Intersection Capacity 1974: An Overview

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This paper presents an overview of intersection capacity as of 1974. A brief background is given of the 1950 and 1965 U.S. Highway Capacity Manuals, and comparisons are made of the English and Australian manuals. The activities of the TRB Intersection Capacity Subcommittee are traced. These activities include the evaluation of the current HCM approach and investigation of alternative approaches. The Intersection Capacity Subcommittee identified and selected top-priority research needs. The results of the evaluation process and the 10 top-priority research topics are given. Each of the 10 topics is discussed. Comments are given and some initial analytical work is described.

Articles on the subject of intersection capacity date back at least to the early 1920s. In the late 1940s, several hundred approaches to signalized intersections were studied. The 1950 Highway Capacity Manual (1) included a chapter on signalized intersection capacity and was based primarily on the field studies of the 1940s. To attest to the international recognition of the 1950 Highway Capacity Manual, over 26,000 copies were distributed and it was translated into at least 10 languages.

In 1954, the highway capacity committee began revising and updating the 1950 manual. Some 1,600 intersection approaches were studied nationwide during 1955-1956. These data were analyzed graphically and by multiple regression techniques (2, 3). The 1965 Highway Capacity Manual (HCM) included a chapter on at-grade intersections and was based on this nationwide study as well as the results of individual research studies and the original manual. The HCM (4) is now in its sixth printing, and more than 27,000 copies have been distributed. It has been translated into French, German, Italian, and Spanish.

Capacity seminars have been held in every state and major city of the United States and in numerous foreign countries to present and discuss the philosophies and procedures described in the HCM. A bibliography of research published before the distribution of the HCM was prepared in connection with the capacity seminars in California (5). In addition to published reports, a number of research projects with primary emphasis on the subject of intersection capacity are currently under way (50-52).

Methods for determining the capacity of signalized intersections have also been developed in England and Australia. An excellent summary of the English method, developed by the Road Research Laboratory, was published in 1966 (6). The Australian method was developed by the Australia Road Research Board and was published in 1968 (7).

INTERSECTION CAPACITY SUBCOMMITTEE

In 1972, an Intersection Capacity Subcommittee was appointed by the TRB Committee on Highway Capacity and Quality of Flow. The subcommittee's main tasks were to review the HCM approach and to evaluate alternatives. In reviewing the current HCM approach, committee members and HCM users were requested to submit comments, criticisms, and suggestions about the chapter on at-grade intersection capacity. The responses were summarized in a 16-page document (8). In January 1974, the Intersection Capacity Workshop was held. The current HCM approach was reviewed, and alternative approaches, identified through literature searches, were evaluated (9).

IDENTIFICATION OF RESEARCH NEEDS

In April 1974, a questionnaire was distributed to all Highway Capacity Committee members and selected HCM users as an aid in identifying needed research on intersection capacity. Twenty-two areas of research were listed, and each individual was requested to rank the 10 that he felt had highest priority. A summary of questionnaire results is given in Table 1. The 10 topics receiving the highest priority are

1. Width of approach versus number of lanes,
2. Left-turning movements,
3. Load factor versus delay evaluation,
4. Overall urban arterial capacity,
5. Signal timing,
6. Special turn lanes and/or phases,
7. Total intersection evaluation,
8. Parking,
9. Pedestrians, and
10. Saturation flow studies.

Research problem statements are now being prepared and are to be included in a forthcoming special publication.

HIGH-PRIORITY RESEARCH TOPICS

Width of Approach Versus Number of Lanes

Both the 1950 and 1965 U.S. manuals use approach width rather than number of approach lanes. Although initially the 1950 manual was to have used number of lanes rather than approach width, trial analysis of the field measurements revealed that intersection capacity varied in almost a direct ratio with the width of the approach, and thus approach width was used. The 1965 manual reported that the width of the approach, rather than the number of traffic lanes, had proved to have the more significant bearing on the capacity of a typical approach.

The English method (6) developed by the Road Research Laboratory also proposed the use of approach width rather than number of lanes. The saturation flow rate was expressed in terms of the approach width by the following equation:

$$S = 160\ W$$

where

S = saturation flow in passenger cars per hour and
W = approach road width in feet.

