Estimating Capacity of an All-Way-Stop–Controlled Intersection

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The factors that influence the capacity of an all-way-stop–controlled (AWSC) intersection have been identified, and a procedure that can be used to estimate intersection capacity has been developed. A theoretical framework for a capacity estimation procedure was first postulated and then validated with field data collected at 20 sites. A statistical analysis of the factors that affect capacity was undertaken, and a method for the estimation of intersection capacity was proposed. The proposed model represents a logical procedure for the determination of the capacity of an AWSC intersection, given the number of lanes on each intersection approach, the distribution of traffic among the approaches, and the proportion of turning movements on each approach. The forecasting performance of this model is significantly better than that of two previously proposed methods for forecasting the capacity of an AWSC intersection.

One of the most important tasks of the traffic engineer is to estimate the capacity of transportation facilities. The 1985 *Highway Capacity Manual* (HCM) (*1*) contains detailed procedures for determining the capacity of nearly all types of facilities (e.g., freeways and signalized intersections). These procedures usually include the determination of a base capacity under ideal conditions and the modification of this base capacity as a function of the actual conditions found at a given site.

Unfortunately, no such detailed procedure exists for one of the most common facilities, the all-way-stop–controlled (AWSC) intersection. Factors that influence the capacity of an AWSC intersection were identified, and a procedure that can be used to estimate intersection capacity was developed. This procedure was developed using 7,129 individual departmental headways measured during capacity operation at 20 AWSC intersection sites over a period of 30 hr of intersection operation.

A theoretical framework for the capacity estimation procedure and the field data that were collected at 20 sites, primarily in the Northwest United States, are described. The factors that influence capacity are statistically analyzed, and a method for the estimation of intersection capacity is proposed.

THEORETICAL FRAMEWORK FOR CAPACITY ESTIMATION

Overview

The HCM (*1*) defines the capacity of a transportation facility as the "maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions." For a signalized intersection, the HCM (*1*) gives the capacity of an approach as the product of the saturation flow rate and the green ratio. The saturation flow rate is computed starting with a base saturation flow rate under ideal conditions and then modified on the basis of the actual traffic and geometric conditions at a particular site. The base saturation flow rate is given as 1,800 veh/hr of green per lane and is equivalent to a saturation headway of 2.0 sec per vehicle.

This basic model is useful when considering a framework for estimating the capacity of an AWSC intersection. Whereas a traffic signal exerts the major control on the traffic flow at each approach of a signalized intersection, no such control system exists at an AWSC intersection to restrict, for specific periods of time, the movement of traffic. Instead, vehicles depart, in turn, at a rate dependent on geometric and traffic conditions. Thus, the green ratio of an AWSC intersection is effectively equal to 1, and the capacity is simply the maximum rate of flow that can be achieved given average driver response characteristics and the geometric and traffic factors at a specific intersection.

As with a signalized intersection, each approach of an AWSC intersection must be considered separately. The problem becomes one of determining, under capacity conditions for a given approach, the factors that influence the rate at which vehicles can successively depart from the stop line. The manner in which these factors may influence the departure headway at capacity (or saturation headway) for a given approach, and thus the basis for the proposed theoretical framework, are discussed in the following sections.

Some terms must be defined. The approach under study is called the subject approach (Figure 1). The opposing and conflicting approaches are also shown in Figure 1. The departure headway for a vehicle on the subject approach is defined as the difference between the times of departure of that vehicle and the previous vehicle on the subject approach. A departure headway is considered to be a saturation headway or capacity headway if, when a given vehicle arrives, another vehicle is ahead of it at the stop line (Figure 2).

Ideal Conditions

The simplest case, which might be defined as having ideal conditions, is a four-way, single-lane approach intersection with no turning movements, no heavy vehicles, and no pedestrians. The primary factor determining the rate at which vehi-

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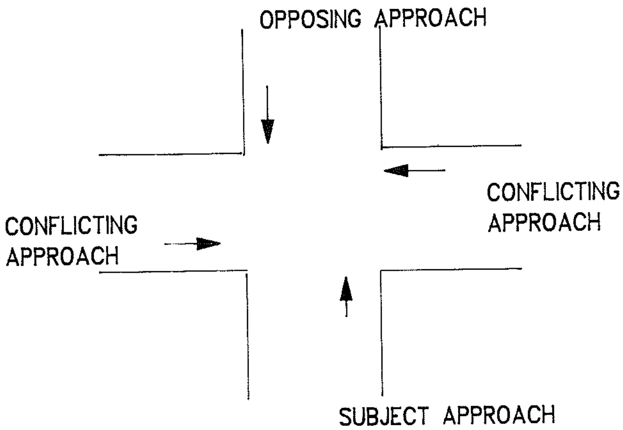

FIGURE 1 Definition of intersection approaches.

