Gaps Accepted at Stop-Controlled Intersections

KAY FITZPATRICK

Gap-acceptance data are used to determine intersection sight distance, capacity, queue length, and delay at unsignalized intersections. They have also been used to determine the need for a traffic signal, the capacity of a left-turn lane, and warrants for left-turn signal phasing and storage lanes. A field study was performed to determine the gap-acceptance values of truck and passenger car drivers at six intersections. Each intersection was formed by two 2-lane roads; the minor road was controlled by a stop sign. The data obtained in the field were evaluated by three methods: Greenshield, Raff, and logit. The findings from the field studies were summarized into generalized values. Passenger car drivers had a 50 percent probability of accepting a gap of 6.5 sec for both left and right turns and an 85 percent probability of accepting a gap of 8.25 sec at a moderate- to high-volume intersection. A 10.5-sec gap represented the 85 percent probability of accepting a gap at an intersection where accepted gaps were influenced by low volume and the intersection's geometry. Truck drivers' 50 percent probability of accepting a gap was 8.5 sec. At a high-volume location, 85 percent of the truck drivers accepted a 10 sec gap; at a low-volume location, 15.0 sec was the accepted gap value.

A driver at a stop-controlled intersection must observe the gaps in the opposing traffic streams and determine whether the gaps are adequate to complete a crossing or turning maneuver. After accepting a gap, the driver should be able to complete the desired maneuver and comfortably join or cross the major road traffic stream within the length of the gap. The evaluation of available gaps and the decision to carry out a specific maneuver within a particular gap are inherent in the concept of gap acceptance.

Gap-acceptance data are used to determine intersection sight distance, capacity, queue length, and delay at unsignalized intersections (*1–4*). These data have also been used to determine the need for a traffic signal, the capacity of a left-turn lane, and warrants for left-turn signal phasing and storage lanes (*5–9*). These procedures are generally based on the gaps accepted by passenger car drivers. However, in those areas that experience significant truck traffic, gaps accepted by truck drivers should be considered. Gaps accepted by truck drivers are typically longer than gaps accepted by passenger car drivers because trucks have different vehicle characteristics (e.g., slower acceleration rates and longer vehicle lengths).

Relatively few studies have determined the difference in gaps accepted by truck drivers and those accepted by passenger car drivers. This field study was performed to determine the gap-acceptance values of truck drivers and passenger car drivers.

Pennsylvania Transportation Institute, Pennsylvania State University, University Park, Pa. 16802. *Current affiliation*: Texas Transportation Institute, Texas A&M University, College Station, Tex. 77843.

PREVIOUS RESEARCH

Several gap-acceptance studies have been conducted at intersections with stop control on the minor road. The findings from the major gap-acceptance studies are listed in Tables 1 and 2. Gap values used in the *Highway Capacity Manual* (*2*) and the *Swedish Capacity Manual* (*3*) are listed in Table 3. Two U.S. studies determined critical gap values for vehicles turning right after stopping. The values were 6.73 sec for Radwan et al. (*13*) and 7.36 sec for Solberg and Oppenlander (*16*). Polus (*14*) in Israel found 7.47 sec as the critical gap. The capacity manuals have lower gap values, ranging from 5.5 and 6.5 sec for the *Highway Capacity Manual* (*2*), and from 5.5 to 7.2 sec for the *Swedish Capacity Manual* (*3*), depending on the speed of vehicles on the major road.

The left-turn maneuver in the United Kingdom is similar to the U.S. right-turn maneuver in that the turning vehicle merges with cross traffic in the near lane. The results from studies in the United Kingdom are generally lower than those from U.S. studies. Cooper et al. (*18*) associated gaps with the approach speed of the vehicle on the major road and found the median accepted gap to range from 5.35 to 6.69 sec. (The gap size did not increase with the higher approach speed; rather, the smallest gap size was associated with the highest approach speed.) Darzentas et al. (*19*) related gap size to light condition, reporting the median accepted gaps as 6.58 sec for daylight conditions and 5.62 sec for dark conditions.

Wennell and Cooper (*20*) collected gap data at four locations in the United Kingdom. They reported gap values that are 2 sec lower than other United Kingdom studies and more than 3 sec lower than the U.S. studies. They filmed during moderate to heavy commuter traffic when the volume for the major road approach lane was between 660 and 890 vehicles per hour (vph). The turning volume on the minor road approach was also high, between 140 and 205 vph. Their study focused on three issues: associating the vehicle's maneuver time with accepted gap size, the difference in gap sizes accepted by men and women drivers, and the effects of passengers on gaps accepted. Their literature review concentrated on other researchers' findings of the presence of differences rather than the value of the differences. Wennell and Cooper did not compare their median gap accepted values with values from previous research.

