HIGHWAY RESEARCH RECORD

Number 267

Parking

2 Reports

Subject Area

53 Traffic Control and Operations
55 Traffic Measurements

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Foreword

The two papers that comprise this RECORD should be of particular interest to highway officials concerned with better ways to appraise the extent and nature of parking problems. Both papers report results of experimental techniques to predict or measure parking influences. When study conditions similar to these are experienced, the application of these findings can bring about substantial savings in time and money.

The paper by Webster describes an attempt to fill a gap in the Highway Capacity Manual—1965 where it is conceded that insufficient data are available to attempt to develop correction factors for such midblock influences as curb parking. The author determined this frictional influence on the flow of traffic using digital simulation as the study method. Conclusions include the finding that delays caused by curb parking maneuvers are not so dependent on turnover rate as on volume of traffic.

The second paper, by Syrakis and Platt, describes a study technique for collecting parking use and duration information. The authors employed color aerial photography in three Ohio cities and report savings of 72 percent in cost and 85 percent in time with this technique compared with the more conventional technique using observer-recorders on the ground. The aerial technique may have more limited application in larger cities with taller buildings and covered or multistoried garages.

Contents

Traffic Delay on Urban Arterial Streets as a Result of Curb Parking Maneuvers

LEE A. WEBSTER, Assistant Professor of Civil Engineering, University of Massachusetts

Urban arterial streets are designed to provide for through traffic movement and some land access, but they are often called upon to store vehicles by providing curb parking spaces. This study was initiated to determine the frictional effect on through movement caused by vehicles maneuvering into and out of these curb spaces. The digital computer simulation method was used following an extensive literature study and limited data collection.

The computer model simulated a two-lane, two-way, 660-ft long urban arterial street block containing 20 parallel curb parking spaces. The model was programmed in FORTRAN for the IBM 7094 computer using a modified physical representation method of simulation with periodic scanning. The experimental design tested three levels of service and seven parking turnover rates. The results of statistical tests on the data indicated that level of service was more influential in determining the amount of delay to through vehicles than parking turnover rate.

•AS AN IMPORTANT link in the highway transportation network, the urban arterial street is designed to provide for through traffic movement and also land access. Although not the largest segment of urban street mileage, these streets handle large volumes of through movement and often provide for vehicle storage in the form of curb parking spaces.

During periods of low to moderate traffic volumes, the travel speed on urban arterial streets is a function of speed limits and midblock and intersectional frictions. The standard practice for analyzing the capacity of these streets involves a study of the traffic-handling ability of the individual intersection approaches (13). Although it is somewhat unrealistic to analyze an arterial street solely as a series of isolated intersections, the Highway Capacity Manual—1965 concedes that "insufficient data are available to attempt to develop correction factors" for such midblock influences as curb parking (8).

Curb parking's most important role is in cities of 250,000 population and smaller, where it accounts for from 40 to 85 percent of all the parking spaces in the urban area (1, 13), and where it meets approximately 50 percent of the parking demand (2). Of the two types of curb parking, angle and parallel, the latter is the most desirable in terms of reducing accident potential (4) and using less of the pavement and right-of-way width. Where traffic volumes allow, curb parking provides useful and convenient access to adjacent land uses. Objections to curb parking include the fact that the parking spaces use street width that could otherwise be used for traffic movement, and that curb parking also contributes some degree of frictional disturbance to traffic movement.

Paper sponsored by Committee on Characteristics of Traffic Flow and presented at the 48th Annual Meeting.

STUDY OBJECTIVE AND APPROACH

The objective of this study was to determine the frictional effect of curb parking maneuvers on the flow of traffic through an urban arterial street block. Because of its efficiency and the ability to control variables, digital simulation was selected as the study method.

The investigation was organized into several work phases. First, a study was made of the literature, followed by an evaluation of current knowledge on those subjects relevant to the study objective. Several limited field data collection efforts were then made in the Champaign-Urbana, Illinois, area to obtain estimates of variables not available in the literature.

On the basis of this information, a computer model was formulated, coded, and evaluated. The model was then employed in an experimental design to obtain information relative to the study objective.

The literature survey revealed that, with the increased use and availability of high-speed digital computers, simulation has become a tool of both engineers and systems analysts (17). Simulation enables the investigator to attack more complicated processes than the mathematical analysis method and yet it does not involve an actual change in the real traffic situation required by the trial-and-error method of problem solving (7).

It was decided to investigate curb parking and its relationship to through traffic movement as a simulation study for several reasons. The simulation approach was considered relatively inexpensive in that it did not require extensive collection of field data. Furthermore, simulation afforded better control of the various conditions to be tested. Had a field study been conducted, it would have been difficult to locate streets with the desired velocity coupled with the desired turnover rates, and the experimental design would have been more complicated.

SIMULATION MODEL DEVELOPED

The physical representation method was selected for simulating the midblock curb parking situation on urban arterial streets because of its close approximation of the actual physical relationship and because it is less complicated to program. Relating the computer locations of such a model to the corresponding physical segment of an arterial street made it possible to visualize the behavior of the moving and parking vehicles as an aid in determining the rules of behavior. This close physical relationship also made it possible to view the output of the simulation and readily see how its operation corresponded with the actual operation.

A modification was made to overcome one of the disadvantages of this method of simulation—that of being unable to keep track of individual vehicles. Instead of using binary ones and zeros to indicate the presence or absence of vehicles, the vehicles were numbered sequentially as they entered the system. A separate two-dimensional matrix was retained that contained, for each vehicle, a number of its characteristics.

A simulation model for this study represented one block of an urban arterial street (16). The block was assumed to be 660 ft long with no traffic control measures for through traffic at the ends of the block. Twenty 22-ft parallel curb parking spaces were available in the block, leaving 110 ft of "no parking" zone at the intersections. Due to symmetry and the assumption that cars could not cross the centerline, only half of the street width, i.e., one through traffic lane (12 ft wide) and one lane of parking (8 ft wide) were included in the model.

Translated into the physcial representation method, one computer storage location represented each 11 ft (longitudinally) of the traffic lane, or 60 locations for the block (6). To account for vehicle lengths (around 18 ft) a minimum of one unoccupied location was maintained between successive vehicles. There was also a series of locations that identified the 20 curb parking spaces and the "no parking" zones.

The model was programmed in FORTRAN II (9, 12), a widely used engineering problem-oriented language, for use on the University of Illinois Digital Computer Laboratory IBM 7094 computer (14). Extensive use was made of subroutines in constructing the model.

Vehicles in the model move through the street block at a constant velocity unless delayed by a vehicle parking or deparking. When a vehicle is entering a parking stall, it is first stopped in the street location adjacent to the stall and held there for the length of time equal to the parking ingress maneuver time. This naturally blocks the vehicles following and causes them to be delayed. These delayed vehicles advance to within the minimum stopped distance of the preceding vehicle and their speed is reduced to zero. Thus vehicles are either traveling at the constant input velocity or are stopped. The transition from moving to stopped occurs over a wide enough time and distance span that the vehicles are not required to accelerate or decelerate at rates exceeding reasonable rates for passenger vehicles.

A simplified explanation of how the model operates is shown in Figure 1. The first step is inputting the parameters necessary for operation. The system then is initialized to set the internal arrays equal to zero and preload the parking spaces. Next the probabilities P_A and P_B for vehicle generation by modified binomial distribution (11) and the probability of parking arrival are calculated.

The actual operation of the system begins at this point and involves investigating each street and parking location at each interval of time, performing the necessary movement of vehicles at that instant, and then updating the time to the next second. The search of street locations begins at the farthest advanced point for street vehicles and progresses backward to the first location where vehicles enter the block.

As shown in Figure 1, each street location is first checked to see if a vehicle is present. If not, the adjacent parking stall (if one exists) is examined to see if a vehicle

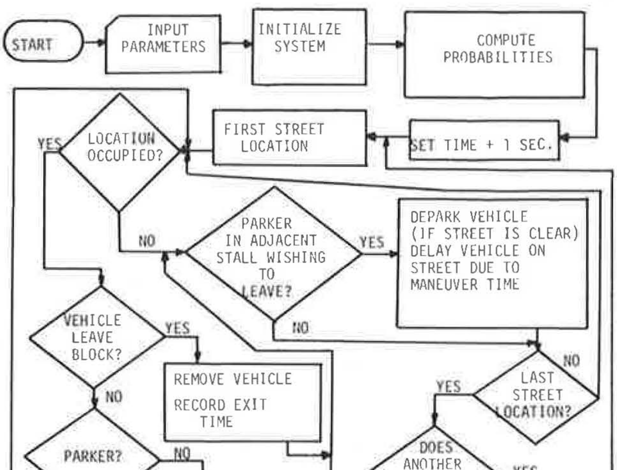

Figure 1. General flow chart of model.

wishes to depark. If a vehicle wishes to depark and there is sufficient clear distance on the street for it to do so, it is placed on the street location and held there for the next 5 seconds (equivalent to the egress maneuver time determined by limited field studies in Champaign, Illinois). If the parker does not wish to depark at that time, the program moves to the next street location.

If the check shows the presence of a vehicle, the program determines whether the vehicle is a potential parker or not. A nonparker is advanced ahead a distance equivalent to the constant velocity for one second providing there is sufficient clear distance ahead. Otherwise the vehicle advances to within the minimum distance of the preceding vehicle. If the vehicle desires to park, a check is made to see if it is close enough to a vacant space to park. If it is, the vehicle advances to the street location opposite the parking stall. It will be held in that location for the length of time equal to the ingress maneuver time. Should the vehicle not be able to reach a space that instant, it would move ahead in the same manner as the nonparker described before.

The investigation of each street location and the subsequent processing of the vehicles continues until the final space is reached. At this point it is necessary to determine whether another vehicle arrives at the present instant, using the modified binomial distribution (11). If a vehicle arrives, the decision is made as to whether it is a potential parker and if so, what the parking duration and ingress maneuver times are for the vehicle. Parking durations were based on the negative exponential distribution (3), and the ingress maneuver times were based on data from a California study that indicated the ingress time averaged about 32 seconds (10). Finally, if the required number of vehicles (for the sample design) have not passed through the block, the time is incremented one second and the check of individual street spaces begins again.