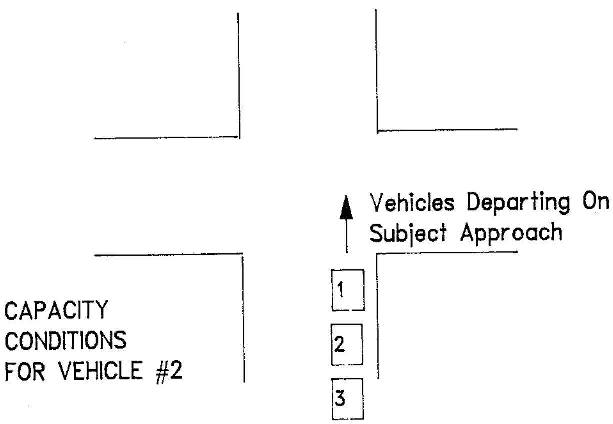

FIGURE 2 Capacity operation.

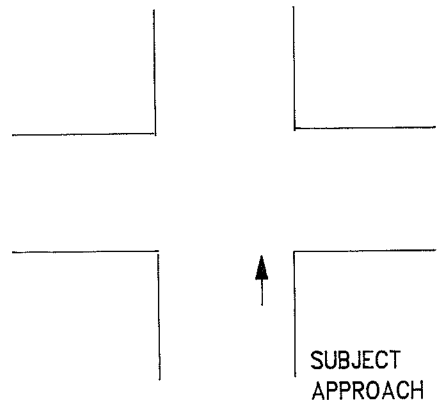

FIGURE 3 Case 1, vehicles on subject approach only.

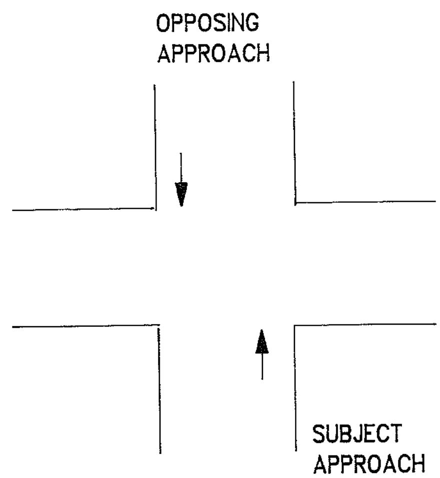

FIGURE 4 Case 2, vehicles on subject and opposing approaches.

cles depart from the stop line on the subject approach is the relative distribution of traffic among the four approaches.

If traffic is present on the subject approach only, vehicles depart as rapidly as individual drivers can safely accelerate into and clear the intersection. Case 1 is shown in Figure 3.

If traffic is present on the other approaches, as well as on the subject approach, the departure headway on the subject approach will increase, depending on the degree of conflict that results between the subject approach vehicles and the vehicles on the other approaches. In Case 2 (Figure 4), some uncertainty is introduced by a vehicle on the opposing approach; thus, the departure headway will be greater than for Case 1. In Case 3 (Figure 5), vehicles on the conflicting approaches further restrict the departure rate of vehicles on the subject approach, and the departure headway will be longer than for Cases 1 and 2. When all approaches are loaded, Case 4 (Figure 6), departure headways are even longer as each traffic stream enters the intersection in turn.

Nonideal Conditions

The introduction of nonideal conditions clearly has an effect on the departure headways for the four basic cases described.

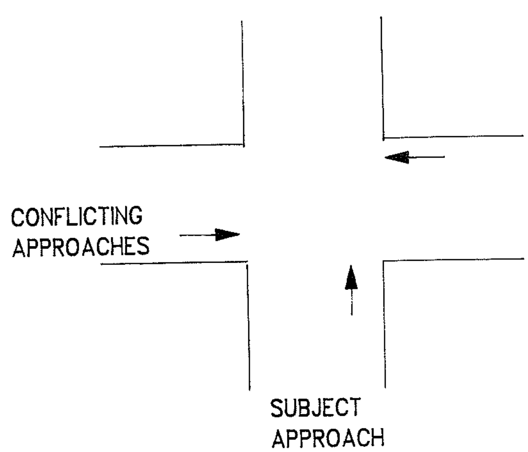

FIGURE 5 Case 3, vehicles on subject and conflicting approaches.

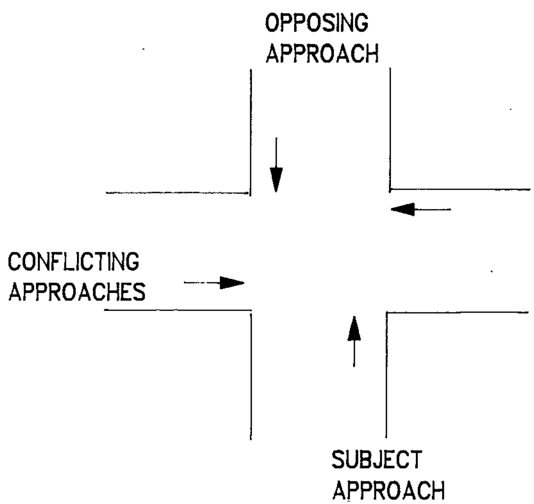

FIGURE 6 Case 4, vehicles on subject, opposing, and conflicting approaches.

