Empirical Analysis of Traffic Characteristics at Two-Way Stop-Controlled Intersections in Alaska

JIAN JOHN LU AND B. KENT LALL

In the United States, the current capacity estimation procedure of two-way stop-controlled intersections was based on the German guidelines. Professionals in the transportation field have called for a modification of this procedure or for development of new procedures verified by U.S. field data. A research study sponsored by Region 10 of the U.S. Department of Transportation University Transportation Center was undertaken to study traffic characteristics at two-way stop-controlled intersections, including delay, capacity, and gap acceptance characteristics. Field data were collected from six test sites in Fairbanks, Alaska. For the analysis of delay and capacity characteristics, about 34 hr of traffic data were recorded in 17 videotapes. Data average intervals of 5- and 15-min were used to reduce field data by using a specialized computer program, called Traffic Data Input Program. The main purpose for using this program was to obtain summarized traffic data from the videotapes with certain average intervals (5 and 10 min), such as service delay, queue delay, major traffic volume, minor traffic volume, movement distribution, and so on. For the gap acceptance data, observers reviewed field pictures shown on a TV set and manually collected the accepted gap data. Researchers used empirical methods to develop regression models that characterize the statistical relationships between service delay and conflicting volume, minor street capacity and conflicting volume, and total delay and minor and conflicting volumes. Researchers used linear, negative exponential, and nonlinear two-variable functions, respectively, to fit these models. Reasonably good fitness of these models resulted and modeling results showed that the major street speed limit did not significantly affect these models. Concerning driver's gap acceptance behavior, the field data were collected to quantify the relationship between service delay and critical gap. Researchers in this field have assumed that minor-street drivers tend to accept smaller gaps as they wait a longer time at the stop line or in queue. Results obtained from this study verified the assumption and researchers obtained a quantitative model to quantify the relationship.

Chapter 10 of the 1985 Highway Capacity Manual (HCM) (*1*) provides the procedure for capacity analysis of two-way stop-controlled (TWSC) intersections. This procedure is based on the distribution of gaps in the major street traffic stream and drivers' judgment in selecting gaps through which to execute their desired maneuvers. In recent years, issues regarding the capacity analysis procedure have been raised to address the inadequacy of the present procedures. The current method is based on the German guideline which was validated with a limited U.S. data base. One of the major limitations is a methodological problem related to the use of the critical gap. As presented in the compendium of papers (*2*) presented at the 1988 International Workshop, Intersection without Traffic Signals, the methodology used in the 1985 HCM to estimate the critical gap usually results in an overestimation of this parameter. The 1985 HCM assumes that the critical gap remains constant without considering the impact of delay or waiting time. Preliminary studies (*3–5*) have shown that the critical gap is not constant because drivers tend to accept smaller gaps as they wait in queue or at the stop line for longer time.

To assess the current HCM and develop new procedures for capacity analysis of TWSC intersections, a work program was developed by the Unsignalized Intersection Subcommittee of TRB. A Transportation Research circular (*6*) was published by the subcommittee to provide guidelines for the standard data collection technique for unsignalized intersection capacity/delay characteristics. Under this program, research studies have been initiated to develop a national data base and new capacity analysis procedures. An NCHRP project entitled New Procedures for Capacity and Level of Service Analysis at Unsignalized Intersections was conducted by the University of Idaho. According to 1993 NCHRP statements (*7*), the major objectives of this NCHRP project were to examine analysis methods, conduct validation studies, recommend revised computational methodologies, and calibrate the recommended procedures that are needed to replace the outdated procedures in Chapter 10 of the 1985 HCM. Another research study entitled Study of Sign Controlled Intersections and Uniform Data Collection and sponsored by Region 10 of University Transportation Center (Transportation Northwest Center), was conducted by the University of Alaska Fairbanks and Portland State University during 1993 and 1994. This paper summarizes some of the research efforts in the study with the activities focused on the following:

> Traffic data at six TWSC intersections were collected in Fairbanks, Alaska, and 34-hr traffic data were recorded by video cameras. The recorded traffic data were reduced from videotapes by a specialized computer program, Traffic Data Input Program (TDIP) (*8*), to generate major and minor street volumes, conflicting volumes, minor queue and service delays, turning movements, gaps, headway distribution, and other characteristics. Empirical methods were used to analyze the interrelationships between conflicting volume, delay, and capacity. The main purpose to develop such models was to seek a simplified method to estimate minor street capacity at TWSC intersections. Drivers' acceptable gap data were collected from these intersections. These gap data were analyzed to generate the statistical relationship between intersection service time (delay) and the critical gap.

