Computer Simulation of Traffic on Nine Blocks of a City Street

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A computer model has been constructed which simulates the volume and movement of traffic on a nine-block section of a city street. The simulated cars are reviewed every quarter-second and are moved according to rules for movement which have been built into the computer program. The simulation run on the computer produces two outputs. The quarter-second car positions are plotted on an oscilloscope and photographed. The result is a moving picture which can be shown in real time. The effect is comparable to viewing the traffic flow from a helicopter. The other output is a series of tables that catalogs all vehicles as they enter the model, clock and count them as they pass a key intermediate point, and, finally, check them out at the end of the course, counting them again and noting their individual running times. Other information is also furnished, such as type of vehicle, speed, and lane use. The tables thus furnish an abundance of quantitative data for measuring and evaluating the performance of the model.

• THIS is a report on a digital computer simulation of automobile traffic at an existing location on city streets. The study was made for the Bureau of Public Roads by the Data Processing Systems Division, National Bureau of Standards, over a period of three years from July 1958 to June 1961.

PURPOSE OF STUDY

The purpose of the work was to simulate the volume and movement of cars with a digital computer, using as the test site a real location where abundant field data were available for control and checking purposes. The test course selected was a nine-block section of 13th Street, N. W., Washington, D. C., from Euclid Street to Monroe Street, in the afternoon rush-hour period when all four lanes are operated one-way northbound (see Fig. 1).

A standard computer-simulation technique involving the use of random numbers "generates" cars at each entering lane in such a manner that the total number entering at each point over a period of time has an assigned expected value. Cars are moved each quarter-second according to detailed "rules of the road" built into the computer program.

Successive car positions have been plotted on an oscilloscope and photographs taken so that the simulated operation can be viewed from moving pictures. Printout tables furnish detailed quantitative data about the volumes, running times, and characteristics of the cars involved.

To the extent that the simulated model can be made to reproduce the known real conditions truly, the volumes and characteristics of traffic and the operating rules then can be changed and the results of a run will represent a prediction of what would happen on the street if the indicated changes were really made. The immediate area of application relates to the use and timing of traffic signals. Simulation runs can be made to study the sensitivity of the traffic flow to altered signal settings, to measure the effect of changed offsets, cycle length, and splits with a view to arriving at optimal timing and to explore the capacity of the signal system to handle increased volumes of traffic. The use of a generalized model can be extended to many other traffic engineering situations.

ANALYSIS OF RESULTS

Several simulation runs have been made. One 4-min real-time run (three complete 80-sec signal cycles) has been selected and is the basis for most of the detail that is to follow.

A moving picture was made of the oscilloscope display. The computer issued printout sheets furnishing detailed numerical data to permit analysis of the behavior of the simulated cars. From this information three summary tables were made.

Tables 1 and 2 summarize the count of cars generated during each cycle for each of the entry points. The figures are shown by cycle, summed for the 4 min, and expanded to an hourly volume. These tables represent the traffic "inputs", whereas Tables 3 and 4 represent "outputs" and are the means for measuring the performance of the simulated cars.

Table 3, the Station B count, gives the results of a count about two-thirds of the way along the 13th Street course, at the maximum load point. In the model, the expansion of the 4-min count at Station B produced an hourly volume of 3,330 simulated cars. This is comparable to the average field volume of 3,168 cars per hour.

TABLE 1

SUMMARY OF CARS GENERATED BY STREET AND BY HOURLY RATE[a]

Street	Hourly Rate (no.)			
	Cycle 1	Cycle 2	Cycle 3	Total Period
13th	3,060	3,105	2,565	2,910
Fairmont	90	90	45	75
Girard	45	90	90	75
Harvard	270	630	90	330
Columbia	540	630	630	600
Irving	360	360	180	300
Kenyon	450	180	90	240
Lamont	0	90	0	30
Park	1,035	630	675	780
Monroe	135	315	45	165

[a] Signal cycle length is 80 sec. Cycle 1 represents 320 quarter-seconds from simulation-run time 1,036 to 1,355; cycle 2, from time 1,356 to 1,675; and cycle 3, from time 1,676 to 1,995.

