Effect of Parked Vehicle on Traffic Capacity of Signalized Intersection

RICHARD M. BARTLE,
Stone and Youngberg, San Francisco, California

● PARKING and parking restrictions are known definitely to affect the traffic capacity of intersections, but more information is needed on the extent of this effect and how it occurs. The research described in this paper was undertaken primarily to evaluate quantitatively the relationship of parking to intersection capacity for the case of a single car parked in the intersection approach.

Studies reported in the "Highway Capacity Manual" give typical values for capacities under various physical and traffic conditions, including parking, and factors for increasing or decreasing capacity as the result of changes in these conditions. These values and factors are based on reports of traffic volumes observed throughout the United States under these various conditions. The research described in this paper is based, however, on the detailed study of traffic performance on a single intersection approach under reasonably constant conditions except for parking a single car close to the intersection.

The two principal traffic capacity problems which were studied are these:

1. The restrictive effect of a single car parked in the intersection approach.
2. The effect on capacity of varying the distance of the parked car from the intersection

With respect fo the first of these problems, many traffic engineers apparently believe strongly in the importance of complete parking prohibition on heavily traveled streets. This has led to adoption of no-stopping "tow-away" regulations under which vehicles parked in violation during peak hours may be towed off the street and impounded. Emphasis of the tow-away appears to be on removing isolated parked cars along curbs which are otherwise clear. There are, however, few reported quantitative data on the effect on traffic capacity of such isolated parked cars.

The "Highway Capacity Manual" (1) contains two brief references to the effect of prohibiting parking near intersections. These are pertinent to the second problem mentioned above. A footnote under one section explains that these conclusions are based on rationalization of available facts and data but that there are insufficient data for statistical analysis. The manual states, with this qualifying footnote:

> "If parking is prohibited more than twenty feet in advance of the crosswalk, add P(D-20)5G percent, where P is the total percentage of turns, D the distance in feet from the crosswalk where parking is prohibited, and G the seconds of green per signal cycle. P cannot exceed 30, and D cannot exceed (5G-20)."(p. 89)

This formula suggests that capacity increases proportionally as P and D increase and as G decreases.

A later section on the same page and without the qualifying footnote states that prohibition of parking in advance of the intersection for a distance in feet equal to five times the green period in seconds is equivalent to a complete prohibition of parking as far as capacity is concerned.

The experiment described here is intended to evaluate critically the effect of a single car parked in the intersection approach. Parking and unparking operations presumably contribute to a reduction in capacity where parking is permitted but are not considered in this study. This study is limited to the effect on intersection capacity of a single car parked in the intersection approach. This absence of parking and unparking is an important difference between the single car situation and the line of parked cars found in a "parking permitted" situation. In addition, the increased maneuvering space made available beyond the parked car away from the intersection may contribute to the difference between the single car case and that of a line of parked cars.

THE EXPERIMENT

An empirical approach was used to evaluate quantitatively the effect of a single parked car in the intersection approach. Parking one car at a predetermined location, observing traffic behavior, and comparing data thus obtained with those obtained without parking should enable a careful experimenter to evaluate the restrictive effect, if any, of the parked car.

To examine the effect of a single parked car on intersection capacity, data were taken at an intersection approach operating under capacity conditions without parking and with a single car parked at two different distances from the intersection. Data were collected on the number of cars entering during short time intervals in each signal cycle as measured from the start of the green period. Mean volumes entering under different parking conditions in these time periods were compared and tested statistically for significant differences. Significant differences among parking conditions, if any, indicate whether or not the parked car and its location restrict intersection capacity and show the portions of the signal cycle in which any such restriction is produced.

Since data were necessarily collected on several different days, the effect of day of data-taking on entering volumes was tested for significance. If there is no significant effect, data taken on several different days under the same parking conditions may be pooled in order to increase sample sizes.

The effect of parking on lane volumes was tested using data for separate lanes and following methods similar to those described above for total volumes.

The analyses described above were designed to test for significant effects of parking on entering volumes under capacity conditions and for significant differences in volumes between parking distances. These analyses indicated the magnitude of these significant effects, if any, and the parts of the signal cycle and the traffic lanes in which they occurred.

The intersection selected for the experiment and the method of data collection and analysis are discussed in the sections which follow.

The southbound approach of Sepulveda Boulevard at Wilshire Boulevard near the Los Angeles campus of the University of California was selected as the site for this experiment. This intersection is on a state highway (Sepulveda) in unincorporated county territory, and traffic is under jurisdiction of the California Highway Patrol. Inspector R. R. Emmett of the Highway Patrol and Captain Walter Sequiera of the Patrol's West Los Angeles office extended their full assistance to aid the experiment.

Sepulveda Boulevard is 52 feet wide curb-to-curb at its intersection with Wilshire Boulevard. Parking is not specifically prohibited by posting on either approach. There is almost no parking at any time, however, since the highway runs through the grounds of a veterans' facility. A cemetery lies on one side of the street, and the other side is vacant near the street. Both sides are fenced.

