Capacity and Delay Characteristics of Two-Way Stop-Controlled Intersections

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Three objectives are sought: (a) to present a data base for two-way-stop-controlled (TWSC) intersections that can be used to investigate the factors that influence delay and capacity, (b) to identify some of the factors that affect delay and capacity at a TWSC intersection, and (c) to develop a set of preliminary models to estimate delay and capacity. Traffic flow, delay, and geometric data were collected at nine TWSC intersection sites in the Pacific Northwest encompassing a total of 13 hr of intersection operation. A total of 970 minor-street (subject approach) vehicles were observed and nearly 2,000 accepted and rejected gaps were identified and recorded. Each site has several common characteristics: four approach legs, single lanes on each approach, and a 25-mph speed limit on the major street. Several factors were identified that may influence delay and capacity at a TWSC intersection. The time waiting in queue (queue time) is affected by the traffic flow rate on the subject and opposing approaches, whereas the time spent waiting at the stop line (service time) is affected by the traffic flow rate on the conflicting approaches. The capacity of the subject approach is also affected by the flow rate on the conflicting approaches. The size of the accepted gap is affected by the length of time that a vehicle has been delayed, the flow rate on the conflicting approaches, and the directional movement of the subject vehicle.

Literature describing both empirical and theoretical studies of two-way stop-controlled (TWSC) intersections is plentiful. One major source is a compendium of papers presented at the 1988 International Workshop, *Intersections Without Traffic Signals* (*1*). These papers represent the latest research efforts in Europe, Asia, and the United States on this topic. Common to much of this work are two elements: (a) the determination of the critical gap as a function of the intersection geometry and major-street flow characteristics, and (b) the hierarchical classification of conflicting traffic streams as the basis for computing movement capacities.

These two elements are essential components of the standard analysis methodology used in the United States, defined by the 1985 *Highway Capacity Manual* (HCM) (*2*). Despite its widespread use, there is a general consensus that the HCM methodology requires substantial modification (*3*). Several empirical and theoretical limitations are most commonly cited:

1. The measure of effectiveness (MOE) used in the HCM procedures is reserve capacity. Although reserve capacity is directly related to delay in the German and Swedish procedures (*4,5*), the HCM provides only a broad description of the delay likely to be encountered for each range of reserve capacity. Thus, it is not now possible to forecast the performance of an intersection operating under various control conditions (e.g., signal control or two-way-stop control) using a single MOE such as delay.
2. The HCM procedure is based on a German method developed in 1972 and has been verified with only limited studies for U.S. conditions (*6*). There is an obvious need to develop a data base for U.S. conditions for TWSC intersections.
3. The Germans have since identified several theoretical problems with their original procedure and have now developed a new set of paper-and-pencil procedures and a computer simulation model (*7*). Also, the German procedures were developed only for single-lane approach sites. Multilane sites in Germany are always signalized.
4. There are several methodological problems with the current HCM procedure, primarily related to the use of the critical gap. First, the methodology used to estimate the critical gap usually results in an overestimation of this parameter. Kittelson and Vandehey in a companion paper in this Record propose a new method to obtain a more accurate estimate of the critical gap; this method deserves consideration. Second, it has been suggested that the critical gap is not constant and that drivers tend to accept smaller gaps the longer they wait in queue or at the stop line. This variability in the critical gap needs to be quantified. Finally, it is likely that the critical gap depends on the direction of the minor-street vehicle. The current HCM procedure assumes that the critical gap varies only with the travel speed and number of lanes on the major street. One solution to this problem may be to adopt the approach used in the United Kingdom (*8*), where empirically based models for delay and capacity have been developed that do not rely on estimation of the critical gap.

Clearly, there is a need to address several major issues with respect to the understanding of traffic flow at TWSC intersections. Three objectives begin to address some of these issues:

1. To present a data base for TWSC intersections that can be used to investigate the factors that influence delay and capacity,
2. To identify some of the factors that affect delay and capacity, and
3. To develop a preliminary set of models that can be used to estimate delay and capacity.

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DEFINITIONS OF TERMS

Intersection Approaches

Queue activity is monitored on one of the minor-street approaches. This approach is called the "subject approach." The other (facing) minor-street approach is called the "opposing approach." The two major-street approaches are called the "conflicting approaches."