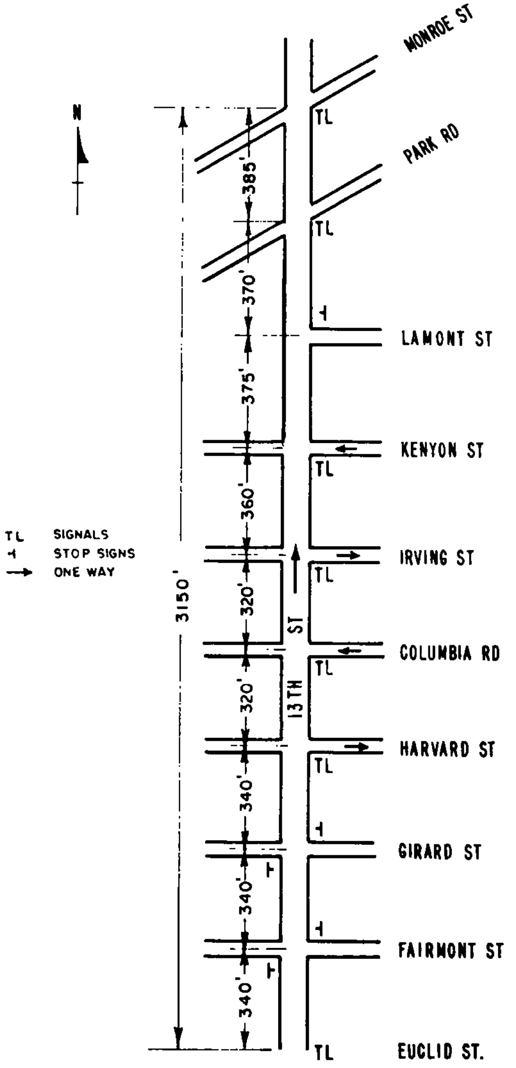


Figure 1. 13th Street layout.

Table 4, the vehicle retirement table, relates to cars leaving the end of the 13th Street test course north of Monroe Street. Again, the simulated cars are counted by cycles and by lanes, and are expanded to an hourly rate. Table 3 also records the running times of those cars which have traversed the full length of the test course from Euclid Street.

The distribution of running times of the simulated cars showed that some of the

TABLE 2

SUMMARY OF CARS GENERATED BY GENERATION POINT AND BY CYCLE

Street	Lane	Signal	Generation Point	No. of Cars Generated			
				Cycle 1	Cycle 2	Cycle 3	Total
13th	1	Green	1	17	15	9	41
		Red	2	2			2
	2	Green	3	19	23	15	57
		Red	4	1		2	3
	3	Green	5	19	18	16	53
		Red	6				
	4	Green	7	10	13	15	38
		Red	8				
Fairmont	1		9	1	2	1	4
	2		10	1			1
Girard	1		11			1	1
	2		12	1	2	1	4
Harvard	1		13	3	8	1	12
	2		14	3	6	1	10
Columbia	1		15	4	7	8	19
	2		16	8	7	6	21
Irving	1		17	3	5	1	9
	2		18	5	3	3	11
Kenyon	1		19	6	1	2	9
	2		20	4	3		7
Lamont	2		21		2		2
Park	1		22	13	8	11	32
	2		23	10	6	4	20
Monroe	1		24	1	3		4
	2		25	2	4	1	7

cars were able to stay in pace with the signal progression but many fell behind. Tables 1, 2, 3, and 4 are summaries of voluminous, full computer printouts which identify individual vehicles, thus making it possible to trace through the movement of any particular vehicles.