- Left-turning movements increase the departure headways on the subject approach. Whereas two opposing through vehicles can travel through the intersection simultaneously without affecting each other, one vehicle will be delayed if the other is turning left.
- Right-turning movements reduce the departure headways on the subject approach as potential conflicts are decreased. More vehicles can travel through the intersection at shorter headways.
- Heavy vehicles have slower acceleration characteristics and take up more space than standard vehicles. Thus, as the proportion of heavy vehicles increases, the departure headways on the subject approach increase.
- Pedestrians have the right of way at an AWSC intersection. Increasing pedestrian flow rates will also increase the basic departure headways, and thus reduce intersection capacity.
- Increasing the number of lanes on the subject approach will reduce the departure headways on the subject approach. More than one vehicle can leave the intersection at one time.
- Increasing the number of lanes on the conflicting and opposing approaches will increase the subject approach departure headways. These additional lanes will increase the uncertainty of drivers on the subject approach as well as the distance required to clear the intersection.

Summary of Proposed Framework

The factors that are hypothesized to affect the capacity of the subject approach are presented in Table 1. A statistical analysis to determine which of these proposed factors actually affect capacity follows.

DATA COLLECTION METHODS AND SITE CHARACTERISTICS

Basic Site Conditions

To provide a means to assess this theoretical framework for the capacity of an AWSC intersection, field data were collected at 20 sites over a period of 30 hr. These sites represent a range of geometric and traffic conditions. A summary of the data is presented in Table 2.

Data were collected using a videocamera. The videocamera was oriented so that the stop lines for all approaches were visible and the queue dynamics on one approach could be observed. Flow rate and vehicle delay data were summarized in 1-, 5-, and 15-min increments. Truck and pedestrian flow data were also collected at most sites. The data collection and reduction method has been described by Kyte and Marek (*2*). Table 3 presents a summary of the important traffic data collected at each site, including mean flow rates, the percentages of time that the subject approach was operating at capacity, turning movements, the proportion of trucks, and pedestrian flow rates.

Capacity Flow and Departure Headways

Identifying the time periods during which the subject approach was loaded, or operating at capacity conditions, was important. The departure headway for each subject approach vehicle traveling during capacity conditions at each of the 20 sites

TABLE 1 FACTORS THAT AFFECT INTERSECTION CAPACITY

Increasing Factor:	Effect on Capacity:
Percent traffic on subject approach	Increases
Percent traffic on opposing approach	Reduces
Percent traffic on conflicting approach	Reduces
Percent left-turning vehicles	Reduces
Percent right-turning vehicles	Increases
Percent heavy vehicles	Reduces
Pedestrian flow rate	Reduces
Number of lanes on subject approach	Increases
Number of lanes on conflicting/opposing approaches	Reduces

TABLE 2 SITE CHARACTERISTICS

Four-Way Intersections, Single-Lane Approaches

Site	Intersection	Date	City/State	Subject Direction	Lanes NB SB EB WB
10	Blaine/Sixth	17-Sep-87	Moscow,ID	EB	1 1 1 1
11	Blaine/White	18-Sep-87	Moscow,ID	SB	1 1 1 1
13	NW 25th/Thurman	25-Sep-87	Portland, OR	NB	1 1 1 1
21	SW 185th/Baseline	25-Mar-88	Aloha, OR	NB	1 1 1 1
22	SW 185th/Baseline	25-Mar-88	Aloha, OR	NB	1 1 1 1
23	SW 185th/Baseline	25-Mar-88	Aloha, OR	NB	1 1 1 1
24	SW 185th/Baseline	25-Mar-88	Aloha, OR	NB	1 1 1 1
26	Milwaukie/Northview	07-Jun-88	Boise, ID	NB	1 1 1 1
27	Maplegrove/Victory	08-Jun-88	Boise, ID	EB	1 1 1 1
29	Maplegrove/Victory	08-Jun-88	Boise, ID	WB	1 1 1 1
30	Maplegrove/Victory	09-Jun-88	Boise, ID	EB	1 1 1 1
32	Cloverdale/Ustick	09-Jun-88	Boise, ID	NB	1 1 1 1
33	Maplegrove/Victory	10-Jun-88	Boise, ID	SB	1 1 1 1

Four-Way Intersections, Multi-Lane Approaches

Site	Intersection	Date	City/State	Subject Direction	Lanes NB SB EB WB
17	Eighth/Sixteenth	05-Nov-87	Lewiston, ID	NB	3 3 2 2
25	Main/10th	02-Jun-88	Ore City, OR	SB	2 1 2 2
34	1st/Fort/State	10-Jun-88	Boise, ID	SB	3 2 2 3

Three-Way Intersections

Site	Intersection	Date	City/State	Subject Direction	Lanes NB SB EB WB
15	Line/Sixth	15-Oct-87	Moscow, ID	WB	0 1 1 1
16	Line/Sixth	16-Oct-87	Moscow, ID	WB	0 1 1 1
19	Summit/Kirkwood	12-Nov-87	Iowa City, IA	SB	0 2 2 1
20	Dodge/Kirkwood	25-Nov-87	Iowa City, IA	SB	0 2 2 1

was measured. These data amounted to 7,129 individual departure headways. The data, which were classified into the four conditions cases, are presented in Table 4. As expected from the proposed model, the observed departure headways for Case 1 were the lowest, and those for Case 4 were the highest. These differences were stable between sites, as shown in Figure 7. No corrections were made for nonideal conditions.