When the simulation is complete, the desired output statistics are calculated. Two measures of effectiveness used were the average delay to through vehicles and percentage of through vehicles delayed.

The computer time to real time ratio of the model ranged from 1:22 to 1:28, depending on the input variables.

EXPERIMENTAL DESIGN

Simulation is basically a sampling technique and is sometimes referred to as "simulated sampling." Despite the speed of simulation on a digital computer, to study the whole range of each variable would require several thousand simulation runs. A statistical design is therefore necessary to handle a manageable finite number of treatment combinations (5).

The problem of delay caused by curb parking maneuvers is essentially dependent on two main factors, namely, the through traffic on the street and the extent of curb parking along the street. These two main factors were the basis of the experimental design.

The concept of level of service was chosen as the indicator of through traffic on the street, and three levels of service were selected for the design. The parking turnover rate, as reflected by the amount and type of parking regulation, was chosen as the indicator of the extent of parking on the street. Seven different rates for which reliable data were available were selected for use in the design.

The experimental design consisted of a two-factor block. Under each of the 21 conditions, 50 vehicles were sampled following an initial period of 20 minutes (real time) to allow the system to attain a stable state at the start of the simulation. (The length of this initial period was determined after several test runs.) The average delay per through vehicle and the percent of through vehicles delayed was determined for this 50-vehicle sample.

For each level of service, the traffic imposed on the system was the same for all seven parking turnover rates. This eliminated the possibility that any difference in delay or percent delayed occurring within a level of service was due to a different input distribution of traffic.

Table 1 gives the input parameters for the three levels of service tested. Table 2 contains descriptive information on the seven parking turnover rates tested.

TABLE 1

INPUT PARAMETERS FOR LEVELS OF SERVICE TESTED

Item	Level of Service		
	A	C	E
Speed (mph)	30.0	22.4	15.0
Service volume/capacity ratio	0.6	0.8	1.0
Volume in one direction (vph)	720	960	1,200
Minimum following distance (ft) (based on one car length/10 mph)	55	44	33
Minimum stopping distance [based on average deceleration of 8 ft/sec (1, p. 27)]	121	66	22

TABLE 2

PARKING TURNOVER RATES AS TESTED

Rate No.	Type of Regulation	Time Limit	Parking Turnover Rate (veh/space/hr) Used	Range of Turnovers in Literature	Average Parking Duration (min) Corresponding to Turnover Rate Used at 90 Percent Occupancy
I	Metered	15 min	5.59	1.29-6.49	10
II	Posted	30 min	2.19	0.36-4.50	25
III	Metered	36 min	1.48	1.17-1.80	37
IV	Metered	1 hr	1.32	0.97-1.72	41
V	Metered	2 hr	1.29	0.62-1.58	42
VI	Posted	1 hr	0.69	0.24-1.13	78
VII	Unrestricted	—	0.30	0.20-0.50	180

TABLE 3

AVERAGE DELAY DATA USED TO TEST NULL HYPOTHESIS

Parking Turnover Rates	Average Delay to Through Vehicles (sec)		
	Level of Service A	Level of Service C	Level of Service E
I	1.04	1.88	1.50
II	1.10	3.74	4.36
III	0	0.08	4.28
IV	0	0.08	4.38
V	0	0	4.06
VI	0	0	0.94
VII	0	0	0

TABLE 4

PERCENT DELAYED DATA USED TO TEST NULL HYPOTHESIS

Parking Turnover Rates	Percent of Through Vehicles Delayed		
	Level of Service A	Level of Service C	Level of Service E
I	12	14	30
II	12	34	48
III	0	2	48
IV	0	2	46
V	0	0	36
VI	0	0	18
VII	0	0	0

The resulting delays to individual vehicles from the 21 simulation runs were widely dispersed, with many cases of no delay. The data were far from normally distributed and the average delay figures contained large standard deviations as an indication of nonnormality. The percent delayed values were also not normally distributed. Nonparametric statistical procedures were therefore employed to study the results of the experimental design.

To test for significant differences across levels of service (which were in effect independent samples), the Kruskal-Wallis analysis of variance test was used (15). To test across parking turnover rates (which were related samples), the Friedman analysis of variance test was used (15). All the statistical tests were done at the 0.05 level of significance.

The value of average delay for each of the 21 conditions tested is given in Table 3. The null hypothesis of no difference among the three levels of service tested was rejected. The null hypothesis of no difference among the seven parking turnover rates was accepted.

The value of percentage delayed for each of the 21 conditions tested is given in Table 4. The null hypothesis of no difference among the three levels of service tested was rejected in this case also. The null hypothesis of no difference among the seven parking turnover rates was accepted.

RESULTS AND CONCLUSIONS

These results led to the following conclusions, based on the statistical tests:

1. There was a statistically different average delay to through vehicles among the three levels of service tested.

2. There was a statistically different percent of through vehicles delayed among the three levels of service tested.

3. There was not sufficient evidence to conclude that there was a difference in average delay to through vehicles among the seven parking turnover rates tested.

4. There was not sufficient evidence to conclude that there was a difference in percent of through vehicles delayed among the seven parking turnover rates tested.

In other words, the results showed that the level of service was a significant factor in determining the average delay to through vehicles and percent of through vehicles delayed. The parking turnover rate, however, was not found to have created a significant difference in these measures of effectiveness.

Figures 2 and 3 are plots of the two measures of effectiveness based on the experimental design figures (Tables 3 and 4), but with a smoothed curve rather than connecting individual data points. Results 1 and 2 above are shown in these plots by the separation of the curves for the three levels of service. Level of service E

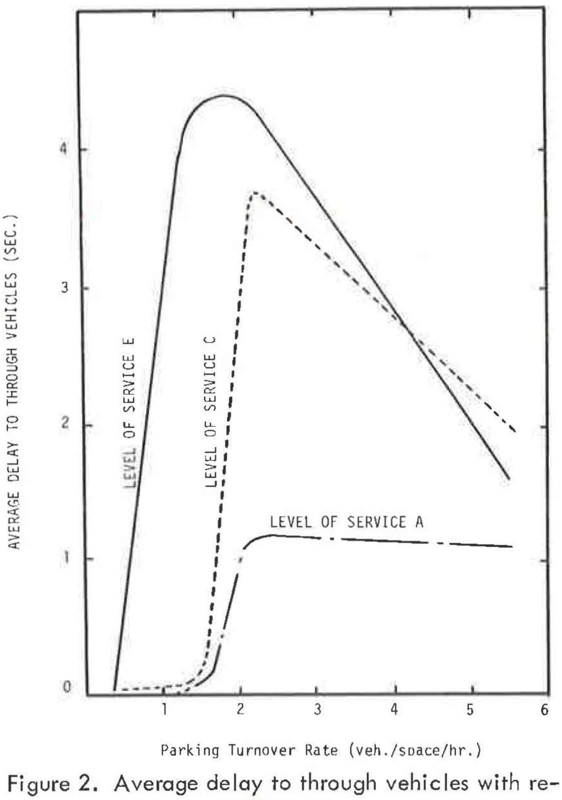

Figure 2. Average delay to through vehicles with respect to parking turnover rate.

caused the highest average delays and greatest percentage of delayed vehicles and level of service A the lowest. Also evident is the fact that the higher levels of service required greater parking turnover rates for delays to begin to occur. Level of service A reached a limit in delay, at which point increasing turnover rates did not increase delay.

Results 3 and 4 are indicated by the dispersal of values across the parking turnover rates. Had the curves all continued upward there might have been a significant difference between the measures of effectiveness for the parking turnover rates. The fact that these curves do peak and decrease with increased turnover rates is partly explained by the additional data presented in Table 5.

For the highest turnover rate (5.59 veh/space/hour), Table 5 shows a peak average delay per through vehicle occurring at 1400 vph. At this turnover a higher volume of traffic (than the experimental design value for level of service E of 1200 vph) was required to cause the maximum amount of delay. An increasing percentage of vehicles delayed also occurred with these increased volumes (Table 5).

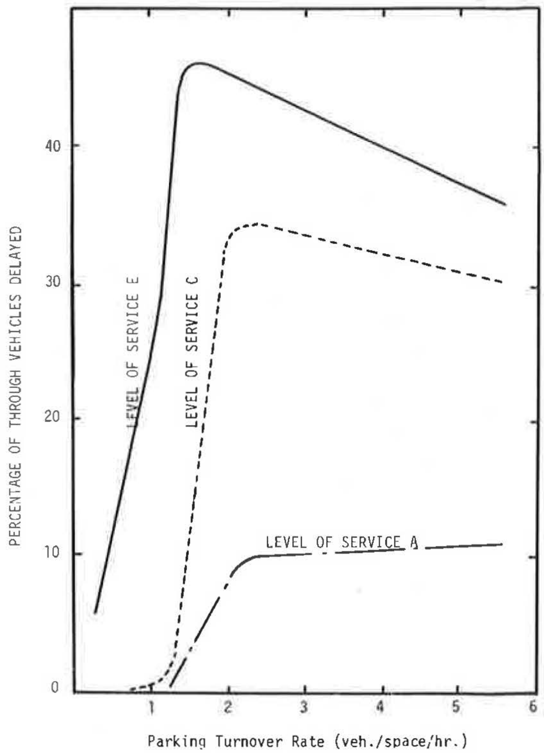

Figure 3. Percentage through vehicles delayed with respect to parking turnover rate.

The results of this study showed that curb parking maneuvers do affect the movement of through traffic on urban arterial streets by causing additional delay to the through vehicles. The amount of this delay depended on the level of service of the street, because with higher volumes moving at slower speeds, the average delay caused by curb parking maneuvers was increased. The amount of turnover in curb space usage did not appear to have any significant effect on delay.

