Application of Digital Computers in Traffic Signal Systems

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INTRODUCTION

Urban environments are experiencing severe traffic congestion today on their roadway systems especially during peak periods in central business districts, major traffic generators, etc. The increasing auto travel in this country, during the last two decades, has almost throttled the free movement condition of auto traffic on our roadway system—especially in major cities.

Use of Only Three Timing Patterns Common

We have been expending efforts in improving our roadway facilities. Some expenditures have also been made in updating and improving traffic signal control systems. However, it seems that our major emphasis has been in the hardware technology in our control system, rather than fully utilizing the ultimate efficiency that can be achieved with the existing state-of-the-hardware technology by optimal design of traffic control systems. Several communities across the nation have shifted to computer-controled traffic signal systems while they were operating at one, two, or at the most, three different timing plans as a fixed-time system. With a three-dial controller and interconnected system, it is possible to have three different cycle lengths, three different splits and nine different timing patterns. Nine different timing patterns can probably handle, in the majority of urban environments, the variations in traffic demand experienced over any 24-hour period. Figure 1 indicates a typical distribution of traffic demand at a roadway section.

A national breakdown of a demand rate indicates that having the capability of nine different timing patterns, it is possible to operate under fixed-time control and still be very close to a demand-responsive system. Another question comes up at this point—the variation in traffic demand between days of the week, variation in weather conditions and also

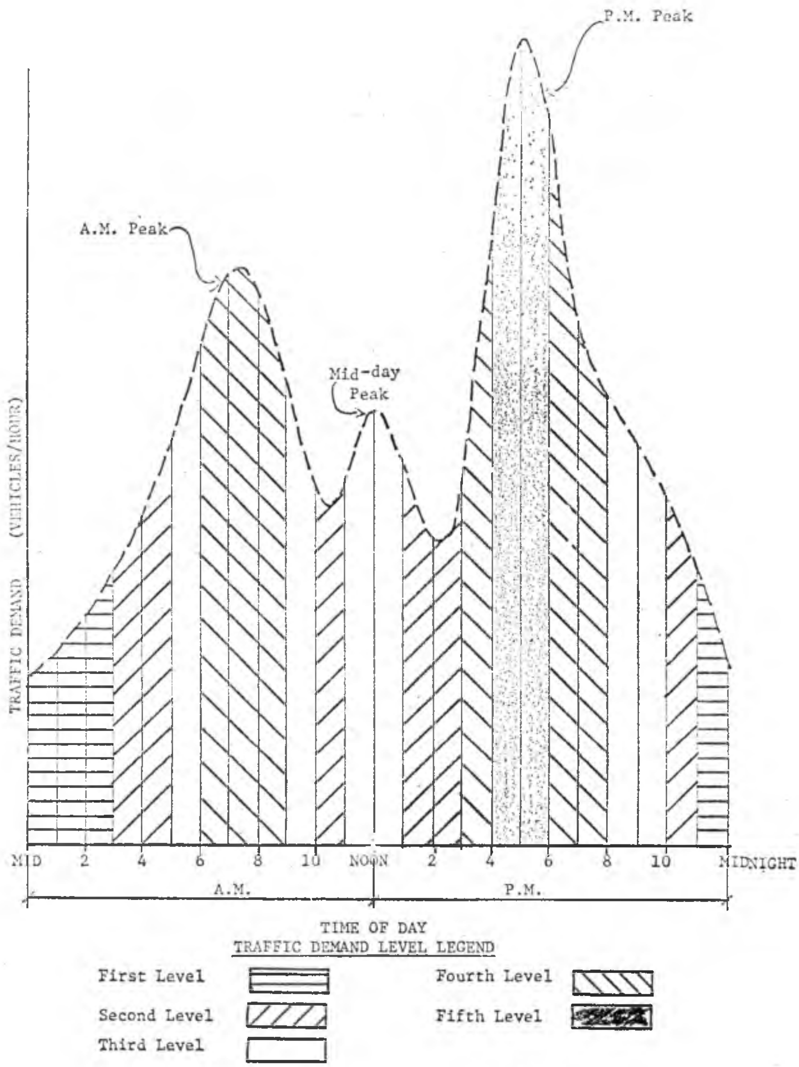

Fig. 1. Typical Traffic Distribution.

