	4,793,431	75.0
Total	2,572,744	100.0	2,807,561	100.0	1,009,002	100.0	6,389,310	100.0

Rear-end crashes constituted about one-quarter of all crashes, one-third of crashes at intersections and about one quarter at non-intersection junctions.

Crashes with pedestrians or bikes make up only about 6% of all crashes, and the rate is lower at intersections (3.0%) and non-intersection junctions (2.1%). However, pedestrian and bicycle collisions are much more likely to result in injury or death.

CROSSING-PATH CRASHES BY TRAFFIC CONTROL DEVICE (TCD)

Because of limitations posed by the accident level TCD code in the 1998 GES data, the present analyses were conducted using the 2000 GES data, which included a single vehicle-level code for TCD but which also had a vehicle-level TCD variable data (i.e., which provided a separate code for each vehicle, and which allowed for a detailed analysis of TCD). An algorithm was developed in which a new and more detailed accident-level variable was derived from the combination of vehicle-level codes.

Of 2,807,561 estimated intersection crashes in year 2000, about half (46%) occurred at signalized intersections, one-quarter (23%) at stop-sign-controlled intersections (16% for two-way and six% for four-way stops), one quarter (26%) with no controls, and about 5% at intersections with “other” traffic controls.

Types of crashes varied by traffic-control configurations. CP crashes constituted about 42% of crashes in signalized intersections, 88% of two-way stop-sign-controlled crashes, and 38% of four-way stop-sign-controlled collisions. At signalized intersections, the predominant type of crash was rear end (about 40%), followed by LTAP-OD (18%) and SCP (14%). In contrast, at two-way stop-sign-controlled intersections, the predominant type of crash was SCP (over 45%), followed by LTAP-LD (around 25%), and then RTIP (about 6%). It is worth noting that LTAP-OD and rear-end collisions constituted only 0.4% each of all crashes at two-way stop-sign-controlled intersections. In contrast, the leading type of crash at four-way stop-sign-controlled intersections was rear end (almost 38%), followed by SCP (more than 20%), and “other” crashes (around 15%). Only 6% of crashes at four-way stop-controlled intersections were LTAP-OD crashes.

Signalized, two-way stop, and four-way stop intersections will be analyzed with respect to (i) pre-crash scenario, (ii) causal factors, (iii) traditional engineering countermeasures, and (iv) potential IDS countermeasures. Because of differences in patterns of crashes among these types of intersections, they will be discussed separately.

Signalized Intersections

Three crash types (LTAP-OD, SCP, and Rear End) make up nearly three-quarters (73%) of crashes at signalized intersections and are discussed separately.

LTAP-OD (Left Turn Across Path—Opposite Direction)

Pre-Crash Scenarios. Chovan and colleagues [1] studied LTAP-OD crashes using a sample of crashes from the Crashworthiness Data System (CDS) [15, 16]. They identified two subtypes of LTAP-OD crashes: one where the subject vehicle (SV) slows but does not stop, begins the left turn, and strikes or is struck by the oncoming primary other vehicle (POV); and one where the SV stops and then proceeds with the left turn and strikes or is struck by the POV.

Unfortunately, observations drawn from CDS data are limited in that they are based on police reports and include a relatively small non-representative sample of “tow-away” crashes (i.e., crashes in which at least one vehicle was towed from the scene).

Ragland and colleagues observed a more complex set of turning patterns as drivers approached and entered an intersection to turn left. Certain combinations of SV and POV

behavior seemed to create potential conflict during the green-amber-red transition. In one scenario, drivers turning left would be delayed by POVs coming from the other direction, and then they would be forced to turn quickly in the latter part of the amber or early red. In the second scenario, drivers queuing to turn during the late green or amber would accelerate to make the turn before the red, or, if within the red, to make the turn before vehicles approaching laterally (on green) entered the intersection.

A report by BMI [17] described a “left-turn trap” in which left-turning vehicles with a yellow signal proceeded into the path of oncoming traffic because they believed that the oncoming traffic *also* had a yellow signal and would stop. However, oncoming traffic had a longer green phase, and a crash ensued (BMI, 2001, B-3). A similar phenomenon might occur if there were no sufficient gaps in oncoming traffic during the green phase, and left-turning drivers had to wait for the amber or red phase to complete their maneuvers. In this case, oncoming motorists could enter on amber or red and create a conflict.

Combinations of SV and POV behaviors could also produce a conflict or crash prior to the green-amber-red transition in cases where the left turning vehicle proceeds to turn left and either misjudges the speed of the POV (i.e., misjudged the gap) or fails to perceive the POV.