In summary, this theoretical study has provided an initial understanding of the problem of curb parking and urban arterial traffic flow. It has indicated that the delays caused by curb parking maneuvers are not so much dependent on the turnover rate as on the volume of traffic, i.e., level of service. This additional quantitative

TABLE 5

DATA ON ADDITIONAL SIMULATION RUNS[a]

Statistic	Volume in Peak Direction (vph)					
	1300	1400	1500	1600	1700	1800
Directional distribution (%)[b]	65-35	70-30	75-25	80-20	85-15	90-10
Average delay/through vehicle (sec)	1.56	7.24	4.02	2.00	1.84	1.90
Percent through vehicles delayed	32	30	34	36	36	38

[a]Runs made with turnover = 5.59 veh/space/hr. Higher traffic volumes under this maximum turnover rate were run in an attempt to load the system.
[b]Directional distribution that would produce the given volume in the peak direction.

information, added to past and needed future research, will eventually lead to the development of improved operational and design procedures that will enable urban arterial streets to fulfill their role in meeting the demands of urban traffic.

SUGGESTIONS FOR FURTHER STUDY

Based on a study of available literature and the results of the present investigation, the following suggestions are made for future research:

1. To provide a verification for this simulation model as well as to provide much-needed additional information and understanding for future research and simulation, an extensive data collection project would be worthwhile. If carried out on a national basis, it could provide information on actual delays and capacity of urban streets with varying durations and turnovers in curb parking.
2. Further simulations (because of the advantage of better experimental control) could then be conducted, based on the data from field surveys and possibly using the memorandum method of simulation for increased computational efficiency. A workable and verified simulation package (including an economic analysis) would be of value to city traffic engineers to help them evaluate their curb parking problems.

ACKNOWLEDGMENTS

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Discussion

JACK C. MARCELLIS, Assistant Traffic Engineer, City of Chattanooga—All traffic engineers would agree that on-street parking does effectively reduce the traffic-carrying capacity of our streets and highways. For example, the 1965 edition of the Highway Capacity Manual indicates an approximate 34 percent reduction in street capacity with the addition of parking on a street having an approach width of 20 ft (8).

Most of us again would concur that normally the parked vehicle's influence is greater than the 6 or 8 ft of actual physical space that the vehicle occupies. The cautious reactions of passing drivers, who fear sudden maneuvers by parked vehicles or doors opening into their paths, result in this larger effective loss. For wide approach widths with low loading, the effective width loss may be as high as 20 ft, while at the other extreme, where the approach widths are narrow and the loading high, the effective width loss may be little more than the width of the parked vehicle. The average effective width loss due to curb parking is approximately 12 to 14 ft.

The Highway Capacity Manual also indicates that approach capacities for two-way streets with parking are approximately 25 percent higher in all areas than in the central business district. Some of the reasons listed for lower capacities on central business district two-way streets with parking compared with other areas are (a) pedestrians causing interference with vehicular traffic; (b) a more circulatory-type traffic flow, involving more turns; and (c) higher curb parking turnover.

The author's conclusion that the parking turnover rate was not a significant factor in determining both the average delay to through vehicles and percent of through vehicles delayed, and his indication from Figures 2 and 3 that both the average delay to through vehicles and percent of through vehicles delayed increased with an increase in the parking turnover rate to approximately a rate of two vehicles per space per hour and then either remained the same or decreased with an increasing parking turnover rate, do not seem consistent with the Highway Capacity Manual. Logically, one would expect that both the average delay to through vehicles and the percentage of the through vehicles delayed would increase with an increase in the parking turnover rate throughout the entire range observed, especially with the severe internal restriction imposed on the delayed vehicles of not being able to cross the centerline and pass the maneuvering vehicle. If these findings did occur, then undoubtly the parking turnover rate would be a significant factor in determining both the average delay to through vehicles and percentage of through vehicles delayed.

Let us investigate more closely the results for level of service E (1200 vph) and the parking turnover rate of 5.59 vehicles per space per hour (average parking duration of 10 minutes). Under these conditions the 50 vehicles studied would pass a given point in 2.5 minutes with an average headway of 3.0 seconds, while 25 percent of the 20 parked vehicles (5 vehicles) in the block would turn over. If on the average 5 vehicles would leave their parking stalls at one time and then another 5 vehicles would enter these same parking stalls at the same time, 11 vehicles (22 percent of the 50 through vehicles) would be delayed a total of 157 vehicle-seconds (3.14 seconds of delay per through vehicle), if the time lost due to deceleration and acceleration is omitted. At the other extreme, each of the 5 egresses and ingresses could be performed at different times. If this did occur, 100 percent of the through vehicles would be delayed an average of 75.00 seconds. Of course, a more plausible occurrence would fall somewhere between these two extremes—that is, between 22 and 100 percent of through vehicles would be delayed with an average delay between 3.14 and 75.00 seconds per through vehicle. The paper indicates values of 30 percent (at the lower end of the range) and 1.50 seconds, respectively. The question, then, is: Why are the report values low? Were the vehicles that were stacked up and delayed trying to get into the block counted along with their length of delay? Would additional or longer simulations averaged together change the results?

The author is to be complimented on his substantial contribution in the art of simulation and in the area of traffic delay on urban arterial streets caused by curb parking maneuvers. Both are comparatively unexplored research areas. The discussant agrees with the author that an extensive data-collection project along with further simulations would be worthwhile in an attempt to verify the results.

JAMES H. KELL and BARRY BENIOFF, Peat, Marwick, Livingston and Co.—The author has approached an important problem using relevant methodology. Parking phenomena are difficult to study empirically because of the need for controlled conditions, the difficulty in observing and measuring the data, the large variance of the sampled data, and the excessive length of time necessary to make the study. In a recent study by Peat, Marwick, Livingston and Co. (18) to determine the effect of parallel parking stall design on ingress time, all of these difficulties were encountered.

The assumptions of the simulated system must be kept in mind when considering the results. The 40-ft street width is typical of many arterials throughout the country, especially those passing through outlying business districts in older parts of cities. It is, however, a common practice on these streets, where traffic permits, for through vehicles to cross the centerline to pass parking and deparking vehicles. Also, many arterials are wider than 40 ft and have more than one lane in each direction.

Certain constants used in the model differ somewhat from those found by Peat, Marwick, Livingston and Co. in two recent studies. The average length of passenger cars was found to be 16.3 ft (19). The mean stopped spacing between vehicles was found to be 6.8 ft in a traffic signal queue (19) and 8.8 ft for a momentary freeway stoppage (20).

The delay to through vehicles by deparking vehicles should depend on the street width. The delay caused by parking vehicles should depend on street width and also on volume. Therefore, the values of 5 and 32 seconds used by the author for parking and deparking, respectively, should have come from studies dealing with similar street widths and volumes.

The modified physical representation used for the model seems to be similar to that used by Bleyl (21) in his intersection simulation model. The representation has the advantages of simplicity and the ability to be visualized, as the author points out. Car-following procedures, however, become limited, and a certain amount of realism is lost. A basic problem can result: What do the measures of effectiveness mean? Is the calculated delay total delay or is it only stopped delay? The delay for a following vehicle that lowers its speed as it closes on another vehicle without having to stop can be missed with certain techniques of physical representation.

The low value of delay and percent delayed at levels of service C and E for the highest turnover rate does not seem reasonable. This could be due to the procedures used for handling backlogging vehicles. The author points out that the simulated volume exceeded capacity in several instances, and some vehicles could not enter the system. These vehicles, however, must be considered as a part of the system and their delay must be accounted for. This can be accomplished by using a backlog reservoir and accumulating the vehicle-seconds in the reservoir, as was done by Bleyl. If this delay was not accounted for by the author, the delay calculated with his model would be too low, especially for the low levels of service and high turnover rates.

The zero delay found for nine of the 21 test conditions is probably due to the small sample size. Consider, for example, the condition with 720 vph and a turnover rate of 0.30 veh/space-hour. The 50-vehicle sample would be obtained in 4.2 minutes of real time. Since, on the average, only 6 vehicles an hour (0.30 veh/space-hour × 20 spaces) would want to enter and leave a parking space on the simulated block, it is easily possible to have no vehicles entering or leaving during the 4.2 minutes studied.

A more extensive exercise of this, or a modified form of the model, is necessary. The sample size of 50 chosen for each condition seems far too small, considering the admitted wide dispersion of the simulated data. If possible, the variance of delay and percent delayed should be calculated with the model and the sample size necessary to predict the mean values with a given accuracy determined.

The levels of the two factors studied should be extended. Only three volume levels and seven turnover rates were considered. Three of the turnover rates were clustered within a range of 0.19 veh/space-hour. Also, two other successive rates had the large range of 3.40 veh/space-hour between them.

It would be desirable to study the sensitivity of the model. Of interest in this regard is the sensitivity to input velocity, following distance, vehicle length, vehicle spacing, ingress time, egress time, and occupancy. Occupancy is of particular interest since, by increasing the occupancy of a given turnover, the average duration of parking will increase. Perhaps, for a given turnover, occupancy and duration have no effect on delay, but this cannot be determined a priori. The need for using a statistical distribution for parking duration, rather than a fixed value, can also be determined from a sensitivity analysis.

The internal validity of the model, i.e., whether it is doing what it is supposed to be doing, should be checked. One test, discussed by the author, is an examination of the flow rates into and out of the system boundaries. Parking behavior should also be checked by measuring simulated turnover, duration, and occupancy. In the long run, occupancy should equal the product of turnover and distribution.

The use of the same traffic for each of the 21 conditions was very important in obtaining comparable results for the different conditions.

Using nonparametric statistical tests, the author concludes that there was a significant effect of service volume on delay and percent delayed, but not sufficient evidence to conclude there was an effect due to turnover rate. Intuition would indicate that there is a turnover effect. Even the author's own plots of delay and percent delayed indicate an effect. This disparity is due either to the small sample size or to the inappropriateness of the statistical tests themselves. Considering the basic objectives of the simulation approach, however, pursuit of the cause becomes irrelevant.