Microscopic or Instantaneous Major-Street Flow Rate

The microscopic analysis requires a definition of the major-street flow as seen by each subject approach vehicle. Consider the following sequence of events. A subject vehicle arrives at time t_1. Two conflicting approach vehicles pass by at times t_2 and t_3, respectively. The gaps $t_3 - t_2$ and $t_2 - t_1$ are rejected by the subject vehicle. The subject vehicle departs at t_4, whereas the next conflicting vehicle passes at t_5. The definition of the conflicting flow rate as seen by this particular subject vehicle is the number of observed conflicting vehicles divided by the observation time, or

$$\text{Flow rate} = \frac{3}{t_5 - t_1} \quad (1)$$

This definition differs from the standard (macroscopic) method of estimating flow rates, in which averages are reported for some fixed period, usually 15 min or 1 hr. This distinction will be noted whenever the microscopic or instantaneous flow rate is used.

Accepted Gap

The standard definition for the accepted gap is $t_5 - t_3$. However, it is common for the conflicting vehicle representing the end of the accepted gap to pass through the intersection long after the departure of the subject vehicle. Thus, the subject vehicle never sees this conflicting vehicle, and the calculated accepted gap is not meaningful. Kittelson and Vandehey in a companion paper in this Record propose that a maximum value be used for the accepted gap based on criteria of sight distance and major-street speed. They suggest in most cases that a maximum of 12 sec is reasonable.

Delay

Stopped delay was calculated for each minor-street subject vehicle by measuring two separate components. The time between the arrival at the end of the queue and the time when the vehicle arrives at the stop line is defined as the "queue time." The time between the arrival at the stop line and the departure from the stop line is defined as the "service time."

COLLECTION AND REDUCTION OF TRAFFIC OPERATIONS DATA

Data were collected during nine different days at four different intersections over a period of 13.1 hr. Each of these days is classified as a sample site. Each site has four approach legs, a single lane on each approach, and a speed limit of 25 mph on the major-street approaches.

Each sample site was videotaped with the camera in a position to observe vehicles on each approach as they passed through the intersection as well as the queue activity on one minor-street approach.

Data collection software was used to record flow rate and delay data while observing the videotapes from each sample site (*9*). The time that each vehicle entered the intersection was recorded and its directional movement (left-turn, through, or right-turn) was noted. Flow rates were calculated on the basis of these data. For one minor-street approach (referred to as the subject approach), the times that each vehicle entered the end of the queue, arrived at the stop line, and entered the intersection were also noted. Delays were calculated on the basis of these data.

OVERVIEW OF SITE CONDITIONS: THE DATA BASE

The first objective is to present a data base for TWSC intersections. Table 1 presents some of the important geometric, traffic flow, and delay data for the nine sample sites.

Sight Distance Data

The sight distance data were assessed for each of the intersection approaches at the nine sample sites. Four categories were used in this assessment, including excellent, good, fair, and poor. Although admittedly qualitative, the assessment may be useful in determining if sight distance affects driver behavior and thus delay and capacity characteristics.

Upstream Control and Platoon Characteristics

The arrival patterns of the traffic on the conflicting approaches have an effect on the behavior of the subject vehicle. Up-

TABLE 1 SITE DATA

Site	Site Distance	Observed Major Street Platoon	Subject Volume, vph	Opposing Volume, vph	Conflicting Volume, vph	Mean Service Time, sec	Mean Queue Time, sec
1	Fair	Cyclic	137	12	642	8.3	3.4
2	Fair	Random	177	27	183	5.6	11.7
3	Excellent	Cyclic	38	69	1100	9.2	2.1
8	Good	Uniform	245	62	279	5.7	8.3
9	Good	Cyclic	388	200	464	6.9	17.7
11	Good	Cyclic	392	187	472	7.0	18.1
12	Fair	Cyclic	299	58	283	5.7	6.3
14	Good	Random	288	277	506	6.8	19.7
15	Fair	Cyclic	69	38	1100	10.3	0.9

stream control devices often have the effect of regulating this arrival pattern in some way. The type of control and the distance upstream to this control device for traffic arriving on the conflicting approaches from both the left and the right of the subject approach and the resulting observed platoon patterns were noted.

Flow Rate Data

Traffic flow rate data were collected for each intersection approach at the nine sample sites. Intersection flow rates varied from about 400 veh/hr at Site 2 to 1,200 veh/hr at Sites 3 and 15.