CONCLUSIONS

A working simulation model of an existing, fairly complex traffic location has been constructed. A computer program causes the cars to behave in what seems to be a realistic manner. The cars stop at red lights, they yield the right-of-way at stop signs, they maneuver into correct positions for turns, they move at different speeds, they accelerate and decelerate, faster cars shift lanes to overtake slower cars, they form queues, and they do most of the definable things that cars can be expected to do in city traffic.

The results in no sense indicate a rigorous validation of the model. Up to the present point, reasonableness is the only criterion for judging the performance. Approximately the correct number of cars are accounted for at key points; their characteristics

TABLE 3

SUMMARY OF STATION B COUNTS[a]

Lane	Cars Passing Station B			
	Cycle 1	Cycle 2	Cycle 3	Total
1	20	22	23	65
2	13	18	24	55
3	11	15	21	47
4	18	17	20	55
Total	62	72	88	222
Hourly rate	2,790	3,240	3,960	3,330

[a] Station B is located on 13th Street just north of Lamont Street. Cycle 1 is from simulation-run time 1,036 to 1,355; cycle 2, from time 1,356 to 1,675; and cycle 3, from time 1,676 to 1,955.

as to speed category, type of vehicle, and intended turns correspond with known input data; their average running times are expectedly somewhat slower than that required to keep up with the progressively timed traffic lights. (see Fig. 2)

To get more information bearing on the validity of the model, two steps may still be done. One is to study the movie display carefully to see whether a "helicopter" view of the cars verifies that they are performing correctly. The other is to compare the simulation running times with actual running times from the field.

A point worth bearing in mind is that even though the simulated running times may not be entirely valid in total, a difference in running time to reflect a changed parameter may be highly significant. The reverse is also true. A particular detail of the simulation may not check completely with reality and yet the total result can still furnish a useful measure. Ideally, the simulation would correspond with reality both in detail and in total, but it has value even if one of these objectives is not immediately accomplished.

AREAS FOR FURTHER RESEARCH

The question remains: What constitutes validation of the model? So far, the test of reasonableness is the only criterion that has been applied. When the

TABLE 4

SUMMARY OF VEHICLE RETIREMENT DATA

Cycle	Volume[a]						Distribution of Running Times in ¼ Sec[b]										
	Lane 1	Lane 2	Lane 3	Lane 4	Total	Hourly Rate	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-599	600-649	Total Cars	Avg. Running Time
1	4	6	11	11	32	1,440		4	3	12	2	3				24	365
2	20	16	17	17	70	3,150			3	12	23	9	7	4	2	60	444
3	11	13	17	17	58	2,610			2	15	9	7	5	11	2	51	464
Total	35	35	45	45	160	2,400		4	8	39	34	19	12	15	4	135	437

[a] Of cars retiring at end of 13th Street.
[b] Of cars traversing entire 13th Street course.

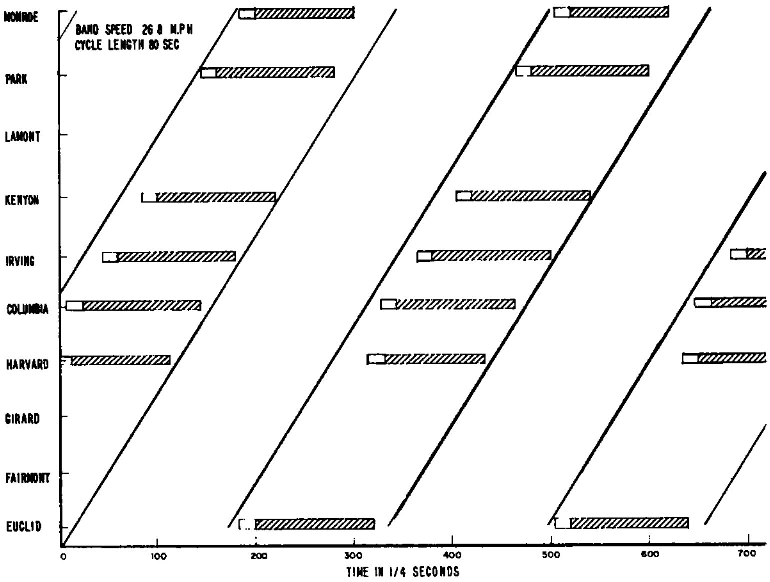


Figure 2. 13th Street signal timing diagram.

performance of the model is accepted as corresponding reasonably closely with actual field conditions, it will be possible to change the parameters and study the new results. From a practical point of view, it is the ability to test untried conditions and to make predictions of likely results that will be the real payoff of simulation as a tool to traffic engineers.