A simulation model is a costly, time-consuming tool to construct. Like a carefully designed physical model, it can be a precise instrument for studying the surrounding environment under controlled conditions. It is a waste to use such a model just to develop data for testing hypotheses regarding statistical differences. The models should be constructed with sufficient validity and operated for a long enough time to develop absolute measures of effectiveness that can be used in traffic operations planning, geometric design, and research.

This study has begun to show the relationship between delay and parking turnover. It should lead to more extensive studies of this relationship.

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R. F. DAWSON, Civil Engineering Department, University of Connecticut—Urban arterial streets are one of the most important links in the highway network. As more and more urban expressways are put into service, the necessity for good urban arterials becomes apparent. Large volumes of urban-oriented traffic are collected on the expressway links in surrounding areas and funnelled to the arterial bottlenecks that are interfaced with the expressway network.

One common cause of congestion and delay on urban arterials is the interruption to the continuity of flow brought about by curb parking and deparking maneuvers. Although there has been much research to determine the effect of parking operations on street capacity, the available data and results are not adequate to establish an acceptable algorithm for describing curb parking influence.

The arterial traffic-parking situation is a complex multivariate system. It is difficult, therefore, to measure and/or control the numerous system variables for research purposes. To overcome these difficulties the author devised a simulation research study.

Although the simulation approach is very realistic, the author's specific model is not a good approximation of a typical arterial street situation. The author attempted to relate delay characteristics (percent of through vehicles delayed and average delay per through vehicle) to arterial street volume and to parking turnover rates. Although he was able to conclude that arterial volumes do have a statistically significant effect on through vehicle delay characteristics, he was not able to establish a statistically significant relationship between delay characteristics and parking turnover rates. It is difficult to accept this latter conclusion.

The results obtained from the simulation samples were affected by the basic structure of the research model, including several aspects that are not realistic. Aspects that are of most concern are the following:

1. Arterial street vehicle generation—Although the typical urban arterial is signalized at major intersections, the author disregarded signal control and employed Lewis's modified binomial distribution as a headway generator. It is difficult to rationalize the specific effect of random vs pulsed traffic flow, but it is likely that the longer time separations between randomly generated arterial vehicles provide more opportunities for parking and deparking maneuvers than would sequences of long gaps alternated with series of short, uniformly distributed gaps.

2. Actual parking turnover rates—The researcher indicated that seven distinct parking turnover rates were studied, and statistical analyses were based on these specific rates. Unfortunately the actual turnover rates that resulted were not considered. It is likely, however, that the parking spaces were blocked at higher arterial volumes so that the desired turnover rates were not realized. This observation is supported by the reported delay data; the average delay per through vehicle reached a peak and then fell off as arterial volume continued to increase. This would occur, of course, as parking maneuvers were blocked by through traffic.

3. Parking duration distribution—The author used a negative exponential function to generate parking durations. However, the probability density for such a model is maximum at minimum parking durations. Such a relationship is not natural. An Erland function, a gamma function, or a Pearson Type III distribution would be more realistic.

4. Gap acceptance for deparking—The specific logic employed by deparking vehicles to determine if the arterial street is clear is not described. A gap acceptance approach would be appropriate for this analysis.

5. Parking space selection logic—The simulation model is apparently designed so that a vehicle that is tagged to park can select only vacant spaces. As in the real world, it would be more appropriate if tagged vehicles were able to detect an impend-

ing vacancy. Of course this would tend to cause longer delays, but the reported simulation delays are too short.

In summary, the author's arterial street parking simulation study is one of the first attempts at a realistic systems approach to the arterial street capacity problem. As such his work is a significant contribution, but the actual results that were obtained from the research are of questionable value. Several basic elements of the simulation model are inadequate approximations of real world phenomena and very likely contributed to the unrealistic delay characteristics.

LEE A. WEBSTER, Closure—The discussions presented are both interesting and constructive. The wide range of items discussed points out the complexity of formulating a model of the curb parking situation.

The model developed was designed to be as simple as possible without being trivial and yet not so complex as to be cumbersome. It was also developed within the limits of data available in the literature.

The problem of sample size is a difficult one, largely because the delays occurring in the model were not normally distributed. The frequency distribution of delays contained large numbers of vehicles with zero delay plus those vehicles with varying amounts of delay. Large standard deviations resulted for the mean values of average delay and percentage delayed. It is difficult to determine what an adequate sample size would be under these circumstances.

Some interesting results in this regard were obtained for three of the parking conditions by operating the model so that it would sample over a 60-minute time interval rather than sample a specific number of vehicles. In two of the three conditions sampled in this manner, the average delay for the large sample size was greater than the average delay for a 50-vehicle sample, but in the remaining case the average delay for the large sample was less than for the 50-vehicle sample:

Level of Service	Turnover	Sample Size	Average Delay	50-Veh Sample
A	5.59 veh/sp/hr	561 veh	2.46 sec	1.04 sec
A	1.48 veh/sp/hr	572 veh	1.09 sec	zero
C	5.59 veh/sp/hr	782 veh	1.25 sec	1.88 sec

These results indicate the difficulty in sampling these types of data. The results are often dependent on having the sample collected during a time period that contains a representative number of parking and deparking maneuvers. Future model runs should therefore be concerned with larger sample sizes.

Messrs. Kell and Benioff questioned the seven turnover rates tested. These rates, and other information such as the modified binominal vehicle generation distribution, the negative exponential parking duration distribution, the average vehicle lengths, and ingress parking maneuver time data, were obtained from previously published studies. The turnover rates were selected because they represented varying degress of parking regulation (metered and posted) and various time limits (15 minutes and up). Additional simulation runs (not reported in the paper) were conducted using other turnover rates (integer values) and the resulting average delay and percentage delayed data followed the general curve developed from the seven turnover rates in the experimental design.

Messrs. Marcellis and Kell and Benioff discussed the backlogging of vehicles, or those times when the simulated block was so full that a vehicle could not enter. The delay to the entering vehicle caused by this congestion was not included in the average delay figures computed for the 21 test conditions. Inclusion, however, would not have changed the results substantially because backlogging occurred only under 3 of the 21 tested conditions (2 of them in level of service E). More importantly, backlogging occurred for only a total of 6 seconds of the more than 5,120 seconds sampled.

Another problem is the unrealistic drop-off in the curves that occurred for the highest turnover rate. Several things may have caused this. First, the modified binomial distribution used for generating vehicles into the system is not as accurate at high volumes of traffic. This, along with the small amount of backlogging that occurred for level of service E, may have resulted in an unrealistic input of vehicles. Also, as Mr. Dawson indicated, under high-volume conditions the gaps may have been too small to allow vehicles to depark and thus the turnover rate was not as high as it should have been. Finally, the small 50-vehicle sample may not have been taken at a time when a proportional number of parking and deparking maneuvers occurred.

Future revisions of this model or an entirely different model could incorporate several elements not included at present. Consideration could be given to allowing vehicles to cross over into the opposing lane to avoid being delayed behind a parker, as suggested by the discussants. This would require information on the gap acceptances of drivers in these circumstances and would be of greatest concern under low-volume conditions. There could also be the logical extension to 4-lane, 2-way arterial streets.

The inclusion of traffic signals at the intersections, as mentioned by Mr. Dawson, would also be of value. It would then be necessary to contend with the additonal variable of the traffic signal characteristics (cycle length, split, and offset) as they affect the delays. Simulation runs with other levels of service, and ranges of volumes in each level of service, would provide further information on the problem.

If data could be obtained on parking ingress and egress maneuver time for different street widths and traffic volumes, as suggested by Messrs. Kell and Benioff, and on gap acceptances for vehicles leaving parking spaces, as suggested by Mr. Dawson, these elements could be incorporated in future models.

In summary, there appears to be general agreement that curb parking as it influences the traffic flow on urban arterial streets is an important problem. Simulation is accepted as a valid and realistic study approach. The challenge is to effectively model this complex system, as this could eventually lead to practical solutions for the traffic engineer.

Aerial Photographic Parking Study Techniques

THOMAS A. SYRAKIS and JOHN R. PLATT, Stark County Area Transportation Study, Canton, Ohio

The conventional method for collecting required data in a parking study is to hire personnel needed to obtain the information by field observation. In Stark County, Ohio, color aerial photography was used in place of field observation for collecting data on parking use and duration. A flight pattern was designed to photograph the cities of Canton, Massillon, and North Canton every 15 minutes between 10 a.m. and 6 p.m. on an average business day. The resulting color photography provided the necessary information to evaluate the on-street and off-street parking conditions for each of these cities' central traffic districts.

At the time of the aerial flight, data were simultaneously collected on the ground in an 8-block area in downtown Canton. Utilizing the control data, comparisons were developed between the two techniques for the purpose of checking the accuracy of the aerial photographic interpretation. Close correlations were found in comparisons of use, accumulation, turnover, and duration. Comparative analysis of study time, personnel requirements, and total cost indicated a 72 percent savings in cost and an 85 percent savings in time.

In the Stark County study, the aerial photographic technique for obtaining the parking information has proved to be a preferable method. It has furnished permanent records of both parking and traffic conditions and has been put to use in other planning and engineering studies.

•THE PURPOSE of this paper is to compare a method of collecting parking use and duration information using color aerial photography with the standard field method of collecting this information from vehicle license plates. The two methods are evaluated as to cost, time, manpower, output, and accuracy of data.

A parking study has as its main objective the compilation of detailed information that will allow an accurate evaluation of and solution to parking problems such as are found in the highly congested central business districts of our cities. To derive this information, the parking inventory should provide data concerning the supply, use, duration, parking habits, accumulation, turnover, fees, meter revenues, and legal restrictions of all existing on-street and off-street parking facilities.

The Stark County Area Transportation Study (SCATS) staff, in reviewing the techniques and practices used in existing parking studies, found three areas of concern that affected the output of a parking study. The first concern was time, since a considerable amount was needed to physically inventory the facilities; the second was manpower, since a large force was needed to collect the detailed information; the third was accuracy, since employing a large manpower force for a short period of time may cause inaccuracies, due to the shortage of qualified and conscientious temporary personnel.