Delay Data

Queue and service times were measured for each minor-street subject vehicle. High mean delays, about 25 sec/vehicle, were observed at Sites 9, 11, and 14. The lowest delays, about 11 and 12 sec, were measured at Sites 1, 3, 12, and 15. The distribution of the queue time and service time components varies widely among the sites.

Major-Street Gap Data

Table 2 presents several important gap data for the nine sample sites. The critical gap was calculated as the gap size at which the percentage of accepted gaps is equal to the percentage of rejected gaps. The critical gap ranges from 5.5 to 7.5 sec. Data from Table 10–2 of the HCM for major streets with 30-mph speed limits and single lanes on each approach exhibit a range for the critical gap of 5.0 to 6.5 sec. Thus the data collected in this study compare favorably with ranges suggested in the HCM.

The zero gap was calculated as the highest measured gap that was rejected by all drivers.

Accepted and Rejected Gap Data

All gaps seen by each subject vehicle were measured. Each gap was classified into one of eight categories. The first gap observed by a subject vehicle is a lag. All others are gaps. Accepted gaps or lags were used only by a subject vehicle. Shared gaps or lags were used jointly by the subject vehicle and one or more opposing vehicles. Used gaps or lags were used by an opposing vehicle and were thus unavailable to the subject vehicle. Rejected gaps or lags were not used by the subject vehicle or any opposing vehicle. Table 2 presents the mean values for each of these gap categories for each site.

Several points can be made about the data presented in Table 2. First, expected differences between gap categories are supported by the data. For example, gaps or lags shared by more than one vehicle are larger than gaps that are accepted or used by only one vehicle. Also, rejected gaps or lags are smaller than accepted gaps or lags. Second, the large values of accepted gaps or lags (all mean values are greater than 11 sec) support the need to develop adjusted values for accepted gaps, as described earlier. Gaps greater than some value (suggested as 12 sec) do not provide any useful information in the analysis of the gap-capacity relationship.

IDENTIFICATION OF BASIC RELATIONSHIPS—MACROSCOPIC ANALYSIS

The second objective is to identify some of the factors that influence delay and capacity. In this section, mean values for several variables from each site are compared to determine, on a macroscopic basis, those factors that influence delay and capacity on the minor-street approach of a TWSC intersection.

Vehicle Delay

Stopped vehicle delay data were collected by measuring two components, queue time and service time. Plots of service time versus both conflicting flow and subject flow are shown in Figures 1 and 2. These flow rates are the measured macroscopic flow rates. Plots of queue time versus conflicting flow and subject flow are shown in Figures 3 and 4, respectively.

Service Time

Service time, or the time spent waiting at the stop line, is affected most directly by the rate of flow on the major street. As major-street flow increases, all other factors being equal, the service time should also be expected to increase. The data shown in Figure 1 indicate a strong correlation between service time and major-street flow rate. If a linear relationship is assumed, the coefficient of determination (R^2) is 0.94.

Figure 2 shows a slight decline in service time with increasing subject approach flow. One supposition that may be made

TABLE 2 GAP DATA

Sample Site	Critical Gap	Zero Gap	Mean Gap	Accepted Gap	Shared Gap	Accepted Lag	Shared Lag	Used Lag	Rejected Lag	Avg Used Gap	Avg Rejected Gap
1	5.5	4.5	5.9	13.8	21.5	18.1	24.2	5.4	3.4	4.9	2.8
2	7.5	4.5	10.2	12.0	20.3	15.6	26.8	11.1	3.8	7.1	3.3
3	6.5	6.5	4.0	12.4	14.1	17.2	0.0	6.1	2.0	3.0	3.4
8	6.5	3.5	12.5	13.0	22.6	17.2	29.1	6.7	2.8	8.6	3.0
9	5.5	3.0	7.8	20.9	22.2	19.7	25.5	8.4	3.1	8.1	2.7
11	6.0	3.0	7.7	15.1	24.4	21.6	25.9	8.0	2.5	9.6	2.5
12	6.5	3.5	13.5	14.8	26.6	17.8	26.2	6.1	3.3	11.8	3.2
14	6.5	3.5	7.3	16.4	21.8	19.4	21.7	7.9	2.5	8.9	2.4
15	5.5	3.5	4.0	11.0	11.1	11.6	8.7	6.5	3.0	3.9	2.9

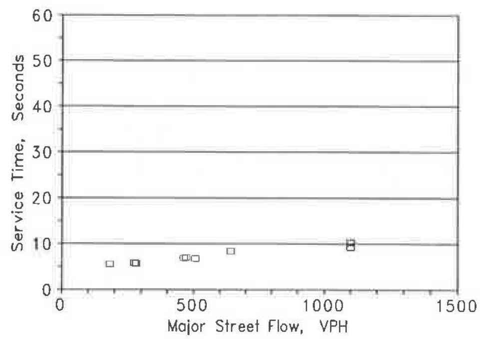

FIGURE 1 Service time versus major-street flow rate.