Under normal operation two lanes of traffic move southbound along Sepulveda Boulevard to enter or cross Wilshire. Sepulveda Boulevard is 26 feet from center to the edge of the roadway, and one 11-foot lane is marked. Vehicles occasionally move two abreast in the remaining 15 feet of width near the intersection. A large number of the vehicles using the extreme right edge of the roadway make right turns onto Wilshire Boulevard. Parking a typical car on this southbound approach would reduce usable street width on that side of the center line to twenty feet. Two lanes of traffic could continue to pass this point although the outer (curb) lane would be only 9 feet wide instead of 15. The extreme right edge of the roadway could be used for movement only between the car and the intersection. A sketch of this intersection is presented in Figure 1.

On the southbound approach, therefore, parking a single car would not block a full traffic lane. Parking reduces the width of one lane and prevents use of the extreme outer portion of the roadway, used primarily for right turns in normal operation. Introduction of the parked car does not block a normally used lane; therefore, differences in traffic movement between the no-parking and parking conditions will be less sharply marked than presumably would be the case if the street were a few feet wider or narrower. The fact that an entire lane is not blocked presents some important advantages to the experimenter. The parked car is likely to cause less disturbance among motorists, and accidents appear to be less likely.

The intersection selected for study is controlled by a fixed-time three-light signal operating on a 60-second cycle. Each street, Wilshire and Sepulveda, is normally given 27 seconds of green and 3 seconds of amber. A California Highway Patrol officer operates the signal manually during periods of extremely heavy traffic. This is done primarily

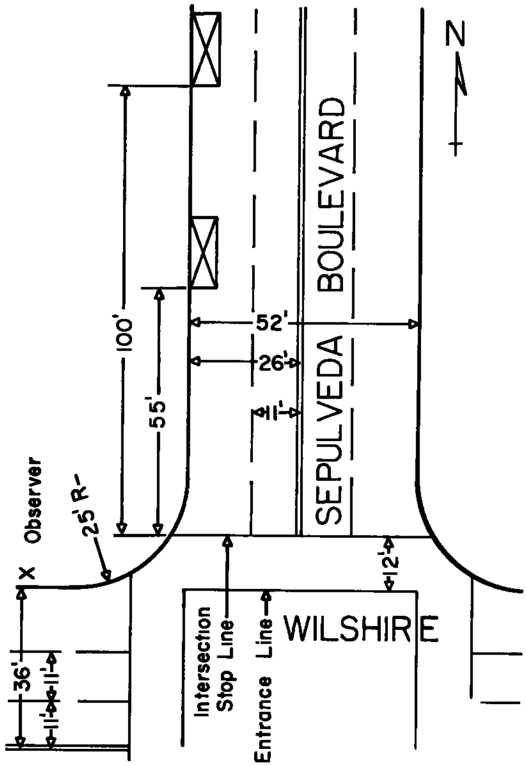

Figure 1. Sepulveda and Wilshire Blvds. showing positions at which cars parked in the experiment.

to avoid blocking an ambulance entrance on the nearby veterans' facility grounds.

To permit quantitative evaluation of the effect of the parked car, data were collected on the number of vehicles entering from each lane in various short time intervals within the 30-second green and amber period of the signal. The data collection method adopted utilized the Esterline-Angus 20-pen operations recorder. An observer recorded a pip on the record chart at the time each vehicle entered the intersection. Only one man was required to collect data, and the events recorded on the chart were so simple that few errors in recording or transcription could be made.

This method produced a graphic record showing the time of entrance of each vehicle from each lane and the beginning of the green signal indication.

Since there was no automatic recording of any kind, human error could be present in recording all events. One-half second on a given observation is estimated as the maximum error. To make a larger error on an entering vehicle would require that the button be pushed when the car was 15 to 20 feet from the stop line.

Throughout all data recording, a car was recorded as entering the intersection when its rear wheels crossed the pedestrian crosswalk line nearest the intersection center.

A brief study of entering volumes per cycle was made during weekday afternoon peak periods in order to determine the necessary sample size. Data for 200 cycles on these weekdays indicate that the mean volume entering the intersection per 30 seconds green period was 19.6 with a variance of about 22. In this study a difference of one vehicle per cycle among the no-parking and the 55-foot and 100-foot parking conditions should be detected. To detect a difference of 1.0 between means at the .05 level of significance with a probability of .80 would require 274 samples under each condition according to the method of Harris, Horvitz, and Mood (2).

To reduce the variance of the number of vehicles entering per cycle, data were collected on Sunday afternoons, when from approximately 3:30 to 6:30 p.m. the southbound approach is overloaded. There is a continuous reservoir of waiting vehicles during this period. Average volume entering per cycle is higher since there is traffic demand for all of every green signal period. Because this demand remains nearly constant during the entire period, variance of the entering volume is lower.