An ideal parking study technique would use experienced personnel for a short period of time with a high degree of accuracy. However, because of shortages of man-

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power and/or equipment, sacrifices usually are made to complete the study within the allotted time period. With a study that utilizes color aerial photography as the base for collecting parking use and duration information, near-ideal conditions can be maintained.

Aerial photography has been used extensively in engineering surveys, land-use studies, and recently in determining vehicular speeds and delays (1). However, the use of aerial photography taken at repeated 15-minute intervals to obtain parking information probably represents a unique application.

PARKING SUPPLY

The collection of parking supply information for the cities of Canton, Massillon, and North Canton was accomplished by field inventory. Aerial photography was not used for obtaining this information because legal restrictions on the curb facilities had to be collected and information such as lot or garage type, number of attendants, peak parking accumulations, and type of operation was required for the off-street facilities. Aerial photography taken as part of the SCATS land-use study was used to a limited degree in checking physical location of the parking lots within the blocks; however, since this photography was not rectified, specific measurements were not made. From this inventory of parking facilities, base maps of the three Central Traffic Districts (CTDs) were made that provided the source documents for extracting the parking information.

If horizontal and vertical ground controls were established prior to the flight, mapping of the CTDs in these three cities could be accomplished with the use of the Aerial Photographic Computer. The CTD for Massillon was mapped by this method and checked against the map prepared by the staff using field information. Both maps were found to be identical. Using the aerial photography would eliminate the necessity of physically measuring the parking facilities.

TEST FLIGHTS

During the summer of 1966, SCATS, with the assistance of the Ohio Department of Highways Aerial Engineering Section, conducted a test flight for the parking study. During the flight, several different photographic scales and film types were tested on Canton's CTD for determining suitable film and scale. This photography also provided samples that were used to test the feasibility of conducting a parking survey with aerial photography.

Upon reviewing both black and white and color film, it was determined that color transparencies allowed easier and more reliable identification of the vehicles and thereby enhanced the task of extracting the data. In addition, the test flight demonstrated that it was feasible to fly a "loop" pattern over the three downtown areas every 15 minutes.

THE AERIAL SURVEY FLIGHT

The parking study program prescribed that the aerial survey flight be conducted by flying a "loop" pattern covering Massillon, Canton, and North Canton every 15 minutes from 10 a. m. to 6 p. m. on an average business day. A local aerial engineering consulting firm was hired to fly and photograph the areas. The contract stipulated the area to be covered, the time intervals to be maintained during the flight, the photographic scale, and the necessity of flying under near-perfect weather conditions.

The aerial flight was made on August 29, 1967, using a Cessna 310 all-weather equipped aircraft manned by the pilot and the photographer. The camera used was a Fairchild K-17 equipped with a 12-in. focal length lens having a shutter speed of 350 at f5.0. Three color filters (HF 3, 4, and 5) were used during the flight to compensate for film and atmosphere conditions.

Six rolls of Kodak Ektachrome Aero (color transparency) Film, type 8842, were exposed on a 9 by 9-in. format, which yielded 416 total exposures. This film type allowed a restoration of color contrast and an increase in color saturation that was about 100 percent greater than comparable materials.

The scale of the photography and the flight altitude above terrain are given in Table 1.

TABLE 1

Area	Photo Scale	Altitude	CTD Dimensions
Canton	1 in. = 450 ft	5400 ft	3000 × 5200 ft
Massillon	1 in. = 250 ft	3000 ft	1500 × 3500 ft
North Canton	1 in. = 250 ft	3000 ft	1000 × 2400 ft

Since the CTD of Canton was nearly twice as wide as the other cities' traffic districts, a larger scale was required in order to cover the total width in one transparency and in one flight pass. Exposures were taken in timed sequences over each city to yield a 60 percent forward overlap, so as to provide complete stereoscopic coverage. The flight began over Massillon at 10:00 a. m., proceeded east a distance of 9 miles to Canton, taking exposures at 10:05, and then north a distance of 5 miles to North Canton at 10:08 (7 minutes were required to fly from North Canton to Massillon, a distance of 15 miles, and begin the next pass). Four exposures were required for each pass over Massillon and North Canton, while Canton required five exposures in order to cover the entire traffic districts, as seen in Figure 1.

During the conduct of the aeial flight, an 8-block area centrally located in downtown Canton was established for control purposes. SCATS field personnel obtained the parking information using the license-plate technique for the 8-block area during the time that the flight was in progress so that an accuracy control check could be made against the aerial photo interpretation. Parking stubs indicating the in and out times were obtained for the same day from selected lots and all garages in Canton, Massillon, and North Canton. Through this ground control check, comparisons were made of parking use, accumulation, duration, and turnover, as described later in this report.

The resulting color aerial photography provided four equally spaced samples (every 15 minutes) of existing parking conditions in each CTD during each hour of the 8-hour study. Upon completion of the aerial flight, the consultant submitted to SCATS six rolls

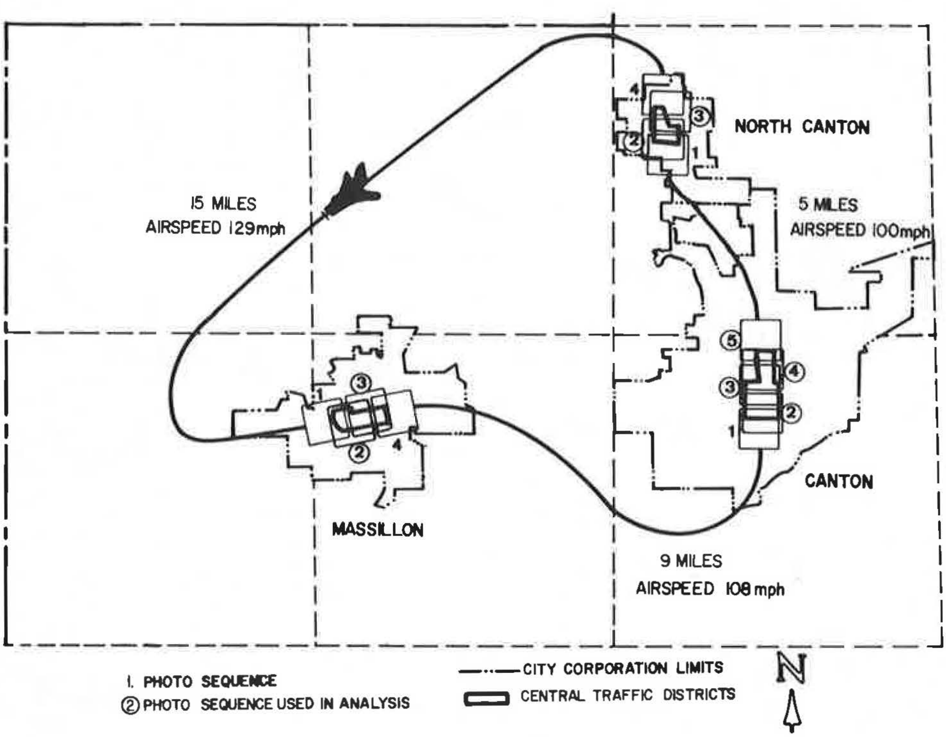


Figure 1. Photo sequences and flight pattern covering the Central Traffic Districts.

of developed film. A sample is shown in Figure 2. The photos were cut into 9 by 9-in. size and inserted into 11 by 14-in. transparent sleeves. The photos were then classified as to location, time, and photo sequence number for purposes of comparing different time periods at similar locations. After examining the ground coverage of each photo sequence, it was determined that sequence numbers 2 and 3 would be used for Massillon; numbers 2, 3, and 4 would be used for Canton; and numbers 2 and 3 would be used for North Canton, as shown in Figure 1.

ANALYSIS OF THE PHOTOS

The analysis of the photographs was accomplished by viewing the color transparencies on a light table using a stereoscopic instrument. An Old Delft Scanning Stereoscope was used for the SCATS project because this instrument allowed adjustment of x and y

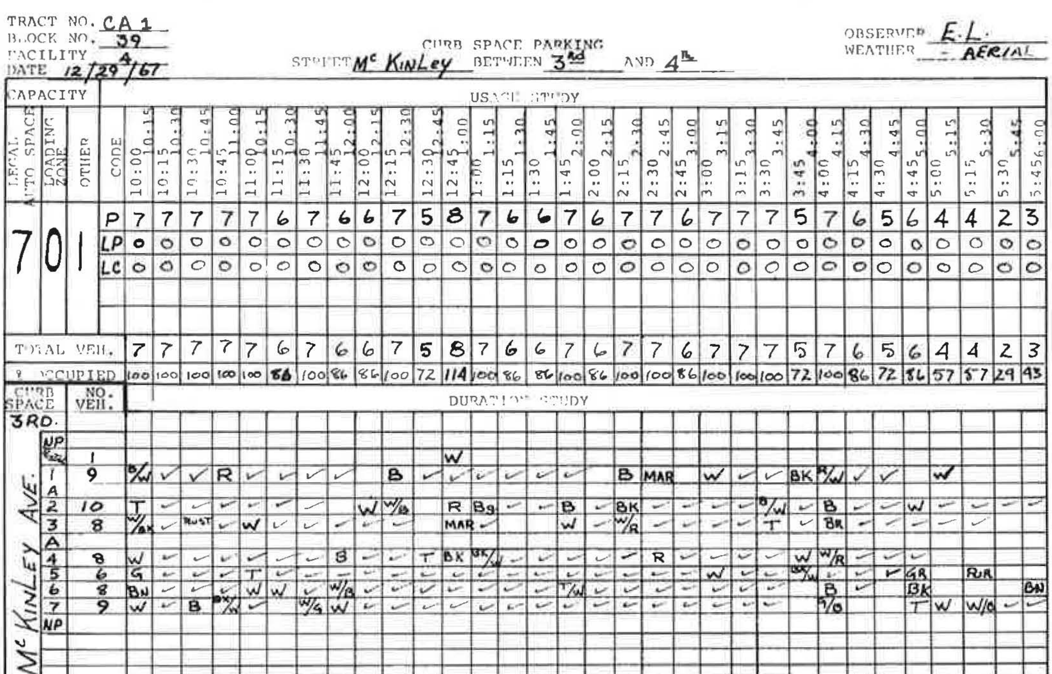
Figure 2. Sample of an aerial photograph taken over Canton.

parallax, thus compensating for any possible tilt difference occurring in the flight. In addition, this instrument had a magnification power of 4.5 times, which allowed a closer analysis of the vehicles and enhanced the color contrasts. By using the x and y scanning devices on the stereoscope, the photographs were viewed in a manner that simulated walking around the block.