Results from studies on left-turning vehicles also produced a range of gap-acceptance values. Solberg and Oppenlander

TABLE 1 GAP VALUES FROM MAJOR GAP-ACCEPTANCE STUDIES

Study (Analysis Method)	Measured	Gap		
Greenshield, 1947 (10) (Greenshield Method)	Crossing	Average minimum acceptable time gap = 6.1 sec		
Raff, 1950 (11) (Raff Method)	Crossing	Critical lag = 5.9 sec Critical gap = 6.1 sec		
Bissell, 1960 (12) 2 intersections (Bissell Method)	Crossing	Critical gap = 5.8 sec		
		Gap accepted by 50 percent of drivers		
Radwan et al., 1980 (13) multilane, divided highways, 6 intersections (Logit Method)	Right Turn	6.73 sec		
	Through, one maneuver	7.90 sec		
	Through, two maneuvers	7.20 sec		
	Left Turn, one maneuver	6.32 sec		
	Left Turn, two maneuvers	6.60 sec		
	Trucks, all maneuvers	8.40 sec		
Polus, 1983 (14) 2 intersections in Israel (Raff Method)		Critical Gap	Critical Lag	
	Right Turn from minor to major, Yield	5.20 sec	5.10 sec	
	Right Turn from minor to major, Stop	7.47 sec	7.55 sec	
Adebisi and Sama, 1989 (15) 2 intersections in Nigeria, Africa left turns, (CHOMP computer program)	Duration Stop Delay (sec)	Mean Delay for Group (sec)	Number of Samples	Mean Critical Gap (sec)
	< 5.0	3.23	91	20.99
	5.1-10.0	7.46	209	18.77
	10.1-15.0	12.01	91	17.58
	15.1-20.0	16.52	61	16.31
	20.1-25.0	21.65	104	9.87
	25.1-30.0	27.53	66	10.46
	30.1-35.0	32.74	76	8.62
	35.1-40.0	36.78	48	8.29
	40.1-60.0	46.66	42	6.78
	>60.0	75.85	16	5.32

(*16*) reported 7.82 sec, and Radwan et al. (*13*) reported 6.32 sec when the minor road vehicle crossed a multilane divided highway in one maneuver. Adebisi and Sama (*15*), in Nigeria, Africa, reported mean critical gaps ranging from 20.99 sec, when the minor road vehicle had been stopped for less than 5 sec, to 5.32 sec, when the vehicle had been stopped for more than 60 sec. The *Swedish Capacity Manual* (*3*) lists values of 6.0 to 7.5 sec for left turns, and the *Highway Capacity Manual* (*2*) lists values of 6.5 to 8.0 sec, depending on the major road vehicle's approach speed. A United Kingdom study of right turns (similar to U.S. left turns) had results that were several seconds less than those of comparable U.S. studies. Cooper and McDowell (*17*) studied the effect of police presence on gaps, finding the values to range from 5.9 sec with police activity to 4.6 sec without police activity.

The findings from studies on crossing maneuvers were more consistent than those for turning maneuvers. Greenshield et al. (*10*), Raff and Hart (*11*), and Bissell (*21*) found values of 6.1, 6.1, and 5.8 sec, respectively. The *Swedish Capacity Manual* (*3*) lists 5.8 to 7.0 sec, and the *Highway Capacity Manual* (*2*) lists 6.0 to 7.5 sec. Solberg and Oppenlander (*16*) had a 7.18-sec result for the crossing maneuver, which agrees with the higher values from the capacity manuals.

Other relevant studies on gap acceptance include observations of the effects of the major street speed, type of sign control, length of stop delay, and the behavior of individual drivers. In 1971, Sinha and Tomiak (*22*) reported that the major street speed significantly affected the size of a gap acceptable to a driver on the minor street. In 1983, Polus (*14*) found that the mean gaps and lags accepted may be influenced by the type of sign control (yield versus stop). Adebisi and Sama (*15*) in 1989 found that for mean stop delays shorter than 25 sec, the mean critical gaps were larger than the value obtained from the aggregated data; for mean delays longer than 30 sec, the mean critical gaps were smaller. Ashworth and Bottom (*23*) concluded in 1975 that the gap acceptance behavior of individual drivers is closer to an "inconsistent behavior" model (each driver has a variable critical gap) than to a "consistent behavior" model (each driver has a fixed critical gap).