The main objective of this effort was to collect traffic data at TWSC intersections under Alaska's environment. These data may be added to the data base of the Pacific Northwest region of the United States and to a national traffic data base for developing TWSC intersection capacity estimation models. Because Alaska is a special state, with larger areas and relatively less traffic compared with other

J. J. Lu, Transportation Research Center, University of Alaska Fairbanks, Fairbanks, Alaska 99775. B. Kent Lall, Department of Civil Engineering, Portland State University, Portland, Oreg. 97207.

states, the data from Alaska may have certain meanings to the data bases used for the development of capacity estimation models.

FIELD DATA COLLECTION AND REDUCTION

To study traffic delay, capacity, and gap acceptance characteristics at TWSC intersections, it was necessary to obtain field data at intersections that typically represented most TWSC intersections. The selection of suitable sites involved considerations of several factors, such as geometric conditions, sight distance, speed limit, traffic volume, traffic directional distribution, and randomness of approaching traffic. In this study, six test sites were selected. Table 1 summarizes these test sites.

As suggested in a TRB research circular (*6*), video cameras were used in the field to record traffic in both major and minor approaches. In addition, time data displayed in the screen of the video cameras were also recorded.

To obtain delay, volume, and gap acceptance data, time data at which each vehicle entered the end of the queue, reached stop line, and entered the intersection were necessary. Time data were obtained from videotapes that recorded time information. For the reduction of delay, capacity, and volume data, the computer program TDIP was used. This program was developed by the University of Idaho to collect traffic volume, delay, movement, and gap (headway) data. In this effort, data collection was performed during the day on normal weekdays, including rush-hour and nonrush-hour traffic. Through field data collection, approximately 34-hr traffic data were collected from Test Sites 1 through 6 for the analysis of delay, capacity, through volume, and gap acceptance characteristics. Statistical traffic data collected from Test Sites 1 through 6 and generated by TDIP were traffic volume on major and minor approaches, queue delay, service delay, total delay, and traffic movement distribution. These data were based on both 5- and 10-min averages and may be contributed to a data base for development of a capacity estimation procedure of TWSC intersections.

DELAY AND CAPACITY MODELS

Empirical methods for estimating minor street capacity at TWSC intersections have been attempted in previous studies (*3, 9–12*). Basically, in these studies, it was assumed that the minor street capacity was a function of the traffic volume and the speed on the major street. The function was estimated by statistical regression analysis with a linear function format or exponential function format. Although the models obtained in these studies were not the final ones, they gave better understanding of the statistical relationships between delay, capacity, and volume at the TWSC intersections. Results from these studies indicated that the empirical model approach might provide an alternative to the gap acceptance method currently used in the 1985 HCM.

The research effort summarized in this paper used the same approach to develop three statistical models for minor street service delay, minor street capacity, and minor street total delay, respectively. In the first model, it was proposed that the minor street service delay was the function of the subject conflicting volume. Raw data indicated that this relationship could be a first-order function. In the second model, minor street capacity data were converted from service delay. Then an exponential function was used to fit the relationship between minor street capacity and conflicting volume. In the third model, the total delay in the minor street approach was fitted by a nonlinear multivariable regression model with the conflicting volume and subject minor street volume as the independent variables. Traffic data were based on 5- and 15-min averages. Data generated through TDIP included major street traffic volume, subject minor street traffic volume, subject minor street queue delay, and subject minor street service delay with a total 408 of data points obtained for each variable if a 5-min average was used and 136 data points for each variable if a 15-min average was used. Besides, the major street speed limit might also affect a driver's judgment to enter the intersection from the stop line. In this case, traffic data were divided into two groups, one with a major street speed limit of 56 kph (35 mph) (Test Sites 1 through 3), and the other with 88 kph (55 mph) (Test Sites 4 through 6). For each model, four equations were obtained: that is, the combinations of two speed limits and two intervals of data average.

Estimation of Capacity from Service Delay

The capacity of a minor approach can be obtained from the corresponding service delay by the following equation:

TABLE 1 Summary of Test Site Conditions at Fairbanks

Test Sites	Major Street	Minor Street	Development Along Minor Street	Major Street Speed Limit	Sight Condition	Minor Approach Grade
1	3rd Ave.	Eagle Ave.	Resident	56 km/hr.	Very Good	Level
2	University Ave.	Davis Rd.	Resident	56 km/hr.	Fair	Level
3	Gaffney Rd.	604th St.	Military Base	56 km/hr.	Very Good	Level
4	Richardson Hwy.	Old Richardson Hwy.	Industry	88 km/hr.	Good	Level
5	Steese Exp.	Farmers loop Rd. (W.B.)	Resident	88 km/hr.	Very Good	Level
6	Steese Exp.	Farmers Loop Rd. (E.B.)	Resident	88 km/hr.	Very Good	Level

Note: 1 km = 0.6 mi.