Two color transparencies having the same photo sequence number but having a 15-minute difference in time were placed side by side on a light table with the earlier photo on the viewer's left. The viewer analyzed the photos using the colors of vehicles as identification to obtain on-street and off-street parking use and duration. The photo viewer using the stereoscope worked around the block face in the same manner as a person would in the field. The vehicles were identified by their characteristics of color, size, shape and storage position. This information was recorded on standard usage and duration forms by the photo recorder (2).

Vehicles of more than one color were coded using the color of the roof over the color of the rest of the car; for example, white on blue would be recorded as W/B in the space provided, as seen in Figure 3. During subsequent 15-minute intervals, if a vehicle observed previously was still occupying the same space, a check mark was made to show the continuation; if the parking space was vacant, the time column for that space was left blank; if a new vehicle was observed, then the color code was recorded in the time space. Whenever a vehicle had remained in the same position from one 15-minute period to the next, it projected a three-dimensional image using the stereoscope. Any vehicular changeover from one period to another projected a flat or hazy image using the stereoscope.

The viewer and recorder began with the 10:00 a. m. photo of a city and worked along the perimeter of the blocks, extracting the on-street parking data. After completing the 10:00 a. m. photo, the 10:15 a. m. photo was inserted on the viewer's right and a


TRACT NO. CA 1
BLOCK NO. 39
FACILITY 4
DATE 12/29/67

CURB SPACE PARKING
STREET Mc KinLey BETWEEN 3rd AND 4th

OBSERVER E.L.
WEATHER - AERIAL

USAGE STUDY

CAPACITY: Legal auto space 7; Loading zone 0; Other 1

CODE	10:00-10:15	10:15-10:30	10:30-10:45	10:45-11:00	11:00-11:15	11:15-11:30	11:30-11:45	11:45-12:00	12:00-12:15	12:15-12:30	12:30-12:45	12:45-1:00	1:00-1:15	1:15-1:30	1:30-1:45	1:45-2:00
P	7	7	7	7	7	6	7	6	6	7	5	8	7	6	6	7
LP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL VEH.	7	7	7	7	7	6	7	6	6	7	5	8	7	6	6	7
% OCCUPIED	100	100	100	100	100	86	100	86	86	100	72	114	100	86	86	100

CODE	2:00-2:15	2:15-2:30	2:30-2:45	2:45-3:00	3:00-3:15	3:15-3:30	3:30-3:45	3:45-4:00	4:00-4:15	4:15-4:30	4:30-4:45	4:45-5:00	5:00-5:15	5:15-5:30	5:30-5:45	5:45-6:00
P	6	7	7	6	7	7	7	5	7	6	5	6	4	4	2	3
LP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL VEH.	6	7	7	6	7	7	7	5	7	6	5	6	4	4	2	3
% OCCUPIED	86	100	100	86	100	100	100	72	100	86	72	86	57	57	29	43

DURATION STUDY

CURB SPACE	NO. VEH.
3RD.	
NP	
(illegible)	1
1	9
A	
2	10
3	8
A	
4	8
5	6
6	8
7	9
NP	
4TH.	
DOUBLE	
DOUBLE	
INFORM	
TOTAL	59

Mc KinLey Ave.

Figure 3. Sample sheet usage and duration study.

comparison of parking use was made with the 10:00 a. m. photo. All parking use, duration, and changes were observed and recorded in this manner, continuing through the photos to 6:00 p. m. and completion.

Off-street analysis proceeded in the same manner as on-street, beginning with the 10:00 a. m. photo and continuing with the comparisons of the photos to completion.

By comparing two photos taken over approximately the same area but separated in time, the photo viewer was able to scan a 6 by 6-in. area without distortion. This large viewing area reduced the setup time considerably, yet the advantage of projecting a stereoscopic image was still realized. The viewer began in the northeast corner of the photo and proceeded in an orderly manner from left to right across and down the photograph. This procedure enabled the viewer to systematically analyze the photo area and easily refer to specific locations whenever a question arose.

Coding of the information from the recording forms was accomplished in the same manner as with a conventional field inventory.

COMPARISONS OF PARKING STUDY METHODOLOGY

Comparisons were made between the aerial photographic method and the conventional field survey method to validate the original hypothesis of realizing savings in cost, time, and manpower by using the aerial method. The comparisons included vehicular data output, cost, time, manpower, and accuracy.

The first concern in evaluating the aerial method was to determine the correlation of aerial data output with that of the conventional method. An 8-block area centrally located in downtown Canton was selected to test this comparison because it offered a representative sample of the varying conditions found in a parking study. This area contained 134 curb parking spaces, of which 95 percent were metered. The posted time limits varied from 10 minutes to 2 hours, with the distribution given in Table 2.

Approximately 1186 space hours were available in the 8 blocks between 10 a. m. and 6 p. m. during the flight day. The practical number of space hours available was determined by applying an efficiency factor of 88.5 percent to the total space hours to compensate for the loss of time in each turnover of space. During the flight day 1051 space hours were used (1047.5 according to the ground method), or about 88.6 percent use of the available practical supply.

Through the aerial photo interpretation, 1482 vehicles were recorded as parking within the 8-block area during the flight day. This compared closely with the ground recording of 1469 vehicles. The parking duration of each of these vehicles was also recorded by both methods, and a comparison is shown in Figure 4.

As can be seen, there is a close correlation of the two methods until a duration of 2 hours and 15 minutes is reached. After that time, the ground method data showed a 15-minute time lapse from the aerial method. This difference came about through the field personnel's ability to record the information, since it required up to 15 minutes to cover the block faces. The correlation between the aerial and the ground methods was especially good for the shorter duration periods, as Table 3 indicates.

One of the most important outputs of the use study is the parking accumulation by time of day. The comparison between the aerial and ground methods of recording vehicle parking accumulation is shown in Figure 5.

The correlations were found to be very close, with the greatest disparity occurring at 4:45 p. m. with a total difference of 9 vehicles. This difference can be explained in part by the influx of drivers serving passengers at 5:00 p. m., which emphasized short parking periods. Because the time of the plane's photo exposure and the time the field crews began walking around the blocks were not exactly concurrent, limited disparities occurred at the periods of greatest turnover, such as 11:45 a. m. to 12:15 p. m.,

TABLE 2

DISTRIBUTION OF PARKING SPACES

Time Limit	Number of Spaces	Percentage of Total
10 minutes	5	3.7
½ hour	4	3.0
1 hour	95	70.9
2 hours	30	22.4
	134	100.0

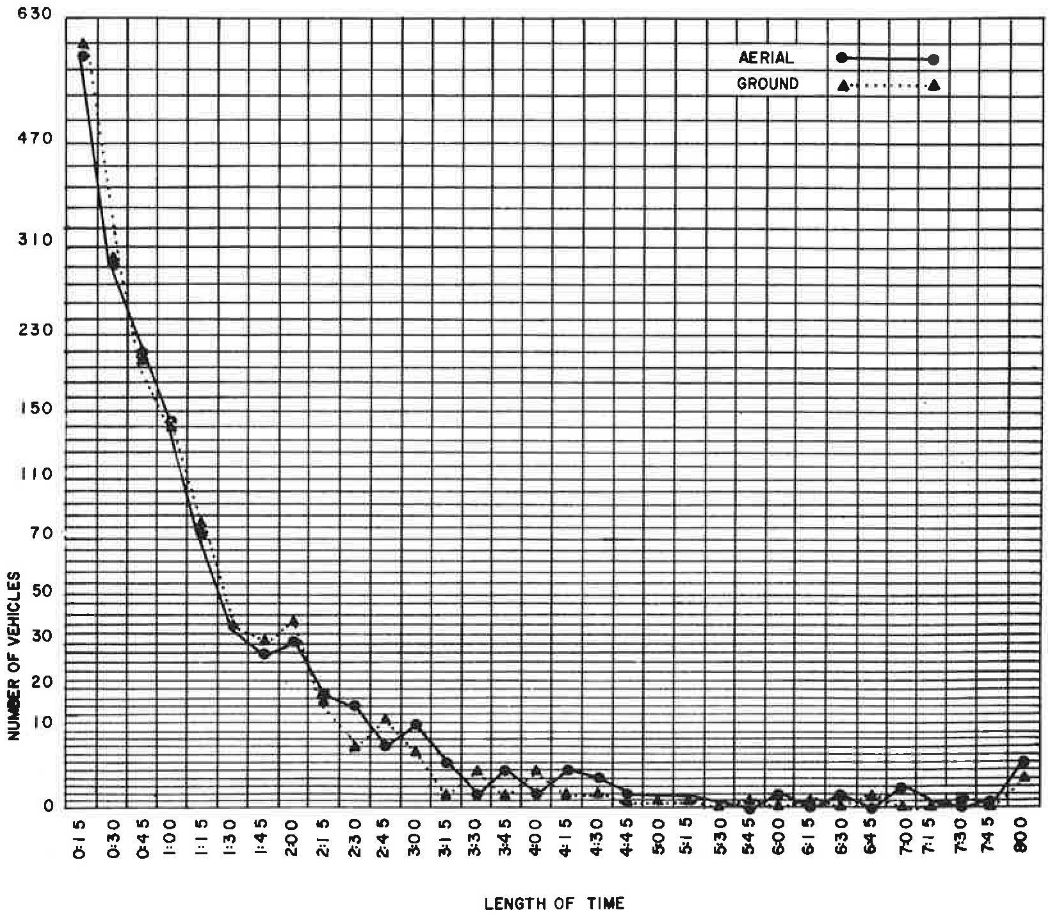


Figure 4. Duration comparison.

