A New Intersection Study Technique

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The objectives of this research were to explore possibilities of more accurate and efficient methods of field measurements at intersections and to study new techniques that would assist in determining whether the best use is being made of traffic control devices. Two data collecting methods were developed utilizing time-lapse cameras suspended over the center of intersections. One method involved a remote-controlled 16-mm Bolex camera installed on a rotating platform. The second method, based on a 70-mm Maurer P.2 camera, used four mirrors to bring all four approaches into the field of vision. Simultaneous traffic data could thus be obtained on all approaches. A digital simulation model was developed and programmed for the IBM 7094 computer. The technique, involving the combined use of the split-image camera and a simulation model of signalized intersections, was tested on a limited scale. The model has been validated by data obtained at a signalized intersection. The effect of changes in the timing of the semiactuated signal has been simulated. The model can also be used to simulate pretimed and fully actuated traffic signals. The three different signal types were compared. Under the traffic conditions investigated, the semiactuated signal was found to be the least efficient. The pretimed signal resulted in reduced stopped-time delay rates, but the most efficient operation was provided by the fully actuated signal.

•PERSONAL mobility provided by private automobiles is a prized element in the quality of American living. The increasing rate of urbanization, however, tends to concentrate traffic demands and accelerate problems of roadway transportation. Difficulties are compounded at intersections. The function of an intersection is to merge, diverge, and cross traffic streams. The efficiency with which this function is performed depends largely on the geometric layout and traffic control in relation to prevailing traffic flow characteristics. Installation of traffic signals is usually preceded by manually conducted traffic studies. Once the signal is installed, continued attention is frequently limited to maintenance of equipment. But traffic conditions change over the years. Intersections that no longer meet current traffic requirements are bound to increase the cost of transportation in terms of delay and accidents.

This study was undertaken as part of research project EES-274, "Development of New Intersection Study Techniques," sponsored by the Ohio Department of Highways in cooperation with the U. S. Bureau of Public Roads. The objective was to develop a new intersection study technique. The specific aims were twofold:

1. To develop an accurate and efficient field observation method, utilizing time-lapse photography that is capable of obtaining simultaneous traffic data on all approach lanes; and
2. To develop a mathematical model of a signalized intersection, programmed for the IBM 7094 digital computer, which is flexible enough to permit the simulation of either pretimed, semiactuated or fully actuated traffic signals.

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The new intersection study technique involves the combined application of the field observation method and the simulation model. Once the model has been adapted to a specific intersection by input data obtained from photographic data collection, the various facets of operating the intersection are studied by experimenting on the model. Traffic demand and traffic control variables are manipulated systematically and the interrelationship is analyzed. By testing alternative traffic control schemes and observing the results, the most desirable scheme can be identified.

DEVELOPMENT OF PHOTOGRAPHIC INSTRUMENTS

When photographic techniques are employed in traffic engineering studies, the position of the camera largely determines the quality and quantity of data. The field of view of a camera mounted on a tripod at street level would generally be inadequate for intersection studies. Better coverage can be obtained by mounting the camera on a hydraulic platform truck. A camera mounted on the roof of a tall building provides the best view if the building is close to the intersection and if other structures do not obstruct the view. Dependence on a conveniently located tall building, however, is a rather serious limitation.

In this study, the cameras were suspended by a steel cable over the center of the intersection. Two cameras were used: a 16-mm Bolex time-lapse camera installed in a housing rotated by remote control, and a 70-mm split-image camera.

Rotating Camera

The equipment consisted of a 16-mm Bolex time-lapse camera mounted on a rotating platform, suspended from a cable attached to the supporting poles of the traffic signal. Electrical power was drawn from the control box. The 10-mm lens has an angle of view of 58° × 38°, which is wide enough to bring both the stop line and the horizon into the field of vision. The platform also housed a television camera (Figs. 1 and 2). The operator, who controls the equipment with remote-controlled