FIELD STUDY

Six intersections with similar geometric characteristics were selected for the field study. Table 4 summarizes the intersec-

TABLE 2 MEDIAN ACCEPTED GAP VALUES FROM MAJOR GAP-ACCEPTANCE STUDIES USING PROBIT ANALYSIS

Study	Measured	Median Accepted Gap
Solberg & Oppenlander, 1966 (16) 4 intersections	Right Turn Left Turn Through	7.36 sec 7.82 sec 7.18 sec
Cooper & McDowell, 1977 (17) effects of police presence and police activity (warning signs or police motorcycle parked in view) at 3 intersections	Right Turn (UK) from minor road and merging with major road	4.6 sec w/o police 5.7 sec with police 5.3 sec w/o police activity 5.9 sec with police activity
Cooper, Smith, Broadie, 1976 (18) 1 intersection	Left Turn (UK) from minor road and merging with the nearside stream	Approach Speed (mi/h) — Median Accepted Gap (sec) (ft) 17.5 — 5.86 — 150 22.5 — 6.69 — 221 27.4 — 5.95 — 240 32.5 — 6.34 — 302 37.4 — 5.35 — 294 D = 38' + 5 V where D is in ft and V is in f/sec
Darzentas, Holms, McDowell, 1980 (19) 1 intersection, 10 evenings	Left Turn (UK)	6.58 sec daylight 6.32 sec twilight 5.62 sec darkness
Wennell and Cooper, 1981 (20) 4 intersections	Left Turn (UK)	Left Turn Site — Cars (sec) — Goods (sec) 1 — 3.91 — 4.63 3 — 3.66 — 5.33 4 — 4.31 — 4.99 5 — 4.41 — 4.91

tion characteristics. Four intersections had predominately passenger car traffic; one intersection had a high percentage of truck traffic on the minor approach from an industrial park. The minor road approaches for the other two intersections were the driveway of an asphalt and aggregate plant (Central Valley Asphalt) and a truck stop exit (Truck Stop 64). The asphalt and aggregate plant is a few miles outside of a small town, and the truck stop is in a rural area less than 1,000 ft from an Interstate exit. The approach from the asphalt and aggregate plant has primarily three- and four-axle trucks; the truck stop and industrial park approaches have five-axle trucks.

A video camera was placed along the minor road approach at each intersection. The position of the camera maximized the length of the road that could be filmed without jeopardizing the resolution of the vehicles on the videotape. Figure 1 shows a typical setup. An internal clock was started when videotaping began. As a vehicle crossed the center of the minor road approach (the reference line), a hand-held flag was raised. The flagging of a vehicle determined its position as it crossed the reference line and provided a permanent record on the videotape for the data reduction process. The times that each minor road vehicle arrived at and left the intersection and the times that relevant major road vehicles crossed the reference line were recorded from the videotapes. These times were used to calculate the gaps rejected and accepted by the minor road drivers.

DETERMINATION OF GAP-ACCEPTANCE VALUES

The quantity of the proposed data to be collected for the gap-acceptance analysis was a compromise between a reasonable, realistic data collection effort and the need for adequate data for numerical analysis. Several combinations of vehicles (passenger cars, five-axle trucks, or trucks with fewer than five axles) and maneuvers (left, right, or through) at an intersection had less than the goal of 50 data points. An analysis was conducted for combinations with data from a minimum of 15 minor road vehicles.

Several difficulties and biases arose in the measurement of the critical gap. For example, the actual critical gap of an observed single driver cannot be measured. The actual value lies somewhere between the length of the largest gap that the driver rejected and the gap that was eventually accepted. Drivers may react differently to a lag (interval from the arrival

TABLE 3 GAP VALUES USED IN CAPACITY MANUALS

Manual	Gap				
Swedish Capacity Manual, 1977 (3)			Secondary Approach Stream		
based on 18 intersections	Speed (mi/h)	Sign	Right (sec)	Straight (sec)	Left (sec)
	31	Yield	4.8	5.2	5.3
		Stop	5.5	5.8	6.0
	43	Yield	6.0	6.0	6.2
		Stop	6.5	6.5	6.8
	56	Stop	7.2	7.0	7.5

Highway Capacity Manual, 1985 (2)	Average running speed, major road (mi/h)			
	30		55	
	Number of lanes on major road			
	2	4	2	4
Right - Stop (sec)	5.5	5.5	6.5	6.5
Right - Yield (sec)	5.0	5.0	5.5	5.5
Left - Stop (sec)	6.5	7.0	8.0	8.5
Left - Yield (sec)	6.0	6.5	7.0	7.5
Cross - Stop (sec)	6.0	6.5	7.5	8.0
Cross - Yield (sec)	5.5	6.0	6.5	7.0

Adjustments and modifications to critical gap (sec):

Right from minor street: curb radius > 50 ft or turn angle < 60 degree = -0.5 sec
Right from minor street: acceleration lane provided = -1.0 sec
All movements: population > 250,00 = -0.5 sec
Restricted sight distance = up to + 1.0 sec