2:45 to 3:30 p. m., and 4:30 to 5:50 p. m. The average difference for the day was less than one percent (0.88 percent).

Close correlations were found once again when comparisons of the standard and aerial methods were made for vehicles inbound (Fig. 6), vehicles outbound (Fig. 7), and vehicular turnover (Fig. 8) in the 8-block control area.

TABLE 3

COMPARISON OF AERIAL AND GROUND METHODS

Length of Time	Number Aerial-Recorded	Number Ground-Recorded
15 minutes	596	609
30 minutes	288	286
45 minutes	190	176
1 hour	139	133
1 hr. 15 min.	75	80
1 hr. 30 min.	39	39
1 hr. 45 min.	29	32
2-3 hours	77	77
3-4 hours	25	16
4-5 hours	12	10
5-6 hours	2	3
6-7 hours	2	3
7-8 hours	8	5
	1482	1469

The small differences between the aerial photo output of information and that collected on the ground may be explained by three observations:

1. The ground control and the aerial flight were not synchronized in time so that a 15-minute difference was possible between the two. Synchronization would have been difficult, if not impossible, since the ground observers could not always see the airplane as it flew over the area.

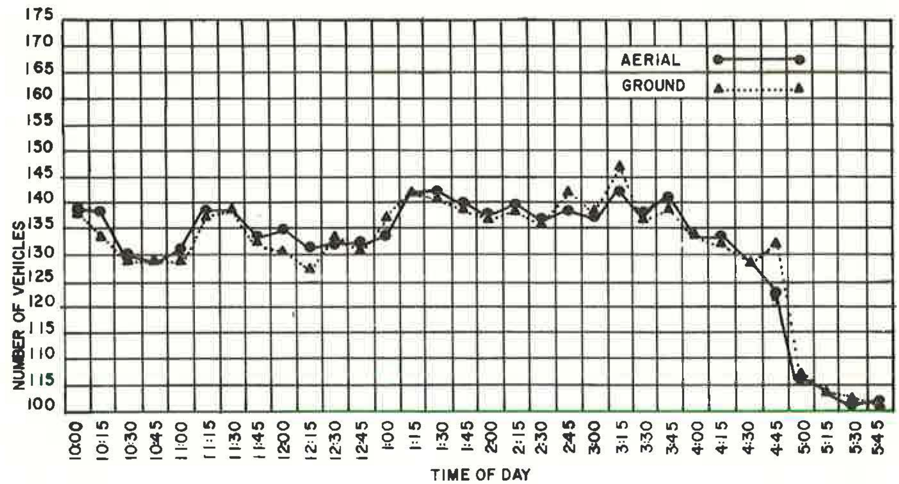


Figure 5. Vehicle parking accumulation.

2. The aerial photograph shows the complete parking situation for one instant in time, whereas the ground control took 10 to 15 minutes to cover the block faces for the same time period. Therefore, changes were occurring before the field personnel could record them.

3. The element of misinterpretation on the part of the ground survey crew was inserted during the relief breaks when a change of personnel was required. The aerial photos, however, were observed by one interpreter who was able to view them continually during the study period.

The aerial photo method produced all the outputs needed for the use and duration studies. Use was obtained by looking at every available parking space and recording

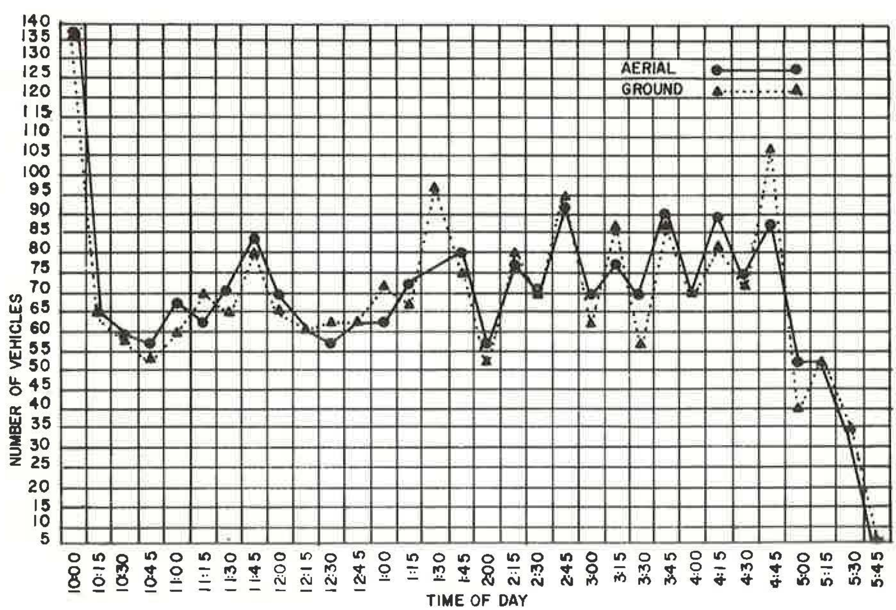


Figure 6. Vehicles inbound.

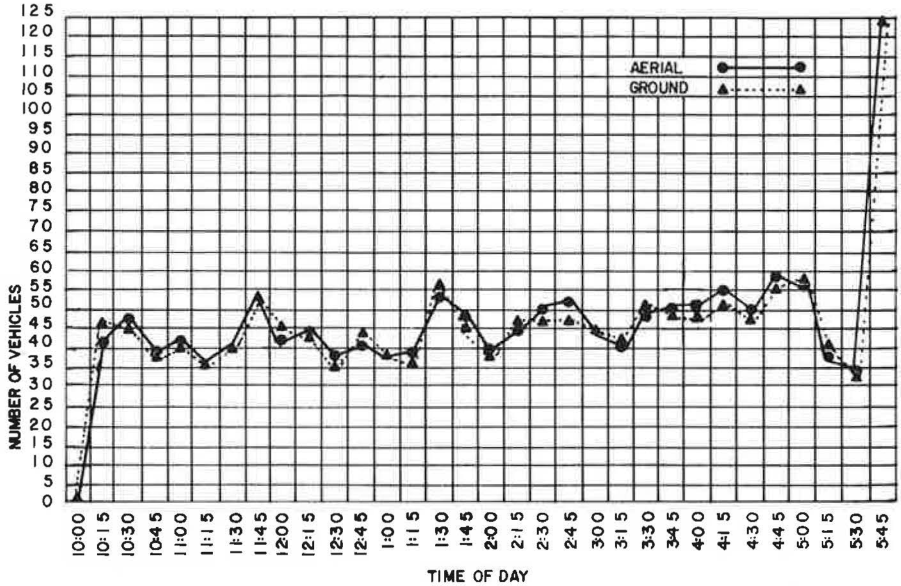


Figure 7. Vehicles outbound.

by time period if the space was empty or filled. Duration was obtained by comparing the photos throughout the day and recording the time a vehicle pulled into the space and the time the vehicle left.

An important consideration of the feasibility of a new method is its cost related to the previous method. Cost comparisons were based on the man-days that were needed by both methods to bring the data to the coding stage. The man-days for the aerial method were the actual time consumed, while the man-days for the standard method were estimated based on the experience of using field crews in other cities in Stark County.

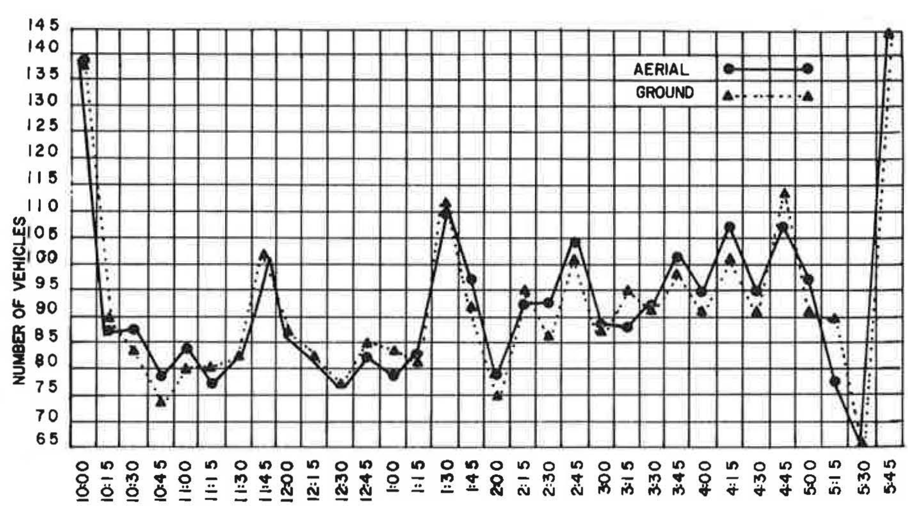


Figure 8. Total vehicle turnover.

TABLE 4

COMPARISON OF TIME REQUIRED FOR TWO METHODS

City	Estimated Man-Days Using Standard Method	Man-Days Using Aerial Method	Percentage of Time Saved Using Aerial Method
North Canton	85	20	76.5
Massillon	175	40	77.2
Canton	695	82	88.2
Total	955	142	Average 85.2

The time and costs related to the ground survey of the 8-block control area were not included with the aerial costs because they were not actually a part of the parking study but were the result of a test of the method itself. The time in man-days needed to complete the parking information by the aerial and standard methods for each of the three cities surveyed is given in Table 4.

Labor time increases are synonomous with increased costs. For the standard method a total of 955 man-days would have been needed to obtain the data in the survey cities as compared to the actual time of 142 man-days using the aerial method. The cost of both methods was calculated at $20 per man-day, which included the cost of supervisory personnel. Applying this figure, a cost of $19,100 was estimated for the standard method, whereas the cost of the aerial method was $2,840 to extract the data and $2,500 for the aerial photo consultant contract, for a total of $5,340. By using the aerial photo method a savings of $13,760, or 72 percent, was realized. The breakdown of time and cost for each method is given in Table 5.