Unfortunately, studies of the timing of LTAP-OD crashes or vehicle-vehicle crashes in relation to the signal phase are not available. Such information could be derived from structured observations of SVs and POVs at signalized intersections.

Causal Factors. Reports based on GES OR CDS data [3] and the BMI reports [16] suggest several potential underlying causes of LTAP-OD: (i) obstruction of view (i.e., crucial information is not available), (ii) the driver looked by did not see (i.e., did not recognize crucial information), or (iii) the driver misjudged the gap (i.e., had information but was not able to interpret it accurately).

Traditional Countermeasures. Left-turn signal phases have been used to reduce the frequency of LTAP-OD crashes at signalized intersections. While effective, this approach may decrease the overall capacity of the intersection [17]. The approach is appropriate when there is a high volume of left turning traffic and when a dedicated left turn will not only reduce LTAP-OD crashes but may increase overall capacity by allowing left-turning vehicles to clear the intersection.

A second approach is to increase the duration of the amber or all-red interval. This approach may have limited application to LTAP-OD, particularly with a protected left-turn phase. Longer amber or all-red phases are considered to effectively reduce or eliminate dilemma zones that could exist on approaches to signalized intersections, but they also reduce intersection capacity. Longer amber and all-red intervals provide drivers with more time to make a decision to stop or to proceed through the intersection. Retiming the signal to provide sufficient green time may reduce running of red lights [18].

IDS Countermeasures. One alternative to traditional approaches would be to provide information about potential risk to drivers as they near or enter the intersection; that is, an “Intersection Decision Support System” or IDS. If successful, this approach could provide information to drivers when risk is high, but it would allow optimum traffic flow at all other times.

Reports based on GES OR CDS data [3] and the BMI reports [16] suggest several potential underlying causes of LTAP-OD: (i) obstruction of view (crucial information is not available), (ii) looked by did not see (did not recognize crucial information), (iii) misjudged gap (had information but was not able to interpret it accurately). The potential common remedy to all three

is to make crucial information salient to drivers. The IDS is being designed to help drivers make better decisions regarding obstructed lines of sight and judgments about gaps in oncoming traffic.

The two critical goals of an IDS system are to identify risk or conflict and to provide information to the driver about the risk or conflict. For prevention of LTAP-OD crashes, algorithms for identifying risk or conflict will need to account for:

- highly variable (and even chaotic) behavior of SVs entering intersections to turn left;
- variable behavior of POVs approaching intersections;
- variation in SV and POV behavior connected with signal phase transitions;
- probable difference in speed of the SV and POV; and
- individual differences in drivers with respect to perception and reaction.

This significant challenge will require understanding of SV and POV behavior under both controlled conditions and under naturalistic roadway conditions. A special problem with LTAP-OD warnings at signalized intersections is adequate coordination of warnings to drivers with the signal phase.

SCP (Straight Crossing Path) and LTAP-LD (Left Turn Across Path—Lateral Direction)

Pre-crash Scenarios. SCP crashes, which account for about 14% of crashes at signalized intersections, consist of the SV proceeding straight across the path of the POV. Standard signal timing prohibits vehicles traveling in perpendicular directions from being in the intersection at the same time, other than when a vehicle is allowed to turn right at a red light. By definition, a SCP crash at a signalized intersection can take place only if at least one of the vehicles has violated the signal, which could take place at any point in the signal phase.

There are two general cases. In the first case, a SCP crash might occur at the green-amber-red transition if one of the vehicles (the SV) enters the intersection near the end of the amber or at the beginning of the red, and it encounters the POV just entering at the beginning of green (i.e., the SV driver attempts to “beat the yellow” by maintaining speed or even by accelerating, a typical event). The likelihood of a crash increases if the driver of the POV attempts to get a “head start” or “jump the red.” It is likely that crashes resulting from this scenario would most likely occur on the far side of the intersection from the viewpoint of the SV, since a delayed entry into the intersection would put the SV directly in front of the POV entering on it’s green from the SV’s right on the intersection far side. If true, this would have implications for which POV is the most important to warn.

In the second case, a SCP crash might occur during the red phase for the SV if the driver simply fails to see or to acknowledge the red signal or deliberately violates it. This event may be relatively rare. However, precisely because it is rare, it will be unexpected from the viewpoint of the POV, and it is therefore is hypothesized to carry relatively high crash risk.