Twenty-five cycles were observed under each of two conditions on Sunday, May 3, 1953, and a pooled mean of 22.92 vehicles entering per cycle with a pooled variance of 6.24 was obtained.

Variance of 6.24 requires a sample of 81 in each condition to reject the hypothesis of equal means for a difference of 1.0 with $\alpha = .05$ and $\beta = .80$. The desirability of collecting data during the Sunday peak traffic period is readily apparent.

Data-taking periods were scheduled to obtain at least 81 cycles of data under each parking condition. All cycles were to be recorded under overloaded intersection conditions: a continuous reservoir of vehicles waiting to enter. The parked car was usually moved only once during an afternoon since moving it required that the experimenter leave his equipment unattended. On the basis of observations at the intersection and analyses of the data, time of day within the 3:30 to 6:30 p.m. period had no effect on the traffic.

TABLE 1

SCHEDULE OF DATA COLLECTION

	Number of Cycles Recorded		
Date	No Parking	Parking at 100 ft.	Parking at 55 ft.
May 3	25	25	—
May 10	30	40	30
May 24	31	32	—
June 21	—	—	70
TOTAL	86	97	100

Data for no parking and parking at 100 feet were collected on three Sundays in May 1953. At least 25 cycles were observed under each condition each day. Weather was clear on all of these days. Daylight saving time was in effect so that daylight continued for more than an hour after data taking was concluded.

Short periods were noted in which no cars were waiting to enter, and these were excluded from the data. Exceptional conditions such as a stalled car entering or cross traffic blocking the intersection also caused cycles to be excluded.

During the data taking on May 10 a car stalled in the intersection approach and was pushed to the curb 55 feet from the nearest crosswalk line. The car remained parked in this position for 30 signal cycles while waiting for repair. Data were taken continuously during this period to determine the effect of parking closer than 100 feet to the intersection. Thirty cycles were recorded on May 10, and 70 more cycles were recorded on June 21 with a car parked in this same position. Table 1 shows the days of data taking and the number of cycles recorded for each condition of parking.

The order of parking and no-parking conditions was varied so that neither condition was observed first on every day. Signal operation was not influenced by the experimenter. The Highway Patrol officer used manual operation when traffic backed up to Sawtelle on Wilshire.

As described above, the time of entrance of each vehicle into the intersection was recorded by lane and by turning movement, if any. Data were transcribed from the Esterline-Angus chart by numbering cars in a given cycle serially and recording each to the nearest half-second of its intersection entrance. The numbers of cars in 5, 10, 15, 20, 25, and 30 seconds were tabulated and summarized for each day and each condition.

ANALYSIS OF THE DATA

A cumulative total of vehicles entering under no-parking, 100-foot, and 55-foot parking conditions is presented in Table 2 and Figure 2. All data are presented in terms of volume per 100 cycles and show the cumulative totals by one-second intervals. For the full 30-second green period traffic entered without parking at the rate of 2356 vehicles /100 cycles compared with 2212 vehicles/100 cycles with a single car parked at 100 feet and 2215 vehicles/100 cycles at 55 feet. The three curves appear almost identical for about 15 seconds after the start of the green. The volumes entering in the first 13½ seconds are equal for no parking and 100 feet, 928 vehicles/100 cycles, and the no-parking cumulative volumes are greater than with parking continuously after this time. At 24 seconds the no-parking volume is a full second ahead of that with parking, 1849/100 cycles without parking compared to 1843/100 cycles for 25 seconds with 100-foot parking and 1835 for 55-foot parking. At 26½ seconds the no-parking volume exceeds that with parking by one vehicle per cycle. At 28 seconds the no-parking volume is 1½ seconds ahead of its counterparts. Throughout the cycle there is little difference between the curves for the two parking distances.

The effect of the parked car on volume entering this intersection is not noticed in the first 15 seconds of the green period, but parking allows less traffic to enter in a given time interval in the second half of the green period.

The sharp difference in volumes entering under the two conditions of parking and no-parking in the last 3 seconds cannot be attributed to the difference between manual and fixed-time operation of the signal. The 27-30 second interval is green under manual control but is amber under fixed-time operation. Forty-two of the 97 cycles (43 percent) observed with 100-foot parking had manual control, but only 25 of 86 no-parking cycles (29 percent) were manually operated. Thirty-one of 100 cycles with 55-foot parking were manually controlled. If an effect of the difference in signal operation is reflected in the 27-30 second interval, the cycles with parking would be expected to carry proportionally the greater volume.

Analysis of variance has been used to test the effect of parking and the effect of days on which data were taken. A three-by-two analysis of variance table was set up using data only for the first 25 cycles observed each day under each of two conditions: no parking and parking at 100 feet.

