BROADSIDE COLLISION SCENARIOS AT UNCONTROLLED INTERSECTIONS

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ABSTRACT

The purpose of this research is to clarify the principal causes of broadside accidents at unsignalized intersections from various pre-crash driving patterns. Driving patterns showing a high incidence of accidents and high accident probabilities were identified by analyzing accident statistics, accident case data, and direct observational data collected at unsignalized intersections. In addition, it was found that primary parties traveling straight ahead tended to collide more often with secondary parties coming from the left side in Japan. This observation was studied from various perspectives, and the most probable causal factor was identified. These analyses have yielded information that is expected to be effective in considering measures for preventing these types of accidents.

INTRODUCTION

Having a good understanding of the realities of traffic accidents is an important factor in implementing measures that are effective in preventing them.

According to statistics on traffic accidents in Japan, approximately 240,000 broadside collisions occurred in 2001, accounting for 26% of all traffic mishaps[1]. Previous studies[2], [3] of broadside accidents have pointed out various causes, based on analyses of actual accident cases. For example, driver distraction by the signal lights at the next intersection increases broadside collisions at unsignalized intersections. Lack of human

peripheral vision is thought to influence broadside accidents at intersections where there is good visibility.

The purpose of this research is to make clear the principal causes of broadside accidents that occur under various pre-crash driving patterns. Comprehensive analyses were made of police-reported accident data, accident case data compiled by the Institute for Traffic Accident Research and Data Analysis (ITARDA), and data collected by direct observation surveys at actual unsignalized intersections. A thorough examination was made of what types of pre-crash driving patterns occurred frequently, what types of driving patterns had high accident probabilities based on the use of statistical tools, and under what sort of scenarios accidents occurred. This paper presents the results of these analyses.

ANALYSIS OF TRAFFIC ACCIDENT DATA

Broadside accidents were analyzed using data obtained from ITARDA, which consisted of traffic accident data for the year 2000. The results of an analysis of the traffic accident data are shown in Table 1-2 and Fig. 1. The results of an analysis of the accident case data are shown in Table 3.

Breakdown of Broadside Accidents

Table 1 shows the numbers and percentages of broadside collisions for different types of intersection and for daytime and nighttime driving. As the data shows, 70% of the broadside accidents in this database occurred during daytime at unsignalized intersections. A closer look at the different unsignalized intersections shows that the largest number of broadside accidents occurred at intersections where the primary party (i.e., the driver of the striking vehicle) was required to stop prior to entering the intersection, whereas the secondary party (i.e., the driver of the struck vehicle)

Table 1. Broadside collisions by type of intersection and day or night

Day or night		Day		Night		Total	
Type of intersection		Number	Share	Number	Share	Number	Share
Intersection							
	With signals	29,182	11.88%	18,369	7.48%	47,551	19.35%
	Without signals	142,239	57.89%	34,968	14.23%	177,207	72.12%
	Stop sign for PP but not for SP	**77,340**	**31.48%**	21,312	8.67%	98,652	40.15%
	No stop sign for PP or SP	50,842	20.69%	10,040	4.09%	60,882	24.78%
	No stop sign for PP but one for SP	10,761	4.38%	2,351	0.96%	13,112	5.34%
	Others	3,296	1.34%	1,265	0.51%	4,561	1.86%
	Others	73	0.03%	33	0.01%	106	0.04%
	Sub-total	171,494	69.79%	53,370	21.72%	224,864	91.51%
Others						20,852	8.49%
Total						245,716	100.00%

PP: Primary party, SP: Secondary party (Limited to accidents involving injury)

was not required to stop. This category accounted for 31% of all the broadside accidents.

Based on these statistics, it was decided to focus the analysis on this subset where the primary party was the non-right-of-way vehicle and the secondary party was the right-of-way vehicle. In addition, the primary parties analyzed here were motor vehicles, which accounted for the largest percentage of the total types of vehicles involved in these accidents.

Pre-crash Driving Patterns of Primary and Secondary Parties

The pre-crash driving patterns of the primary and secondary parties are categorized in Table 2. This analysis refers to the stop sign for PP, but not for SP data. The most frequent driving pattern found for the primary parties was starting-off (i.e., beginning to move through an intersection from a stationary state), which accounted for 37% of the total. That was followed by a pattern of cruising straight ahead at nearly a steady speed, which represented 22% of the total. For secondary parties, steady-speed cruising was the most frequent driving pattern at 85%, followed by decelerating, which represented slightly less than 10%. In the latter pattern, the secondary parties were traveling straight ahead while braking their vehicles to slow down.