TABLE 4 SELECTED INTERSECTION'S CHARACTERISTICS

Intersection			ADT Volume[a]		Percent Trucks[a]		Speed Limit[b] (mi/h)	85th %-ile Speed[b] (mi/h)
Major Road	Minor Road	City in Penn.	Major Road	Minor Road	Major Road	Minor Road		
RT 26	Central Valley Asphalt Plant	Pleasant Gap	14,000	175	15	90	45	47
RT 64	Truck Stop 64	Lamar	7,000	500	20	95	40	51
Trindle	Railroad	Harrisburg	20,000	2,000	20	25	40	40
Whitehall	Research	State College	5,900	650	2	4	45	--[c]
College	Cato	State College	11,400	1,025	4	5	45	--
Easterly	Pugh	State College	7,600	2,100	2	2	35	--

[a]Values are unadjusted count volumes obtained during the study.
[b]Major roadway approach.
[c]Approach speeds not measured.

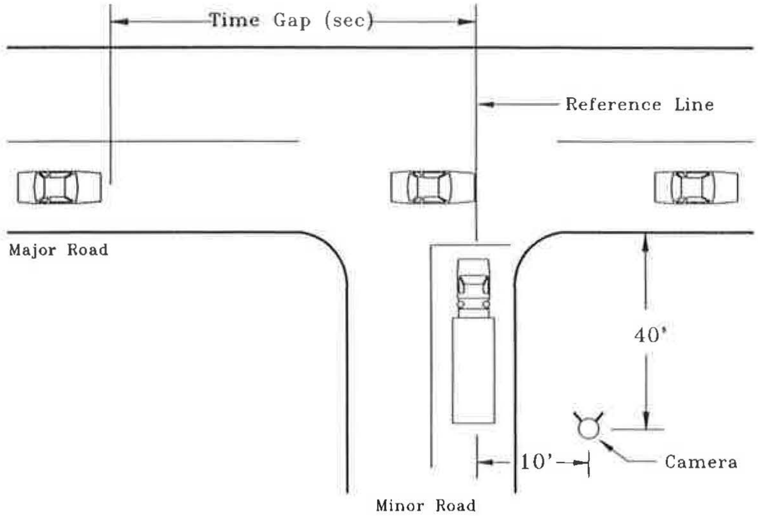

FIGURE 1 Typical setup for data collection.

of a side-street vehicle at the intersection to the arrival of the next main-street vehicle) than they do to a gap (interval from the arrival of one main-street vehicle at the intersection to the arrival of the next main-street vehicle). This problem can be avoided only by using data pertaining to lags. Unfortunately, using these data results in the loss of valuable information and may introduce bias in estimates of the critical gap/lag distribution. Identifying the start time of the lag presents other practical problems.

As a result of such difficulties, many methods of measuring the critical gap have been developed (*24*). Three methods were selected to evaluate the gap data obtained in this field study: Greenshield, Raff, and logit.

Greenshield Method

The classical Greenshield method was selected for its simplicity in performing gap-acceptance analyses. Greenshield et al. (*10*) used histograms to represent the time gaps accepted and rejected by minor-road drivers. The vertical axis represents the number of gaps accepted or rejected per time gap, which is the horizontal axis. Greenshield et al. defined the "average minimum acceptable time gap" as the minimum time gap that is accepted by more than 50 percent of the drivers. Figure 2 illustrates an example of the Greenshield method (*10*) for five-axle, right-turning trucks at the Trindle and Railroad intersection. In the example, the average minimum acceptable time gap occurs at 8.25 sec (three drivers accepted and three drivers rejected the gaps between 8.0 and 8.5 sec).

Raff Method

Raff and Hart (*11*) defined the critical lag, *L*, as the size lag for which the number of accepted lags shorter than *L* is the same as the number of rejected lags longer than *L*. Raff and