From these departure headway data, the mean departure headway and capacity flow rates for each site can be calculated. The mean departure headway is the weighted average of the departure headways for each case, weighted according to the number of observations for each case. The mean capacity flow rate is 3,600 divided by the mean departure headway for the site. These data are presented in Table 5.

STATISTICAL ANALYSIS OF FACTORS AFFECTING APPROACH CAPACITY

Methodology

Regression analysis was used to identify the factors that affect the variation of the mean capacity flow rate between sites. The mean capacity flow rate for each site was regressed against the previously described independent variables, including number of approach lanes, distribution of volume by approach, proportion of turning movements, percentage of trucks, and pedestrian flow rates. The single-lane approach sites were studied first. Once a set of basic relationships was developed, the effects of the number of approach lanes were included in the regression models.

TABLE 3 TRAFFIC CONDITIONS

Four-Way Intersections, Single-Lane Approaches

Site	Duration Of Study (Hr:Min)	Time At Capacity (%)	Subject Approach Flow (vehicles per hour) Maximum	Mean	Subject Approach Flow (%)	% Turns LT	RT	Trucks (%)	Pedestrian Flow (Per Hour)
10	1:00	40	544	426	50	37	10	n/a	n/a
11	1:12	59	412	352	37	27	24	n/a	n/a
13	1:00	30	580	477	52	9	21	n/a	n/a
21	2:03	43	448	366	30	18	17	3	2
22	1:55	44	440	366	26	19	16	4	2
23	1:55	74	460	432	28	19	17	3	5
24	1:55	78	472	425	26	17	17	3	2
26	2:01	62	556	446	39	14	15	1	39
27	1:31	39	508	372	43	13	22	0	0
29	1:46	56	660	469	47	18	15	1	5
30	2:01	31	604	339	44	14	23	1	0
32	2:01	35	372	290	30	17	15	3	0
33	1:31	36	480	365	41	12	22	0	0

Four-Way Intersections, Multi-Lane Approaches

Site	Duration Of Study (Hr:Min)	Time At Capacity (%)	Subject Approach Flow (vehicles per hour) Maximum	Mean	Subject Approach Flow (%)	% Turns LT	RT	Trucks (%)	Pedestrian Flow (Per Hour)
17	1:18	49	444	394	21	21	24	n/a	n/a
25	1:33	73	440	408	28	29	21	1	15
34	1:32	31	468	399	34	23	26	2	25

Three-Way Intersections

Site	Duration of Study (Hr:Min)	Time At Capacity (%)	Subject Approach Flow (vehicles per hour) Maximum	Mean	Subject Approach Flow (%)	% Turns LT	RT	Trucks (%)	Pedestrian Flow (Per Hour)
15	0:46	45	372	344	36	25	21	n/a	355
16	1:00	72	436	423	37	24	22	n/a	n/a
19	1:00	17	384	318	21	29	24	1	8
20	1:00	46	440	422	32	30	14	1	3

Note: The subject approach flows are measured over 15 minute periods.

Analysis of Single-Lane Approach Sites

The mean capacity flow rate for each of the 13 single-lane approach sites was regressed separately against each of the proposed independent variables. Table 6 presents the correlations (R^2 values) that resulted from this analysis.

From this preliminary analysis, the most important factors that influence approach capacity were identified:

1. Distribution of traffic among the subject and opposing approaches,
2. Proportion of left turns on the opposing and conflicting approaches,
3. Proportion of right turns on the opposing and conflicting approaches, and
4. Proportion of trucks in the traffic stream.

These variables were combined into linear multivariate regression models to determine their collective effect on approach capacity. Three of the best models are presented in Table 7. The most important factors that influence approach capacity, for the single-lane approach intersections observed, are the distribution of traffic among the approaches, the proportion of left turns on the opposing and conflicting approaches, and the proportion of right turns on the opposing and conflicting approaches.