There are limited data on the timing of SCP crashes to determine which of the two scenarios (“beating the yellow” versus “overt violation”) is the more prevalent or whether these two scenarios are points on a continuum of behaviors. Studies on red-light violations suggest that most such violations occur at the beginning of the red phase and then drop sharply but continuously with each moment into the phase [19, 20]. This suggests that entering patterns with respect to signal phase by SVs and POVs are defined by somewhat continuous (but only partially independent) probability distributions, with regions of the joint probability distribution defined by relatively high frequency but low risk and regions defined by low frequency but very high risk.

The LTAP-LD crash may be similar to the SCP with the difference that the SV in the LTAP-LD crash may be slowing down for the turn or waiting for the vehicles in the opposite direction to clear. The LTAP-LD is less frequent (about 4% of crashes at signalized intersections) than the SCP. It is not clear whether this is because SV vehicles turning left are less likely to violate the signal, or whether the relative frequency of LTAP-LD versus SCP simply reflects the general traffic patterns that include less left turns and more driving straight through intersections.

Causal Factors. Chovan and colleagues [3] have conducted an analysis of SCP crashes at intersections using data from the CDS. In their analysis, drivers who were attempting to beat the amber phase caused 16 per cent of the crashes, and drivers who were unaware of the signal presence and its status caused 41% of reported crashes. However, as mentioned above, generalizability of findings based on the CDS is limited.

Traditional Countermeasures. One potential countermeasure is to increase the duration of amber or all red-intervals, which effectively reduces or eliminates dilemma zones on approaches to signalized intersections. Presumably, longer amber and all-red intervals give drivers more time to make a decision to stop or to proceed through the intersection. This type of countermeasure might reduce the type of SCP (or LTAP-LD) crash in which the SV is attempting to “beat the yellow” and/or the POV is attempting to “jump the red.” However, there is some indication that longer intervals create more uncertainty as to whether a driver would stop or proceed through, which may contribute to an increased rate of rear-end crashes [19]. In sum, while increasing the duration of amber or all-red intervals may decrease intersection capacity, it might also contribute to increased rear end crashes.

A second potential countermeasure is photo enforcement for running red lights. This method, now adopted in numerous cities, involves automated detection of vehicles violating the red phase (i.e., vehicles entering at some pre-determined point after the beginning of the red phase), taking a picture of the vehicle, identifying the owner via the license number, and then citing the owner by mail. While this method has proven effective in reducing the incidence of red-light running, its impact on reducing crashes involving red light running is unclear [20]. Despite its promise, this approach is controversial because of privacy issues, and it is not clear whether red light running photo enforcement will be deployed on a scale large enough to impact SCP (and LTAP-LD) crashes on a national basis.

Potential IDS Countermeasures. A potential IDS countermeasure for SCP (and LTAP-LD) crashes is aimed at detecting the potential “violator” and then warning either the violator or the drivers of the other vehicles. This type of warning is a mid-phase warning (i.e., after the all-red phase) designed to detect motorists who run a red light either intentionally or because they did not see the signal due to inattentiveness or obstruction by other vehicles or road geometry. Ferlis [14] has conducted a detailed analysis of infrastructure and infrastructure-vehicle cooperative systems at SCP crashes at intersections. A deployment model is developed that assumes sequential introduction of warnings first to infrastructure only-systems (i.e., warnings to all drivers) followed by roadside to vehicle communications (i.e., in vehicle warning systems). Based on the model developed by Ferlis, an estimated 88% of SCP crashes could be addressed by providing warnings either to the “violators” or to other drivers entering the intersection. While having promise for preventing crashes when the SV driver violates during the mid-phase period, it is not as clear whether this approach would be effective for preventing crashes that occur closer to the phase transition. In general, IDS countermeasures offer the promise of preventing SCP and LTAP-LD crashes without reducing intersection capacity.

Rear-End Crashes

Pre-Crash Scenario. Rear-end crashes represented about 40% of crashes at signalized intersections, which was almost as many as all CP crashes at intersections combined (about 42%). A rear-end crash occurs when one vehicle (lead vehicle) is struck from behind by another vehicle (following vehicle). The GES codes a number of scenarios. The lead vehicle may be stopped, moving with a constant speed, accelerating or decelerating. The following vehicle may also be moving with a constant speed, accelerating or decelerating. One possible scenario in a signalized intersection is that a rear-end crash occurs when a signal phase changes from green to amber to red, and the lead vehicle is stopped or decelerating while the following vehicle is moving with a constant speed, accelerating or decelerating. A second scenario is when vehicles intending to perform a left turn are stopped in the left lane waiting for a suitable gap in opposing traffic or for pedestrians crossing the lateral direction across the intended path. Therefore, many rear-end crashes at signalized intersections are probably due vehicles creating uncertainty for the following vehicle. Based on an analysis of 1991 and 1992 CDS data [21, 22], driver inattention and following too closely were causal factors in a majority of rear end crashes.

