

Traffic Simulator with a Digital Computer

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MANY mathematical models of traffic flow have been advanced in the past. Not all of these models are adaptable to situations involving complicated networks and control systems. A further difficulty is the insufficient number of specially trained traffic engineers who are capable of using these mathematical methods. In general, the design of traffic systems still involves much guesswork.

In the utility industry, as a result of the large investments involved, it is a recognized fact that expensive network analyzing equipments can be bought with full justification. Take the instance of water distribution systems, seemingly obvious guesswork solutions to increase pressure at certain points on a distribution network often turn out to be of little value when checked by a fluid network analyzer. The design of traffic systems, involving a much larger investment, is therefore in need of some form of mechanical computational aids in view of the present inadequacy of hand computing. The use of simulation methods with a digital computer was tried and presented here for the consideration by traffic and computer engineers.

Description of the Simulation System

No fixed pattern is necessary in the use of a digital computer for the purpose of traffic simulation. The following general description may serve as a broad outline and the example tested illustrates in detail a special case. The thoughts in this paper are directed toward highway and street traffic but its use can certainly be adapted to other traffic systems.

The first step is to divide the roadway into unit car-lengths (UCL). By UCL is meant the length of an average car. The space occupied by a rectangle one UCL long and one lane wide is called one unit block (UB). Each UB may contain one car or none. The cars can only move in a

discrete fashion. For most purposes, it is sufficiently accurate to allow the cars to move an integral number of UB.

There is the question of simultaneity, which cannot be easily simulated with a general-purpose digital computer. It is practicable, however, to divide time also into discrete intervals and allow the cars to move one at a time, according to some previously assigned order, during that interval of time. If the time interval is short enough, an approximation of the real situation results.

The cars move according to their own behavior, subject to the constraints of the traffic control systems. Both the behavior and control system may be functions of location, time, and traffic conditions. In addition, the behavior of cars may also be functions of some random processes. In the case when both behavior and control system are functions of traffic conditions, there is a rather complicated interaction between the two.

The computing program may be divided into several more or less independent parts. In other words, each part may be changed relatively independently of the others.

1. DESCRIPTION OF THE ROAD SYSTEM

This part can be handled similarly to an electric network,¹ once the road is divided into UB. Each UB may be considered as a junction and oriented lines join these junctions for all permissible car movements.

2. CONTROL SYSTEMS

For a given road system, the control system can be varied independently to

test the efficacy of a given control system.

3. CAR OR DRIVER BEHAVIOR

These can be obtained by psychological tests or by statistical methods. Since the behavior varies according to external circumstances such as weather, effect of holiday, etc., this part of the program should also be capable of being independently modified.

4. DATA HANDLING

The final portion of the program is the main routine which sets the cars in motion and gathers the desired information. Because the desired information varies, it is obvious that this part of the program must be capable of being modified independently of the other parts.

The construction of the above parts of the program is admittedly a time-consuming affair. However, once it is available, traffic engineers can use this particular computing system similarly to a network analyzer. The advantage of a direct analogue cannot be denied.

Tests and Results

A very small example of the aforementioned system was tried on the Institute for Advanced Study machine. As a result of the limited time and effort available, the program was made for this special case, which is considerably less elegant than the clean separation described earlier.

The road system under test is a section of a 12-lane boulevard with six lanes for traffic in each direction. Fig. 1 shows the configuration under study and Fig. 2 shows how it is divided into UB and then enumerated so that it can be handled like a network. The UCL is chosen approximately 18 feet so that the speed of the cars assume discrete levels each 12.5 miles per hour (mph) apart.

From each UB, three directions of motion are permitted, these are diagonal left, straight, and diagonal right. Of course in the case of lane 0, for example, diagonal left motion cannot be made because of the limit of the road.