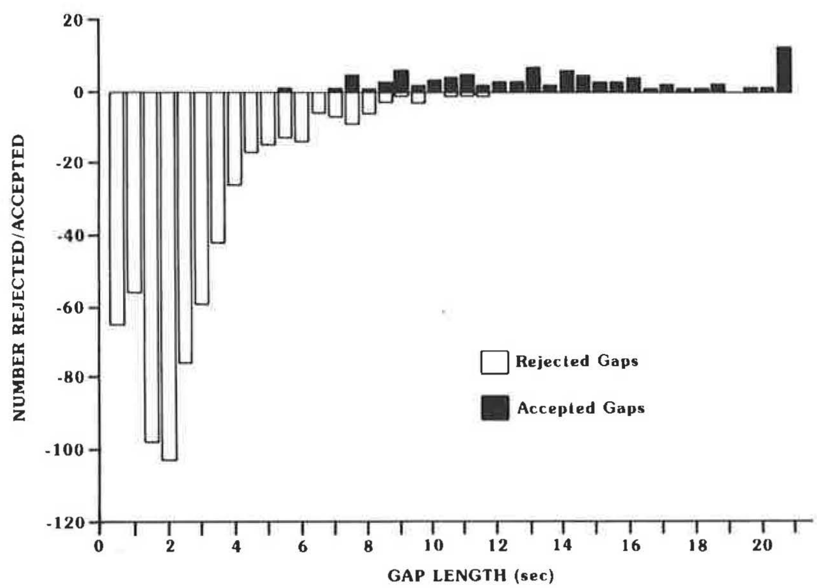

FIGURE 2 Greenshield method plot for a sample vehicle.

Hart did not include gaps in the study, arguing that one driver will only accept a gap of a particular size, but another driver may reject several gaps of the same size. More recent studies indicate that the acceptance of lags is not significantly different from the acceptance of gaps and that the lag and gap data can be combined (*12,16*). Therefore, the lag and gap data for each vehicle-maneuver combination were merged in this study. An example of the Raff graphical method is illustrated in Figure 3. The critical gap value for five-axle trucks turning right at the Trindle and Railroad intersection occurs at 8.5 sec.

Logit Method

When the dependent variable is an indicator variable (i.e., either the acceptance or rejection of a gap), the shape of the response function will frequently be curvilinear and can be approximated using a logistic function (*25*). One property of a logistic function is that it can be easily linearized. The transformation is called the logistic, or logit, transformation. The simple, dichotomous choice logistic function is

$$P = \frac{1}{1 + \exp\left[-(\beta_0 + \beta_1 X)\right]} \qquad (1)$$

where

P = probability of accepting a gap,
X = variable related to the gap acceptance decision, gap length, and
β_0,β_1 = regression coefficients.

The mean response is a probability when the dependent variable is a 0 or 1 (accept or reject) indicator variable. The logistic function can be easily linearized with the following transformation:

$$P' = \log_e \frac{P}{1 - P} = \beta_0 + \beta_1 X \qquad (2)$$

where P' equals the transformed probability.

A sample logistic curve and equation for five-axle trucks turning right at Trindle and Railroad are shown in Figure 4. The probability of accepting a gap is determined by solving Equation 2 for a particular time value. The time gap for a 50 percent probability can be determined by substituting 0.5 for P in Equation 2:

$$\log_e \frac{0.5}{1 - 0.5} = -9.58 + 1.12X_{50\%}$$

$$X_{50\%} = 8.52 \text{ sec} \qquad (3)$$

Fifty percent of the truck drivers at Trindle and Railroad accepted a gap of 8.52 sec, and 85 percent accepted a gap of 10.06 sec.

Findings

Tables 5 and 6 contain the results for passenger cars and trucks from these methods. In general, the methods yielded critical gap values within a 2.0-sec range.

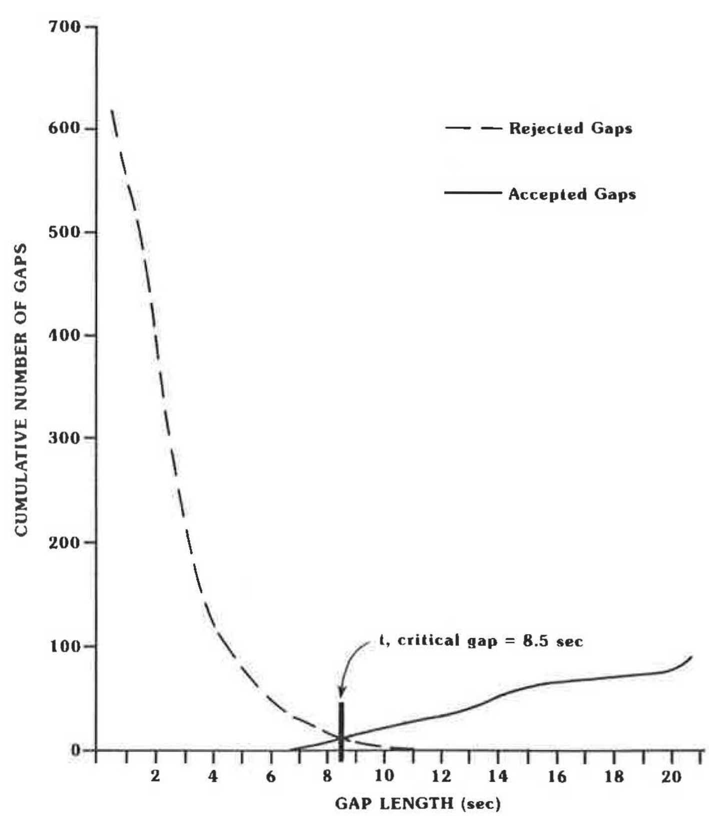

FIGURE 3 Raff method plot for a sample vehicle.

