Effect of Curb Parking on Intersection Capacity

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To increase the traffic capacity through signalized intersections, many traffic engineers have resorted to complete prohibition of parking on heavily traveled arteries. As a consequence, appropriate regulations have been adopted under which parking can be restricted for various reasons.

This paper attempts to show, through quantitative evaluation, the effects on intersection capacity, of varying lengths of clear distance adjacent to an intersection. By controlling conditions at the study intersection, factors influencing capacity, such as pedestrian and parking maneuvers, are kept to a minimum in order to more accurately establish the relationship between clear distance and intersection capacity.

The intersection selected for study consists of a three-lane one-way street intersecting a two-lane two-way street. Blocking off nearly a full lane first on one side of the one-way approach and then on the other side, and then allowing vehicles to utilize varying lengths of clear distance in the curb lanes, it was possible to obtain sufficient data to suggest a relationship between clear distance in the curb lane and intersection capacity.

The relationship is tested statistically by the students "t" method and correlation by ranks.

The results as they pertain to the specific intersection involved are that maximum volumes of traffic can be moved through an intersection without complete prohibition of parking, and that on the approach the clear distance adjacent to the intersection required for maximum volumes is related to the percentage of turning movements.

● IN AN ATTEMPT to move as much traffic as possible through areas subject to high volumes of vehicular movements, many traffic engineers apparently believe strongly in the importance of complete prohibition of parking on heavily traveled streets. As a consequence, appropriate regulations have been adopted under which parking can be restricted for various reasons.

Parking and parking restrictions are known to affect traffic capacity of intersections, as evidenced by reported studies in the Highway Capacity Manual (1). Typical values for capacities under various physical and traffic conditions include parking, turning movements, location of intersection with respect to downtown areas, and factors for increasing or decreasing capacities as a result of changing these conditions to suit a particular problem. The sources of these data are reports of traffic volumes observed at many intersections in several cities throughout the United States.

The stated values in the manual apply to complete parking permitted or prohibited conditions. A correction factor is applied for conditions of partial parking. The factor is determined by the formula $P\,(D-20)/5G$ percent where P is the total percentage of turns (1). D is the distance in feet from the crosswalk and G the seconds of green per signal cycle. Maximum values for P and D are limited by 30 and $(5G-20)$, respectively. In addition, the manual states that prohibition of parking in advance of an intersection for a distance in feet equal to five times the green period is equivalent to a complete prohibition of parking.

THE PROBLEM

The purpose of this report is to determine the effect on the intersection capacity of a one-way street by varying the length of curb parking adjacent to the intersection.

To examine the effect of varying the length of clear distance on intersection capacity, data were taken at an intersection approach operating under saturated traffic conditions. Observations were made without parking and then by coning off a traffic lane so that it was possible to obtain data for clear distances in multiples of 22 ft, a unit parking space length. Data were collected on the number of vehicles entering the intersection in each cycle as measured from the start of the GO period for each curb lane. In addition, the number of vehicles stored in the curb lane was recorded before each GO period. Mean discharge per cycle under different lengths of clear distance were compared and tested statistically for significant differences. Significant differences indicate whether or not intersection capacity is affected by the length of clear distance.

Parking and unparking maneuvers contribute to a reduction in intersection capacity but these factors have not been included in this study. In addition, the presence of traffic cones are assumed to have the same influence as a line of parked cars on the approaching vehicles.

STUDIES CONDUCTED

Definitions of Terms Used

Left Curb Lane. For the purpose of this paper, the left curb lane is defined as that lane adjacent to the left curb on the approach to the intersection.

Right Curb Lane. That lane adjacent to the right curb on the approach to the intersection.

Center Lane. That lane situated between the left and right curb lanes.

Clear Distance. That distance in feet measured in either curb lane from suitable reference points to the first parked car or, as applicable in this paper, to the first cone on the approach side of the intersection.

Initial Study at Prospect and Grove Streets

In order to acquaint the author with first hand field conditions to be faced in undertaking a study such as the one described in this project, a pilot study was made at the intersection of Prospect and Grove Streets in New Haven, Connecticut on October 11 and 13, 1956. The leg considered was the southbound approach of Prospect Street, 36 ft wide curb-to-curb with a painted centerline dividing the two-way roadway into two 18-ft legs.