Volumes in the intervals 0-10, 0-15, 0-20, 0-25, 0-30 (full green period), 10-20, 10-25, 15-25, 15-30, and 20-30 seconds were analyzed. The values in each cell are assumed to be normally distributed. A rather large variance for no-parking data on May 3, first day of data taking, caused rejection of the hypothesis of equal variance for 0-25, 0-30, 15-25, and 15-30 at the one percent level. These intervals with non-homogeneous variance were not tested.

Table 3 shows the mean volumes entering in each of these intervals by days and by parking condition, and summarizes the six analyses of variance.

The effect of different days was found not significant for all of the intervals tested. There is no reason, therefore, to expect days to have a significant effect on the volumes in other intervals not tested this way. Parking was found to have a significant effect in three of the six intervals tested. No significant interaction between parking and days was found for any of the tested intervals.

TABLE 2
CUMULATIVE VOLUMES ENTERING BY ONE SECOND INTERVALS SEPULVEDA BOULEVARD SOUTHBOUND AT WILSHIRE BOULEVARD

May 3, 10, and 24, and June 21, 1953[a]

Seconds After Green Begins	Cumulative Volumes Entering: No Parking 86-cycle Total	No Parking 100-cycle Equivalent	Single Car Parked 100 Feet 97-cycle Total	Single Car Parked 100 Feet 100-cycle Equivalent	Single Car Parked 55 Feet 100-cycle Total
1	1	1	2	2	0
2	9	11	24	25	12
3	43	50	73	75	74
4	114	133	156	161	153
5	174	203	224	231	222
6	241	280	296	305	311
7	319	371	373	385	380
8	401	467	460	474	468
9	463	539	532	549	551
10	538	626	613	632	633
11	611	711	688	710	706
12	692	805	769	793	793
13	763	887	853	880	871
14	844	982	937	967	955
15	906	1054	1005	1037	1022
16	983	1155	1087	1121	1104
17	1057	1241	1169	1206	1178
18	1120	1311	1244	1283	1260
19	1196	1402	1335	1377	1349
20	1275	1483	1397	1440	1441
21	1357	1577	1483	1530	1523
22	1433	1665	1558	1607	1600
23	1503	1747	1645	1697	1679
24	1591	1849	1719	1773	1759
25	1662	1933	1788	1843	1835
26	1728	2009	1873	1932	1912
27	1803	2096	1942	2003	1997
28	1899	2207	2021	2085	2072
29	1963	2282	2095	2161	2150
30	2026	2356	2146	2212	2215

[a] All data taken on Sundays.

Since these six analyses show that the days of data taking had no effect on volumes entering the intersection, additional tests may be made for other intervals and additional data. While 86 cycles without parking and 97 with a car at 100 feet were recorded, only 75 of each could be used in the analysis of variance described above.

The assumption of independence of day of data-taking could be extended to data collecte with a single car parked at 55 feet. Therefore, comparisons among the three conditions, no parking and parking at 100 and 55 feet, could be made with the t-statistic and utilizing all data for each parking condition.

Tables 4 and 5 present the results of comparison among the three conditions as tested with the t-statistic. No significant differences in volumes between the 100-foot and 55-parking conditions were detected. When compared with the no-parking condition, tests involving the two parking distances produced almost identical results. Significantly more cars entered without parking than with parking at either distance for the first 25 seconds and for the full 30-second green (or green and amber) period. Significant differences in volume were noted in all the smaller intervals tested: 10-20, 10-25, 15-25, 15-30, and 20-30 seconds after the start of the green.

The volume without parking exceeds that with 100-foot parking by at least 0.81 vehicle per cycle with a probability of .95. No-parking volume exceeds that with 55-foot parking by 0.77 vehicles per cycle or more with the same probability.

These test results demonstrate clearly that parking has an effect and that the effect is noted almost entirely in the last half of the green period. In this case, significant differences were detected in the 10-20 second interval, but these were comparatively smalle than those found in later parts of the green period. The last ten seconds of the green

TABLE 3

MEAN VOLUMES ENTERING PER CYCLE IN SELECTED TIME INTERVALS WITHOUT PARKING AND WITH PARKING 100 FEET FROM THE INTERSECTION

Sepulveda Boulevard Southbound at Wilshire Boulevard
May 3, 10, and 24, 1953 (a)

Seconds After Green Begins	No Parking				Parking at 100 Ft.				F-ratios		
	3	10	24	Total	3	10	24	Total	Interaction	Parking	Days
0-10	6.32	6.27	6.19	6.26	6.52	6.08	6.47	6.32	0.87	0.00	0.16
0-15	10.80	10.43	10.42	10.54	10.48	10.13	10.56	10.37	0.77	0.30	0.09
0-20	15.36	14.57	14.65	14.83	14.48	14.20	14.56	14.40	0.27	3.72	0.83
0-25	19.72	19.20	19.13	19.33	18.60	18.08	18.69	18.43			
0-30	23.72	23.53	23.48	23.56	22.12	22.00	22.31	22.12			
10-20	9.04	8.30	8.45	8.57	7.96	8.08	8.09	8.08	2.60	4.88(b)	0.93
10-25	13.36	13.00	12.94	13.07	12.08	11.98	12.22	12.11	0.84	16.00(c)	0.43
15-25	8.92	8.77	8.71	8.79	8.12	7.95	8.13	8.07			
15-30	12.92	13.10	13.03	13.02	11.64	11.88	11.72	11.76			
20-30	8.36	8.97	8.81	8.73	7.64	7.80	7.72	7.72	0.46	20.90(c)	1.27