$$\text{Capacity} = \frac{3600}{\text{Service Delay}} \quad (1)$$

where the unit of capacity is vehicle per hour and the unit of service delay is a second. The calculation of capacity from service delay using Equation 1 may not be used in a practical case. According to the definition, the minor street capacity is the maximum number of vehicles that cross the stop line and enter the intersection from the subject minor street approach. Practically, this capacity can be calculated by Equation 2:

$$\text{Capacity} = \frac{3600}{T} \quad (2)$$

where T is the average interval (seconds) of two successive vehicles entering the intersection from the subject minor street approach and T is not equal to service delay. Assume at time t_1, the first vehicle begins to enter the intersection. Meanwhile, the second vehicle begins to move to approach to stop line if lost time is ignored. At time t_2, the second vehicle arrives at the stop line. This vehicle has to stop at the stop line and look for an available gap to enter the intersection. The time taken by the second vehicle waiting at the stop line is the service delay. At time t_3, the second vehicle accepts an available gap and begins to enter the intersection. Service delay is the interval between t_2 and t_3 or

$$\text{Service Delay} = t_3 - t_2$$

and

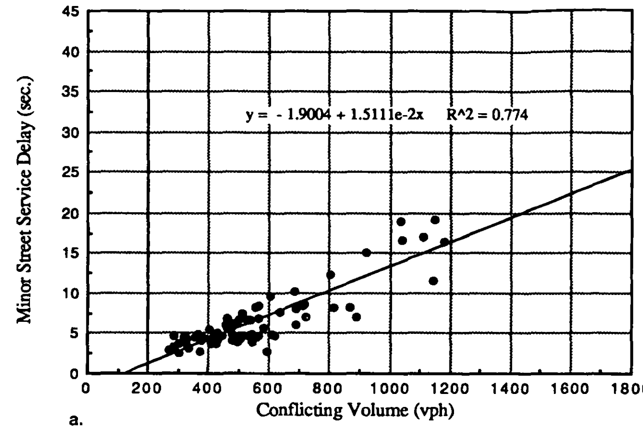
$$T = t_3 - t_1 = t_3 - t_2 + t_2 - t_1 = \text{Service Delay} + \Delta \quad (3)$$

where $\Delta = t_2 - t_1$ and Δ should be greater than 0. Generally, Δ is not affected by traffic on the major street and is dependent only on driver's behavior and vehicle's acceleration characteristic. In fact, T can be considered the follow-up gap of the subject minor street approach. Statistically, Δ can be estimated from field observations. By reviewing videotapes, an average Δ value (4.1 sec) was obtained. Capacity, therefore, can be calculated by Equation 4:

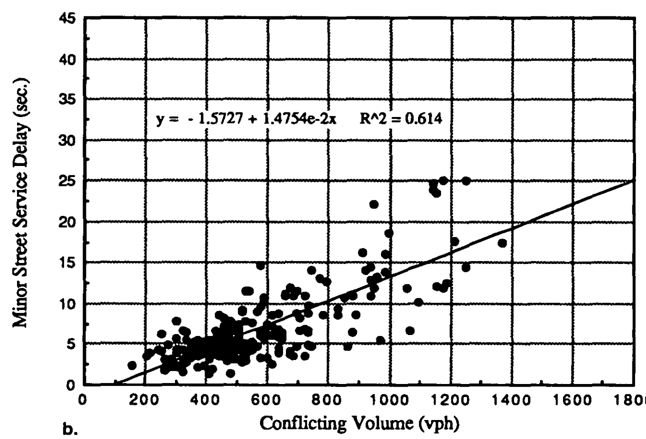
$$\text{Capacity} = \frac{3600}{\text{Service Delay} + 4.1} \quad (4)$$

Service Delay versus Conflicting Volume

Service delay or service time is defined as the time between the arrival of minor approaching traffic at the stop line and the departure from the stop line. The major factor that contributes to service delay is the conflicting volume or major traffic volume because what a driver needs is an acceptable gap between two successive vehicles in the conflicting traffic stream. Figures 1 and 2 present the relationships between service delay and conflicting volume for the test sites with major street speed limits of 56 kph (35 mph) and 88 kph (55 mph), respectively. Parts *a* and *b* of each figure represent the relationships with 5- and 10-minute averages, respectively. Statistical regression models and correlation coefficients are shown in the corresponding figures from which it can be seen that these models have relatively good fitness, meaning service delay can be adequately estimated directly from the conflicting volume. Figure 3 shows the statistical relationship between service delay and conflicting volume for different major street speed limits and time averages. On the basis of this figure, two conclusions can be made. First, the factor of data average interval does not significantly affect the statistical models if enough data points were obtained. Second, the minor approach service delay is slightly more sensitive to a higher speed limit in the major street when the conflicting traffic is heavier. However, the impact of speed limit on minor street service delay is not significant. It should be stated that these statistical equations cannot be used for the case that the conflicting volume is very low (≤200 vehicles per hour) because the models were developed on the basis of the conflicting volume that was heavier than 200 vehicles per hour.



Note: 1 km = 0.6 mi.