TABLE 4 OBSERVED DEPARTURE HEADWAY DATA

Four-Way Intersection, Single-Lane Approaches

Site	Case 1		Case 2		Case 3		Case 4		Total Observations
	Headway	Obs	Headway	Obs	Headway	Obs	Headway	Obs	
10	4.1	99	5.3	19	6.8	80	8.8	22	220
11	4.2	62	5.9	28	7.6	124	9.4	58	272
13	4.1	52	7.3	10	6.5	53	14.5	10	125
21	3.0	67	5.4	50	6.1	141	8.3	141	399
22	3.8	44	4.7	51	6.5	113	8.5	155	363
23	2.9	69	5.0	69	6.6	123	8.4	398	659
24	4.2	65	6.1	97	6.7	129	8.4	374	665
26	3.5	203	5.2	74	6.6	265	7.7	162	704
27	4.5	92	4.9	18	6.1	173	7.1	41	324
29	3.3	292	5.7	64	6.4	186	8.5	68	610
30	4.2	117	6.0	19	5.8	190	7.7	32	358
32	3.9	114	5.5	79	6.2	87	8.5	72	352
33	4.0	92	5.4	9	6.3	133	7.7	24	258

Four-Way Intersections, Multi-Lane Approaches

Site	Case 1		Case 2		Case 3		Case 4		Total Observations
	Headway	Obs	Headway	Obs	Headway	Obs	Headway	Obs	
17	1.3	76	3.2	26	6.5	77	10.0	127	306
25	4.3	82	5.8	36	6.8	157	9.0	199	474
34	2.1	97	5.4	37	5.7	86	8.6	60	280

Three-Way Intersections

Site	Case 1		Case 2		Case 3		Case 4		Total Observations
	Headway	Obs	Headway	Obs	Headway	Obs	Headway	Obs	
15	5.2	23	5.8	54	7.0	14	10.7	39	130
16	3.9	66	6.0	120	6.7	20	10.3	101	307
19	1.1	22	M	.	6.2	67	M	.	89
20	1.6	42	M	.	6.7	193	M	.	235

Note: Headway is the mean departure headway in seconds per vehicle. Obs are the number of observations for each case.

Analysis of All Sites

All 20 sites, including the multilane approach intersections, were studied next. Three of the best models are presented in Table 8.

In addition to the factors identified for the single-lane approach sites, a linear regression analysis of all 20 sites showed that the number of lanes on the subject approach and the opposing approach also affect the subject approach capacity. The number of lanes on the conflicting approaches did not have a statistically significant effect on the subject approach capacity. No nonlinear models showed significant improvements over these linear regression models.

Summary

The regression analysis resulted in a logical, and expected, set of factors that affect the approach capacity of an AWSC intersection.

1. Number of Approach Lanes. The number of lanes on the subject approach increases the capacity of the approach. This was expected, because increasing the number of lanes on the subject approach means that more vehicles can depart simultaneously from the stop line. Increasing the number of lanes on the opposing approach, however, reduces the subject approach capacity. Again, this was expected, because the

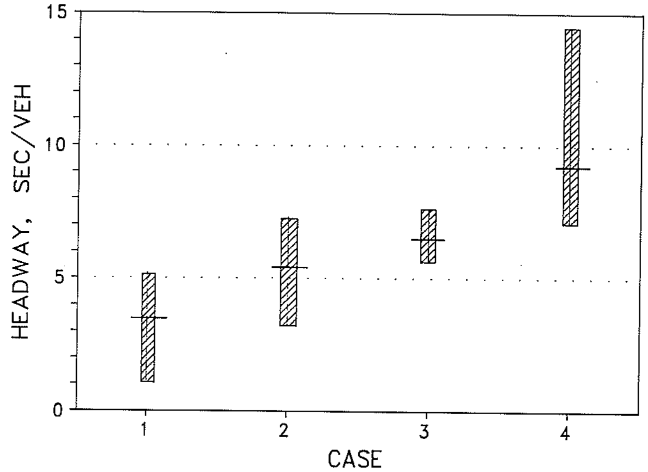

FIGURE 7 Departure headway data.

TABLE 5 MEAN DEPARTURE HEADWAYS AND CAPACITIES FOR THE SUBJECT APPROACH

Four-Way Intersections Single-Lane Approaches

Site	Mean Headway (seconds/vehicle)	Mean Capacity (vehicles/hour)
10	5.7	637
11	7.0	512
13	6.2	580
21	6.3	574
22	6.8	531
23	7.1	505
24	7.3	492
26	5.8	619
27	5.7	631
29	5.1	709
30	5.5	660
32	5.8	624
33	5.6	645

Four-Way Intersections Multi-Lane Approaches

Site	Mean Headway (seconds/vehicle)	Mean Capacity (vehicles/hour)
17	6.4	564
25	7.2	499
34	5.0	715

Three-Way Intersections

Site	Mean Headway (seconds/vehicle)	Mean Capacity (vehicles/hour)
15	7.3	494
16	7.0	514
19	4.9	729
20	5.8	622

TABLE 6 FACTORS AFFECTING APPROACH CAPACITY

Variable	Coefficient of Determination (R^2)
% subject approach volume	0.82
% opposing approach volume	0.50
% conflicting approach volume	0.05
% conflicting approach left turns	0.82
% opposing approach left turns	0.65
% subject approach left turns	0.34
% intersection left turns	0.25
% opposing approach right turns	0.57
% conflicting approach right turns	0.44
% subject approach right turns	0.21
% intersection right turns	0.06
% trucks	0.56
pedestrian flow rate	0.01

TABLE 7 REGRESSION MODELS FOR ESTIMATING CAPACITY AT SINGLE-LANE APPROACH SITES

Variable	Coefficients		
	Model 1	Model 2	Model 3
% subject approach volume	12.271	13.747	12.937
% opposing approach volume	6.424	9.157	8.814
% conflicting/opposing left turns	-	-3.150	-3.011
% conflicting/opposing right turns	-	-	0.846

Notes: The variables % trucks and pedestrian flow rates were not statistically significant in any of the multivariate models.