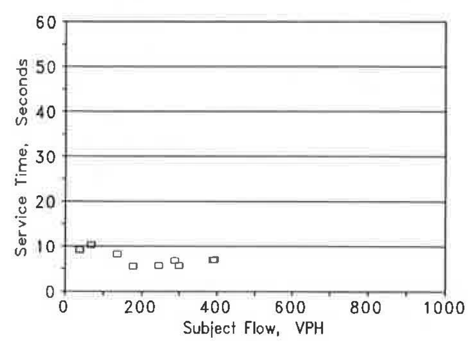

FIGURE 2 Service time versus subject approach flow rate.

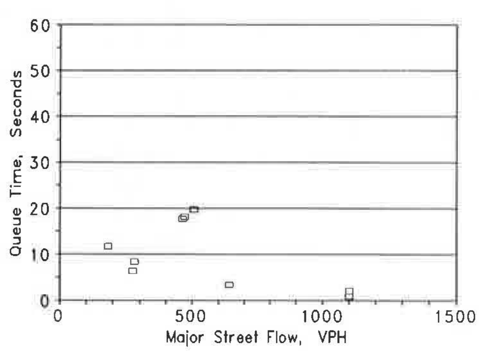

FIGURE 3 Queue time versus major-street flow rate.

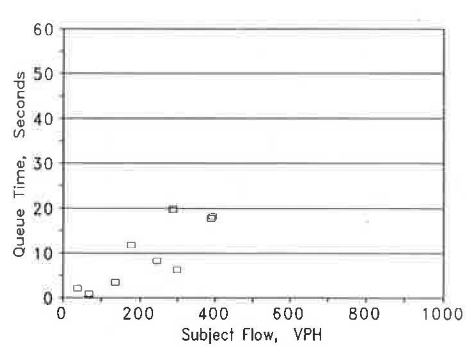

FIGURE 4 Queue time versus subject approach flow rate.

from the data in Figure 2 is that the pressure from increasing subject approach flow rates results in drivers accepting smaller major-street gaps and thus experiencing lower service times.

Queue Time

Queue time, or the time spent waiting in queue until arriving at the stop line, is a function of both the number of vehicles that are waiting in the queue and the rate at which the vehicle at the stop line is able to depart. The data shown in Figure 4 indicate a good correlation between queue time and the subject approach flow rate. Although other variables such as arrival patterns may also be important, the subject approach flow rate may be a good indicator for the number of vehicles likely to be in a queue on the minor street. If a linear function is assumed, the coefficient of determination (R^2) for this relationship is 0.70.

The data shown in Figure 3 do not, at first glance, support the contention that queue time is affected by major-street flow. However, a more detailed analysis may, in fact, bear out this supposition. If, for example, the three points in the lower right quadrant of Figure 3 are eliminated from the plot, the data indicate that queue time does increase with service time. The elimination of these data may in fact be justified because these three data points (sample Sites 1, 3, and 15) are from sites with the lowest subject approach flow rates (less than 150 veh/hr). Because these are cases in which subject approach queuing is low or nonexistent, it would not be expected that a variation in the major-street flow rate would have any effect on the queue time. However, the limited number of data points prevents a definitive conclusion at this time.

Minor-Street Capacity

Minor-street (subject approach) capacity was calculated using Equation 2 and the service time for each subject approach vehicle.

$$\text{Capacity} = \frac{3{,}600}{\text{Service Time}} \tag{2}$$

Figure 5 shows a strong linear correlation between the minor-street capacity and the major-street (conflicting approaches)

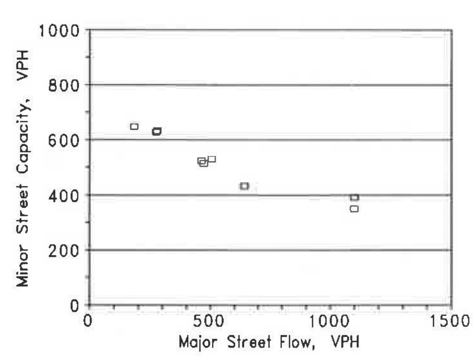

FIGURE 5 Minor-street capacity versus major-street flow rate.

flow rate. Although other variables are likely to affect capacity (e.g., major-street approach speed and turning proportions), the coefficient of determination (0.91) indicates the importance of major-street flow rate.