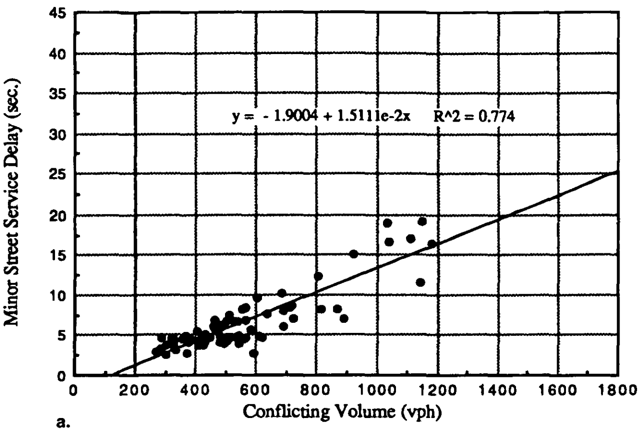


Note: 1 km = 0.6 mi.

FIGURE 1 Relationship between minor street service delay and conflicting volume. Major street speed limit: (*a*) 56 kph; average interval, 15 min; (*b*) 88 kph; average interval, 15 min.

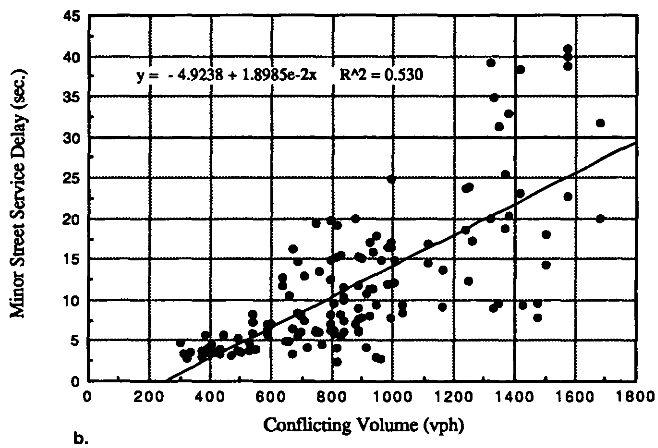
Minor Street Capacity versus Conflicting Volume

Minor street capacity at TWSC intersections can be calculated by Equation 4 if service delay data are available. On the basis of field data, the relationships between subject minor street capacity and



a.

Note: 1 km = 0.6 mi.



b.

Note: 1 km = 0.6 mi.

FIGURE 2 Relationship between minor street service delay and subject conflicting volume. Major street speed limit: (*a*) 88 kph, average interval, 15 min; (*b*) 88 kph; average interval, 5 min.

conflicting volume were obtained and shown in Figure 4 with a major street speed limit of 56 kph (35 mph) and Figure 5 with a major street speed limit of 88 kph (55 mph). Parts *a* and *b* of these figures represent the results with 5- and 10-min averages, respectively. According to the data points shown in these figures, an exponential functional form was used to fit these curves. Statistical capacity estimation models are listed as follows:

Speed limit, 56 kph (35 mph), 15-min average:

$$\text{Capacity} = 683.76\, e^{-0.0011744\, V_c} \qquad R^2 = 0.774 \tag{5}$$

Speed limit, 56 kph (35 mph), 5-min average:

$$\text{Capacity} = 665.27\, e^{-0.0011196\, V_c} \qquad R^2 = 0.602 \tag{6}$$

Speed limit, 88 kph (55 mph), 15-min average:

$$\text{Capacity} = 675.13\, e^{-0.0011519\, V_c} \qquad R^2 = 0.689 \tag{7}$$

Speed limit, 88 kph (55 mph), 5-min average:

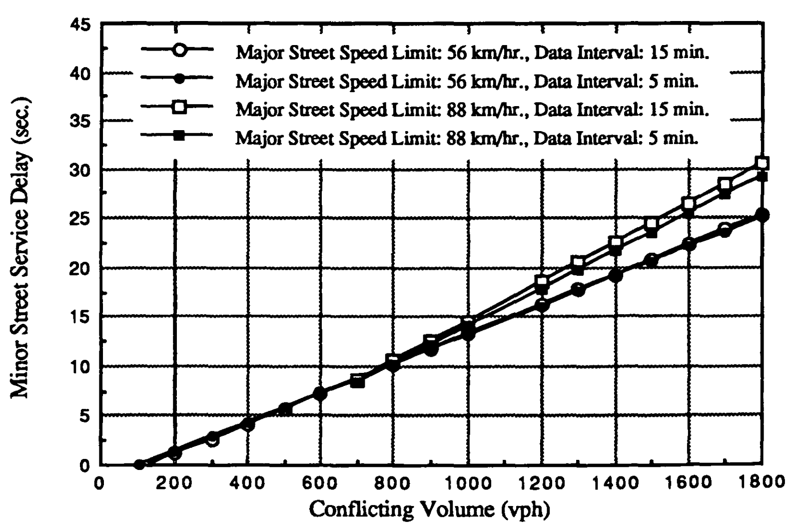
$$\text{Capacity} = 661.69\, e^{-0.0010795\, V_c} \qquad R^2 = 0.565 \tag{8}$$

where V_c is the conflicting volume.