Normally, traffic approaches the intersection in one lane with right-turn vehicles frequently stacking up parallel to the through- or left-turn movements after each GO period.

For these initial observations, attempts were made to place a single parked car at varying distances from the intersection. Data were recorded under conditions of saturated flow; that is, a continuous reservoir of vehicles waiting to enter the intersection.

The single parked car presented a hazard to traffic by reducing the effective width of the leg from 18 to 10 ft, thereby forcing some vehicles to cross over into the opposite traffic lane. In addition, its position in the roadway necessitated dangerous weaving maneuvers for those vehicles approaching the intersection in the curb lane. Consequently, limited data were taken, precluding quantitative evaluation and, therefore, excluded in the analysis.

Inasmuch as the single parked car was obstructing the free movement of traffic and causing inconvenience to motorists, it was decided to abandon further study of this intersection. Furthermore, heavy pedestrian volumes and far side curb parking introduced elements which would have presumably influenced the results of this experiment.

On the basis of the experience gained from the initial study, it was felt desirable to select an intersection which, by virtue of actual or imposed regulations, would have eliminated these factors.

Study Site at Springdale Avenue and North Service Road

The North Service Road of the Garden State Parkway at Springdale Avenue in East Orange, New Jersey, was selected as the site for this experiment. The service road is under the jurisdiction of the Garden State Parkway Authority and signals thereon, within city limits, are under the jurisdiction of the City of East Orange. Arthur T. Brokaw, City Engineer, and his staff extended their full assistance to aid in this project.

The North Service Road is 40 ft wide, curb-to-curb, at its intersection with Springdale Avenue. Parking is not specifically prohibited by posting on either approach. Particular care was taken during recording of data to insure that parking on the far approach was non-existent. In this manner, interference with traffic flow through the intersection was kept at a minimum. No driveways or houses front on the east side of the service road; a retaining wall is present on the west side.

Under normal operation, three lanes of traffic move northbound along the service road to enter or cross Springdale Avenue. The service road is 30 ft wide on the approach, and a left turn bulb is provided at the intersection. For purposes of this study, the left turn bulb was considered non-existent since it was coned off while data were recorded.

On the northbound service road, coning off what is normally used for parking, some 8 ft, would block off one full lane of traffic. In this manner, the approach would be physically reduced to 22 ft. Differences in traffic movement between no parking and various parking conditions would be more sharply marked than presumably would be the case if the restriction blocked less than a full traffic lane. Under conditions of this study it was not possible for three lanes of traffic to move along to service road.

The intersection selected for study is controlled by a fixed-time three -light signal. The cycle length is 90 sec and the traffic controller is in a progressive system which includes the intersection of Arlington Avenue and the service road. Referring to Figure 1, the major portion of traffic using this section of the service road is fed from the Arlington Avenue off-bound ramp from the Garden State Parkway. The parkway is restricted to passenger cars throughout the area studied. Normally, traffic flows along the service road through the progressive system very smoothly and the signal splits favor Springdale Avenue. The service road, under normal operation, is given 25 sec of green and 3 sec of amber.

Volume counts made during the selected period of study revealed a heavy left turn movement in the magnitude of 40 percent while the right turns were less than 5 percent of the total approach volumes.