The time step is chosen to be 1 second, so that when the velocity $V=0,1,2,3,4, \dots$ UB, they correspond to 0, 12.5, 25, 37.5, 50, . . . mph. The information about the presence or absence of a car and the behavior and records of the car is carried in a word stored at a location in the memory corresponding to the enumeration in Fig. 2. For each time step, the cars are moved one at a time in the order of enumeration, according to a set of rules. The set of rules can best be illustrated by

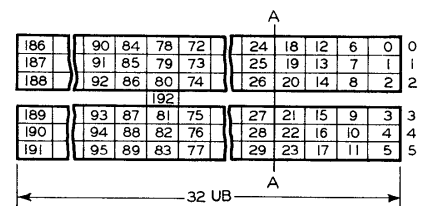


Fig. 1. Road section under study

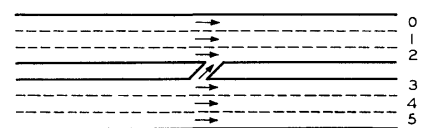


Fig. 2. Method of division and enumeration

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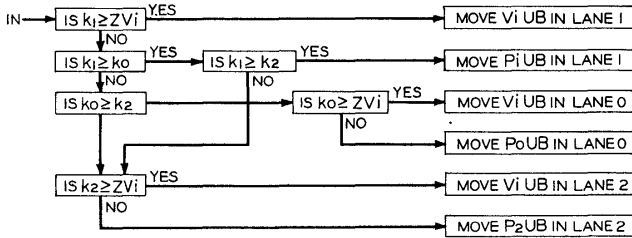


Fig. 3 (left). Program for rules governing lane 1

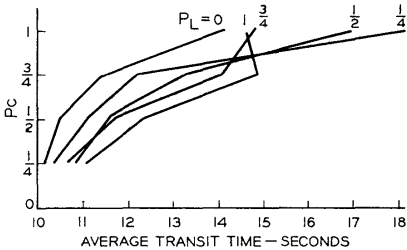


Fig. 4. Effect of left turn cars

the portion of program governing lane 1, which is shown in block form in Fig. 3.

At the end of each time step, a mechanism generates a random number x for each lane, and whether a car should appear or not at the input depends on whether x is less than a constant P_c or x is greater or equal to P_c . Both x and P_c lie between zero and one. If a car should appear at the input of a certain lane, a similar mechanism decides what the intended speed should be according to some previously decided distribution. In this particular case, the distribution used for speeds of 25, 37.5 and 50 mph are 0.25, 0.5, and 0.25, respectively. A storage pool is provided for each lane; if a car cannot be introduced, this car will be introduced at the next time step. The waiting time in the storage pool is not counted.

The gap between lanes 2 and 3 is provided for cars in the right-hand section to be transferred to the left-hand section,

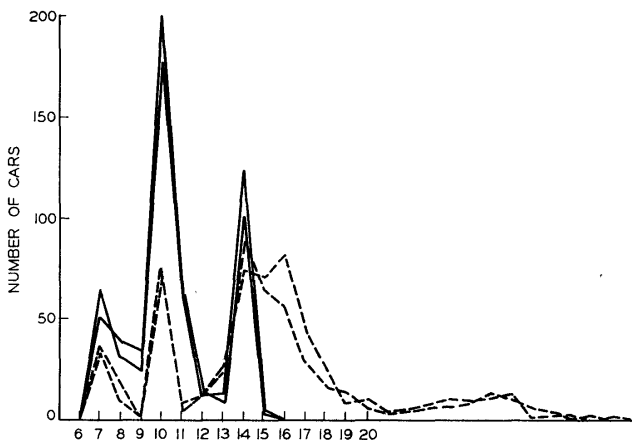
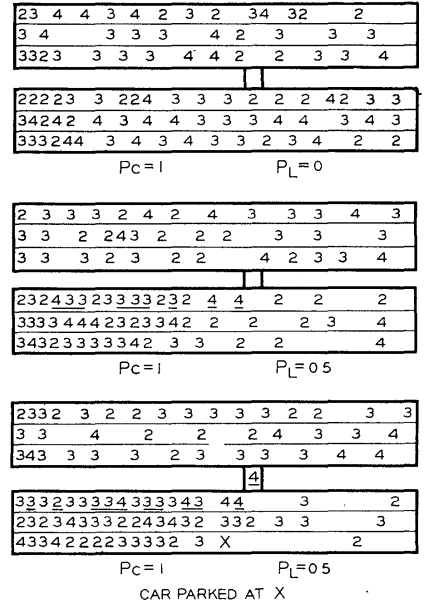