These functions in Equations 5 through 8 are drawn together in Figure 6 to show the differences between these functions. From Figure 6, it can be concluded that (*a*) the factor of major street speed limit is not an important one to affect the subject minor street capacity, and (*b*) the data average interval does not show a significant impact on the modeling results. By averaging the models with 5- and 15-min data averages, the following capacity models can be obtained.

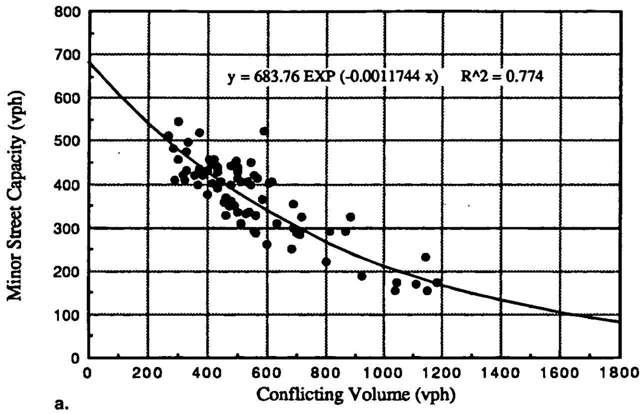
Speed limit, 56 kph (35 mph):

$$\text{Capacity} = 674.52 e^{-0.001147\, V_c} \tag{9}$$

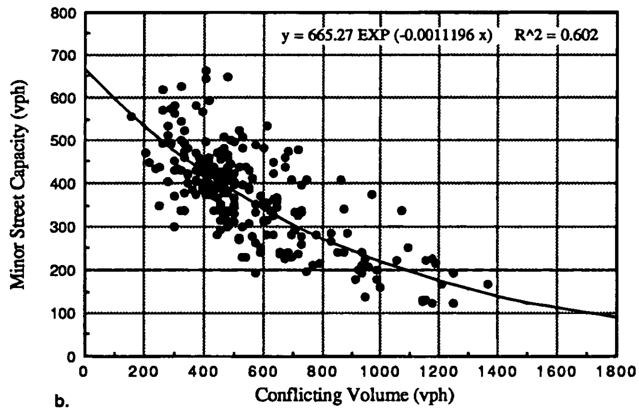


Note: 1 km = 0.6 mi.

FIGURE 3 Statistical relationship between minor street delay and conflicting volume.

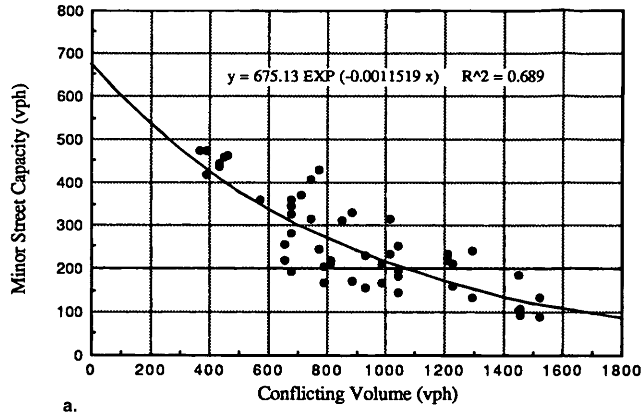


Note: 1 km = 0.6 mi.

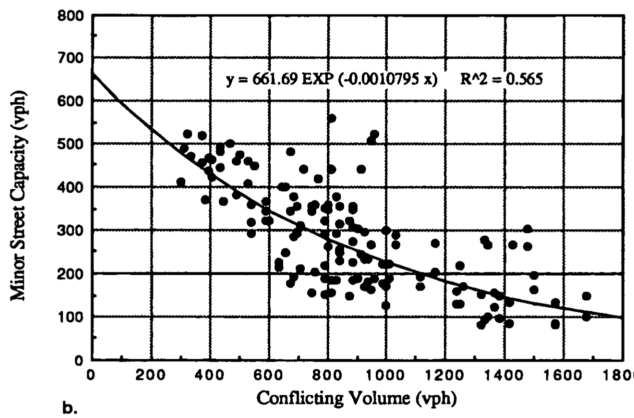


Note: 1 km = 0.6 mi.

FIGURE 4 Relationship between minor street capacity and conflicting volume. Major street speed limit: (*a*) 56 kph, data interval, 15 min; (*b*) 56 kph, data interval, 5 min.