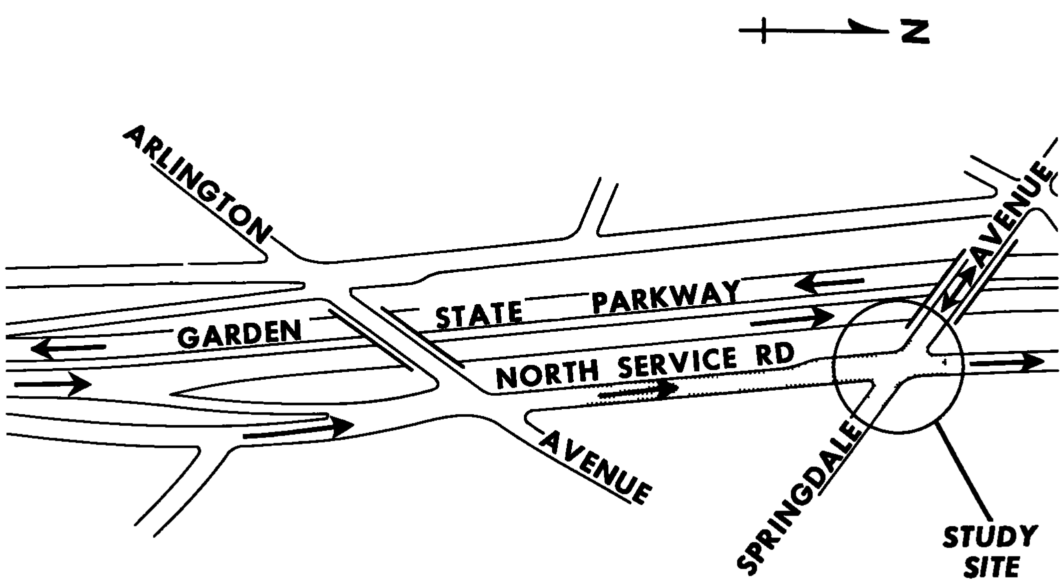

Figure 1. Location plan.

METHOD OF STUDY

To permit quantitative evaluation of the effects of varying lengths of clear distances on capacity, data were collected on the number of vehicles entering from each lane for each cycle under different parking conditions. Hand denominators mounted on clip boards were used to facilitate recording the data. Cones were set up 8 ft from the curb and 22 ft apart along the entire approach leg. In this manner, removal of one cone at a time produced the desired clear distances and prevented vehicles from approaching the intersection in the coned-off lane. As a consequence, the hazards of weaving induced by the single parked car technique were eliminated. Figures 2 and 3 depict the manner in which the curb lanes were coned off during data taking periods.

Collection of Data

The intersection selected for study, as previously indicated, is normally part of a progressive system, and under usual traffic conditions operates efficiently. Since it was felt desirable to conduct this study under conditions of saturated flow, the green time alloted to the service road was reduced from 25 sec to 16.5 sec and 20.0 sec on the two days of observations. In this manner, it was possible to destroy the progression, creating conditions of saturated flow and causing the approach to fill up rapidly with vehicles. Once this condition was obtained, data were taken.

With the green time reduced to 16.5 to 20.0 sec for both right and left curb parking conditions, it was possible to maintain saturated conditions for periods of 3 hr on each day of data taking.

Occasionally, the back up would overflow to the preceding intersection and danger of blocking the exit ramp from the parkway was present. To avoid this latter condition, the signal splits were periodically readjusted by a signal technician who was present throughout the field study. During this period, data were not taken.