All coefficients are statistically significant at the .05 level.

Each of the models listed above is linear and is of the form:

$$C = aX_1 + bX_2 + cX_3$$

TABLE 8 REGRESSION MODELS FOR ESTIMATING CAPACITY AT ALL SITES

Variable	Coefficients		
	Model 4	Model 5	Model 6
Number of subject approach lanes	184.466	195.507	202.023
Number of opposing approach lanes	-57.092	-74.200	-118.795
% subject approach volume	10.897	11.890	10.376
% opposing approach volume	1.803	6.783	6.515
% conflicting/opposing left turns	-	-3.337	-2.885
% conflicting/opposing right turns	-	-	2.145

Notes: The variables % trucks and pedestrian flow rates were not statistically significant in any of the multivariate models.

All coefficients are statistically significant at the .05 level.

Each of the models listed above is linear and is of the form:

$$C = aX_1 + bX_2 + cX_3$$

number of vehicles opposing the subject approach flow increases driver uncertainty and the potential for conflict.

2. Volume Distribution. The distribution of traffic among the approaches affects the rate at which vehicles leave the subject approach stop line. Increasing the proportion of vehicles on the subject approach means that fewer vehicles will be traveling on the opposing or conflicting approaches. Further, increasing the proportion of traffic on the opposing approach at the expense of the conflicting approach tends to increase the subject approach capacity.

3. Turning Movements. A higher proportion of left-turning vehicles reduces the capacity of the subject approach. Conversely, a higher proportion of right-turning vehicles increases the capacity of the subject approach.

4. Other Factors. Although higher proportions of heavy vehicles and pedestrians could be expected to reduce approach capacity, no statistical verification of this situation could be found at the sites studied.

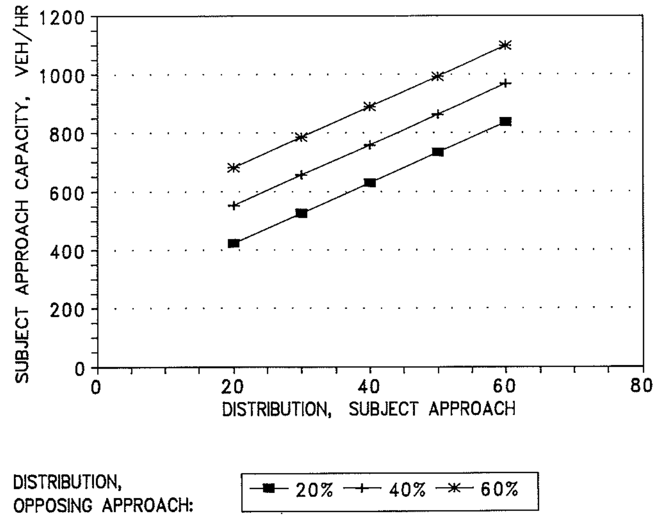

FIGURE 8 Subject approach capacity versus distribution.

PROPOSED CAPACITY ESTIMATION METHOD

Overview

The statistical analysis described in the previous section provides a good foundation for a method to estimate the approach capacities of an AWSC intersection. The statistically significant factors represent a broad range of the standard geometric and traffic conditions typically used in the capacity analysis of a transportation facility. The proposed method (Model 6) is the model that includes the broadest range for the number of lanes on the intersection approaches, the distribution of volume among the approaches, and the relative proportion of turning movements.

Proposed Method

The proposed forecasting equation is presented in Table 9 and shown in Figure 8 for ideal conditions over a range of volume distributions for a single-lane approach intersection. Tables 10 through 13 present the application of the model to some typical conditions. The capacity estimates in Tables 10 and 11 are for one- and two-lane approach intersections with even volume distributions. Tables 12 and 13 present capacity estimates for uneven volume distributions and 10-percent turning movements.

Comparison With Previous Work

Capacity estimation methods were proposed in previous studies by Hebert (*3*) and Kyte and Marek (*4*). The Hebert method, based on a study of three sites in Chicago, related approach capacity to the proportion of traffic on the major street.

$$C = \frac{3,600}{10.15 - S} \tag{1}$$

where C is the subject approach capacity and S is the volume split on the major street. This initial estimate is adjusted according to the proportion of right-turning traffic at the intersection. The capacity is increased by 0.2 percent for every 1 percent of right-turning automobiles. Every two additional

TABLE 9 PROPOSED APPROACH CAPACITY FORECASTING EQUATION

Variable	Coefficients
Number of Approach Lanes	
Subject Approach	202.023
Opposing Approach	-118.795
Volume Distribution	
%Subject Approach	10.376
%Opposing Approach	6.515
Turning Movements	
%Left Turns on Opposing and Conflicting Approaches	-2.885
%Right Turns on Opposing and Conflicting Approaches	2.145

Notes: All coefficients are statistically significant at the .05 level.