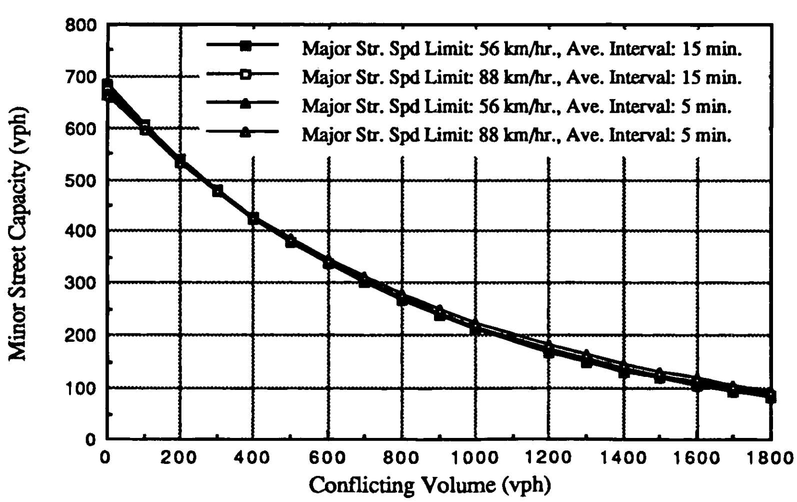


Note: 1 km = 0.6 mi.



Note: 1 km = 0.6 mi.

FIGURE 5 Relationship between minor street capacity and conflicting volume. Major street speed limit (*a*) 88 kph; data interval, 15 min; (*b*) 88 kph; data interval, 5 min.



Note: 1 km = 0.6 mi.

FIGURE 6 Statistical relationship between minor street capacity and conflicting volume.

Speed limit, 88 kph (55 mph):

$$\text{Capacity} = 668.41e^{-0.0011157\,V_c} \tag{10}$$

Total Delay versus Subject Minor and Conflicting Volumes

The total delay at the subject minor street approach consists of service delay and queue delay. The queue delay, or queue time, is defined as the time spent waiting in queue until arriving at the stop line. The queue delay is not only the function of the conflicting volume, but also the function of the subject minor street approaching traffic volume. In this case, the total delay can be considered the function of both conflicting volume and minor volume. The following equational form was tried in the effort:

$$D_t = a + b\,V_{mi} + ce^{dV_c} \tag{11}$$

where

D_t = the subject minor street total delay (sec);
V_c and V_{mi} = conflicting volume and minor traffic volume, respectively; and
a, b, c, and d = coefficients to be estimated.

As stated previously, major street speed limit did not significantly affect the minor street capacity or service delay. The data base used to develop the model represented by Equation 11, therefore, included data with both major street speed limits of 56 kph (35 mph) and 88 kph (55 mph). Statistical analysis was conducted to obtain the coefficients shown in Equation 11. Table 2 shows the modeling results for both average intervals of 5 and 15 min. The regression parameters b, c, and d are positive, meaning that as traffic volumes in subject conflicting approach or subject minor street approach increases, or both, the total delay in the subject minor approach increases. This represents the real situation because as more minor street traffic approaches the intersection, more vehicles wait in the queue line, resulting in a longer queue delay. If all data with both 5- and 15-min averages are combined together, a final model can be obtained as shown in Equation 12.

$$D_t = -\,3.411 + 0.022\,V_{mi} + 5.634\,e^{.00125\,V_c} \tag{12}$$

The corresponding statistics are shown in Table 2.

IMPACT OF SERVICE DELAY ON GAP ACCEPTANCE BEHAVIOR

Traffic gap acceptance characteristics have been used to calculate the capacity of unsignalized intersections, decide the warrants for stop signs, analyze the capacity of weaving and merging areas, select parameters for ramp metering, and solve other design problems. The availability of quantitative data for gap acceptance characteristics, therefore, is very important for these applications. One of the main tasks studied in this research effort was to verify whether a driver waiting at the stop line would take a smaller gap if he or she had waited a longer time at stop line. The statistical relationship, which characterizes this behavior, was quantified in this task.

The 1985 HCM uses constant critical gaps to estimate minor street capacity with the assumption that the critical gaps do not change over time. In recent years, suggestions have been made to state that the critical gaps are not constant and that drivers waiting at the stop line tend to accept smaller gaps as they wait a longer time at the stop line or in queue. Efforts were made in this study to quantify the variability in the critical gap related to the minor street approach service delay. Gap data used for this task were collected from Test Sites 1 through 6. Vehicles approaching the stop line from the subject minor