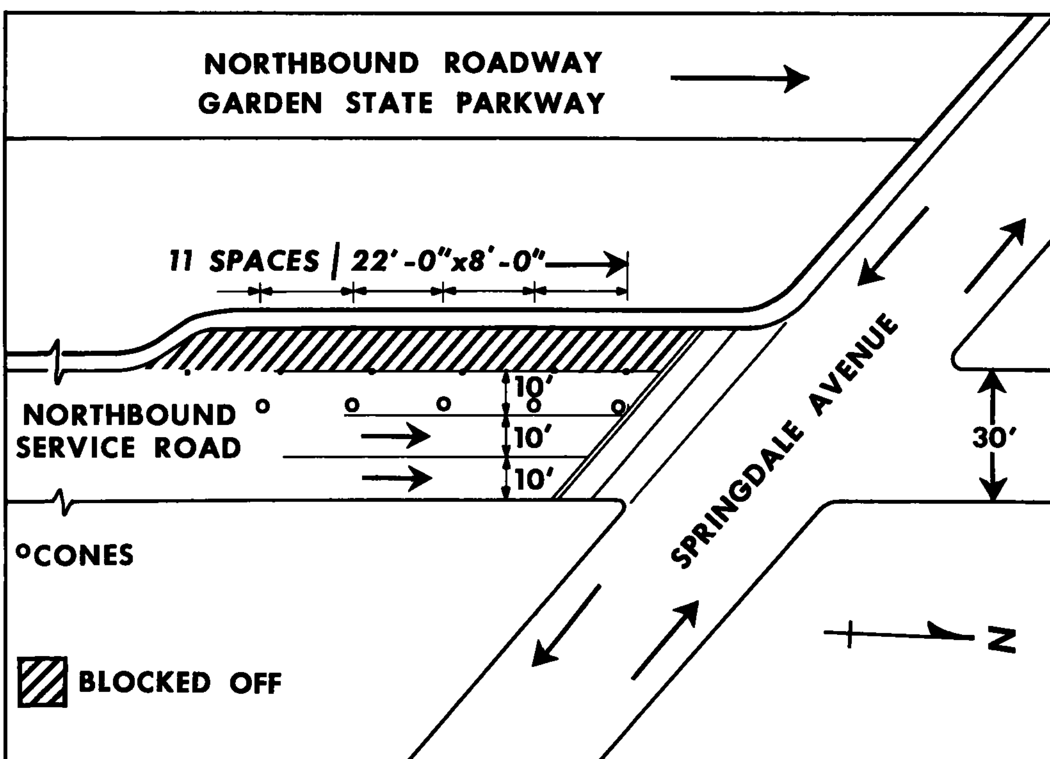

Figure 2. Left curb lane parking conditions.

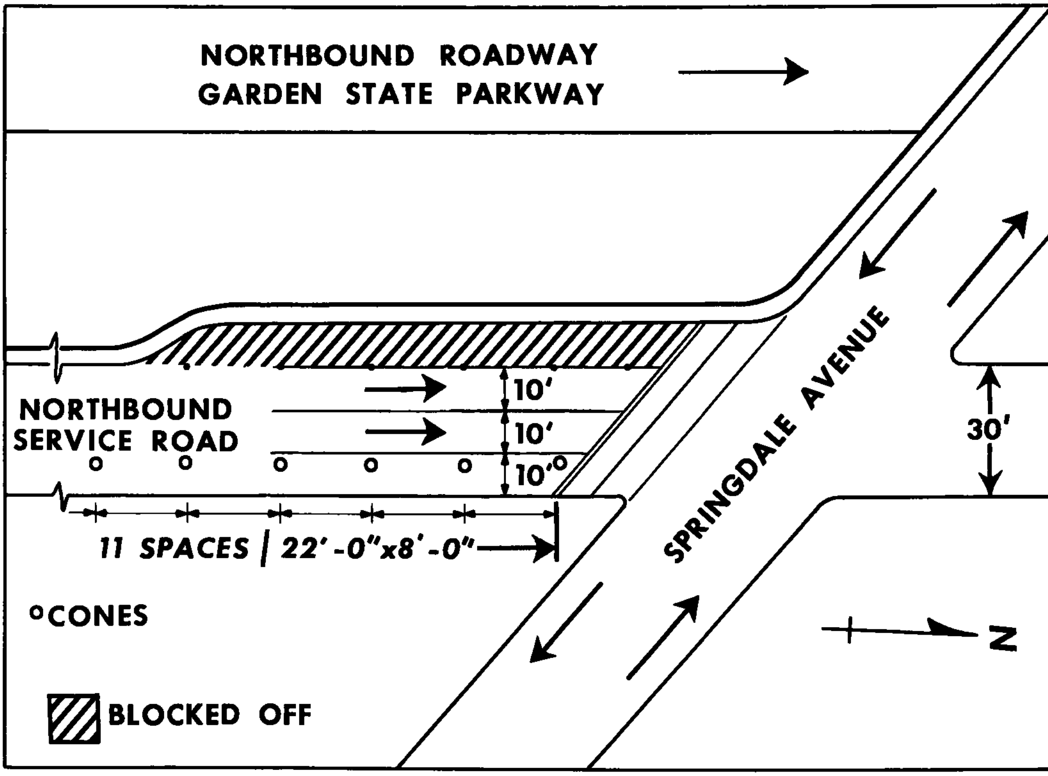

Figure 3. Right curb lane parking conditions.

Cycles during which the intersection was blocked by a stalled or stopped vehicle were noted and omitted from analysis, as well as cycles during the period when the splits were changed in order to avoid overflow of back up onto the parkway. Pedestrian traffic was non-existent during the survey period and hence could not have influenced the results of the study.