Apart from the immediate objective of getting practical answers for 13th Street are several broader objectives. Study should be made of how to generalize the model in various ways. A model should be made where the main street is two-way rather than one-way. Additional features should be added such as random delay factors, standing vehicles, bus stops, wider range of speeds and acceleration rates, pedestrians, and additional count stations.

Study should be made of what is required to make the model applicable to other locations by "plugging in" different basic data at key points in the program.

Another area of study is the question of how fine the model needs to be to furnish good answers. The present model is very fine. The basic time unit is one-quarter second and the basic distance unit is one-hundredth part of 12 ft (1.44 in). These small units lead to an enormous number of computations even for a high-speed electronic computer. To what extent, if at all, would the usefulness of the results be jeopardized if the model used larger time and distance units? To answer this important research question, it is necessary to use a model that is capable of a fine breakdown. To seek an answer to this question using a coarse model would be impossible.

HISTORY OF PROJECT

The late Professor H. H. Goode of the University of Michigan was one of the first persons to stress the possibilities of digital computer simulation as an aid to engineers in solving traffic engineering problems. He gave a paper on this theme before the Highway Research Board in 1956 (1).

A simple model was constructed under his direction. Each street carried a single lane of traffic in each direction. When cars moved, they all moved at the same speed. In the computer model each car was represented by a single bit. Thus, all cars were regarded as alike and were processed uniformly.

Concept of More Sophisticated Model

It was Goode's idea that instead of describing each car by only one bit it would be possible to represent each car by a whole computer word. In this way the car could be assigned individual characteristics as to speed, type, and destination.

The Bureau of Public Roads entered into an initial agreement with the National Bureau of Standards in July 1958 under which NBS would develop a considerably more advanced simulation model, utilizing several of Goode's concepts.

Selection of 13th Street Site

The 13th Street test site selected is 3,240 ft in length and comprises nine blocks. Seven of the intersections are controlled by traffic lights and three by stop signs. The operation relates to the peak hour of the afternoon rush, when the four lanes of 13th Street are operated one-way northbound.

DESCRIPTION OF METHOD

Each lane of each street is divided into 12-ft sections called unit blocks. Computer storage reserves a place for information about each unit block (UB). If there is a car in a UB, full information about its exact location and its physical characteristics is stored. Another portion of the storage word furnishes any necessary information about the road at that point.

The time cycles for searching all UB's for cars, moving the cars, generating new cars, and preparing any outputs is one quarter-second of simulated real time.

COMPUTER PROGRAM

The basic working program for the IBM-704, including working constants and the input parameters, contains about 6,000 instruction words. The program searches methodically for cars to be processed. Starting at UBO, the first UB in lane 1, the search continues through lanes 1, 2, 3, and 4 of 13th Street, then the lanes of all the cross-streets, and finally the diagonal UB's (for turns).

A Layout and B Layout

The cars are found on what has been called the A layout. To keep matters straight, because it is impossible to process all the cars simultaneously, each car as it is processed is moved to its new position on the B layout. For the remainder of the review cycle the car continues to appear on the A layout in its old position.

When all the cars found in the A layout have been moved to new positions in the B layout, the scanning is completed. Then the A layout is erased and the B layout becomes the starting point for the next scan.

Generation

At the end of each cycle, the car generation routine is performed. If a car is generated, its characteristics are also determined including its destination or "exit." A newly generated car will be launched if this can be done safely. Otherwise, it will be retained on a backlog list for the particular generation point in question until it can be safely launched. Finally the clocks are advanced one quarter-second and the program is ready to repeat the cycle.