The cost savings using the aerial method do not include the additional administrative costs connected with the hiring of many additional personnel for the short period of time needed for the standard method. These administrative costs have not been added due to the difficulty in estimating them; however, a figure of 10 percent would be realistic.

In contrast, the aerial method used two full-time persons for the complete interpretation of the photos. After the initial orientation with the photo-interpretation technique, supervision was limited to only spot checking of the data output for accuracy.

The aerial photo interpretation was accomplished in a time period of 2½ months using two persons and one scanning stereoscope. The length of time needed to analyze the photos and extract the data for each city is given in Table 6.

The spaces per man-day figures in Table 6 represent the number of spaces that the photo observer could analyze completely through the 8-hour survey period and provides a guideline in estimating the labor time needed to analyze the photographs. As the number of spaces available increased, the photo interpretation method became more efficient due to the fixed photo setup times for all the cities.

The final comparison of the two methods was concerned with accuracy. The standard method relies upon a number of field observations to provide the needed information and is therefore vulnerable to misinterpretation. In the case of observing off-street parking, the field technician must record the full license number of every vehicle entering or leaving the selected facility. These license numbers must be recorded accurately because they are matched to determine the duration of parking. Any mistake reduces considerably the accuracy of the duration information because once a vehicle leaves its parking space it is gone forever.

In contrast, the aerial method utilizes photographs that provide a historical record of the parking situation at a precise moment in time. The photos can then be referred to whenever the need arises. Human error was further reduced in the aerial technique by using

TABLE 5

COMPARISON OF COSTS FOR TWO METHODS

Method	Man-Days	Labor Cost	Fixed Cost	Total
Standard	955	$19,100	-0-	$19,100
Aerial	142	2,840	$2,500	5,340
Cost difference (72 percent savings)				$13,760

TABLE 6
TIME REQUIRED FOR DATA EXTRACTION

City	Population	Man-Days	Total Available Spaces	Spaces per Man-Day
North Canton	11,000	20	552	27.50
Massillon	32,000	40	1,757	43.92
Canton	120,000	82	9,606	117.14
Total		142	11,915	Average 84.47

only one photo viewer in a given photo area, thereby maintaining a consistency of interpretation. The aerial method proved to be more accurate than the standard method because of the reduction of human error encountered in obtaining information by field observation.

EVALUATION OF THE AERIAL METHOD

The problems related to using aerial photographs were few in number, and these were due to the nature of aerial photography itself rather than to the parking application.

Trees partially hiding the vehicles parked below proved to be the greatest problem to the photo interpreter. Fortunately, in the business districts of the cities, a minimum number of trees was encountered, so that in no case did trees completely block the view of the ground.

The second problem was that of photo blurring due to haze and smoke in the atmosphere and to the movement of the aircraft. Either of these conditions produced a veiling effect, which reduced contrast in the photo scene and obscured details. The scanning stereoscope instrument overcame these problems with the machine adjustments for parallax and the 4.5× magnification, which enlarged the details and compensated for the blurring. Vehicles parked over the painted lines marking the spaces slowed down the analyzing process to a slight degree.

Prior to the aerial flight the greatest problem expected in the photo analysis was one of difficulty in identifying two vehicles of the same color. This anticipated problem was never encountered because vehicle identification was made not only by color but also by size, storage position, and overall appearance, which eliminated the chance of identifying vehicles incorrectly. Vehicle make and model were even identifiable upon occasion, as was the determination of truck vs passenger car identification.

Two parking lots in Canton were known to shuttle vehicles within the lots in their normal operation. Prior to the aerial survey the attendants at these lots were contacted and asked to keep a record of the total number of vehicles that used their facilities during the flight day. These totals were then used as a control figure for the aerial photo interpretation. Particular attention was given to these lots by the interpreter so that if a car had been shuttled, it would be noticed. By concentrating on these lots, the photo interpreter came within five vehicles of the control totals obtained by the attendants. This possible problem of over-recording the number of vehicles was eliminated by the preparations made for these lots.

Building overhang and building shadows were two problems that were expected but were never encountered. The building overhang problem was eliminated by using a 12-in. focal length lens on the camera and by the 60 percent forward overlap on the photo sequences. The use of the 12-in. focal length lens reduced the vertical variance in the photos, thereby yielding a flatter image. Building shadows decreased the color contrast in the photos but vehicle identification was not impaired.

The greatest disadvantage to the aerial method is the dependency on atmospheric conditions to make proper exposures of the color transparency film. This film requires a considerable amount of light and an especially clear day in order to develop the sharp color contrasts needed for the parking study. Weather is extremely important because the study must run continuously for an 8-hour period of time and near-perfect conditions must be present throughout the flight time in order to avoid a costly flight abort.

Time of year is also important to color photography. The summer months of June, July, and August offer ideal conditions for color exposures. The angle of the sun during this period affords a sharper color contrast and in addition keeps building shadows to a minimum.

Ideally the flight should maintain a constant altitude so that a constant color contrast is likewise maintained. The SCATS flight required a change in altitude over Canton, which necessitated time-consuming camera filter changes and pilot reorientation at the new altitude level.

The advantages of the aerial photographic method are many; some of the most important are the following:

1. Time, because the aerial flight survey can be completed in any one day, thus eliminating the chance of having special events disrupt the pattern of parking.
2. Manpower, because a limited number of personnel can accomplish what would require a large manpower force in the field.
3. Accuracy, because the photos provide a historical record that can be referred to for analyzing at any time. In addition, photo interpretation by one individual alone allows a consistency unmatched in the field.
4. Cost, because the aerial method provides a saving of money, labor, and time, which in the case of SCATS amounted to $13,760.

OTHER USES OF THE AERIAL PHOTOGRAPHY

The aerial photography was put to use in other planning and engineering studies in addition to the parking analysis. The uses included displays, studies of land use, intersection layouts, and the determination of various physical features used in a pilot traffic engineering study.

The color transparencies were used as a check of land-use changes that occurred since 1965. New construction and demolition that occurred during the 3-year interval were pinpointed and field personnel were directed to areas of question or change.

The aerial photography was also used in the Canton "TOPICS" study. TOPICS (Traffic Operations Program to Increase Capacity and Safety) is a pilot study designed to use modern traffic engineering principles to increase the capacity and safety of existing streets on an areawide basis. The photos were used in this engineering study to determine various physical features such as trees, poles, signs, signals, fire hydrants, building setbacks, pavement widths, and pavement markings. Intersection layouts collected by field inventory in the TOPICS study were checked for accuracy using the scanning stereoscope to interpret the aerial photos. In addition, the aerial photos were used in the Aerial Photographic Computer to prepare traffic operational plans for Canton's TOPICS project.

MEASURING PARKING DEMAND

A comprehensive parking study must include in its work program the measurement and identification of parking demand by area. In the SCATS study parking demand will be synthesized from the 1965 Origin and Destination Survey of Travel Patterns, utilizing the reported trip purpose and destination by the auto drivers in a manner that is common to both aerial and field methods.

SUMMARY AND CONCLUSION

The aerial photographic method of conducting a parking study has proved to be a less costly and more accurate way of collecting parking use and duration information. When compared with the standard field method on the basis of output, time, cost, manpower, and accuracy, the aerial method is far superior.

In the case of SCATS, using the aerial method represented an 85 percent savings in time and a 72 percent savings in cost from the estimated amounts for the standard method. Comparisons of the two methods revealed a close correlation in terms of data output. These comparisons were made on an 8-block control area that was inventoried simultaneously in the field and by aerial photographs.

The problems encountered were few and were directly related to the nature of aerial photography. The greatest disadvantage was that color aerial photography is very dependent on atmospheric conditions, so that ideal weather is needed to properly develop the color contrasts.

The advantages of aerial photography included the savings of time, labor, and cost, as well as the increase in accuracy of the information collected. Time was saved because the parking information was gathered in one day; labor was saved because a photo interpreter and a recorder completed the analysis in about one-fourth of the time needed for the field collection; money was saved because labor and time were less than the standard method; and accuracy was increased because the photos provided a permanent record of the parking situation and were instantly available for review.

The aerial photo method has proved in the case of SCATS to be a superior method of obtaining the use and duration elements of the parking study. The aerial photographs provided a running pictorial story of the traffic movements on the city streets and parking habits for on-street and off-street facilities.

Using the O-D travel survey data to formulate demand by trip purpose has provided the final element needed for a comprehensive parking study. Along with the use and duration information collected from the aerial photography, a more complete view of parking habits was accomplished. To omit either of the data sources would have restricted the reliability of the report and its overall usefulness.

STUDY RECOMMENDATIONS

Based on the evaluation of the aerial photographic method used in the SCATS study area, this method has proved to be applicable to other urban areas. Taking the photographs at intervals of less than every fifteen minutes will yield little additional information for the added cost. Based on the evaluation of aerial photography in the SCATS area the following recommendations can be made:

1. That adequate preparation be made before the flight so that the area is outlined and the photo scale is determined to eliminate in-flight problems.
2. That the aerial flight consultant insure to the contractee the development of the color photos, the proper time sequencing of the photos, and the absorption of the cost in case of a flight abort.
3. That a scanning stereoscope be used to extract the data.
4. That garage information be field-collected on the same day as the aerial flight if possible.
5. That a 12-in. focal length lens be used on the aerial camera to greatly diminish building overhang.
6. That one interpreter be used to analyze a particular area from start to finish (10:00 a.m. to 6:00 p.m. photos).
7. That a constant flight altitude be maintained to assure a constant color contrast.
8. That procedures as developed in this report be adhered to so that the best results can be obtained.

The application of photography to engineering and planning studies seems to be limitless. Work is continuing on these applications and promises to be a major tool for the researcher. The use of color aerial photographs taken in specified time periods over Canton, Massillon, and North Canton, has proved to be superior to the standard field method of collecting parking information. The basic data needed for the study of parking use and duration has been provided by the aerial photographic method.

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