Table 2. Pre-crash driving patterns of primary and secondary parties

Driving pattern		Primary party		Secondary party	
		Number	Share	Number	Share
Starting off		24,548	**37.4%**	708	1.1%
Traveling straight ahead					
	Accelerating	3,975	6.1%	958	1.5%
	Cruising	14,265	**21.7%**	55,886	**85.1%**
	Decelerating	7,585	11.6%	6,266	9.5%
Turning right		8,541	13.0%	497	0.8%
Turning left		6,185	9.4%	159	0.2%
Others		571	0.9%	1,196	1.8%
Total		65,670	100.0%	65,670	100.0%

Types of primary parties: motor vehicles

Types of secondary parties: motor vehicles, motorcycles, 1st class mopeds and bicycles

Approach Direction of Secondary Parties Relative to Primary Parties

An investigation was made to determine whether primary parties that were either starting off or traveling straight ahead collided more frequently with secondary parties coming from the right side or from the left side. The results are shown in Fig. 1. Because people drive on the left side of the road in Japan, as non-right-of-way vehicles pass through an intersection they first cross the right-of-way traffic stream coming from the right side (for the U.S. and other countries that drive on the right side of the road, right and left should

be considered in reverse here). Accordingly, it was presumed that primary parties would collide more frequently with secondary parties approaching from the right. However, the results in Fig. 1 indicate that primary parties collided more frequently with secondary parties coming from the left side in all four driving patterns, including starting off and cruising. A noticeable difference is seen especially for cruising straight ahead at a steady speed.

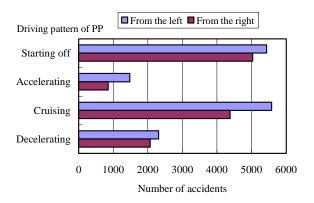Types of primary and secondary parties : motor vehicles

Figure 1. Comparison of accident counts by approach direction of secondary parties.

Collision Avoidance Action by Primary and Secondary Parties

Among the accident case data compiled by ITARDA for 1993 to 1996 in and around Tsukuba City, 71 broadside accidents between motor vehicles at unsignalized intersections were analyzed to determine whether primary and secondary parties took any collision avoidance action and what type of action was taken. The results are shown in Table 3. Primary parties acted to avoid an collision in approximately 25% of the cases, whereas secondary parties braked their vehicles or took some other avoidance action in approximately 50% of the cases.

The non-right-of-way primary parties could have been expected to take action to avoid a collision, but these

Table 3. Collision avoidance action by primary and secondary parties

		Primary party		Secondary party	
		Number	Share	Number	Share
No avoidance		42	59.2%	29	40.8%
Avoidance action	Braking only	12	16.9%	30	42.3%
	Braking & steering	2	2.8%	4	5.6%
	Steering only	3	4.2%	3	4.2%
	Accelerating	1	1.4%	0	0.0%
	Horn & steering	0	0.0%	1	1.4%
	Sub-total	18	**25.4%**	38	**53.5%**
Unknown & others		11	15.5%	4	5.6%
Total		71	100.0%	71	100.0%

data are for accidents, so they by definition were not avoided. In contrast, the right-of-way secondary parties, many of whom were cruising at a steady speed as seen in Table 2, attempted more collision avoidance action just prior to the crash.

ESTIMATION OF BROADSIDE ACCIDENT PROBABILITIES FOR EACH DRIVING PATTERN

The probability of a broadside accident occurring under each driving pattern was estimated in order to quantify the risk potential of the non-right-of-way vehicle in each pattern at an unsignalized intersection. Bayes' theorem[4] was used as the statistical method for making the estimates.

Method of Estimating Accident Probabilities Using Bayes' Theorem

Bayes' theorem is a statistical method for estimating incidence probabilities under a certain given condition by integrating the prior probability before acquiring data and the data subsequently acquired[4]. The probability of a broadside accident occurring, $P(A/D)$, under each driving pattern was found with the following equation(1) by applying Bayes' theorem.

$$P(A/D) = \frac{P(D/A)\ P(A)}{P(D/A)\ P(A) + P(D/\text{-}A)\ P(\text{-}A)} \qquad (1).$$

- $P(A)$: Probability of a broadside accident occurring

per vehicle passage through an intersection (prior probability)

At an intersection with a stop sign:

$$P(A) = 3.069*10^{-7}$$

This value was found by dividing the total number of broadside accidents that occurred at stop-sign-controlled intersections in 2000 by the total number of vehicle passages through such intersections. The total number of vehicle passages was calculated by multiplying the number of passages in one year by the vehicle population[1] in Japan, assuming that there were ten vehicle passages on average per day.