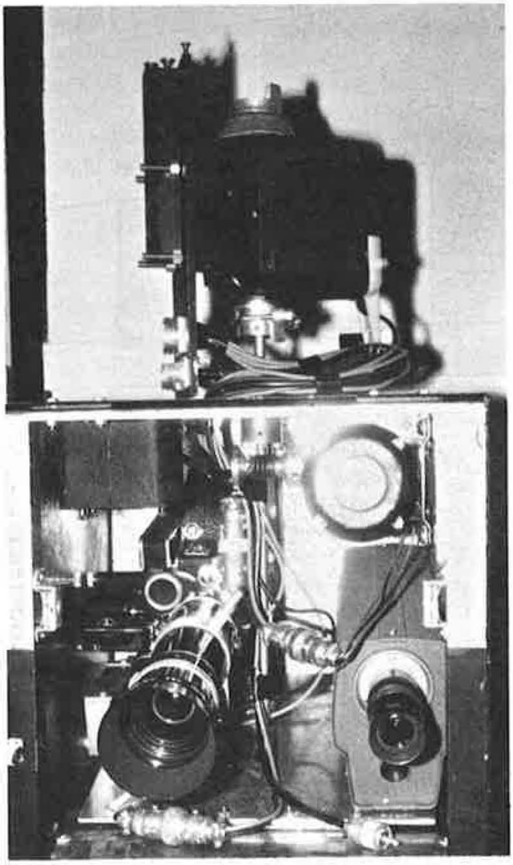

Figure 1. Rotating platform with the Bolex and the television cameras.

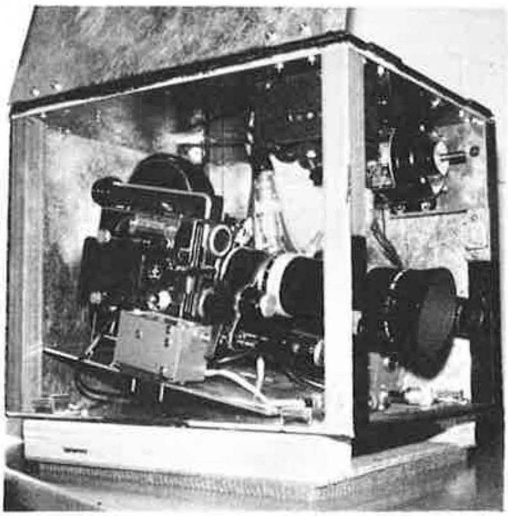

Figure 2. Remote-controlled rotating camera.

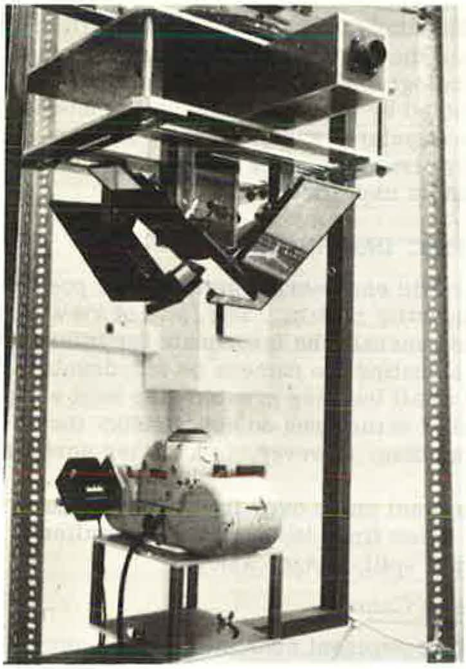

Figure 3. The 70-mm camera with mirror system.

Tenna-Rotor, can rotate the camera to the desired direction by viewing a closed-circuit television receiver. Both cameras can be tilted on a horizontal axis to insure the proper field of vision.

Split-Image Camera

The second instrument was designed to provide traffic data on all four approaches simultaneously. Based on a 70-mm Maurer P.2 camera, it was made available by the Wright-Patterson Air Force Base. The camera was mounted vertically on the bottom of a frame. It was aimed at a set of four mirrors installed above camera (Fig. 3). Each mirror was adjusted to bring one of the four approaches into view. Between the four mirrors, a data chamber contained a set of lights synchronized with the traffic signal lights. Each photograph, therefore, recorded the traffic condition on all approaches and the state of the traffic signal (Fig. 4).

Figure 4. Photograph taken by split-image camera.

The camera was operated from a control console installed in the back of a station wagon parked near the intersection. A frame counter, within the console, recorded automatically the movement of the film through the camera. This camera can be used with 50- or 100-ft magazines. At one frame per second exposure rate, the 100-ft roll can record approximately nine minutes of traffic data.

Figure 5. Installation of the rotating camera.