Figure 6 shows a plot of accepted gap versus major-street flow rate. The accepted gap data shown in this figure have not been modified as described earlier. One possible hypothesis that can be suggested on the basis of Figure 6 is that the size of the accepted gap first increases as major-street flow increases, and then decreases. The change point may represent the point at which a driver's frustration level caused by the delays experienced at higher major-street flow rates begins to affect the decision-making process.

IDENTIFICATION OF BASIC RELATIONSHIPS—MICROSCOPIC ANALYSIS

In order to further meet the second objective, a microscopic analysis of the data was undertaken. In this microscopic analysis, the conditions faced by each subject approach vehicle were taken into account; that is, consideration was given to the major-street flow rate as seen by the driver, the gaps that were presented, and so on. Several other points should be made about this analysis.

1. The gap acceptance and delay data for each minor-street subject vehicle were calculated and the gaps were classified according to the definitions described earlier.
2. Only those cases in which a subject vehicle did not face any opposing approach vehicles were considered (in effect simulating the operation of a one-way minor street crossing a two-way major street).
3. The microscopic major-street flow rate and the accepted gap were calculated as described earlier.
4. Not all of the sample sites are shown in every assessment: a sample site is only shown if all cells for a particular table had at least 10 observations.

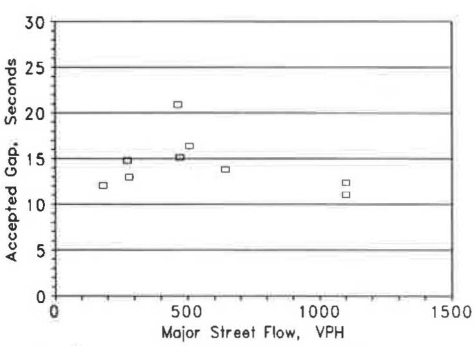

FIGURE 6 Accepted gap versus major-street flow rate.

Accepted Gap

Four assessments of accepted gap are presented here. These assessments are intended to identify whether the following variables influence the size of the gap accepted by a driver: whether a vehicle waited in queue or not, the major-street flow rate, the queue time, the service time, and movement direction of the subject approach vehicle.

Several conclusions may be stated from the following assessments. The most important is that the accepted gap is not a constant, but varies as a result of several factors: queue time, service time, number of gaps that have been rejected, major street flow, and directional movement of the subject vehicle.

Accepted Gap as a Function of Number of Rejected Gaps and Presence of Queue

The assessment presented in Table 3 indicates that most vehicles that wait in a queue accept shorter gaps than vehicles that do not wait in a queue. Table 3 also indicates that most vehicles that reject one or more gaps eventually accept a shorter gap than vehicles that accept the first gap. One possible inference is that the longer a vehicle waits, the greater the driver's frustration, and a gap that previously seemed too short now becomes acceptable. Another possible inference is that a learning process takes place as the driver waits at the intersection. The longer the wait, the better a driver can estimate the size of an acceptable gap. Both of these inferences are tentative conclusions, and they should receive further study.

Accepted Gap as a Function of Major Street Flow

Table 4 indicates that the size of the accepted gap decreases as the microscopic major-street flow rate increases. With increasing major-street flow rates, the size of the available gaps

TABLE 3 ACCEPTED GAPS, NUMBER OF REJECTED GAPS, AND QUEUE TIMES

Sample Site	Accepted Gap, Seconds			
	Zero Gaps Rejected		One or More Gaps Rejected	
	No Queue	Queue	No Queue	Queue
1	11.3	10.8	10.2	8.9
2	10.1	10.0	9.0	8.4
3	-	-	-	-
8	10.0	9.6	9.5	10.5
9	10.8	10.3	9.7	9.4
11	10.7	9.4	10.5	9.2
12	10.9	10.2	9.5	9.4
14	10.8	9.7	9.9	9.2
15	-	-	-	-