- $P(A|D)$: Likelihood of each driving pattern by primary parties in broadside accidents (accident data)

   This indicates the proportion of each driving pattern by non-right-of-way primary party vehicles in daytime broadside accidents at intersections with a stop sign in 2000.

- $P(D|-A)$: Likelihood of driving pattern occurrence (observation data)

   Observation surveys were conducted at four stop-sign-controlled intersections Kanagawa Prefecture. The observation surveys were all conducted at medium-size urban intersections having limited visibility.

   The likelihood of each driving pattern occurring was estimated from the proportions of the driving patterns actually observed for non-right-of-way vehicles at the time they entered the intersection.

Results

The data used and the estimated accident probabilities are shown in Table 4. Although the largest number of accidents occurs as non-right-of-way vehicles start off, this driving pattern has the lowest accident probability.

There are very few instances (approximately 0.8%) where non-right-of-way vehicles are cruising at a

steady speed when they enter an intersection, but the probability of an accident occurring under this driving pattern is 50 times greater than for starting off.

Table 4. Calculated accident probabilities by driving pattern

Driving pattern		Accident $P(D|A)$	Observation $P(D|-A)$	Accident probabilities $P(A|D)$	Factor
Starting off		**0.374**	**0.747**	**1.535E-07**	**1**
Traveling straight ahead	Accelerating	0.061	0.001	1.858E-05	121.0
	Cruising	**0.217**	**0.008**	**8.382E-06**	**54.6**
	Decelerating	0.116	0.115	3.089E-07	2.0
Turning right		0.130	0.054	7.430E-07	4.8
Turning left		0.094	0.074	3.882E-07	2.5
Others		0.009	0.001	2.668E-06	
Total		1.000	1.000	3.069E-07	

Factors were calculated letting starting off equal 1.

Based on the results of this analysis and the broadside accident data, it is thought that it is particularly important to address broadside accidents involving non-right-of-way primary parties that are cruising at a steady speed, a driving pattern that shows a large number of accidents and a high accident probability rate at unsignalized intersections. Accordingly, a detailed examination was made of the principal reasons why primary parties more often collide with secondary parties coming from the left side, which is a distinctive characteristic of broadside accidents that occur when primary parties are cruising at a steady speed.

BROADSIDE ACCIDENT SCENARIO UNDER STEADY-SPEED CRUISING BY PRIMARY PARTIES

For a non-right-of-way vehicle to enter a stop sign-controlled intersection at a steady cruising speed is extremely dangerous driving behavior that entails a very high probability of an accident. Various reasons can be considered for why primary parties would enter an intersection at a steady cruising speed, including careless or inattentive driving or a mistaken assumption that no right-of-way vehicle is coming. Moreover, it is thought that secondary parties, having the right of way,

do not expect a non-right-of-way vehicle to enter an intersection at a steady cruising speed. However, these factors concerning broadside accidents in general do not explain the reason why broadside accidents more frequently involve secondary parties approaching from the left side.

Hypotheses for the Higher Incidence of Accidents with Left-side Secondary Parties

The following hypotheses were formulated concerning the cause of the higher incidence of broadside accidents with secondary parties coming from the left side.

(1) Lateral asymmetry of intersections: Primary parties' visibility of secondary parties coming from the left side is worse because of irregular intersection geometries, presence of obstructions or other factors.

(2) Influence of another vehicle: A secondary party coming from the left is in a primary party's blind spot because another vehicle passes through the intersection at the same time.

(3) Influence of the corner triangle or road width: The corner triangle or road width makes it more difficult for primary parties to see secondary parties coming from the left side.

(4) Propensity of primary parties to look in the other direction: Primary parties tend to look to the right.

(5) Partiality of primary parties' attention: Primary parties pay attention only to the right side.

(6) Partiality of secondary parties' awareness: Secondary parties do not consider that primary parties are coming from the right side.

While poor visibility at an intersection or the creation of a momentary blind spot by another vehicle (hypotheses (1) and (2) above) could give rise to a broadside accident, it is thought that they have a low possibility of being the principal reason for the higher incidence of collisions with secondary parties coming from the left side. Hypothesis (4) is also thought to have a low possibility of being the main reason because drivers do not necessarily look only to the right side.