Field Installation

A hydraulic lift truck was used to raise the equipment and personnel (Fig. 5). The truck was parked so that traffic could flow as freely as possible. Apparently, the camera did not attract attention during operation. Suspended between several traffic signal heads and directional signs, it was quite inconspicuous (Fig. 6).

Rear Projection Console

The Maurer P.2 camera uses 70-mm film. A motion picture projector capable of handling this film is expensive and not readily available. Therefore, a Beseler Slide King projector, originally designed to handle slides up to a $3\frac{1}{4}$- by 4-in. size, was converted to our specifications (Fig. 7). Two auxiliary reels powered by an electric motor were added to advance the film through the projector. The motor, controlled from the viewing console, can be operated either continuously at an approximate rate of 4 sec per frame or finer adjustments can be made by depressing a pushbutton. The image is projected on a glass plate covered by drafting paper and built into the top of a console (Fig. 8).

Before installation of the camera, white paint marks were sprayed at 25-ft intervals at both edges of all approach lanes. The marks were only 3 in. wide and 12 in. long to avoid any biasing effect on the traffic data. Most of the marks are visible on the photographs and provide a built-in reference scale. Missing marks were reconstructed by a technique based on the fundamental principle of projectivity (the theory of cross ratio). The same principle was utilized to develop from the 25-ft-interval marks a grid on which

Figure 6. The rotating camera in position.

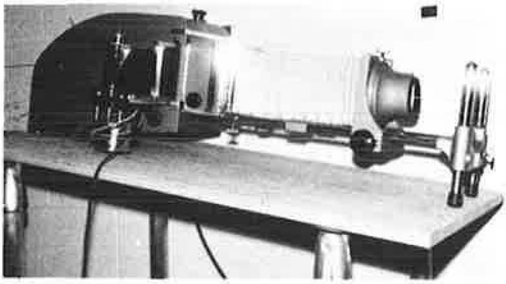

Figure 7. Revised Beseler projector.

every 5-ft line is shown. The grid system extended 200-ft on all approach lanes. A Kodak Analyzer was used to analyze the 16-mm film.

Advantages of the Photographic Technique

Application of the photographic technique to the investigation of complex traffic problems at intersections has numerous advantages over more conventional methods. It is especially valuable when personnel are limited. A two-man crew can install the camera and collect the required data. Data analysis can be performed by one person in the laboratory. Some information readily obtainable by photographic techniques is very difficult to collect by other techniques. The advantages of the photographic technique increase with the complexity of the data, because the film is a permanent record of all visible aspects of the traffic situation at an intersection. The film can be projected repeatedly at the convenience of a laboratory. Furthermore, it provides a 100 percent sample, and the method of analysis can be changed to meet the accuracy required for a specific purpose, It is most useful where the interrelationships of several factors are investigated because all factors are observed simultaneously.

The development of the split-image camera provides a practicable method by which simultaneous traffic data can be obtained on all approaches to an intersection. The results of this study suggest that (a) simultaneous data (including traffic volumes, arriving times and stopped-time delay) are necessary for any meaningful investigation of intersection operation, and (b) time-lapse photography is the best method to obtain these data.

A DIGITAL SIMULATION MODEL OF SIGNALIZED INTERSECTIONS

Purpose

The objective of this phase of the study was to develop a model that could simulate the operation of a signalized intersection so accurately that the effect of traffic control could be predicted. In the model, this control can be effected by fixed-time, semi-actuated, or fully actuated traffic signals. The efficiency of control is measured in terms of delay. For each lane the number of stopped vehicles and the sum of the stopped-time delay are determined.

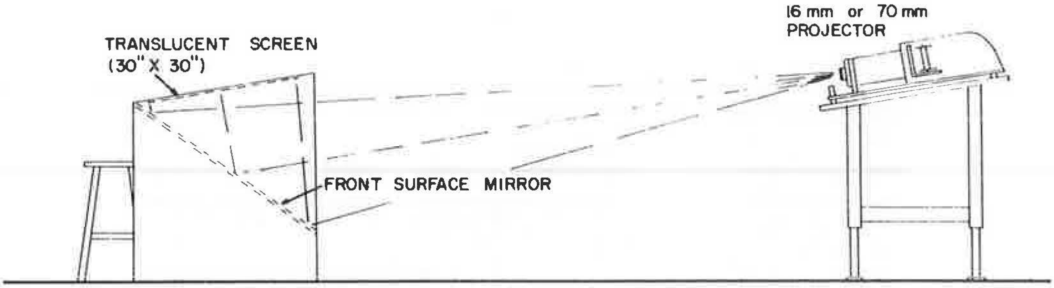

Figure 8. Setup of the rear projection console.