Permissible Speed

When a car is found for processing, virtually the first task of the program is to consider the car's desired speed in relation to its present speed and its allowable acceleration rate. Each car carries with it an information package describing various physical characteristics and details.

Sight Distance

When the permissible speed has been determined (in terms of a jump per quarter-second), the equivalent of required sight distance is determined by a table look-up. The program then probes ahead, UB by UB, attempting to achieve the "goal points" necessary to satisfy the sight distance requirement.

Two prime considerations are whether there is a car ahead and whether there is any irregularity about the roadway (such as a traffic signal or a turn). In every case, the key to the information appears in the UB word format (Fig. 3) and can be found by systematic checking of every UB involved (ahead, behind, right, or left as required).

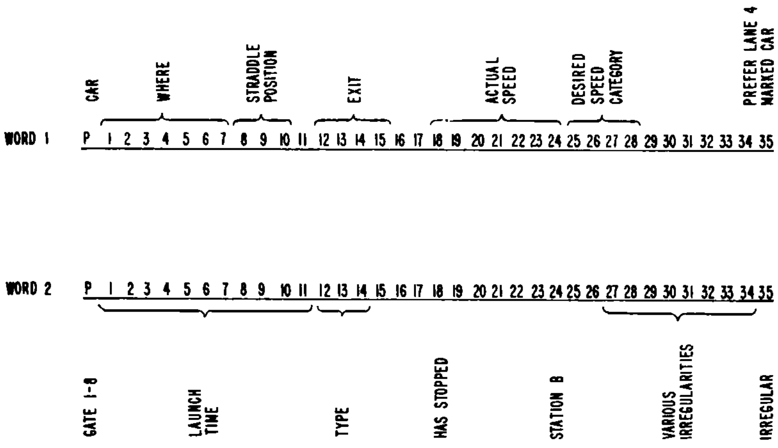
If the goal points can finally be verified, the stated jump can be made (onto the B layout). If the goal points are not adequate, then a table is consulted to determine what reduced jump can be made safely.

Irregular Unit Blocks

During the processing, the program is constantly on the alert to comply with the requirements of any of the roadway "irregularities." If a UB is responsive to a traffic signal, the program must check the signal indication. If there is a turn ahead, the program must test whether the car is intending to turn. If the car passes a count station, it must be properly tallied and clocked. If the car reaches the end of a lane, it must be checked out. A number of other special situations may occur, singly or together. In general, each situation has one or more subroutines which can be called on to determine the proper move. There are 37 main routines, subroutines, and table look-up routines.

ASSUMPTIONS AND PARAMETERS

In many instances, in the absence of specific answers from field data, it was necessary to make certain assumptions or to assign certain arbitrary values to parameters. In most cases, these can be readily changed if desired. These assumptions relate to either one of two areas: the characteristics of the car or the rules governing the movements. Examples of these parameters are the initial lane distribution, the assignment



IRREGULARITY-BIT #35

BEGINNING	34	CROSS FLOW	30
END	33	LAST CHANCE	29
TRAFFIC LIGHT	32	STOP SIGN	28
SIMPLE TURN	31	LEFT TURN	27

Figure 3. Two-word format.

of desired speeds, acceleration and deceleration rates, clearances, criteria for overtaking, reduced speed for going around turns, acceptable gaps, and reaction time.

It is not presumed that this is a validated model but it is a device that works mechanically and, in general, it would be very easy to change any of the parameters when there are authoritative values to substitute.

ACKNOWLEDGMENT

This paper is a greatly condensed version of NBS Technical Note 119, PB 161620, by the same author, entitled "Computer Simulation of Street Traffic."

REFERENCE

1. Goode, H. H., Pollmar, C. H., and Wright, J. B., "The Use of a Digital Computer to Model a Signalized Intersection." HRB Proc., 35:548-557 (1956).