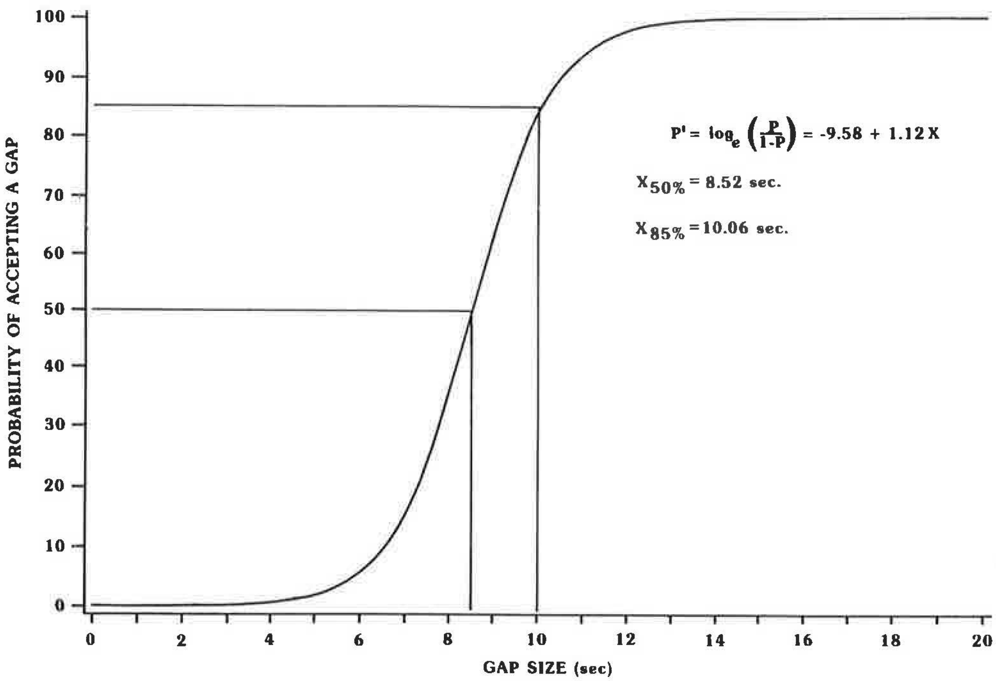

FIGURE 4 Logit method plot for a sample vehicle.

TABLE 5 FINDINGS FROM GAP ACCEPTANCE ANALYSIS FOR PASSENGER CARS

Intersection	Data Sets	Greenshield	Raff	Logit at 50 Percent	Logit at 85 Percent
LEFT-TURNING PASSENGER CARS					
Trindle & Railroad	128	6.00	6.25	6.19	7.49
Whitehall & Research	124	6.00	6.00	5.75	8.14
College & Cato	38	7.50	7.00	7.20	9.27
Easterly & NB Pugh	11	Insufficient Data*	Insufficient Data*	Insufficient Data*	Insufficient Data*
Easterly & SB Pugh	27	5.00	7.75	8.08	10.44
RIGHT-TURNING PASSENGER CARS					
Trindle & Railroad	149	6.00	5.75	6.03	7.47
Whitehall & Research	27	4.50	6.25	6.33	8.12
College & Cato	122	6.00	6.00	5.94	7.19
Easterly & NB Pugh	10	Insufficient Data*	Insufficient Data*	Insufficient Data*	Insufficient Data*
Easterly & SB Pugh	36	6.50	6.55	7.49	10.23
THROUGH PASSENGER CARS					
Easterly & NB Pugh	76	7.50	7.25	7.83	10.41
Easterly & SB Pugh	65	6.00	7.25	7.80	10.41

* Analyses were not performed for data sets containing less than 15 accepted gaps (i.e., 15 minor road vehicles).