Structure

The model is a computer program which, when given a certain set of input parameters related to the intersection, manipulates these components so that they will act in a manner comparable to a real intersection.

The three components of an intersection are the physical properties of the intersection, the traffic control, and the traffic flow. The properties of the components are represented by three methods: (a) mathematical equations, (b) variables, and (c) statistical distributions. The time-scanning technique is used to update the system. At each time period, the following procedure is repeated:

1. The traffic signal is checked and reset if required;
2. The list of arriving times is checked for arriving vehicles and the list of vehicles in the system is updated if necessary;
3. The position and velocity are recomputed and a new acceleration rate is assigned for each vehicle as dictated by prevailing conditions;
4. If any vehicle has exited the system, the list of vehicles in the system is updated; and
5. Current time is checked against the time limit; if the time limit has been reached, the results of the simulation are printed out and the run is terminated.

The model simulates an intersection with two approach lanes from each direction. The minimum length of the simulated approach lanes is 200 ft. Beyond the stop line, the model considers only that portion of a traffic lane where a potential conflict exists between left-turning vehicles and straight-through or right-turning traffic.

The vehicles are represented by a set of double-subscripted variables. The subscripts identify the lane in which the vehicle is traveling and the order in which the vehicles arrive. Three of the variables are recomputed during each scanning interval: (a) the position, POS(I,J); (b) the velocity, V(I,J); and (c) the acceleration rate, A(I,J). The simulation procedure is summarized in Figure 9.

Description

The program deck is made up of 18 parts; the initialization, 16 subroutines, and the data deck.

Subroutine TGI—Traffic Generator—When arriving times are not read in as input, subroutine TGI is used to generate traffic by a random process. The hourly rate of flow, VOL(I) is read in for each lane. The corresponding headway distribution is approximated by the log-normal distribution. The probability density function is given as follows:

$$f(x) = \begin{cases} \dfrac{1}{x\sigma\sqrt{2\pi}}\, e^{-\dfrac{(\lg x - \mu)^2}{2\sigma^2}} & x > 0 \\ 0 & x \le 0 \end{cases}$$

For the mean μ and the variance σ^2 the maximum liklihood estimates $\hat{\mu}$ and $\hat{\sigma}^2$ are substituted. From field data consisting of samples ranging from 339 vph to 1369 vph, $\hat{\mu}$ and $\hat{\sigma}^2$ values were computed. Regression equations were then developed using volume as the independent variable and the mean and variance as dependent variables:

$$\hat{\mu} = \text{YMEAN(I)} = 2.076 - 0.001\ \text{VOL(I)}$$
$$\hat{\sigma}^2 = \text{VARY(I)} = 0.5670 - 0.00006\ \text{VOL(I)}$$

The probability of a headway occurring between x - ½ sec and x + ½ sec is obtained by integrating the probability density function over the interval from x - ½ to x + ½ sec. The Monte Carlo method is then used to generate headways for traffic arriving on a given lane.