Implications for IDS. While the IDS Project is not intended to reduce rear-end crashes, at the very least, IDS measures should be designed that avoid increasing the number of rear-end crashes. Ideally, IDS measures would reduce CP crashes while also reducing rear-end crashes.

As currently conceptualized, one type of information to be provided by IDS is one of warning; i.e., to identify a risk or potential conflict. Presumably, a successful IDS message would be followed by a change in a driver's speed or direction. While this change might reduce the chance of a CP conflict or crash, from the viewpoint of the driver in the following vehicle, the movement of the vehicle responding to the IDS information may include rapid changes in speed or direction, which in turn create uncertainty and potentially contribute to a rear-end crash.

The following steps might be taken. First, observations could be made of "following" vehicles to determine patterns of behavior in response to changes in speed or direction of "leading" vehicles. Second, algorithms could be developed to model behavior of following vehicles. Finally, information from these two steps should be considered in designing and implementing IDS measures for avoiding CP crashes. Potential mitigating features might include IDS messages conveyed to both the lead vehicle and to all potentially affected vehicles.

Intersections Controlled by Two-Way Stop Signs

At intersections controlled with two-way stop signs, nearly three-quarters of all crashes are attributed to SCP (45.5%) or LTAP-LD (24.7%). RTIP and LTIP account for a combined total of about 12%. Overall, more than 82% of crashes at intersections controlled by two-way stop signs involve vehicles initially approaching one another from lateral directions. Remarkably, LTAP-OD and rear-end crashes account for only 0.4% each. Discussion here will focus on SCP and LTAP-LD together given their similarities.

Pre-Crash Scenarios for SCP and LTAP-LD. An intersection controlled by two-way stop signs is one in which there are stop signs along one of two intersecting roadways (the "minor" roadway) and either no controls or just warning signs or signals on the other "major" roadway. Most often, the major roadways will have more traffic and traffic with higher speeds than the minor roadway. In addition, vehicles approaching the intersection from the minor roadway will often enter the intersection from a complete stop.

Crashes may occur when a vehicle on the minor roadway stops at the stop sign and then enters a primary roadway, having to navigate higher traffic volumes, higher vehicle speeds, or

both. Whether the vehicle entering the roadway from the secondary roadway is turning (either left or right) or proceeding straight through the intersection, the primary task is to choose an appropriate “gap” in traffic on the primary roadway. Crashes may also occur when the vehicle entering the intersection from the minor road simply does not see or acknowledge the stop sign and enters the intersection without stopping first. While relatively rare it, this event probably carries high risk because it would be unexpected by drivers on the major roadway.

Traditional Countermeasures. One countermeasure is to convert the intersection into a signalized intersection. However, a signal may create substantial delay along the major roadway or increase rear end crashes significantly. Another countermeasure is to install signs that warn drivers on the major roadway of possible merging or crossing traffic. Other countermeasures could focus on the minor roadway such as using “Stop Sign Ahead” warning signs and rumble strips to increase drivers’ awareness of the stop sign ahead. While potentially reducing the likelihood of running the stop sign, such countermeasures would not help drivers from minor roadway to choose an appropriate gap to enter the intersection.

IDS Countermeasures. For drivers running stop signs, IDS measures could be developed to detect vehicles that are likely to violate the sign and to provide information to the driver before he or she runs the stop. Drivers would need to receive the information with sufficient time to stop the vehicle, and information would need to be salient enough to gain the attention of a driver who presumably did not notice the sign. One potential risk would be rear-end crashes, which are apparently very low under ordinary conditions at intersections with two-way stop signs. Similar information (that a vehicle was about to violate the stop sign) could also be provided to the drivers along the major roadway. Again, the value of helping a driver on the major roadway to avoid conflict with the violating vehicle would have to be weighed against the risk of increasing rear end or other crashes.