Fig. 6 (right). Typical traffic pattern

Numbers indicate intended speed
Left cars underlined



and for that purpose only. It was assumed that cars intending to make the left turn at the gap would choose lane 3 initially. Therefore, as a special addition, cars that originate at the input of lane 3 go through a further decision process by comparing a random number x with a constant P_L to decide whether the car intends to make a left turn or not. When x is less than P_L , the car intends to make a left turn. For a left-turn car, no overtaking of other cars will be made, so as to make sure of reaching the gap. When a left-turn car reaches UB93, V is reduced to 12.5 mph until it reaches UB74.

Each car also carries its own clock whereby the transit time between input and the line AA is recorded. At the end of each time step, all cars that have traveled beyond line AA are counted and their clock examined so that a tally is made on a distribution plot. The cars beyond AA are then wiped out and a new time step initiated. After an arbitrary number of 512 cars has passed, the distribution plot is printed out and the average transit time calculated. In this fashion, one may plot the average transit time against P_c for various values of P_L , as shown in Fig. 4. Note that transit times for $P_c=1$ follow a different trend than other values of P_c . For the curve corresponding to $P_L=0$, that means no left turn is permitted. The foregoing study therefore gives a quantitative study of how much increase in transit time was caused by the left-turn gap.

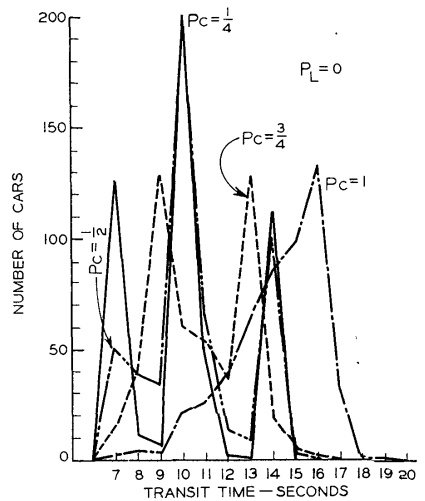
To check the variance between independent experiments in a qualitative fashion, the distributions of transit times of two sets of two experiments each are plotted in Fig. 5. It can be seen that the experimental results are not random.

Fig. 6 shows typical traffic patterns which are analogous to aerial photographs. Successive patterns then resembled a series of time elapse pictures. Figs. 7 to 11 are distribution plots of transit times for various values of P_c and P_L . As P_c increases, less and less cars can maintain their intended speed. By the use of these distribution curves, perhaps a "pleasure factor" can be derived to measure the ability of cars to maintain their intended speed on a given road.

The foregoing example is of course based on rather arbitrary rules of behavior and therefore can be viewed only in a qualita-