Therefore, the possibility that hypotheses (3), (5) and (6) might be the principal cause was investigated in detail as explained below.

Study of Visibility Conditions Related to the Road Width and Corner Triangle

To examine the validity of hypothesis (3), a study was made to determine if there are cases where visibility conditions related to the road width, corner triangle or other factors make it more difficult for primary parties to see secondary parties approaching from the left side.

Methodology

A right-angle intersection like that shown in Fig. 2 was modeled in this study. A primary party and a secondary party entering this intersection at a steady cruising speed would collide. The positions at which each party would be able to see the other vehicle were found. Since the position at which the other party becomes visible is determined by the speed of the two vehicles, road width and corner triangle, the following calculation conditions were defined for calculating the distance from that position to the crash point.

Calculation conditions

The vehicle speed of the primary and secondary parties was set at 20-40 km/h and 30-50 km/h, respectively. These speed ranges were determined on the basis of accident statistics and represent 80% of the driving speeds reported to the police by primary and secondary party drivers who were involved in broadside accidents at stop sign-controlled intersections while traveling at a steady cruising speed. (The reported driving speed represents how fast drivers stated they were traveling at the moment they became aware of the other vehicle and before taking action to avoid an accident.)

The road width was set at not less than 5.5 m (the typical width at a medium-size intersection) and the corner triangle was set at not less than 0 m.

The overall vehicle width and length were set at 1.5 m

and 4.5 m, respectively. The driver's eye point was set at 0.35 m to the right side of the vehicle centerline and at a distance of 2.2 m from the vehicle front-end.
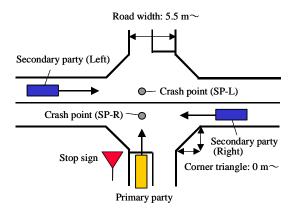

Figure 2. Modeled intersection.

Results

One example of the calculated relationship between the corner triangle and the distance at which the primary and secondary parties can see each other is shown in Fig. 3. The conditions used in the calculation were a road width of 6.5 m, a primary party vehicle speed of 30 km/h and a secondary party vehicle speed of 40 km/h. The following tendencies can be observed under all of the conditions in the figure.

- The distance at which the primary party can see the secondary party is nearly the same for both the right and left sides and does not depend on the corner triangle.
- The distance at which the secondary party can see the primary party is somewhat longer for a secondary party approaching from the left side.

The results suggest that visibility conditions related to the road width and corner triangle are, on the contrary, favorable for primary parties and secondary parties coming from the left side. Accordingly, this analysis shows that hypothesis (2) has a low possibility of being the principal cause of the higher incidence of broadside collisions with secondary parties approaching from the left side.
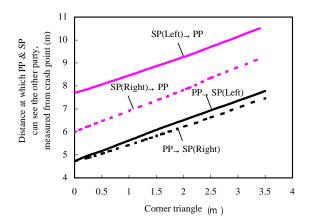

Figure 3. Distance at which PP and SP can see the other party.

Study of Collision Avoidance Possibility under Steady-speed Cruising by Primary and Secondary Parties

To examine the validity of the remaining hypotheses (5) and (6), the possibility of avoiding a broadside accident when primary and secondary parties are cruising at a steady speed was examined.

Methodology

It was assumed that primary and secondary parties entered a right-angle intersection like that in Fig. 2 at a steady cruising speed and that they executed emergency braking at the moment they became aware of the other vehicle. The possibility of avoiding a cross-traffic collision in this case was examined. The following conditions were used in the calculations.

- The speed ranges of the primary and secondary party vehicles were the same as those in foregoing paragraph.
- The primary and secondary party vehicles decelerated by 0.5 G and 0.6 G, respectively, as a result of evasive braking.
- The road width was 6.5 m and the corner triangle was 2.5 m, representing the general conditions at medium-size intersections.
- Collision avoidance was assumed to be possible under a condition where the distance from the

point of recognition of the other vehicle to the crash point was longer than the stopping distance.

Results

The distances calculated from the point of recognition to the crash point under the above-mentioned conditions are shown in Fig. 4. In addition, Table 5 shows the respective collision avoidance possibilities for the primary and secondary parties.

- Excluding the cases where primary and secondary parties are traveling at identical speeds, the secondary party can see the primary party from a farther distance.
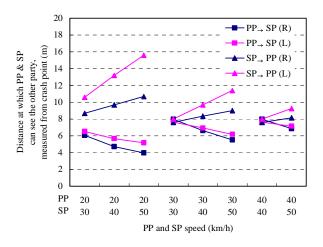

Figure 4. Distance at which PP and SP can see the other party, measured from crash point.