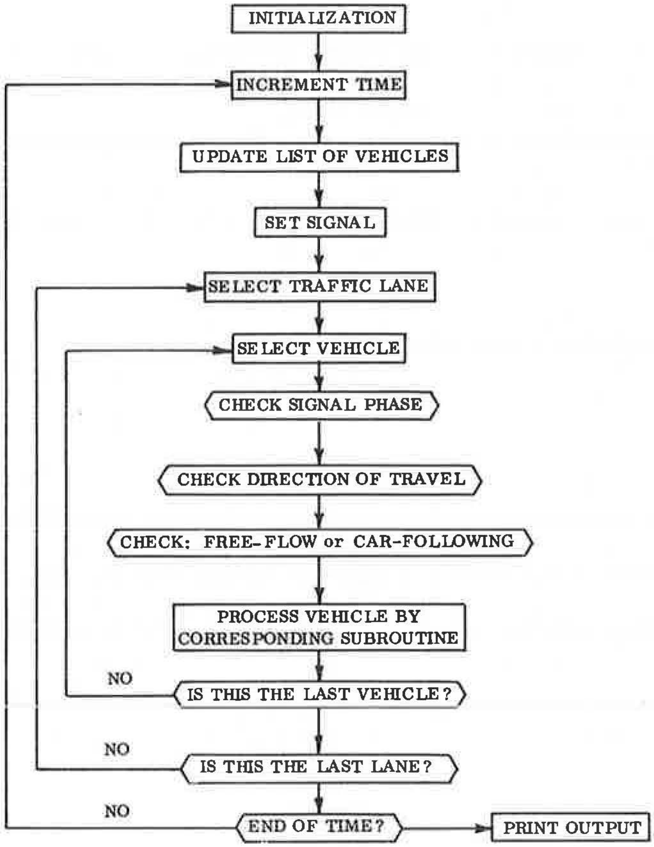

Figure 9. Summary of simulation process.

Subroutine SC2—Pretimed Signal—Subroutine SC2 is included in the program only when pretimed signal control is simulated. The corresponding input data include the length of the cycle as well as the starting time of all phases, measured from the begining of the cycle. During each time increment, the current time is compared with the starting times of the phases.

Subroutine SC3—Semiactuated Signal Controller—Subroutine SC3 replaces SC2 when semiactuated traffic control is simulated. It is used in conjunction with Subroutine SD5, which simulates the operation of the detectors.

Subroutine SC4—Fully Actuated Signal Controller—For fully actuated signals, both the minimum and the maximum green phases are specified for both directions. The vehicle detectors are simulated by Subroutine SD6.

Subroutine UD7—Update List of Arrived Vehicles—During each time increment, current time is compared with this list of arriving times. If it matches one of the items in the list, then the following steps are taken:

1. The position of the vehicle is defined as the entrance line. If there is a queue extending past the entrance line, the newly arrived vehicle is moved back as far as necessary.

2. For vehicles in the outside lane, the direction of travel is determined by the Monte Carlo method. All vehicles in the inside lane are to turn left.

3. The two variables, NVP(I) and KSUM(I), are incremented by one. The first variable indicates the number of vehicles present in the lane considered; the latter variable indicates the number of cars that have arrived.

Subroutine QU8—Queue Discharge—The simulation of a platoon starting up at the beginning of the green phase is based on the following assumptions: (a) a starting delay time separates the beginning of the acceleration of the first vehicle from the beginning of the green phase; (b) a constant response time separates the movement of any vehicle in the platoon from the movement of the preceding vehicle.

Subroutine FG9—Free Flow on Green; Straight-Through or Right-Turning Traffic—The velocity of a straight-through vehicle is compared with its desired velocity. If the difference exceeds a specified margin, a uniform acceleration rate is assigned to the vehicle. Right-turning vehicles are to assume the turning velocity when they reach the stop line. The acceleration rate is computed accordingly.

Subroutine CFG10—Car-Following on Green; Straight-Through or Right-Turning Traffic—Based on the current relative position of two subsequent vehicles, an acceleration rate is assigned to the following vehicle if there is a difference in the velocities. The minimum spacing to be maintained at a given speed is equal to the sum of the specified minimum spacing between stopped vehicles and the distance traveled during one second. If a right-turning vehicle is following a straight-through vehicle, the acceleration rate required to reduce the velocity to the turning velocity is also computed. The lower of the two rates will be applied.

Subroutine FG11—Free Flow on Green; Left Turns—When the left-turning vehicle approaches the intersection within a predetermined distance, gaps in the opposing traffic stream are investigated. All time lags or time gaps equal to or greater than 5 sec are accepted. If the gap is not acceptable, the turning vehicle decelerates to stop at the waiting point.

Subroutine CFG12—Car-Following on Green; Left Turns—This car-following Subroutine is based on the same principles as Subroutine CFG10.

Subroutine FA13—Free Flow on Amber; Straight Through and Right Turns—A vehicle traveling in the outside lane when the signal changes to amber will enter the intersection only if it cannot stop at a moderate deceleration rate.

Subroutine FA14—Free Flow on Amber; Left Turns—Delayed left-turning vehicles tend to take advantage of the caution phase and complete the turning movement. Consequently the stop-or-go decision is based on a different assumption from that in Subroutine FA13. It is assumed here that a "go" decision is made if the left-turning vehicle can enter the intersection on amber.