Each of the models listed above is linear and is of the form:

$$C = aX_1 + bX_2 + cX_3$$

TABLE 10 CAPACITY ANALYSIS WORKSHEET, EXAMPLE 1

Conditions: Single-lane approach intersection, with ideal conditions and even volume distribution among the approaches.

	NB	SB	EB	WB
Approach Lanes	1	1	1	1
Volume Distribution (%)	25	25	25	25
Right Turns, Percent	0	0	0	0
Left Turns, Percent	0	0	0	0
Approach Capacity	506	506	506	506
Intersection Capacity	2024			

TABLE 11 CAPACITY ANALYSIS WORKSHEET, EXAMPLE 2

Conditions: Two-lane approach intersection, with ideal conditions and even volume distribution among the approaches.

	NB	SB	EB	WB
Approach Lanes	2	2	2	2
Volume Distribution (%)	25	25	25	25
Right Turns, Percent	0	0	0	0
Left Turns, Percent	0	0	0	0
Approach Capacity	589	589	589	589
Intersection Capacity	2356			

TABLE 12 CAPACITY ANALYSIS WORKSHEET, EXAMPLE 3

Conditions: Single-lane approach intersection, with 10% turns and heavy volumes on one approach.

	NB	SB	EB	WB
Approach Lanes	1	1	1	1
Volume Distribution (%)	40	20	20	20
Right Turns, Percent	10	10	10	10
Left Turns, Percent	10	10	10	10
Approach Capacity	606	529	399	399
Intersection Capacity	1941			

TABLE 13 CAPACITY ANALYSIS WORKSHEET, EXAMPLE 4

Conditions: Two-lane approach intersection, with 10% turns and heavy volumes on one approach.

	NB	SB	EB	WB
Approach Lanes	2	2	2	2
Volume Distribution (%)	40	20	20	20
Right Turns, Percent	10	10	10	10
Left Turns, Percent	10	10	10	10
Approach Capacity	690	612	482	482
Intersection Capacity	2274			

lanes of cross traffic reduces the subject approach capacity by 5.2 percent.

The method proposed by Kyte and Marek (*4*), based on a study of seven single-lane approach sites, related approach capacity to the proportion of traffic on the subject approach. The model does not consider any adjustment factors.

$$C = -3.894\,(\%\mathrm{SAV}) + 8.2099 \quad (2)$$

where C is the subject approach capacity and %SAV is the percentage of volume on the subject approach.

A comparison of the approach capacities predicted by these three methods for a range of volume distribution conditions for single-lane approach intersections is presented in Table 14. A further comparison of the three methods is presented in Table 15. Capacity forecasts were prepared using each method for the traffic and geometric conditions at the 20 sites used in this study. The method yielded the best capacity forecast for most of the 20 sites.

Boundary Conditions

The proposed model was designed for a specific range of input conditions. Care should be taken when the model is applied to a set of conditions outside the ranges presented in Table 16.

In addition, the proposed model should conform to a certain set of boundary conditions. For example, when the proportion of traffic on the subject approach is zero, the model should predict zero capacity for that approach. The model does not yield correct results (i.e., zero capacity) when the proportion of traffic on the subject approach tends to zero. This limitation of the proposed method can be resolved with further development of alternative functional forms.

Effects of Heavy Vehicles and Pedestrians

Observation of traffic flow at these 20 sites confirmed that heavy vehicles and pedestrians affect intersection operations. Thus even though these variables were not statistically significant in the regression analysis, they still need to be accounted for. One problem may be that the pedestrian and heavy-vehicle data were not available for 6 of the 20 sites. Further, the proportions of heavy vehicles did not vary significantly between the sites.

Implications for Capacity

An analysis of the model proposed here yields several important implications on the capacity of an AWSC intersection.

1. The rate at which vehicles can depart from the stop line of an AWSC intersection is a function of the conditions present on the other approaches. Maximum departure rates are achieved when no traffic is on any of the other intersection approaches. Minimum departure rates result when traffic is present on all of the other approaches.

2. This microscopic perspective has a direct analogue at the macroscopic level. The maximum flow rate on a given approach can be achieved if no traffic is on any of the other approaches. The minimum flow rate results if traffic is evenly distributed among all of the intersection approaches. Thus, the key variable in the determination of intersection capacity is the relative distribution of traffic volumes among the approaches. This variable is called volume distribution. When traffic is evenly distributed among the approaches, the capacity of a single-lane approach is 500 veh/hr, and the capacity of a four-leg intersection is 2,000 veh/hr under ideal conditions. The capacity of a single-lane approach, when no traffic is on any of the other approaches, is 1,100 veh/hr under ideal conditions.