TABLE 4 ACCEPTED GAPS AND MICROSCOPIC (INSTANTANEOUS) MAJOR-STREET FLOW RATES

Sample Site	Accepted Gap, Seconds			
	Major St Flow 0-300 vph	Major St Flow 300-600 vph	Major St Flow 600-900 vph	Major St Flow >900 vph
1	12.0	10.2	10.5	6.8
2	12.0	9.6	8.3	6.1
3	12.0	10.5	9.0	8.1
8	12.0	11.6	9.0	6.9
9	12.0	10.6	7.8	6.9
11	12.0	11.0	8.8	6.8
12	12.0	10.9	7.5	6.1
14	12.0	11.4	7.7	5.6
15	-	11.7	8.9	7.7

becomes smaller. But these results may also mean that when faced with higher flow rates, drivers may anticipate the need to accept what is available, even if the available gap size is smaller than desired.

Accepted Gap as a Function of Service Time

Table 5 indicates a slight decrease in the size of the accepted gap as the service time increases. More data are needed to determine if these results are statistically significant. Again, the trend may point to two factors discussed earlier: the accepted gap may be influenced by driver frustration level or by learning, or both. Both factors directly relate to the length of time spent at the intersection stop line (service time).

Accepted Lag as a Function of Directional Movement

Table 6 indicates the importance of the directional movement of the minor-street vehicle and the size of the lag that is accepted by the subject vehicle. Because a through-vehicle must only clear the intersection, the size of the required lag is smaller than for a turning vehicle, which must also merge into the conflicting-vehicle stream. The data presented in Table 6 seem to confirm this assertion.

Delay

Two assessments of vehicle delay are presented here. Both assessments tend to confirm the conclusions reached in the macroscopic analysis.

Service Time as Function of Major-Street Flow

Table 7 indicates that, for most sites, service time and total delay increase as major-street flow rates increase. This relationship was also observed in the macroscopic analysis.

Total Delay as a Function of Major-Street Flow

Table 8 indicates that, for most sites, total delay increases as major-street flow rates increase.

DEVELOPMENT OF PRELIMINARY MODELS FOR CAPACITY AND DELAY

On the basis of the analysis presented earlier, a set of equations has been developed that indicates some important fac-

TABLE 5 ACCEPTED GAPS AND SERVICE TIMES

Sample Sites	Accepted Gap, Seconds		
	Service Time, 0-5 sec	Service Time, 5-10 sec	Service Time, > 10 sec
3rd/Hayes (Sites 2, 8, 12)	10.1	9.9	9.7
29th/Freya (Sites 9, 11, 14)	9.9	9.7	9.6

TABLE 6 ACCEPTED LAGS AND DIRECTIONAL MOVEMENT

Sample Sites	Accepted Lag, Seconds			
	Left Turns	Throughs	Right Turns	All
2	10.0	8.7	10.9	10.0
8	10.0	9.2	10.6	9.8
12	10.7	10.0	11.1	10.6
9	-	9.6	11.2	10.4
11	-	9.1	10.9	9.9
14	-	8.8	11.1	10.0

TABLE 7 SERVICE TIMES AND MAJOR-STREET FLOW RATE

Sample Sites	Service Time, Seconds		
	Major St Flow < 300 vph	Major St Flow 300-600 vph	Major St Flow > 600 vph
2	3.8	4.1	8.0
8	3.9	4.6	4.8
12	4.2	5.0	6.7
9	3.3	4.5	6.5
11	3.8	3.8	5.2
14	4.1	3.8	5.7

TABLE 8 TOTAL DELAYS AND MAJOR-STREET FLOW RATE

Sample Sites	Total Delay, Seconds		
	Major St Flow 0-300 vph	Major St Flow 300-600 vph	Major St Flow > 600 vph
1	4.7	9.5	13.5
2	13.7	14.9	23.0
3	9.5	9.1	11.1
8	10.0	13.0	14.5
9	16.4	16.2	21.4
11	17.1	19.1	23.9
12	8.4	9.6	10.2
14	15.4	24.6	25.9
15	7.1	6.2	13.1

tors that affect minor-street capacity, total minor-street delay, queue time, and service time.