For drivers on the minor roadway who have stopped and who are about to enter the major roadway, the primary task is to select an adequate gap and then to successfully execute entrance onto the roadway. A critical task is to determine what gaps are sufficient. This is complicated by (i) individual differences in driver abilities and driving patterns, (ii) differences in vehicle performance, and (iii) uncertainty about the intended vehicle maneuver. A critical issue is whether information should be communicated when there is risk (i.e., when gaps are narrow or infrequent), or alternatively, when there are “safe” gaps. In the former case, there is danger that absence of a message might be interpreted to indicate a safe gap. In the latter case, there is danger that a message could be interpreted as a protected period of time. These are critical issues for which careful research and consideration are required as IDS countermeasures are developed.

Intersections Controlled by Four-Way Stop Signs

At intersections controlled by four-way stop signs, SCP, LTAP-OD, and LTAP-LD crashes comprised around 31% of all crashes (21%, 6% and 4% respectively), while rear-end crashes constituted nearly 38%. Differences in crash patterns compared with intersections controlled with two-way stop signs (especially in SCP, LTAP-LD, and rear-end crash rates) indicate possible differences in causal factors. However, these differences have not yet been explicitly addressed in the literature.

SCP, LTAP-OD, and LTAP-LD Crashes

Pre-Crash Scenarios. At an intersection controlled by a four-way stop sign, vehicles approaching along either of two intersecting roadways are supposed to stop and then proceed.

The rules concerning right of way are statutory; i.e., if two vehicles arrive at the intersection from different approaches at about the same time, the vehicle that arrives first has the right of way. If two vehicles arrive (more or less) simultaneously, then the vehicle to the right has the right of way. Based on typical requirements for a four-way-stop intersection, the two intersecting roadways will be closer in traffic volume and speed than will two-way stop controlled intersections.

At an intersection controlled by a four-way stop sign, a crash can occur when (i) one or both of the vehicles run the stop sign, or (ii) two vehicles approaching laterally both stop at a stop sign and then proceed with one or both of the drivers being unaware of the other. A possible alternative scenario for an LTAP-OD includes two vehicles that approach and stop at an intersection controlled by a four-way stop sign (either simultaneously or separated by a small period of time). The driver intending to turn left fails to indicate this intention. Two vehicles start simultaneously, and the turning driver attempts to turn left, which is unexpected by the driver that proceeds straight, and a conflict ensues.

Causal Factors. The majority of crashes at a four-way stop occur when one or both of the drivers run the stop sign or when there is confusion about right of way at the intersection.

Traditional Countermeasures. Installation of traffic signals as well as reduction of speed limits have been used to reduce the rate of CP crashes at intersections with four-way stop signs. Installation of “Stop Sign Ahead” warning signs and rumble strips could be used to increase drivers’ awareness of the stop sign.

Potential IDS Countermeasures. IDS systems may be employed to alert the likely violators or the drivers on lateral approaches that a possible violation of a stop sign is imminent. Certain factors are important in determining the warning point, and these include (a) the approach speeds of both SV’s and POV’s (which could be highly variable); (b) decelerations of these vehicles, and (c) their distances to the intersection. Reliable algorithms to determine the likely stop sign violators and the threshold for providing warning to the drivers are essential, as significant number of false alarms would reduce effectiveness, and warnings would be useless if issued too late.

Rear-End Crashes

Similar rates of rear-end crashes were observed at intersections controlled by four-way stop signs (38%) and signalized intersections (40%). The pre-crash scenarios are, of course, substantially different. At signalized intersections, rear-end crashes most likely occur when a leading vehicle is either stopping for a red light or waiting to turn left turning a green or amber phase. The higher rate of rear-end crashes at four-way stops than at two-two stops may reflect heavier traffic. As with IDS warnings given for potential red light violators in a signalized intersection, IDS warnings given to potential violators of a stop sign in a four-way stop could result in sudden reductions in speed, which might increase the risk of a crash with a following vehicles. IDS measures for preventing stop-sign violations should be designed with potential rear-end collisions in mind.

INTERSECTION CRASHES BY SPEED LIMIT

A majority of intersection crashes take place where the speed limit is relatively low. For example, about three-quarters (72%) of intersection crashes take place where the speed limit is 40 miles per hour or less; an additional 21% take place where the speed limit is 45-50 miles per

hour. Only 7% take place where the speed limit is 55 miles per hour or greater. Even if the average vehicle speed is higher than the posted speed, this finding suggests that most intersection crashes occur between vehicles traveling at moderate speeds.