Data-taking periods were scheduled in order to obtain between 5 and 10 cycles for each clear distance, in multiples of 22 ft, up to approximately 250 ft from the intersection for each curb lane. All cycles were recorded under saturated intersection conditions.

Observations were made first with the right lane coned off on October 22 and then with the left lane coned off on November 5. Weather was cool and clear on both days.

ANALYSIS OF DATA

Study of Left Curb Lane Parking Conditions

Table 1 summarizes the mean discharge, expressed in vehicles per cycle, in addition to the observed storage in the left curb lane just before the signal turned green.

From Table 1, it is apparent that the storage is a function of the clear distance back from the intersection and the relationship is approximately linear.

The discharge from the left lane, between 44 and 110 ft from the intersection, lies within the range of 0.0 and 9.6 vehicles per cycle with an average discharge of 4.8 vehicles per cycle. Beyond 110 ft the discharge from the left lane is within the range of 8.8 and 9.9 vehicles per cycle with an average discharge of 9.4 vehicles per cycle.

Discharge from the center lane decreases from a maximum of 9.6 vehicles per cycle at 44 ft to a minimum of 5.6 vehicles per cycle at 110 ft and then begins to rise beyond 110 ft. It is interesting to note that the decrease in the center lane takes place at the same time that the discharge from the left lane increases.

TABLE 1

SUMMARY OF DATA—LEFT LANE PARKING CONDITIONS

Clear Distance (ft)	Storage Left Curb Lane-Veh	Mean Discharge—Veh/Cycle			
		Left Lane	Center Lane	Right Lane	Total All Lanes
44	0	0.0	9.6	7.8	17.4
66	2	3.0	7.8	10.4	21.2
88	3.2	7.8	6.2	9.6	23.6
110	3.8	9.6	5.6	9.8	25.0
132	5.0	9.0	6.6	9.0	24.6
154	5.2	8.8	7.0	9.0	24.8
176	5.6	9.6	7.0	9.3	25.9
198	6.0	9.4	7.8	7.8	25.0
220	6.2	9.1	8.2	7.6	24.9
242	8.0	9.9	8.0	7.8	25.7

This relationship is better illustrated in Figure 4 where both the left curb lane and center lane are plotted. This characteristic appears to be due in part to the fact that when the left lane is almost entirely coned off, drivers are forced to make left turns from the center lane. As the clear distance is increased, those desirous of turning left could use the curb lane and drivers going through the intersection will use both the remaining center and right lanes. As a consequence, gaps are left in the center lane resulting in a decrease of discharge.

Discharge from the right lane does not appear to be affected by the varying offset in the left lane.

Relationship Between Intersection Capacity and Clear Distance

The hypothesis that intersection capacity is proportional to the length of clear distance adjacent to the intersection was tested by the "t" statistical method. Provision of only 22 ft in the left curb produced significant effects on the total volumes discharged up to 88 ft.

Table 2 depicts the values of "t" for the difference in mean volumes between offsets of 44 and 66 and 66 and 88 ft from the intersection.

Significance levels 0.01 and 0.01 are noted. This indicates that the hypothesis of equal means would be rejected at a significance level of 0.01 or lower.

On the basis of the results shown in Table 2, it is unlikely that the volumes observed came from the same population or that the difference in means could be attributed to variations in turning movements.

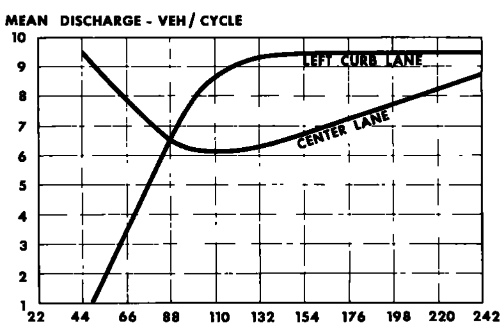

Figure 4. Discharge—left and center lane left lane parking conditions.