Subroutine TR15—Traffic Flow on Red—The first vehicle in each lane stops at the stop line. The following vehicles are governed by the car-following equation which provides a uniform spacing between stopped vehicles.

Subroutine WO16—Write Output—Subroutine WO16 specifies what is to be printed as output, depending on the objectives of a given simulation run. The type of traffic control is identified and the input parameters are also printed out. The tabulated results characterisiically include the specified traffic volume, the actual generated volume, the number of stopped vehicles, and the stopped delay per lanes.

TESTING THE NEW TECHNIQUE

Scope

The digital simulation model was designed to be employed in conjunction with the split-image camera in the study of signalized intersections. The technique was tested at the intersection of Ohio 3 and Ohio 161. The test achieved the following three objectives:

1. Simultaneous traffic data on all four approaches to the intersection were obtained by the split-image camera;
2. The simulation model was adapted to this intersection by thorough comparison of simulated and observed situations; and
3. The application of the technique to the investigation of various traffic-control elements in relation to their effect on the traffic flow was demonstrated.

Results

Approximately 16 minutes of traffic data were obtained on two 100-ft rolls of 70-mm film and used in the preparation of the traffic input for the simulation runs. The input consisted of the arriving times, average approach speeds, average turning speeds, and turning volumes. The intersection was controlled by a semiactuated traffic signal. Traffic control input included the minimum and maximum green phases on Ohio 3; the minimum green phase, the unit extension time, and the location of the detectors on Ohio 161; and the yellow phase and the all-red period for both highways. The results of the simulation runs were the subject of intensive comparative analysis (Table 1). The simulated results represent the arithmetic mean of three simulation runs. The agreement between the observed and the simulated conditions is quite close. Comparing the 2940-sec stopped delay time observed during the total 16-min study period with the 2879 sec obtained through simulation, the difference is only 2.1 percent. The difference between the simulated and the observed average stopped delays per stopped vehicles is 1 sec. The agreement is even better when stopped delays for all vehicles are compared: observed and simulated delays are equal on Ohio 3; the difference is 0.4 sec on Ohio 161; and the difference, considering the whole intersection, is 0.3 sec.

Once the model was adapted to the study site, it was used to evaluate the effect of various changes in traffic control. Timing of the semiactuated signal was systematically revised, and the resulting changes in delay were observed. It was found, for example, that under conditions represented by the traffic data, total stopped-time delays could be reduced significantly by reducing the minimum green phase on Ohio 3 and increasing the vehicle extension time on Ohio 161. The reduction of the minimum green phase to 25 sec on Ohio 3 results in a 10 percent reduction in the simulated stopped delay at the intersection. The reduction in delay effected by a 1 sec increase in the unit extension time is 8.7 percent. When both changes are introduced simultaneously, the total stopped-time delay is reduced by 17.5 percent, or nearly the sum of the reductions achieved separately by each change in the signal timing. The detailed results of the improvement (referred to as improved semiactuated signal) in the timing of the signal are given in Table 2.

Considering that the minor roadway carried higher traffic flow during the study period than the roadway favored by the signal, it seems that the semiactuated signal is not well suited to the control of this intersection. Although it was shown that changes in the signal timing could result in significant reduction of delay, other types of traffic signals were expected to perform better. The efficiency of the semiactuated signal control was compared with the efficiency of the fully actuated and the pretimed signal control (Table 2). The fully actuated signal is timed to have 12-sec minimum green

TABLE 1

SIMULATION COMPARED WITH DATA—COMBINED FILMS D3A AND D3D
(16 minutes and 7 seconds)

Roadway	Ohio 3	Ohio 161	Combined
No. of vehicles during study period	110	140	250
No. of stopped vehicles:			
Data	39	94	133
Simulated	34	104	138
Stopped delay time, sec:			
Data	501	2439	2940
Simulated	503	2376	2879
Difference, percent	0.4	2.6	2.1
Stopped delay per stopped vehicles, sec:			
Data	12.8	25.9	22.1
Simulated	14.8	22.8	20.8
Difference, sec	2.0	3.1	1.3
Stopped delay per all vehicles, sec:			
Data	4.6	17.4	11.8
Simulated	4.6	17.0	11.5
Difference, sec	0	0.4	0.3