INTERSECTION CRASHES BY AGE AND GENDER

Older drivers were somewhat over-represented in CP crashes compared to other crashes. For example, older drivers were 11% of all drivers in CP crashes, compared to 6% of all drivers in other crashes. Younger drivers are over-represented in single-vehicle crashes. Female drivers were slightly over-represented in CP crashes, while male drivers were over-represented in single-vehicle crashes. The differences for CP collisions do not seem large enough to be important in designing IDS measures

SUMMARY OF FINDINGS AND IMPLICATIONS FOR IDS

Junctions are High-Risk Sites for Crashes

Crashes at junctions overall represent about 60% of U.S. crashes, and most of these (or about 44% of all crashes) occur at intersections. Because junctions, and intersections in particular, represent a very small proportion of all streets and highways, they carry a much higher risk for crashes than other types of roadway segments. Therefore, safety enhancements at such sites would be an efficient investment. Specifically, IDS countermeasures designed to prevent crashes at junctions in general, and at intersections in particular, could efficiently address a significant share of all traffic crashes.

Crossing-Path Crashes are a Significant Problem

Crossing-path crashes represent 25% of all U.S. crashes. While each type of crash represents different pre-crash vehicle movements and a different mix of causal factors, IDS countermeasures could potentially be tailored to each type, supporting driver decisions at intersections and other junctions.

Most Intersection Crashes Occur at Controlled Intersections

Among intersection crashes, most (74%) occurred at intersections with some type of traffic control device in place, including 46% at signalized intersections, 16% at two-way stop-sign intersections, 6% at four-way stop sign intersections, and 5% at intersections with some other type of control. IDS approaches should coordinate with existing traffic control devices.

Many Crashes Occur at Uncontrolled Intersections

About one quarter (26 per cent) of intersection crashes occur at intersections with no physical traffic control devices. While statutory controls may apply at these intersections, the GES codes them as “uncontrolled”. If uncontrolled intersections have such light traffic that they do not yet warrant a physical control device, there is probably no justification for an IDS infrastructure installation. Collisions at intersections with no traffic control devices may be best addressed by vehicle-based systems.

Types of Crashes at Intersections Vary by Type of Traffic Control

Crash types at intersections differ substantially by type of traffic control configuration. The differences represent the impact of traffic control on vehicle flow and reflect varying pre-crash

vehicle movements. IDS approaches will need to address the different patterns of crash types occurring with different traffic control configurations.

Driver Errors are Primary Causal Factors in Intersection Crashes

Based on police reports, driver failure is the most frequently identified causal factor in crashes including failure to see crucial information (e.g., obstruction of view, driver distraction); and failure to correctly judge available information (e.g., misjudged speed of or distance to another vehicle). IDS is designed to address both of these factors by increasing the salience and relevance of information available to drivers about potential risks as drivers navigate an intersection.

Most Crashes Occur at Moderate Speeds

A substantial proportion of intersection crashes takes place at intersections where speed limits are relatively moderate: 72% with speed limits of 40 miles per hour or less; an additional 21% occur with speed limits between 45 and 50 miles per hour; and only seven% take place where the speed limit is 55 miles per hour or greater. Even assuming that the average vehicle speed before a crash is higher than the posted speed, most intersection crashes are likely taking place at moderate speeds. This has implications for IDS algorithms for detection of conflicts and for providing information to drivers since vehicle speed is a predominant variable in these algorithms.

Many Non-Crossing Path Crashes Also Occur at Intersections

Rear end crashes make up about 32% of crashes at intersections. While the IDS project only addresses crossing path crashes directly, it is important to note the possible impacts of IDS measures on other types of crashes.

IDS Countermeasures May Reduce Risk Without Reducing Intersection Capacity

Traditional engineering countermeasures that currently address crossing path crashes and other crashes at intersections may reduce intersection capacity. IDS countermeasures may be able to reduce risk for crossing path crashes at intersections by providing salient and relevant information to drivers while maintaining intersection capacity.

CONCLUSIONS

Crashes at intersections represent a very high percentage of all US crashes, making intersections relatively high risk compared to other roadway segments. In particular, crossing-path crashes constitute about 45% of crashes at intersections. Patterns of crossing-path crashes differed substantially by type of intersection (defined by traffic control device), and these differences reflected varied underlying causal factors. Crossing-path collisions at intersections took place at moderate speeds. IDS countermeasures need to account for these and findings from other studies of intersections that address driver behavior and vehicle movement and conflict. While there are significant challenges in detecting potential risk and providing appropriate information to drivers, IDS countermeasures show promise of addressing a significant portion of crossing-path collisions at intersections.

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