TABLE 2 Multiple Regression Analysis for Total Delay Model

	Coefficient	Std. Err Estimate	t Statistic	Prob>t	R^2
Part a Data Average Interval: 15 Min.	a = -1.403	2.152	-0.652	0.516	0.560
	b = 0.025	0.014	1.752	0.082	
	c = 3.309	0.269	12.306	0.000	
Part b Data Average Interval: 5 Min.	a = -3.697	1.590	-2.324	0.021	0.333
	b = 0.022	0.006	3.651	0.000	
	c = 5.833	0.429	13.602	0.000	
Part c Modeling Results with All Data	a = -3.411	1.308	-2.609	0.009	0.365
	b = 0.022	0.005	3.957	0.000	
	c = 5.634	0.334	16.878	0.000	

street at each site were monitored to get their service delay and accepted gap data. These gap data were divided into three groups according to the corresponding service delay (Group 1, Service delay = 1 to 10 secs; Group 2, Service delay = 11 to 20 sec; and Group 3, Service delay ≥ 21 sec) without consideration of traffic movement. In each group, a critical gap was calculated. The cumulative distribution (percent acceptance) curves of accepted gaps in each service delay group was fitted by a logit equation and is shown in Figure 7 with the resulting critical gaps shown as follows:

Group 1: Critical gap = 8.39 sec,
Group 2: Critical gap = 8.21 sec, and
Group 3: Critical gap = 7.84 sec.

Statistically, it was found that as service delay increased, the corresponding critical gap decreased or the drivers waiting at the stop line seemed to accept smaller gaps. This conclusion verifies the assumption mentioned previously. To quantify the relationship between the critical gap and service delay, a second-order polynomial equation was used with the following definition of a new variable, g:

$g = 1$ (if service delay belongs to Group 1),
$g = 2$ (if service delay belongs to Group 2), and
$g = 3$ (if service delay belongs to Group 3).

Then, the critical gap was mathematically fitted by the following equation:

$$\text{Critical gap} = 8.38 + 0.105g - 0.095g^2 \tag{13}$$

This equation is graphically shown in Figure 8. This curve does not assume that as service delay continuously increases the corre-

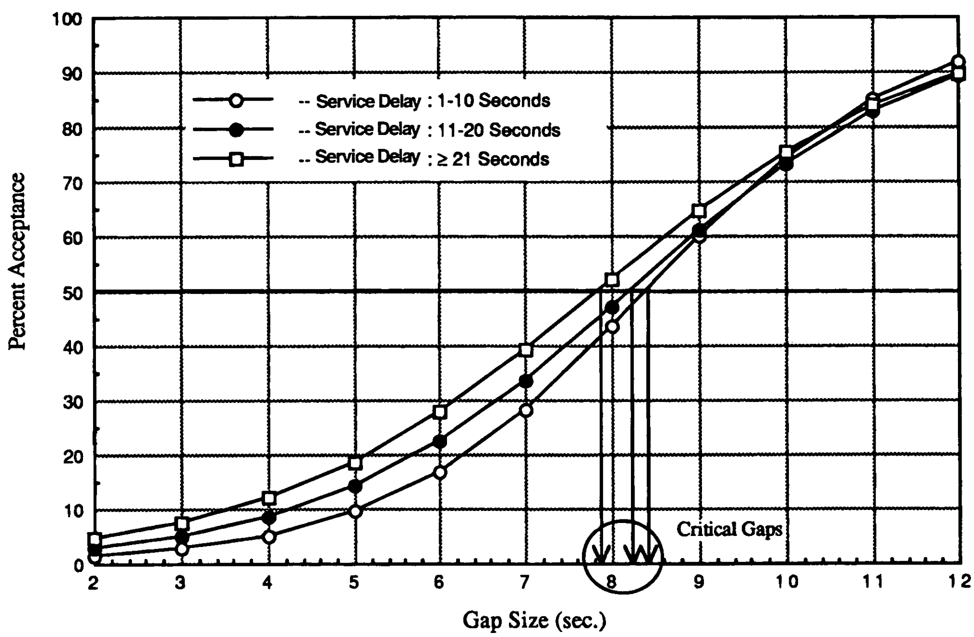


FIGURE 7 Impact of service delay on driver's gap acceptance behavior.

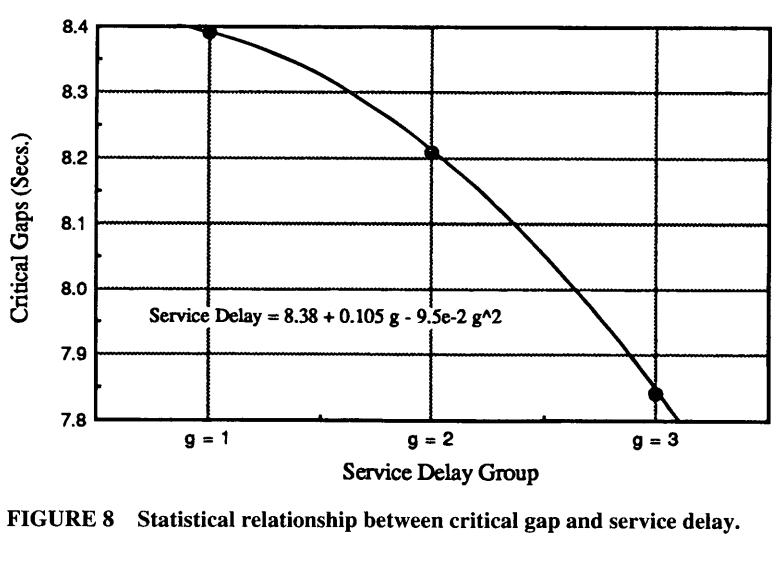


FIGURE 8 Statistical relationship between critical gap and service delay.

sponding critical gap would unrestrictively decrease. A certain limitation should be reached. The detailed behavior is yet to be studied.