(a) All data taken on Sundays.
(b) Significant at .05
(c) Significant at .005

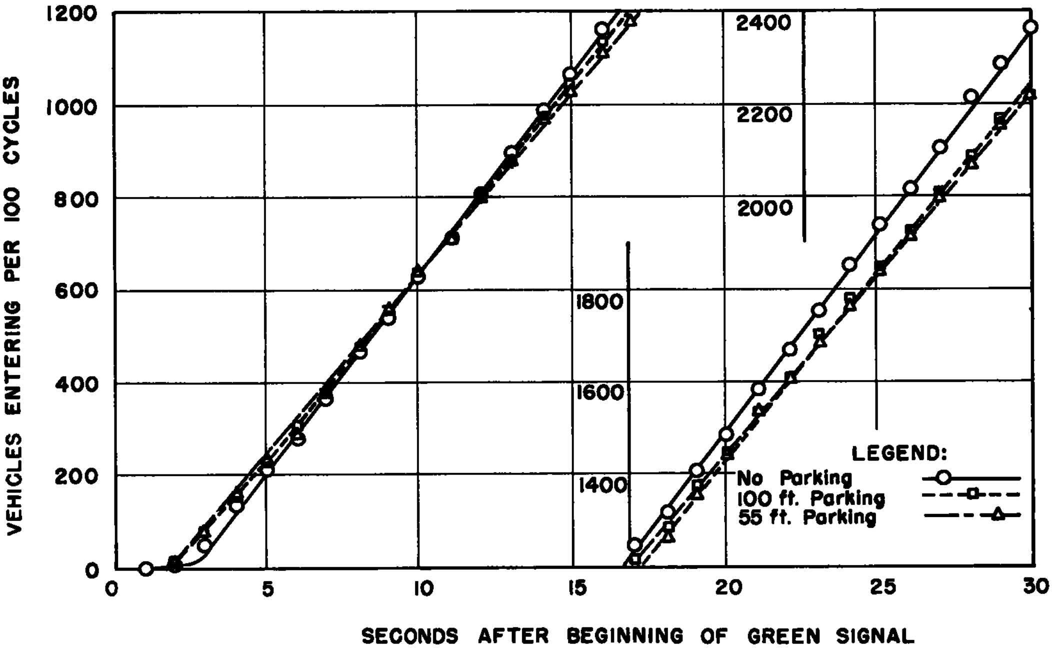

Figure 2. Cumulative entering volumes with and without parking.

demonstrated the effect of parking very clearly. For the entire green period the probability is .95 that the no-parking volume exceeds that with parking by at least 0.8 per cycle. In the last 10 seconds, however, the probability is .95 that no-parking volume is larger by about 0.6 per cycle.

Review of the physical situation involved suggests a more restrictive effect on traffic volume should result if the car is parked closer to the intersection. If this is so, additional

TABLE 4

MEAN VOLUMES ENTERING PER CYCLE IN SELECTED TIME INTERVALS WITH NO PARKING AND PARKING AT 100 FT. AND 55 FT.

Time Interval (Seconds)	No Parking	Parking at 100 Ft.	Parking at 55 Ft.
0-10	6.26	6.32	6.33
0-15	10.54	10.37	10.22
0-20	14.83	14.40	14.41
0-25	19.33	18.43	18.35
0-30	23.56	22.12	22.15
10-20	8.57	8.08	8.08
10-25	13.07	12.11	12.02
15-25	8.79	8.07	8.13
15-30	13.02	11.76	11.93
20-30	8.73	7.72	7.74

experimentation should result in significant volume differences between the 100-foot and 55-foot parking conditions. The data collected and analyzed here do not, however, support this contention.

Observed traffic volumes on this intersection approach were very much higher than the theoretical capacities of the approach calculated according to methods of the "Highway Capacity Manual." The approach is 52 feet wide, there are no left turns and 5 percent right turns, 10 percent of the traffic is commercial, and green constitutes 27/60 of the signal time. Following the method of page 79 of the manual, the possible capacity is 1088 vehicles per hour.

This computation assumes this intersection can be considered as "downtown with parking prohibited," which results in the highest capacity value. If it is classified instead as "intermediate," the possible capacity is reduced to 955 vehicles per hour.