Rank Correlation Analysis

A rank correlation analysis (6) was made to ascertain the degree of correlation between clear distance and the mean discharge per cycle. The coefficient of correlation was found to be 0.86 with a probable error of 0.06. The high correlation

TABLE 2

COMPARISON OF MEAN VOLUMES LEFT LANE PARKING CONDITIONS

Clear distance (ft)	44		66		88
Number of cycles	8		7		7
Mean discharge (veh/cycle)	17.4		21.2		23.6
Value of "t"		4.50		3.75	
Significance level (3)		0.01		0.01	

value of 0.86 indicates the relationship that the length of clear distance is proportional to intersection capacity.

Figure 5 shows the relationship of total discharge per cycle and clear distance adjacent to the intersection. The volume discharged increases linearly to approximately 23.5 vehicles per cycle when a clear distance of 88 ft was provided adjacent to the intersection. The maximum mean discharge was approximately 25.5 vehicles per cycle and at 110 ft the mean discharge observed was 25.0 vehicles per cycle.

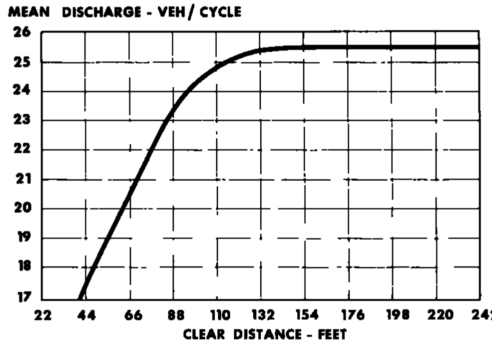

Figure 5. Discharge—all lanes—left lane parking conditions.

Study of Right Curb Lane Parking Conditions

Table 3 summarizes the mean discharge expressed in vehicles per cycle when the right curb lane was coned off in intervals of 22 ft. Shown also is a breakdown by lane of the total discharge.

TABLE 3

SUMMARY OF DATA—RIGHT LANE PARKING CONDITIONS

Clear Distance (ft)	Mean Discharge—Veh/Cycle			
	Left Lane	Center Lane	Right Lane	Total All Lanes
22	6.6	6.8	0	13.4
44	7.3	6.8	0.2	14.3
66	7.2	7.5	0.2	14.9
88	7.3	7.8	1.1	16.2
110	7.4	8.2	0.6	16.2
132	7.7	7.6	3.1	18.4
154	7.4	7.5	3.0	17.9
176	7.8	8.4	4.4	20.6
198	7.2	7.7	4.9	19.8
220	7.1	8.3	4.2	19.6
242	7.0	7.2	4.5	18.7

While there is an increase in total discharge in a manner similar to the study conducted when the left lane was coned off, the slope of the increase is considerably less steep.

In comparison to the condition where the left lane was coned off, it was demonstrated that from 44 ft from the intersection to 110 ft an increase of 7.6 vehicles per cycle followed, as compared to an increase of 14.3 to 20.6, or 6.3 vehicles per cycle, in an aggregate distance of 176 ft less 44, or 132 ft.

Notwithstanding a 3.5 sec difference in green time for both conditions, it appears that this difference could be attributed to the higher percentage of left turns and the absence of right turns. Had parking been retained on the far side of the intersection, this difference could have been partially attributed to this condition. However, as brought out earlier in this report, parking was not permitted on the far side of the intersection.

Since this was the case, it appears that the low discharge in the right curb lane could be attributed to driver reluctance to use the right lane as a through lane.

This is more clearly shown in Figure 6. It is evident that the increase in discharge from the right curb lane is very gradual and only amounts to approximately 5.0 vehicles per cycle. The mean discharge from the center lane is relatively constant and varies from approximately 7.0 to 8.0 vehicles per cycle, as opposed to the dip from a high of 9.6 to a low of 5.6 vehicles per cycle and then a gradual increase under the left curb lane parking conditions described.