CONCLUSIONS

The following conclusions can be made:

1. Empirical methods have been proven to be an alternative for the estimation of minor street capacity at TWSC intersections. On the basis of empirical methods, a procedure to estimate minor street capacity at TWSC intersections can be developed.

2. Service delay is mainly caused by the conflicting traffic or major street traffic. A linear equation high correlation was obtained to represent this relationship.

3. Minor street capacity can be directly estimated from the conflicting traffic volume or major street traffic volume with an exponential equational form. The models developed in this effort showed good correlation between capacity and conflicting volume. As discussed previously, the minor street capacity is not inversely proportional to service delay, but the follow-up gap of the subject minor street traffic. The follow-up gap consists of service delay and a time interval Δ defined previously. The time interval Δ is dependent on driver's behavior and vehicle acceleration characteristics. Estimation of Δ was made in this effort. However, further study of this variable is recommended because it appears that no studies have been conducted to evaluate this variable, which definitely affects the capacity in the subject approach.

4. Total delay depends on not only the conflicting traffic volume or major street traffic volume but also the subject minor street traffic volume. As more vehicles approach the intersection, the corresponding total delay will increase because more vehicles may enter the queue line in the subject minor street approach. A nonlinear multivariable model was used in this effort to describe this relationship. Reasonably good fitness of the model was obtained.

5. It appeared from this study that the factor of major street speed limit did not significantly affect service delay and capacity estimation models, and modeling results did not show a significant difference between 5- and 15-min averages.

6. It was proven that drivers tended to accept smaller gaps in the subject traffic stream as service delay increased. To develop better-capacity estimation procedure, this behavior should be taken into consideration.

REFERENCES

1. Special Report 209: Highway Capacity Manual, Chapter 10, TRB, National Research Council, Washington, D.C., 1985.
2. W. Brilon (ed.), *Intersections Without Traffic Signals,* Springer-Verlag, New York, 1988.
3. Kyte, M., C. Clemow, N. Mahfood, B. K. Lall, and C. J. Khisty. Capacity and Delay Characteristics of Two-Way Stop-Controlled Intersections. In *Transportation Research Record 1320,* TRB, National Research Council, Washington, D.C., 1991, pp. 160–167.
4. Kittelson, W. K., and M. A. Vandehey. Delay Effects on Driver Gap Acceptance Characteristics at Two-Way Stop-Controlled Intersections. In *Transportation Research Record 1320,* TRB, National Research Council, Washington, D.C., 1991, pp. 154–159.
5. Brilon, W., M. Grossmann, and B. Stuwe. Toward a New German Guideline for Capacity of Unsignalized Intersections. In *Transportation Research Record 1320,* TRB, National Research Council, Washington, D.C., 1991, pp. 168–174.
6. *Transportation Research Circular 373:* Interim Materials on Unsignalized Intersection Capacity, TRB, National Research Council, Washington, D.C., 1991.
7. *Briefs of Research Problem Statements Considered by the AASHTO Standing Committee on Research for the 1993 Program of the NCHRP.* TRB, National Research Council, Washington, D.C., Oct. 1991.
8. Boesen, A., M. Kyte, and B. Rindlisbacher. *Traffic Data Input Program (TDIP), Program Documentation and User's Manual Version 3.0.* University of Idaho, Moscow, March 1991.
9. Kyte, M., B. K. Lall, and N. Mahfood. Empirical Method to Estimate the Capacity and Delay of the Minor Street Approach of a Two-Way Stop-Controlled Intersection. In *Transportation Research Record 1365,* TRB, National Research Council, Washington, D.C., 1992, pp. 1–11.
10. Kimber, R. M., and R. D. Coombe. *The Traffic Capacity of Major/Minor Priority Junctions.* TRRL Supplementary Report 582. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1980.
11. Kimber, R. M. Gap-Acceptance and Empiricism in Capacity Prediction. *Transportation Science,* Vol. 23, No. 2, May 1989, pp. 100–111.
12. Semmens, M. C. *The Capacity of Major/Minor Priority Junctions on High Speed Roads.* Working Paper TMN 157. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, Oct. 1987.

The contents of this paper reflect the views of the authors, who are responsible for the facts and the data presented herein. The contents do not necessarily reflect the official views or policies of FHWA. This paper does not constitute a standard, specification, or regulation.

Publication of this paper sponsored by Committee on Traffic Control Devices.