The Australian method (7), however, found that saturation flows are related to the

Table 1. Priority ranking of capacity research topics.

Research Topic	Total Score	Priority Ranking
Approach width versus number of lanes	99	1
Parking	50	8
Load factor versus delay	84	3
Peak-hour factor	15	
Metropolitan area population	14	
Location within metropolitan area	16	
Right-turning movements	18	
Left-turning movements	98	2
Special turn lanes and/or phases	60	6
Trucks and through buses	2	
Local transit buses	13	
Signal timing	78	5
Marking of approach lanes	22	
Unsignalized intersections	25	
Pedestrians	49	9
Total intersection evaluation	51	7
Urban arterial capacity	79	4
Ambient conditions	8	
Geographical regional factors	6	
Grades	12	
Saturation flow studies	41	10
Nationwide data collection	9	

Figure 1. Comparison of English and Australian methods (approach width versus number of lanes).

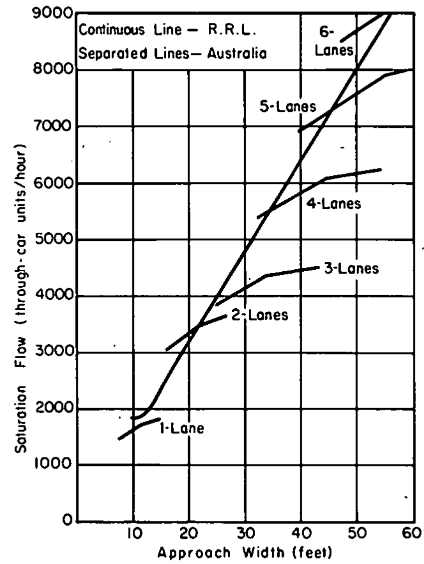


Figure 2. Effect of left turns on capacity at two-lane signalized approach.

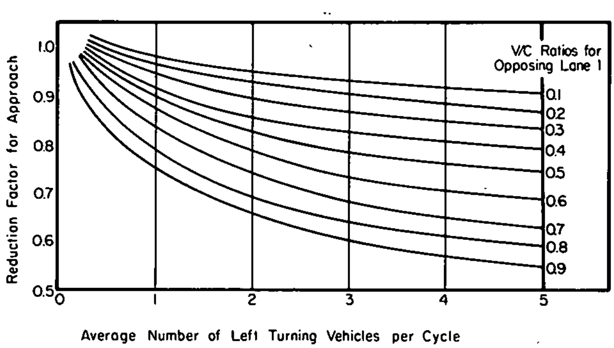


Figure 3. Relationship between average individual delay and load factor.

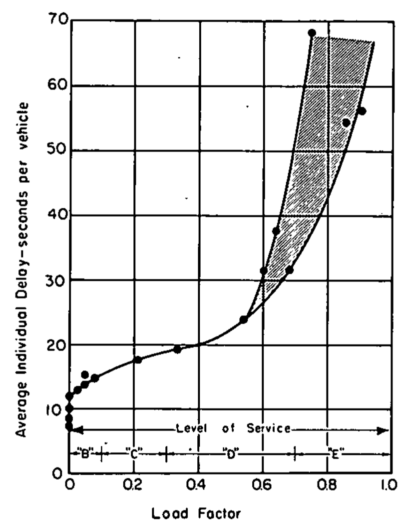
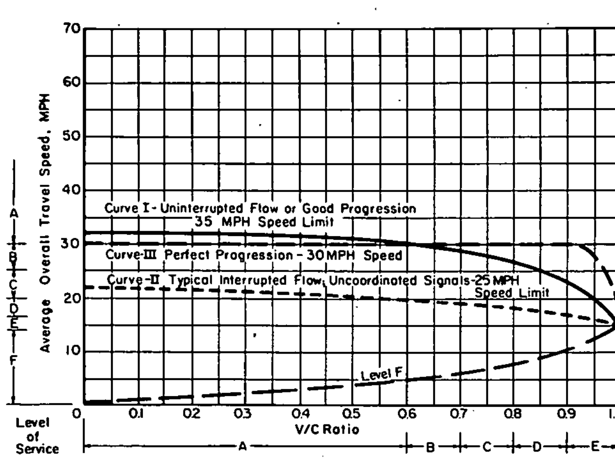


Figure 4. Typical relationship between volume-capacity ratio and average overall travel speed.



number of lanes, not to the approach width. It was determined that lane width had very little effect on saturation flow rate or capacity over a range of 10 to 13 ft. Figure 1 shows a comparison of the English and Australian methods and illustrates the difference between the approach width and number of lanes procedures. If the number of lanes rather than approach width could be shown through use of U.S. data to be a better method (or as good) for determining capacities, the U.S. method could be simplified.