Curves presented in the manual indicate that the capacity of a downtown intersection is reduced 29 percent by permission of parking and that in an intermediate area by 45 percent.

The observed volumes for almost five hours of data taken averaged 1413 vehicles per hour with no parking and 1328 vehicles per hour with a car parked. The volume was reduced six percent by the parked car. The observed volume without parking averaged 30 percent higher than the calculated possible capacity under the most favorable conditions.

If the intersection is assumed to be part of a high-type facility, possible capacity is 1316 vehicles per hour.

As noted above, data for each condition of parking were collected under both fixed-time and manual control of the signal. For the purpose of this study manual operation differs from fixed-time only in that longer cycles were used under manual operation. The 27-30 second interval is amber under fixed-time but green under manual control. Green time in excess of 30 seconds in any cycle was not analyzed for effect of parked vehicles.

There is a probability of .95 that volume in the 25-30 second interval under fixed-time control is at least .13 vehicle per cycle less than that under manual control. This finding serves to reinforce the conclusions with respect to the effect of the parked car since more cycles with manual control were recorded with parking than without.

Having determined where in the green signal period the effect of a parked car becomes significant, lane volumes were studied. The analysis presented here is based only on the volumes per lane entering in the full 30-second green (or green and amber) period of each cycle.

A two-way analysis of variance was made to test the effects of day of data taking and of condition of parking. Analyses were made for Lane 1 (center), Lane 2 (curb), and right turn volumes. Normality was assumed, and the hypothesis of equal variance among the six cells was not rejected at the .01 level. Only the first twenty-five cycles for each cell were utilized in the analysis of variance.

Day of data taking was not significant for any of the volumes tested although the significant interaction (.05) in Lane 2 volumes suggests some effect due to days. The number of right turns under no-parking conditions was significantly greater than with a car parked at 100 feet.

Assuming that day of data taking has no significant effect on lane volumes permits comparison of volumes under the several parking conditions using the t-statistic. Significant interaction outlined in the paragraph above suggests a possible effect of days and may raise some question about the conclusions of the t-tests.

Lane 1, nearest the roadway center, was not significantly affected by parking. Mean volumes under the three conditions were nearly equal for this lane, and the t-test showed no significant difference.

Volumes straight through the intersection in Lane 2 were significantly greater without parking. This lane is also used by right-turners who have been excluded from this analysis. As in the case of earlier analyses using the full cycle and all lanes, no significant differences were detected between volumes with parking at 100 and at 55 feet.

The mean number of right turns per cycle varied greatly. Significantly more right turns were made without parking than with parking at 100 feet. The mean right turns with parking at 55 feet did not differ significantly from those under either of the other conditions. Mean right turns per cycle were 2. 40, 1. 67, and 2. 03 for no parking, parking at 100 feet, and parking at 55 feet.

TABLE 5

TEST OF DIFFERENCE BETWEEN MEAN VOLUMES ENTERING WITHOUT PARKING AND WITH PARKING AT 100 FT. AND 55 FT. t-STATISTIC APPLIED TO POOLED DATA

No parking: 86 cycles. 100-ft. parking: 97 cycles. 55-ft. parking: 100 cycles.

Time	No Parking vs. 100-Ft. Parking			No Parking vs. 55-Ft. Parking			100-Ft. vs. 55-Ft. Parking		
(sec)	d.f.	t	Diff.	d.f.	t	Diff.	d.f.	t	Diff.
0-10	181	0. 63	NS	184	0. 35	NS	195	0. 27	NS
0-15	181	0. 74	NS	161	1. 42	NS	195	0. 70	NS
0-20	181	1. 74	NS	184	1. 58	NS	195	0. 08	NS
0-25	167	3. 27**	0. 37	184	3. 31**	0. 40	195	0. 23	NS
0-30	181	4. 60***	0. 81	184	4. 39***	0. 77	195	0. 07	NS
10-20	181	2. 91**	0. 17	164	2. 83**	0. 15	195	0. 16	NS
10-25	156	4. 80***	0. 59	184	4. 92***	0. 64	195	0. 33	NS
15-25	153	4. 33***	0. 40	184	3. 63***	0. 30	190	0. 53	NS
15-30	181	5. 83***	0. 83	184	4. 93***	0. 65	195	0. 86	NS
20-30	181	5. 29***	0. 63	184	5. 06***	0. 60	195	0. 06	NS

* Difference significant at . 05
** Difference significant at . 01
*** Difference significant at . 005
NS Difference not significant at . 05

Column Headings:

d.f. Degrees of freedom
t t-statistic
Diff. Difference between means exceeded or equalled with probability of . 95.
Where variances under the two conditions were not significantly different, the degrees of freedom are two less than the sum of the observations. Where variances are significantly different, the degrees of freedom are reduced. Refer to pp. 104-5, Dixon and Massey, Introduction to Statistical Analysis. (7)

The significantly larger number of right turns observed under the no-parking condition is difficult to explain and may affect some of the other results. There is insufficient evidence, however, to indicate whether or not parking had a significant causative effect on the mean number of right turns per cycle.