TABLE 6 FINDINGS FROM GAP ACCEPTANCE ANALYSIS FOR TRUCKS

Intersection	Data Sets	Greenshield	Raff	Logit at 50 Percent	Logit at 85 Percent
LEFT-TURNING 5-AXLE TRUCKS					
Central Valley Asphalt	1	Insufficient Data*	Insufficient Data*	Insufficient Data*	Insufficient Data*
Truck Stop 64	5	Insufficient Data*	Insufficient Data*	Insufficient Data*	Insufficient Data*
Trindle & Railroad	16	7.25	8.25	8.27	9.84
RIGHT-TURNING 5-AXLE TRUCKS					
Central Valley Asphalt	0	Insufficient Data*	Insufficient Data*	Insufficient Data*	Insufficient Data*
Truck Stop 64	134	10.75	12.50	12.43	14.78
Trindle & Railroad	91	8.25	8.50	8.52	10.06
LEFT-TURNING LESS-THAN-5-AXLE TRUCKS					
Central Valley Asphalt	58	10.25	10.50	11.16	13.89
Truck Stop 64	2	Insufficient Data*	Insufficient Data*	Insufficient Data*	Insufficient Data*
Trindle & Railroad	8	Insufficient Data*	Insufficient Data*	Insufficient Data*	Insufficient Data*
RIGHT-TURNING LESS-THAN-5-AXLE TRUCKS					
Central Valley Asphalt	23	10.75	12.50	13.17	15.86
Truck Stop 64	7	Insufficient Data*	Insufficient Data*	Insufficient Data*	Insufficient Data*
Trindle & Railroad	26	6.25	6.50	7.25	8.87

* Analyses were not performed for data sets containing less than 15 accepted gaps (i.e., 15 minor road vehicles).

COMPARISON OF FINDINGS

Different Methods of Measuring Critical Gap

The Greenshield analyses for several of the combinations were questionable because of limited data. For example, only three of 23 trucks with fewer than five axles turning right at Central Valley Asphalt accepted gaps of less than 20 sec. The smallest gap accepted (10.75 sec) became the minimum accepted gap according to Greenshield's method because only one rejected gap occurred at the same time value. The Raff and logit methods produced higher critical gap values of 12.50 and 13.17 sec.

The Greenshield method had a critical gap more than 1.0 sec smaller than that of either the Raff or logit methods in four vehicle/maneuver/intersection combinations. Because the Greenshield method involves inspecting the gap accepted at isolated times, it does not consider the number of gaps accepted or rejected at other time gaps. Because the Raff method considers cumulative distributions and the logit method considers the probability of accepting different size gaps, the results are influenced by the several accepted gaps of more than 20 sec. Other combinations produced results within a 1.0-sec range from all three methods.

Because of these limitations in the Greenshield method and the more general acceptance of the logit method over the Raff method, the logit method results were used in the comparison with the literature findings and for the generalization of the field study findings. The logit method is also appropriate for a situation in which subjects (drivers) have a series of opportunities (gaps) in which one of two discrete choices (acceptance or rejection) is made.

Findings for Passenger Car Intersections

Because the findings at the Easterly and Pugh intersection were typically between 1.0 and 2.0 sec greater than the findings at the other passenger car intersections, investigations into potential causes were conducted. The average daily traffic (ADT) volumes (see Table 4) for Easterly and Pugh are not the lowest volumes for the four passenger car intersections. However, the speed limit for the major road was the lowest (35 mph rather than 40 or 45 mph). Additional inspection of the intersection geometrics revealed that even though the roads intersect at 90 degrees, the minor road approaches are offset by approximately 5 ft and Easterly begins curving just east of the intersection. Elimination of the Easterly and Pugh data was considered, but the findings were included to illustrate the influence that roadway and traffic characteristics have on gap acceptance. However, the results from this intersection must be used with caution because of these influences.

Findings from the logit method at the 50 percent gap-acceptance level for right-turning passenger cars at the Trindle and Railroad, Whitehall and Research, and College and Cato intersections were within 0.5 sec (5.94 sec to 6.33 sec). Findings for left-turning passenger cars at the Trindle and Railroad intersection and Whitehall and Research intersection (each included data for more than 120 minor road vehicles) were also within 0.5 sec (5.75 sec to 6.19 sec) for the logit method 50 percent gap acceptance. After inspection of the results, the gap-acceptance values were generalized as 6.5 sec for both right and left turns.

The logit method 85 percent probability was generalized as 8.25 sec for right and left turns. All combinations except those at the College and Cato intersection, which had a small data set, had 85 percent probability gap-acceptance values of less than 8.25 sec.

The 50 percent probability of accepting a gap for passenger car crossing maneuvers, which were measured only at the Easterly and Pugh intersection and therefore should be used with caution, was 7.8 sec. The 85 percent probability for all movements at Easterly and Pugh was less than 10.5 sec.

Findings for Truck Intersections

The critical gap accepted findings at the Central Valley Asphalt plant appear large when compared with those of other high-volume intersections. The Central Valley Asphalt intersection has unique qualities that may explain the differences. The intersection is 2,000 ft north of a signalized intersection. Drivers turning right noticeably waited for the end of a platoon that formed at the signal. Also, the vehicles leaving the plant were fully loaded, three- or four-axle aggregate or asphalt trucks with low acceleration capabilities.