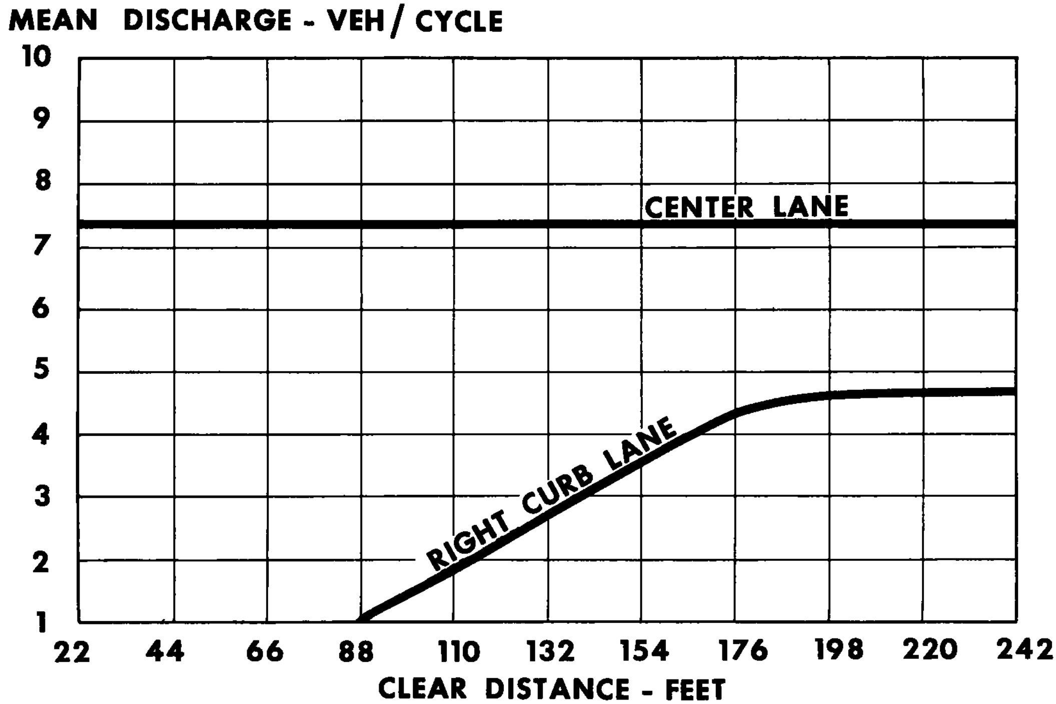

Figure 6. Discharge—right and center lane right lane parking conditions.

The total mean discharge for the conditions of this study is shown in Figure 7. The general shape of the curve very nearly approaches that of the curve for the study with the left lane coned off and there can be no doubt that as the clear distance increases, the mean discharge increases. This increase takes place until there is a gradual leveling off of the total mean discharge, until the effect of curb parking is not apparent in the discharge at the intersection.

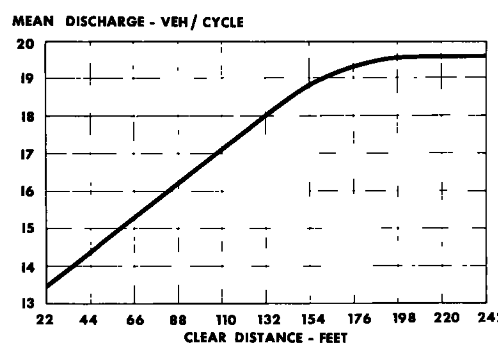

Figure 7. Discharge—all lanes—right lane parking conditions.

Relationship Between Intersection Capacity and Clear Distance

A "t" statistical analysis was made to test the significance of the difference in mean discharge for the study with the right lane coned off in intervals of 22 ft. The results are shown in Table 4.

An analysis of the results of the "t" test indicate that for the right lane clear distances of 88 and 66 ft were necessary to detect significant differences in mean discharge per cycle. The study with the left lane coned off showed that distances of as little as 22 ft caused significant differences in mean discharge per cycle.

TABLE 4

COMPARISON OF MEAN VOLUMES RIGHT LANE PARKING CONDITIONS

Clear distance (ft)	22		110		176
Number of cycles	8		9		5
Mean discharge (veh/cycle)	13.4		16.2		20.6
Value of "t"		2 27		3.25	
Significance level (3)		0.05		0.01	

As brought out previously, the high percentage of left turns as opposed to a very negligible number of right turns could have made the difference.

Rank Correlation Analysis

A rank correlation analysis (6) was also made to ascertain the degree of correlation between the curb offsets in the right lane and the mean discharge. The coefficient of correlation was found to be 0.87 with a probable error of 0.05 . The high correlation of 0.87 supports the contention that the length of clear distance is proportional to intersection capacity.