Additional analyses were made of the effect of parking on entering volumes for cycles with the same numbers of right turns. In general, the results of these tests with numbers of right turns equalized were the same as those for combined data.

As in the analyses presented above, the segregated analyses demonstrate that Lane 1 is not significantly affected by parking and that no real difference in any lane or in total volume exists as a function of distance parked from the intersection.

The effect of parking with turning conditions equalized on volumes in the interval 15 to

30 seconds after the beginning of the green was also studied. The mean values are presented in Table 6 and show that the mean number entering without parking in this interval is greater than with parking for any number of turns per cycle.

TABLE 6

MEAN VOLUMES ENTERING 15-30 SECONDS AFTER BEGINNING OF GREEN SIGNAL WITH NO PARKING AND PARKING AT 100 FEET AND 55 FEET

Cycles with Equal Numbers of Right Turns

Right Turns	No Parking	Parking at 100 Ft.	Parking at 55 Ft.
0	12.40	11.69	11.42
1	13.11	11.83	12.17
2	12.74	11.67	12.07
3	13.00	11.87	11.73
Over 3	13.48	12.00	11.91
Total	13.02	11.76	11.93

These results indicate that the greater number of right turns without parking does not affect the major conclusions of this paper. For cycles with the same number of right turns significantly larger volumes entered without parking than with a single car parked for most numbers of turns, and qualitative examination of the data suggests that significant differences would be found in all parking vs. no parking cases if a larger sample of cycles were analyzed.

SUMMARY AND CONCLUSIONS

At the overloaded intersection approach studied a single car was parked at the curb at distances of 100 feet and 55 feet from the intersection stop line. Data were collected on numbers and times of entrance of cars entering the intersection without parking and with the single car parked in each of these two positions. The analyses of these data constitute the body of this paper.

With the single car parked in the approach, traffic was able to pass it in two lanes. This is the same pattern as when there is no parking although the lane nearest the curb is considerably narrowed by the parked vehicle. Although other considerations governed the selection of this particular intersection for study, this chosen approach is typical of cases in which a complete new lane is not made available to traffic as a result of the parking prohibition. Effective width of the curb lane is increased, however, with resultant greater freedom of traffic movement.

All data analyzed as part of this experiment were collected under overloaded traffic conditions. There was a continuous reservoir of waiting vehicles on the approach under study, and volumes may thus be considered "capacity" volumes.

In these analyses the traffic pattern was not a function of the position of the parked car. With the quantity of data available, no significant differences were found between entering volumes with the car at 100 feet and at 55 feet from the intersection stop line, indicating that differences, if any exist, must be very small.

The parked car at either location had no effect on volumes entering the intersection during the first fifteen seconds of the green signal indication. From 15 to 30 seconds after the start of the green the effect of the parked car became increasingly pronounced. In the last 15 seconds the probability is .95 that the volume with no parking exceeds that with 55-foot parking by at least .65 vehicle per cycle and that with 100-foot parking by at least .83 vehicle per cycle. These differences represent between 5 and 8 percent of the mean volume entering in this 15-second period.

The no-parking volumes were found to be significantly greater than those with parking at the .05 level for the following time intervals after the beginning of the green; 0-25, 0-30 (entire green period), 10-20, 10-25, 15-25, 15-30, and 20-30 seconds. No significant differences were found in the first 10, 15, or 20 seconds. No other intervals were tested.

Data used in this experiment were collected on four different Sundays. Analysis of variance using data from three of these days showed no significant effect due to day of data taking. Therefore, all data from all days were pooled in reaching the other conclusions of the report.

The traffic lane next to the centerline, designated Lane 1 in this study, was not significantly affected by the parked car. The effect of the parked car was almost entirely on the curb lane, which included traffic moving straight through the intersection and right turning traffic. The latter constituted between 7½ and 10 percent of total traffic under various parking conditions. Significantly more right turns occurred with no parking than with a car parked at 100 feet, and this fact tended possibly to obscure some results.

Analyses were, therefore, conducted using cycles with equal numbers of right turns. The results of these analyses tended to support the conclusions obtained from the pooled data. For cycles with equal numbers of right turns, the effect of parking appeared reasonably well demonstrated. These analyses of parking effect using cycles with equal numbers of right turns were less sensitive than with the pooled data since the degrees of freedom were reduced when cycles were classified by numbers of turns.

These results can be summarized briefly as follows:

1. The effect of a parked car on entering traffic volumes under capacity conditions was found to be significant, but the absolute difference in volumes was small.
2. The effect of parking was not noted in the first half (15 seconds) of the green, but it was pronounced in the last half.
3. The center lane of traffic was not affected by the car parked at the curb.
4. Although approximately one hundred cycles were recorded for each of the two parking positions used, 100 feet and 55 feet, no significant differences in entering traffic volumes were noted between them.