3. Increasing the number of lanes does not necessarily result in a corresponding increase in the capacity of an approach, as it does in other highway facilities. This fact seems to result from the nature of traffic flow at an AWSC intersection. For single-lane approach intersections operating at capacity, a two-phase operation results, with traffic on opposing approaches flowing simultaneously. However, for multilane approaches, a different operation results. The addition of lanes, particularly on the conflicting approaches, seems to introduce such a degree of uncertainty among drivers that a four-phase operation results. That is, traffic on each approach flows as a group. This observation has an important implication for intersection capacity. When traffic is present on only one approach (not a very practical or likely occurrence), the capacity of the approach directly increases with each increase in the number of lanes. That is, under ideal conditions, if one lane

TABLE 14 COMPARISON OF CAPACITY ESTIMATION METHODS FOR SINGLE-LANE APPROACH INTERSECTIONS UNDER IDEAL CONDITIONS

Volume Distribution		Forecasted Approach Capacity On Major Street (vehicles per hour)		
Major Street	Minor Street	Hebert Method	Kyte/Marek Method	Kyte Method
50%	50%	471	497	506
55%	45%	486	504	548
60%	40%	503	511	590
65%	35%	522	518	632
70%	30%	541	526	674

TABLE 15 CAPACITY FORECASTS FOR EACH SITE

Site	Mean Observed Capacity	Hebert Model		Kyte/Marek Model		Kyte Model	
		Capacity	%Error	Capacity	%Error	Capacity	%Error
10	637	558	12%	575	10%	666	5%
11	512	545	6%	532	4%	571	12%
13	580	513	12%	557	4%	584	1%
21	574	535	7%	511	11%	544	5%
22	531	544	2%	506	5%	554	4%
23	505	544	8%	506	0%	554	10%
24	492	536	9%	500	2%	537	9%
26	619	536	13%	538	13%	609	2%
27	631	548	13%	551	13%	624	1%
29	709	571	19%	571	19%	698	2%
30	660	556	16%	554	16%	628	5%
32	624	548	12%	511	18%	577	8%
33	645	550	15%	554	14%	626	3%
MAPE			11%		10%		5%

Site	Mean Observed Capacity	Hebert Model		Kyte/Marek Model		Kyte Model	
		Capacity	%Error	Capacity	%Error	Capacity	%Error
17	564	1441	167%	-	-	608	8%
25	499	535	9%	508	2%	446	11%
34	715	1044	89%	-	-	678	5%
MAPE			88%		-		8%

Site	Mean Observed Capacity	Hebert Model		Kyte/Marek Model		Kyte Model	
		Capacity	%Error	Capacity	%Error	Capacity	%Error
15	494	626	27%	529	7%	635	29%
16	514	623	21%	532	4%	639	24%
19	729	804	76%	-	-	610	16%
20	622	842	56%	-	-	739	19%
MAPE			45%		-		22%

Note: The MAPE is the mean absolute percent error for each intersection group.

TABLE 16 RANGE OF INPUT CONDITIONS

Variable	Minimum	Maximum
Departure Headways		
Case 1	1.1	5.2
Case 2	3.2	7.3
Case 3	5.7	7.6
Case 4	7.1	14.5
Mean Capacity	492	729
Volume Distribution		
%Subject Approach	21	50
%Opposing Approach	0	44
%Conflicting Approach	20	79
Number of Approach Lanes		
Subject Approach	1	3
Opposing Approach	0	3
Conflicting Approach	1	5
Proportion of Left-Turns		
Subject Approach	0	80
Opposing Approach	0	36
Conflicting Approach	6	71
Intersection	9	37
Proportion of Right-Turns		
Subject Approach	1	47
Opposing Approach	0	62
Conflicting Approach	9	52
Intersection	10	26
Percent Trucks	0	4
Pedestrian Flow Rate	0	355

can carry 1,100 veh/hr, two lanes can carry 2,200 veh/hr, and three lanes can carry 3,300 veh/hr. However, when traffic is distributed among all approaches, at worst, the number of approach lanes does not affect the capacity of the intersection as a whole. At best, the addition of approach lanes may slightly increase the capacity of the intersection.

CONCLUSION

A theoretical framework for a capacity estimation procedure was first postulated and then validated with field data collected at 20 sites to identify the factors that influence the capacity of an AWSC intersection and to present a procedure to estimate intersection capacity. A statistical analysis of the factors that affect capacity was undertaken, and a method for the estimation of intersection capacity was proposed. This model represents a logical procedure for the determination of the capacity of an AWSC intersection, given the number of lanes on each intersection approach, the distribution of traffic among the approaches, and the proportion of turning movements on each approach. The forecasting performance of this model is significantly better than that of two previously proposed methods for forecasting the capacity of an AWSC intersection.

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Publication of this paper sponsored by Committee on Highway Capacity and Quality of Service.