Comparison of Calculated and Maximum Observed Capacity

A clear distance of approximately 110 ft in the left curb lane yielded a maximum volume of 1,000 vehicles per hr. In the right curb lane, approximately 132 ft was required to yield a maximum volume of 750 vehicles per hr.

TABLE 5

RELATIONSHIP OF CALCULATED AND MAXIMUM OBSERVED CAPACITY—VEH/HR OF GREEN

Lane	Calculated	Maximum Observed	% Difference
Left lane parking conditions	835	1,000	+16.5
Right lane parking conditions	685	750	+ 8.7

These comparisons are depicted in Table 5. Observed traffic volumes on this intersection approach are somewhat higher than the theoretical capacities calculated on the basis of maximum volumes observed and stated in the Traffic Engineering Handbook (4).

CONCLUSIONS

For both conditions of parking studied, capacity through the intersection increased in proportion to the length of clear distance. The increase in capacity for the left curb lane parking conditions was apparent up to a distance of about 110 ft. No significant increase in discharge was evident beyond this distance. This finding very closely agrees with the statements made in the Highway Capacity Manual, that is, a distance in feet equal to five times the green period in seconds is equivalent to complete prohibition of parking in regard to capacity. The right curb lane parking conditions, on the other hand, required a distance of 132 ft beyond which no significant increase in discharge was noted. For this condition, agreement with the Highway Capacity Manual is not noted. As indicated in the analysis, this may be due to the absence of right turns in addition to driver reluctance to use the curb lane as a through lane.

Significant increases were found in the volume discharged per cycle when additional clear distance at the intersection was available for moving traffic in both cases tested by the t-statistic. While additional clear distances of 22 ft provided significant effects in the left lane, a distance of approximately 80 ft was required when the right lane was coned off. This difference also appears to be attributable to the high percentage of left turns as opposed to a very small percentage of right turns in addition to driver reluctance to use the curb lane for through movements.

A correlation analysis between the clear distance adjacent to the intersection and the discharge resulted in a high correlation coefficient for both parking conditions. This finding supports the hypothesis that capacity through an intersection will increase in proportion to an increase in clear distance.

COMPARISON OF OBSERVATIONS WITH THOSE OF PREVIOUS STUDIES

Bartle's Observations

Bartle's paper (2) presented the results of a similar study at a four-lane two-way intersection. In this study the restrictive effect of a single car was studied at two distances from the intersection. Bartle found the effect of the single car to be significant, although the difference in absolute volumes was small. He attributes the small difference in absolute volumes to the fact that an entire traffic lane was not blocked off. It is further suggested that single cars parked at mid-block locations between signalized intersections may have no restrictive effect on capacity, based on the two distances of parking from the intersection.

Wickstrom's Observations

Wickstrom's thesis (5) offers a more direct comparison in a study of a similar nature at an intersection of a one-way street in a downtown area. Wickstrom's study included observations at and below saturated capacity. The characteristics of the curves for both conditions are similar. While the study described herein was conducted during saturated conditions, the similarity of the relationship between observed volumes and clear distance is noteworthy. Both studies suggest that the maximum volumes through a signalized intersection occur when the clear distance, in feet, is approximately equal to five times the green time when turning volumes are in the neighborhood of 30 to 40 percent of the total approach volumes.

APPLICATION OF RESULTS

The experiment described in this paper has demonstrated that maximum volumes of traffic can be moved through an intersection without complete prohibition of parking. It has further been shown that the clear distance required for maximum volumes is a function of the percentage of turns. It is realized that the effect of vehicles maneuvering during parking operations constitutes a detriment to traffic approaching an intersection. This effect was not measured in this study.

In applying the findings presented herein, consideration should be given to the parking characteristics of the intersection studied. Where turning volumes are low and parking on the far side on an intersection is not a factor, perhaps proper signing will encourage greater utilization of the clear distance.

Need for Further Research

While only one street width was considered in this project, the findings suggest a possible relationship between street width, percentage of turning movements and volumes of traffic. Similar studies on streets of different widths and turning movements will be a valuable contribution in determining whether such a relationship exists. In this manner, it would be possible to more fully understand the effect of curb parking on intersection capacity.

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