TABLE 2

COMPARISON OF THREE TYPES OF TRAFFIC CONTROLS
(Data: Film D3D—521 sec)

Traffic Control	Ohio 3	Ohio 161	Combined
No. of vehicles	64	89	153
No. of stopped vehicles:			
Semiactuated:			
Present	24	57	81
Improved	27	51	78
Pretimed:			
50/50 split	29	52	81
42/58 split	35	41	76
Fully actuated	35	54	89
Stopped delay time, sec:			
Semiactuated:			
Present	409	1321	1730
Improved	508	920	1428
Pretimed:			
50/50 split	501	893	1394
42/58 split	608	772	1380
Fully actuated	388	609	997
Stopped delay time per stopped vehicles, sec:			
Semiactuated:			
Present	17.0	23.2	21.4
Improved	18.8	18.0	18.3
Pretimed:			
50/50 split	17.3	17.2	17.2
42/58 split	17.4	18.8	18.2
Fully actuated	11.1	11.3	11.2
Stopped delay time per all vehicles, sec:			
Semiactuated:			
Present	6.4	14.9	11.3
Improved	7.9	10.3	9.3
Pretimed:			
50/50 split	7.8	10.0	9.1
42/58 split	9.5	8.7	9.0
Fully actuated	6.1	6.8	6.5

and 40-sec maximum green phase on both highways. The vehicle detectors are located 110-ft from the stop line. The pretimed signal is tested with two designs; with 50/50 split of the green time and with 42/58 split. The latter is based on the distribution of the traffic volumes on the two highways. The cycle is 60 sec in both cases. The delay obtained by the pretimed signals is much lower than that obtained by the semiactuated signal at the present, and slightly lower than that obtained by the improved timing of the semiactuated signal. The total delay is not reduced significantly by changing the split from 50/50 to 42/58. However, the number of stopped cars is reduced and is more evenly distributed on the two roadways. It can be concluded that under the condition represented by the traffic data on film D3D, the pretimed signal is more efficient than the semiactuated signal. A further reduction in delay is observed when the intersection is controlled by a fully actuated signal. The average stopped-time delay per vehicles is reduced from 11.3 to 6.5 sec. This represents a very significant reduction of 42.5 percent. The trend in Ohio is to phase out the semiactuated signals in favor of the fully actuated signals. The proportion of expected saving in stopped-time delay and the corresponding saving in transportation cost provide strong support for this policy.

CONCLUSIONS AND FUTURE PLANS

The study procedures are summarized in the form of a block diagram in Figure 10. The major achievements can be related to four phases of the study.

1. A technique of obtaining simultaneous traffic data on all approaches of an intersection by a split-image camera, suspended over the center of an intersection, was successfully developed and tested.

2. An inexpensive rear-projection console was built and tested in conjunction with a modified slide projector in the analysis of the 70-mm film.

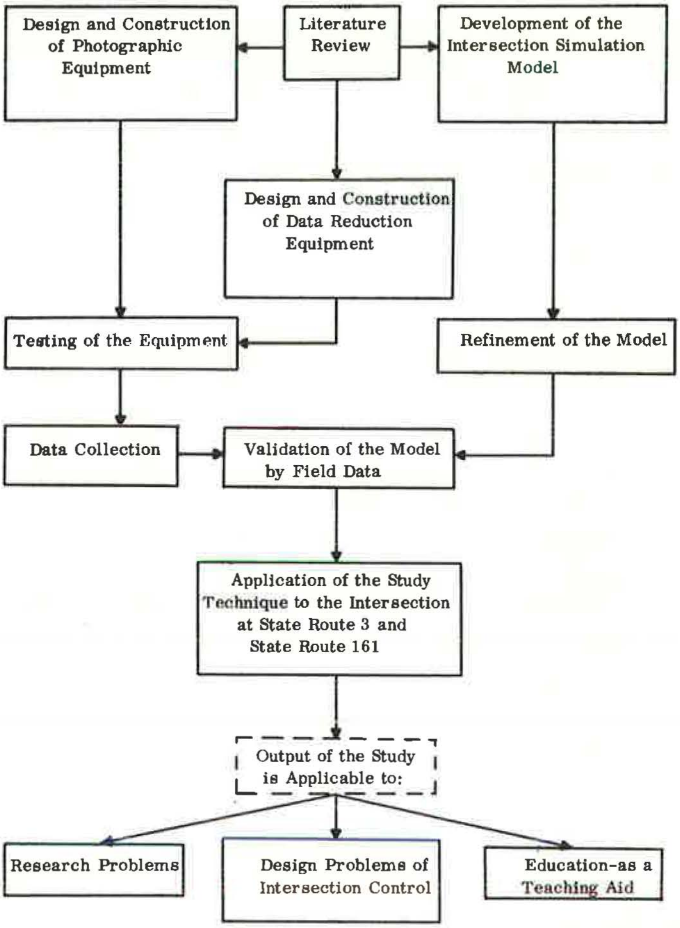

Figure 10. Schematic summary of the research.