These results appear to support the "Highway Capacity Manual" statement that prohibition of parking for a distance back from the intersection in feet equal to five times the green period in seconds is equivalent to prohibiting parking entirely. There was no parking on the far side of the intersection and the effect of parking here was not studied. A small effect was noted for the 10-20 second interval in this study, and this would not have been the case if the manual's statement were entirely correct. With a car at 100 feet the first 20 seconds of the green should not be affected by parking. No difference was noted here for different parking positions. If the manual's statement were to be borne out fully, the closer parking position would be found more restrictive.

The results of this study indicate that the practical benefits of removing a single car parked in an intersection approach are not great except under certain traffic conditions. The mean difference in entering volumes for the 30-second green period at this intersection was about 1. 5 vehicles per cycle with either parking position. This is only 5. 5 percent of the entering volume per cycle.

The loss of one and one-half vehicles per cycle from the capacity of the intersection can accumulate an overload in a short time. Ninety vehicles per hour will be unable to enter the intersection, and almost four full cycles will be required to enable these accumulated cars to clear the intersection. The above statement assumes traffic demand will be continuously high during the entire period with at least as many vehicles arriving per minute as are able to enter the intersection without parking.

Removal of a car parked in this position seems justified if and only if every signal cycle is fully occupied. At the southbound approach of Sepulveda to Wilshire, the car has a serious restrictive effect only on Sunday afternoons since normal fluctuations in volumes arriving at the intersection on weekdays will allow any accumulated backlog to clear periodically.

This study was conducted at a single intersection and did not cover the situation in which a single parked car blocks a normally used traffic lane. The results in such a case would be quite different. On Sepulveda Boulevard at Wilshire the single parked car reduced the usable street width but did not reduce the number of lanes normally passing the point at which the car was parked. The results of this study can properly be extended to all situations in which the latter condition prevails: parking does not reduce the number of normally used lanes.

Extending the conclusions of this study suggests that single cars parked in mid-block locations between signalized intersections may have no restrictive effect on capacity. These studies have, however, examined only two distances of parking from the intersection.

Isolated parked cars may present an important safety hazard. This factor has not been considered in the above discussion of the desirability of removing them from the street. In the present study a red flag was attached to the parked car to assure adequate attention and thus help to avoid collisions.

No significant effect was demonstrated as a result of using two different parking positions. Additional experimentation to determine quantitatively the effect of parking positi on volumes entering is needed. Additional data on 100 feet and 55 feet would eventually show a significant difference in restrictive effect if the hypothesis of the "Highway Capacity Manual" is correct. Perhaps more important is to determine the closest distance at which parking can be permitted without its having a significant effect on entering volumes. At the intersection studied this critical distance is greater than 100 feet but has not been established by this experiment. This critical distance is certainly less than 10 car lengths and would probably occur at a somewhat shorter distance. This experiment suggests that large quantities of data will be necessary to draw any definite conclusions about the effect of parking position on entering volume.

The method presented here may prove useful in further studies of intersection operation. The results of this study indicate that recording of entrance times for vehicles represents a suitable method for study of effects of various factors on intersection capacity. The method of field collection of data described here is very simple and reasonably accurate. Additional use of entrance times as basic data will permit important simplification of transcription and analysis of the data.

The practical results of this experiment indicate that parking has a significant but small effect on intersection capacity under conditions such as were studied here. A single car should be removed, if possible, if the approach is overloaded continuously for long periods. Parking a single car certainly should not be permitted where such parking blocks a normally used lane. In this case under study, the intersection was overloaded for less than three hours per week, and parking did not block a normally used lane. Strict prohibition of parking here would be valuable from a capacity standpoint only for a few hours each Sunday afternoon.

In practice, the results of this experiment suggest that traffic engineers and police officials should study traffic conditions very carefully before enforcing parking prohibitions of the tow-away type. The situations in which the single parked car has an important effect are definitely limited.

While only a single street width was studied in this experiment, the findings suggest that interesting results may be found from studies of entering volumes on streets of different widths. The Committee on Highway Capacity presented the relationship of capacity to street width as a smooth curve. The addition of only a few feet of width to the approach of Sepulveda Boulevard studied here, however, might permit use of a full new lane with a resultant large increase in entering traffic volumes. The true relationship of capacity to width may be a type of step function with the sharp capacity increases noted for certain increases of width which permit full utilization of additional lanes. No attempt has been made in this study to evaluate quantitatively the effect of width on capacity. The results suggest, however, that study of this relationship would be desirable.

The effect of parking may also be different on streets of different widths. Certainly this will be the case where the parked car reduced the number of usable lanes. Even where the number of lanes is not reduced, however, street width may be an important factor. Studies similar to this but using wider or narrower streets would be valuable in contributing to the understanding of the effect parking on intersection capacity.

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