Left-Turning Movements

A study at Northwestern University (48) demonstrated with field measurements that the HCM does not reflect the effects of different levels of opposing traffic volume for the basic case of no separate left turn lanes or signals. This study also identified the need for further study of the effect of number of moving lanes, presence of a left turn storage lane, prohibition of parking and standing in the approach, cycle length, actuated versus pretimed control, width of exit roadways, and turning radius. Figure 2 shows the overall effects of left turn vehicles on capacity as determined in the Northwestern University study.

Load Factor Versus Delay Evaluation

The introduction of the level-of-service concept is one of the important contributions of the HCM. Load factor is used as the measure of level of service at signalized intersections. Although it is relatively easy to measure in the field, some users have proposed that a measurement of delay be used to represent level of service. The results of a study at the University of California (25), however, raised questions about the validity of an assumed direct relationship between load factor and delay. Figure 3 shows the results obtained in a simulation study of the relationship between average individual delay and load factor.

Urban Arterial Capacity

Chapter 10 of the HCM provides only approximate means for determining overall urban arterial capacity and levels of service. In fact, the 1965 manual suggests intersection by intersection analysis supplemented by judgment. There is obviously a need for further research because of the significant amounts of travel on major arterials and because most individual trips pass through more than one signalized intersection.

The recognition of the importance of research in this area is undoubtedly related to the recognition of the need for further research into the influence of signal timing (priority 5) and total intersection approach to capacity (priority 7). Figure 4 shows the relationship of average overall travel speed to volume-capacity ratio in one direction of travel on arterial streets as given in the 1965 U.S. manual.

Signal Timing

In the study of an existing signalized intersection, one variable that the traffic engineer can control directly and that has a significant effect on capacity and level of service is signal timing (i.e., phasing, cycle length, and offsets). The relationships of offsets to overall urban arterial capacity (priority 4) and of signal phasing to total intersection approach capacity (priority 7) have been established.

The English method uses an effective green time in computing the G/C ratio rather than the green phase length. Figure 5 shows the relationship between effective green time and the green phase length and its importance when saturation flow (priority 10) is used.

Special Turn Lanes and/or Phases

At multiapproach intersections and at intersections with a relatively high percentage of turning movements, special turn lanes or phases can improve the level of service. Although the HCM describes methods for analyzing special turn lanes and/or phases, these methods are only approximate and are based on limited field data. More attention needs to be given to vehicle arrival distributions, number of turning lanes, loss time between phases, turn curvature, and associated user delay and capacity. Procedures are needed to determine when multiphase signalization is warranted. This research is also related to the effect of left-turning movements (priority 2). Figure 6 shows a proposed structure of special turn lanes and/or phases.

Total Intersection Evaluation

All existing methods for calculating intersection capacity are accomplished on a single approach basis. The G/C ratio used for this single approach affects the available G/C ratio for the opposite and crossing approaches. The HCM suggests that each approach be analyzed separately; the optimum solution, as the G/C ratio, is obtained manually through trial and error procedures. A procedure should be developed for determining the effects of intersection capacity and levels of service on a total intersection basis, which would result in the optimum signal settings. This research topic is closely related to influence of signal timing (priority 5).

The method developed by the Road Research Laboratory (6) proposes a procedure for determining optimum cycle length and green times. The cycle length that results in the minimum delay is obtained by differentiating the overall delay equation:

$$C_o = \frac{1.5L + 5}{1 - Y}$$

where

L = total lost time per cycle in sec,
Y = summation for the whole intersection of the y values,
y = maximum ratio of flow to saturation flow for a given phase, and
C_o = optimum cycle length in sec.

The green times that minimize delay were derived from the overall delay equation:

$$\frac{g_1}{g_2} = \frac{y_1}{y_2}$$

where

g_1, g_2 = effective green times of phases 1 and 2 in sec, and
y_1, y_2 = maximum ratio of flow to saturation flow of phases 1 and 2.