3. A versatile digital simulation model of a signalized intersection was developed and tested. The results of the simulation compared well with field observations.
4. The efficiency of the intersection operation was successfully related to alternative schemes of traffic control by simulation.

The limitations of the technique are the following:

1. The split-image camera unit is based on a relatively expensive and rare camera;
2. The capacity of the camera is limited to approximately nine minutes at one frame per second; and
3. Vehicle movement within the center of the intersection cannot be recorded.

Future plans call for the elimination of these limitations. A new unit will be designed and built, based on a 35-mm camera. The capacity of the magazine should be much higher than that of the 70-mm camera. The center of the intersection will be brought into the view of the camera. The improved data collection method and the simulation model will be used in a study aimed at the investigation of the effect of left-turning storage lanes on the efficiency of intersection operation.

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Discussion

ROBERT L. MORRIS, Texas Instruments Incorporated—While there are many advantages to the photographic intersection study technique described, it seems that methods using conventional vehicle detectors could prove useful. One alternative system would consist of vehicle detectors in each of the approaching lanes of the intersection combined with a recorder that would have as inputs the state of the traffic signal, the vehicle detector outputs, and the time of day. Each lane would have a detector at the stop line and at least one detector some distance back from the stop line. The intersection should be chosen so that the spacing between detectors would bot be constrained by minor entrances to the roadway or proximity to adjacent intersections. If space allows, additional detectors could be installed further away from the intersection so that characteristics of the traffic flow could be determined before reaching the direct influence of the intersection signal. The recorder storage medium would be of a type that is readily machine-transferable to computer storage.

The recorded vehicle count from the detectors could be the total for a set time period or for each phase interval of the intersection signal. A small, general purpose computer would be programmed for processing the recorded data to determine the efficiency of the intersection control system. Using available vehicle detectors, the exact number of vehicles stopped for each phase of the intersection controller cannot be obtained as it can with photographic methods. However, an approximation to the number of stopped vehicles could be obtained by computer calculation, and other quantities such as average speed, density and volume of the traffic flow for each lane could also be obtained. It is possible that this measurement technique could show that maximizing the volume while minimizing density could be a meaningful and readily measured criterion for the efficiency of an intersection control system.

The cost of installing permanent types of vehicle detectors could not normally be justified for an intersection survey. There could be some cases, however, where additional permanently installed detectors could be used in more complex controllers planned for the future. For the usual case, temporary vehicle detectors would be used to supplement those existing detectors. A version of the pneumatic tube-type detector could be useful; for multilane roads a transition to rigid tubing can be made for crossing adjacent lanes in which detection is undesired. Another possibility is the development of a "tape-on loop" for a temperory RF loop detector or a thin-film or Hall effect magnetometer-type detector that could be temporarily attached to the road surface. Vehicle detectors of the type that produce a single indication per vehicle would be preferred to the axle-counting types.

Advantages of using vehicle detectors for intersection study include simpler installation, simpler operation (reloading the camera would mean traffic interruption, a special vehicle, and additional personnel), and less complex equipment from the view point of the usual signal installation maintenance organization. The survey time capacity of the photographic technique is presently nine minutes; this could be improved somewhat, but could not approach a continuous 24-hr surveillance on a practical basis, whereas 24-hr surveillance could easily be accomplished by the use of a recorder suitable for storing the vehicle detector output and signal data. Unsuspected conditions could be discovered using a 24-hr surveillance, whereas with a limited-time capacity, a judgment must be made on what time periods are meaningful. Transfer of the data from the recorder to processor would be done by machine, as opposed to the tedious process of human examination of the photographic data. An intersection control study based on data from vehicle detectors could give additional insight into the use of these devices in traffic control systems.