Minor-Street Capacity

A correlation analysis was undertaken to identify the factors that affect minor-street capacity. The strongest linear correlations are between minor-street capacity and the volume on the conflicting approaches (R^2 = 0.91), the critical gap (R^2 = 0.42), the mean gap (R^2 = 0.88), and the volume on the subject approach (R^2 = 0.31).

Equation 3 shows the best model resulting from a regression analysis with minor-street capacity as the dependent variable.

$$C = 687 + 0.307q_c \quad (3)$$

The model of Equation 3 has been compared with capacity models estimated in two other countries. Equation 4 was developed from simulation data in Poland by Marion Tracz (*10*). Equation 5 was developed by the Transportation Road Research Laboratory in the United Kingdom (*11*). There is a strong similarity between the three equations in both intercept and slope, indicating that the capacity model developed with data from this current study compares favorably with models developed in Poland and the United Kingdom.

$$C = 887 - 0.547q_c \quad (4)$$

$$C = 675 - 0.400q_c \quad (5)$$

Total Minor-Street Delay

A correlation analysis was undertaken to identify the factors that affect total minor-street delay. The strongest linear correlations are between total minor-street delay and the volume on the subject approach (R^2 = 0.60), the volume on the opposing approach (R^2 = 0.83), and the minor-street approach volume-to-capacity ratio (R^2 = 0.68).

Equation 6 indicates the best model resulting from a regression analysis with total minor-street delay as the dependent variable and the volumes on the subject and opposing approaches as the independent variables.

$$d_t = 8.0 + 0.0153q_s + 0.0505q_0 \quad (6)$$

Minor-Street Queue Time

A correlation analysis was undertaken to identify the factors that affect minor-street queue time. The strongest linear correlations are between minor-street queue time and the volume on the subject approach (R^2 = 0.70), the volume on the conflicting approaches (R^2 = 0.30), the volume on the opposing approach (R^2 = 0.74), and the volume-to-capacity ratio (R^2 = 0.70).

Equation 7 indicates the best model resulting from a regression analysis with minor-street queue time as the dependent variable and the volumes on the subject and opposing approaches as the independent variables.

$$d_q = 0.0428q_0 + 0.0245q_s \quad (7)$$

Minor-Street Service Time

A correlation analysis was undertaken to identify the factors that affect minor-street service time. The strongest linear correlations are between minor-street service time and volume on the conflicting approaches (R^2 = 0.94), and the volume on the subject approach (R^2 = 0.43).

Equation 8 indicates the best model resulting from a regression analysis with minor-street service time as the dependent variable and volume on the conflicting approaches as the independent variable.

$$d_s = 0.0048q_c \quad (8)$$

SUMMARY AND CONCLUSIONS

The first objective was to develop a data base for traffic operations at TWSC intersections. To meet this objective, nine TWSC sample sites were studied covering 13 hr of traffic operations. A total of 970 minor-street subject vehicles and nearly 2,000 gaps that were accepted or rejected were studied.

The second objective was to identify some of the factors that affect delay and capacity. Several conclusions can now be stated on the basis of the macroscopic and microscopic analyses.

When the average delay and flow rate data for each of the nine sites are compared, several general delay and capacity relationships can be identified.

1. The average time spent waiting in queue (queue time) increases as the subject approach flow rate increases.
2. The average time spent waiting at the stop line (service time) increases as the flow rates on the conflicting approaches increase.
3. The minor-street capacity decreases as the major-street flow rate increases.

A microscopic analysis of the behavior of individual minor-street vehicles, effectively operating as a one-way minor street crossing a two-way major street, confirms some of these same conclusions and suggests several additional ones:

1. The mean accepted gap tends to be lower for drivers who have waited in a queue than for drivers who have not waited in a queue.
2. The mean accepted gap tends to decrease as the major-street flow rate increases.
3. The mean accepted gap tends to decrease as the queue time or service time increases.
4. The mean accepted gap is lower for through vehicles than for turning vehicles.
5. The time in queue is not correlated to the major-street flow rates.
6. Service time and total stopped delay increase as the major-street flow rates increase.

The third objective was to develop a set of equations to forecast delay and capacity. The equations for forecasting minor-street capacity depend on traffic volumes on the conflicting and opposing approaches. Total delay on the minor street (subject approach) depends on traffic volumes or the volume-to-capacity ratios on the subject and opposing approach. Queue time depends on traffic volumes or volume/capacity ratios on the subject and opposing approaches. Service time depends on the traffic volume on the conflicting (major-street) approaches.

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