There are two limitations to this approach. First, only the most critical approach is considered in each phase. Second, if the selected cycle length is significantly different from the optimum cycle length (i.e., in the case of pedestrians crossing wide streets), the calculation of green times may not result in minimum total intersection delay. Figure 7 shows the effect of cycle length and green times on total intersection delay.

Parking

The HCM analyzes the influence of parking for only two conditions: parking and no parking (i.e., no parking within 250 ft of the intersection). The English method handles the influence of parking as a function of the distance between the stop line and the nearest parked car (Fig. 8). The effective loss of approach width is given by

Figure 5. Relationship between effective green time and green phase length.

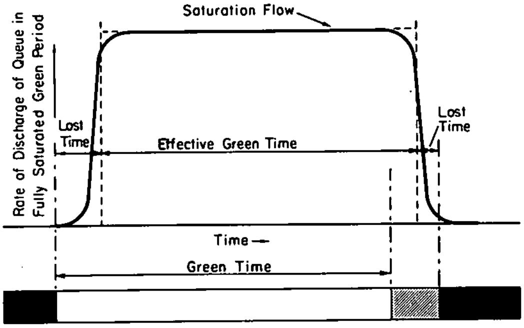


Figure 6. Structure of special turn lanes and/or phases.

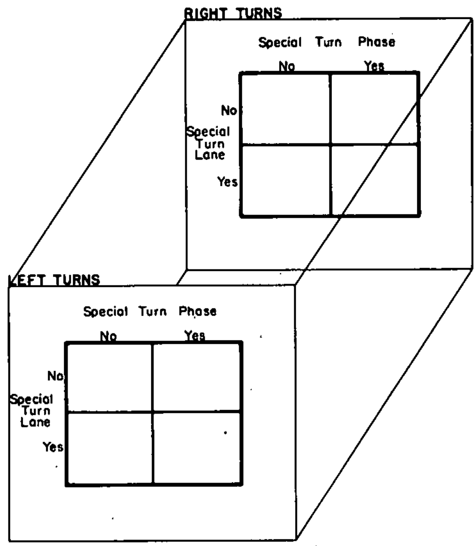


Figure 7. Delay for total intersection approach.

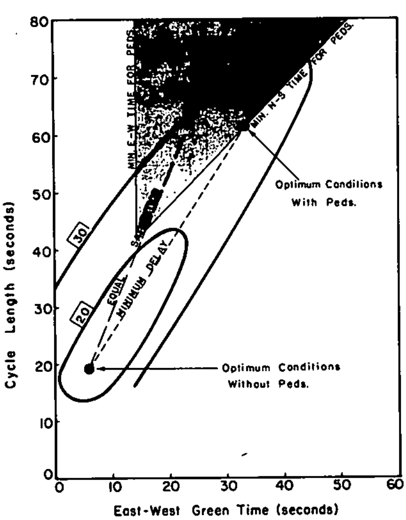
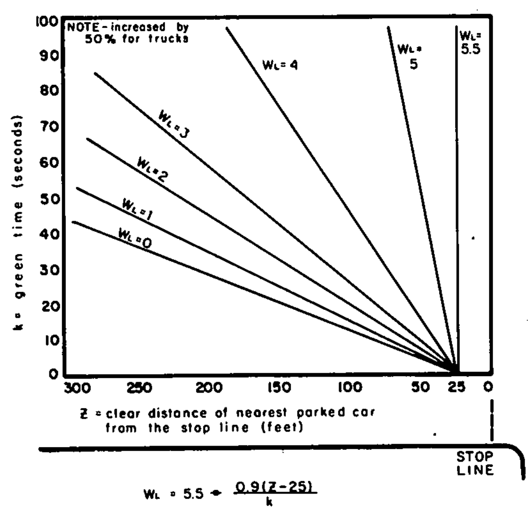


Figure 8. Effective loss in approach width due to parking.



$$W_L = 5.5 - \frac{0.4(z - 25)}{k}$$

where

Z = clear distance of the nearest parked car from the stop line in feet (if Z is less than 25 ft, let Z = 25),
k = green time in sec, and
$W_L \geq 0$ = effective loss in approach width in feet.