Fig. 5 (left). Comparison of independent experiments

Fig. 7 (right). Transit time distributions



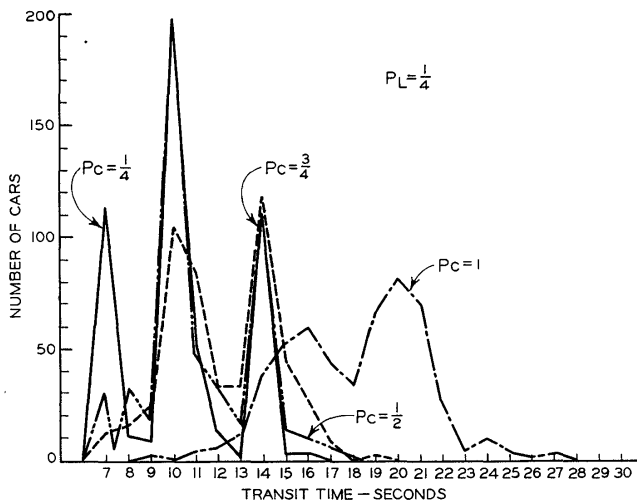


Fig. 8

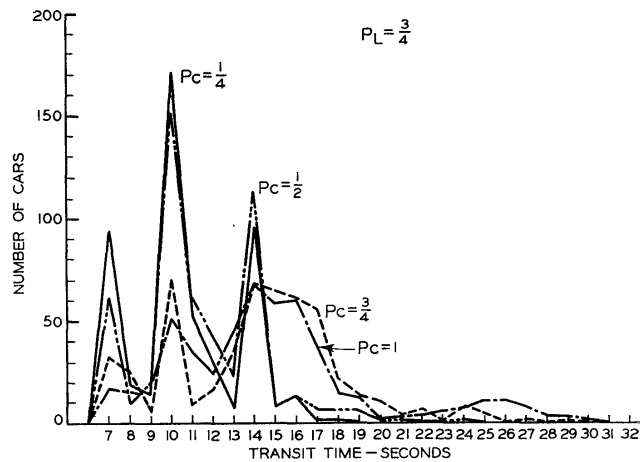


Fig. 10

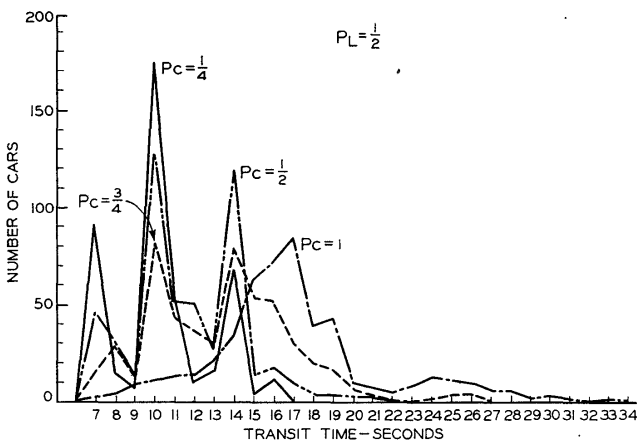


Fig. 9

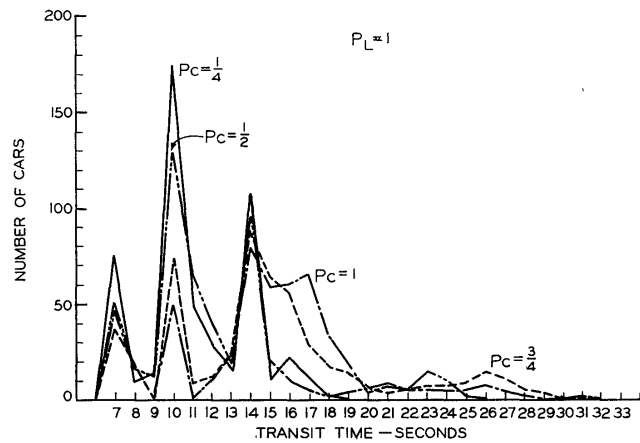


Fig. 11

Figs. 8-11. Transit time distributions

tive manner. There is no reason why a more realistic set of rules cannot be substituted. In any case, the traffic engineer can certainly make use of the type of information obtained to design a good road.

This problem was calculated with the machine running at a memory-access time of 125 microseconds, about one fifth of its normal speed. One time step (1 second) requires 1.7 seconds to complete. With the large capacity and high speed machines now coming into being, speed of computation required should

not be regarded as a limiting factor.

Conclusions

This paper has shown, by way of an example, that it is practicable to program the digital computer to solve traffic problems using only elementary arithmetics. When properly programmed, the traffic engineer should be able to use a digital computer similarly to the way an electrical engineer uses the network analyzer. It is hoped that this paper will bring the computer engineer into closer co-operation

with the traffic engineer for a better study of this important everyday problem of traffic.

References

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