The ADT on the major road at Truck Stop 64 is 7,000. Very large gaps were available at this low volume, and several truck drivers waited for these large gaps (defined in this study as greater than 20 sec). Almost all of the trucks turning right out of Truck Stop 64 entered one of the Interstate entrance ramps located 500 ft and 1,000 ft from the truck stop exit. Truck drivers may have accepted larger gaps than usual because they would be accelerating for only a short distance before slowing to make the turn onto an entrance ramp.

The truck drivers at the Trindle and Railroad intersection were pressured to accept smaller gaps than those accepted at the other sites. The frequency of gaps greater than 20 sec was small, and long queues occasionally formed on the minor road behind the truck. The five-axle trucks typically encroached into the far lane of the major road to complete the turn maneuver.

Findings at the 50 percent gap-acceptance level for left- and right-turning five-axle trucks at the high-volume Trindle and Railroad intersection were similar. Left-turning trucks accepted an 8.27-sec gap, whereas right-turning trucks accepted an 8.52-sec gap.

Right-turning trucks with fewer than five axles at the Trindle and Railroad intersection accepted a 7.25-sec gap, which is more than 1.0 sec less than the gap accepted by larger trucks. Left-turning trucks with fewer than five axles, loaded with asphalt and aggregate at Central Valley Asphalt, accepted an 11.16-sec gap.

The 85 percent probability of accepting a gap at the high-volume Trindle and Railroad intersection was generalized as 10.0 sec. The turning trucks had values near (10.06) or less (9.84 and 8.87 sec).

Comparison of Findings with the Literature

The study most similar in data collection and analysis procedures to this field study was performed by Solberg and Oppenlander (*16*). Their results for left and right turns (7.82 sec and 7.36 sec) were approximately 1.0 sec greater than the results listed in Table 4. Solberg and Oppenlander's intersections had an average major road volume of 330 to 590 vph, whereas the passenger car intersections in this study had major road volumes of 580 to 2,000 vph. Solberg and Oppenlander's result for through movement (7.18 sec) was 0.6 sec less than that found at Easterly and Pugh (7.80 sec), but data from Easterly and Pugh were influenced by the geometry of the intersection.

Radwan et al. (*13*) conducted field studies on minor-road drivers crossing or merging with four-lane, divided major road traffic at stop-controlled intersections. As expected, the ADT on the four-lane roads in the Radwan et al. study was greater than the ADT in this study. Also, their findings were for vehicles crossing or turning onto a four-lane divided highway rather than a two-lane highway. However, the number of minor road vehicle data sets used by Radwan et al. was comparable with the number used in this study, and the study methodologies were similar. Therefore, some comparisons between the findings of the two studies were reasonable. The gap accepted by left-turning vehicles in the study by Radwan et al. (6.32 sec) was similar to the gaps accepted in this study (5.75 to 6.19 sec). Right-turning vehicles accepted a slightly larger gap in the study by Radwan et al. (6.73 sec) than in this study (5.94 to 6.33 sec).

Radwan et al. combined the truck data for all maneuvers (right, through, and left) because the number of data points was small: 34, 75, and 43, respectively. This study's findings at the high-volume Trindle and Railroad intersection for five-axle trucks (8.27 and 8.52 sec) were similar to Radwan's findings for all truck maneuvers (8.4 sec). The similar methodologies of the two studies and the results of Radwan et al. support the findings in this study.

SUMMARY AND RECOMMENDATIONS

Gap acceptance is the act of safely joining or crossing the major road traffic stream within the length of the accepted gap. Gap-acceptance data are used in designing intersections and in evaluating operations at intersections. Truck drivers' gap-acceptance values should be considered at intersections with significant truck traffic.

Passenger car drivers' 50 percent probability of accepting a gap was generalized as 6.5 sec for both left and right turns and as 8.25 sec for the 85 percent probability of accepting a gap at a moderate- to high-volume intersection. A 10.5-sec gap represents the 85 percent probability of accepting a gap at an intersection where the accepted gaps were influenced by low volume and the intersection geometry. Truck drivers'

50 percent probability of accepting a gap was generalized as 8.5 sec. In general, at a high-volume location, 85 percent of the truck drivers accepted a 10.0 sec gap; at a low-volume location, 15.0 sec was the accepted gap value.

The data collection and reduction procedures were tedious and required several hours to film the operations of the intersections and view the videotapes to acquire the needed gap times. Alternative procedures for obtaining the gap data should be investigated.

Some of the critical gap values determined at several of the intersections were influenced by geometric or traffic characteristics, such as offset approaches and low traffic volumes. Additional research is necessary to determine the extent to which different characteristics (e.g., intersection configuration, rural versus urban location, and high versus low volume) affect gap-acceptance values. These findings could be incorporated into a gap-acceptance procedure adopted by an agency.

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