The English method also proposes that the effective loss be increased by 50 percent if the parked vehicle is a truck.

Other concerns about the 1965 manual include the inconsistencies between the parking and no-parking approach volume-approach width relationships, the lack of handling angle parking, and the lack of attention to the effect of parking maneuvers on traffic delay.

Pedestrians

The 1965 manual only makes mention of pedestrian influence, and the effect of pedestrians is only indirectly handled by the use of the location in metropolitan area factor. This area of research is related to signal timing (priority 5) in determining green times, cycle lengths, and special phasing required for exclusive pedestrian and/ or left turn movements. In addition, no attention has been given to the level of service provided to pedestrians and to the combining of pedestrian and vehicular level of service.

Saturation Flow Studies

The English and Australian methods use saturation flow in determining intersection capacity. Saturation flow is defined as the flow that would be obtained if there were a continuous queue of vehicles and they were given 100 percent green time. It is generally expressed in vehicles per hour of green time. The capacity is obtained by multiplying the saturation flow by the G/C ratio (note G is effective green time, not necessarily green time) and by other factors (i.e., turning, grades). The English equation is

$$CAP = f[160(W - PVF)], (RT), (LT), (VCF), (G/C), (PF), (GF), (SF)$$

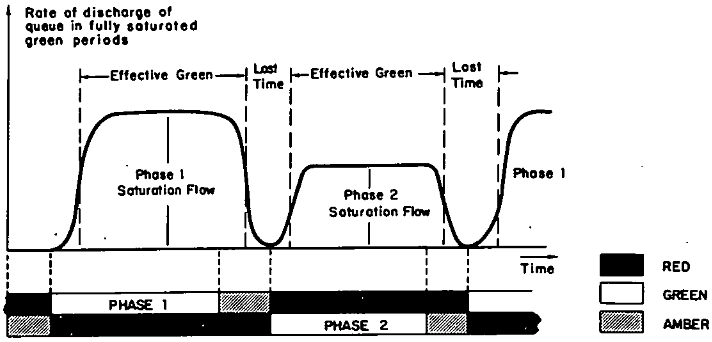
where

CAP = capacity in vph,
W = approach width in feet,
PVF = adjustment factor based on parked vehicle clearance distance,
RT = adjustment factor based on percentage of right turns,
LT = adjustment factor based on percentage of left turns,
VCF = adjustment factor based on vehicle composition,
G/C = effective green time to cycle time ratio,
PF = adjustment for off-peak period,
GF = adjustment factor based on percentage of grade, and
SF = adjustment factor for site characteristics.

The HCM uses a similar procedure except the term is referred to as approach volume and is hidden empirically by combining it with other influencing factors. The similarity between the two methods can be seen by comparing the previous English equation with the equation below.

$$SV = f(AV_{W,LF}), (POP, PHF), (LIM), (RT), (LT), (TF), (BF), (G/C)$$

Figure 9. Saturation flow concept.



where

SV = service volume in vph,
$AV_{W,LF}$ = approach volume based on approach width and load factor in vehicles per hour of green,
POP, PHF = adjustment factor based on metropolitan area size and peak-hour factor,
LIM = adjustment factor based on location in metropolitan area,
RT = adjustment factor based on percentage of right turns,
LT = adjustment factor based on percentage of left turns,
TF = adjustment factor based on percentage of trucks and through buses,
BF = adjustment factor based on local buses and bus stop type, and
G/C = green phase time to cycle time ratio.

It is argued that the saturation flow approach is more fundamental and represents the base condition. Capacity influencing factors are then empirically determined, and modify the saturation flow value. This approach to signalized intersections is somewhat similar to the HCM approach to freeways (i.e., the capacity of a freeway under ideal roadway and traffic conditions is 2,000 passenger vehicles per hour per lane and then influencing factors are applied).

Research into the saturation flow approach may not only improve the accuracy of capacity calculations but also provide the mechanism for better understanding of the phenomena of intersection capacity (Fig. 9).

SUMMARY

This paper has provided an overview of intersection capacity and proposes the direction for future research. The capacity committee welcomes your comments, suggestions, and criticisms. Furthering knowledge on capacity depends on the research that we undertake now.

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