Table 5. Collision avoidance possibilities under steady-speed cruising by primary and secondary parties

PP speed (km/h)		20	20	20	30	30	30	40	40
SP speed (km/h)		30	40	50	30	40	50	40	50
PP braking	0.5G	OK	OK	OK	OK	-	-	-	-
→ SP (R)	0.6G	OK	OK	OK	OK	OK	-	-	-
PP braking	0.5G	OK	OK	OK	OK	-	-	-	-
→ SP (L)	0.6G	OK	OK	OK	OK	OK	OK	-	-
SP (R) braking	0.5G	OK	-	-	OK	-	-	-	-
	0.6G	OK	-	-	OK	-	-	-	-
SP (L) braking	0.5G	OK	OK	-	OK	-	-	-	-
	0.6G	OK	OK	-	OK	-	-	-	-

OK: Possible

- : Impossible

- Collision avoidance as a result of emergency braking by the primary party is possible in about 50% of the cases.
- Collision avoidance as a result of emergency braking by the secondary party is impossible, except for some low-speed situations.

At the point where the other vehicle is seen, the secondary party is usually farther away from the crash point than the primary party. However, when the primary party enters the intersection at a steady cruising speed, the secondary party often does not have sufficient time to execute emergency braking. Accordingly, hypothesis (6) concerning second parties' potential awareness has a low possibility of being the principal cause of the higher incidence of cross-traffic collisions between primary parties and secondary parties coming from the left side.

Order in which Primary Parties See Right- and Left-side Secondary Parties

A comparison was made to determine whether primary parties see right-side or left-side secondary parties first in the process of approaching an intersection, assuming that both parties are on a collision course. Based on the data in Fig. 4, the vertical axis in Fig. 5 has been
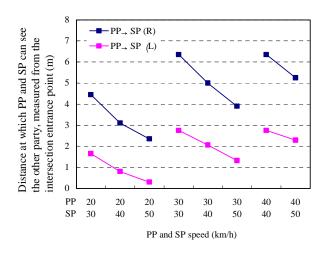

Figure 5. Distance at which PP and SP can see the other party, measured from the intersection entrance point.

changed to indicate the distance to the intersection entrance (not the crash point) from the point where primary and secondary parties can see each other. It is clear from Fig. 5 that primary parties always see secondary parties on the right side at a farther distance from the intersection than cross traffic on the left side. This suggests that primary parties see secondary parties coming from the right side at an earlier point in the process of approaching an intersection. This is attributed to the fact that people drive on the left side of the road in Japan.

Based on the foregoing characteristics, a scenario like that in Fig. 6 is considered concerning hypothesis (5) about the partiality of primary parties' attention. In short, it is thought that as primary parties approach an intersection, if there are no vehicles coming from the right side, they mistakenly assume that there is no cross traffic approaching from the left side either; consequently, they do not pay any attention to the left side. This scenario is thought to have the highest probability of being the principal reason for the higher incidence of broadside accidents with secondary parties coming from the left side.

CONCLUSION

The purpose of this research is to provide useful information for considering measures to address broadside accidents at unsignalized intersections. In this scenario, broadside accidents are the fault of primary parties, making it difficult for secondary parties to avoid such collisions. Accordingly, it is thought that measures for avoiding broadside accidents need to be directed at non-right-of-way vehicles. Measures for getting such vehicles to stop at intersections should be considered first of all, in as much as this driving pattern shows high accident probabilities and also a high incidence of accidents.

Because people drive on the left side of the road in Japan, it is thought that primary parties see right-of-way vehicles approaching from the right side at an earlier point in time. This difference in
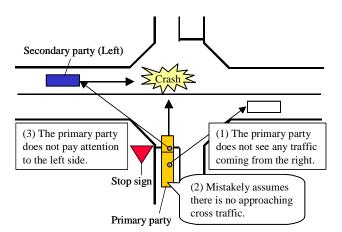

Figure 6. Scenario for broadside collisions with left-side secondary parties.

recognition timing between right- and left-side cross traffic is thought to be a factor that induces more accidents with secondary parties coming from the left side. With regard to this factor, it is hoped that measures can be applied to roads to eliminate this difference in recognition timing between the right and left sides. That could be accomplished, for example, by giving non-right-of-way traffic a larger corner triangle on the left side of intersections than on the right side.

ACKNOWLEDGMENTS

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