seasonal variations. An extensive study of a signal system may produce timing patterns which can take care of all the above variability even on a fixed-time basis and be close to a demand-responsive system. However, the man-hours necessary to design and to change the controller settings for a fixed-time interconnected system which can handle hourly, daily, seasonal variations and variations due to weather conditions is prohibitive. As such, most communities operate with one, two or three timing patterns the year round.

COMPUTERS AND TRAFFIC SIGNAL SYSTEMS

The development of computer technology has opened doors to the traffic engineers for efficient timing pattern design for signal systems in urban environments. A computer can serve two basic functions in the field of traffic signal systems: design of optimal timing patterns and control of traffic signal controllers in real-time systems.

In view of the current energy problem, it is essential that our emphasis be on improvement in traffic control strategy rather than street widening programs to increase the productivity of our existing facilities. This does not preclude the fact that there will always be a need for street widening, alternative route construction, intersection improvements, etc., at specific locations. However, more thorough analysis and and testing may be necessary to justify a widening project now than ever before. This juncture of time needs, more so than ever, emphasis on use of our know-how in the design and operation of optimal signal control strategy.

Most Cities Use Manual Methods for Designing Timing Patterns

A recent study (NCHRP project no. 3-18 (2)) indicated that urban evironments, with populations under 500,000, have used more operational schemes to alleviate traffic congestion problems. The same study also indicates that almost all cities under 50,000 population use manual (hand) methods for designing timing patterns for traffic signal systems. The same trend is true for all cities.

This study brings forth the fact that traffic engineers responsible for managing our urban environments tend to rely more on their intuition and past experience, rather than utilizing digital computers. Often intuitive design of signal timing plans do not work, and we tend to conclude that physical improvement is necessary. On the other hand engineers using computer programs for timing-plan design sometimes fail to recognize the feasibility parameters, and when such plans are implemented, they fail to perform the control functions as expected. Thus reliance on computer design decreases. It is a fact that manual design of traffic signals in our urban scene is inefficient, expensive, inadequate and should be eliminated as far as possible.

Early Failures in Use of Computers Slows Extensive Use

In the past, the signal timing design (manual-graphical) function was mostly restricted to single arterial streets. That is why we find today, wherever there is a crossing of two major arterial streets, traffic in one must stop. During the last decade, there has been considerable effort in the development of software technology for designing optimal signal-timing patterns for flow in two directions and networks of such streets. Some of the programs are quite flexible and efficient. However, the experience in the traffic engineering community, with some of the computer-aided systems, is not too good. This contributes to low utilization of computer applications in the design process and increases reliance on intuitive manual design. Most computer programs ignore the criteria of feasibility of a timing plan before optimizing.

Models Neglect Important Traffic Variables and Interrelationships

The unfeasibility sometimes arises because the models neglect important traffic variables and their interrelationships. Most programs use speed as a single parameter in determining the optimal signal-timing plans for progressive speed in linear and network systems.

Feasible Speed by Floating-Car Method Still in Use

Some communities, which still follow basic manual design of signal-timing plans, use continuous checks on feasible speed for specific demand levels (generally, hours of day and night) by the floating-car method. The progression systems obtained in such areas work fairly well. This, of course, is not due to manual design, but due to recognition of progression speed as criteria for feasibility.

Must Understand Interrelationships—Speed, Volume, Density

The characteristics of a traffic stream cannot be fully understood without a thorough knowledge of the major factors, which, either singly or in combination, influence the movement of vehicular traffic in our roadway systems. These relationships impose an added degree of complexity and require an acknowledgment of the inseparable relationships of the variables in finding a feasible solution in signal-progression models.

Speed (U), volume (Q) and density (K) are the three basic traffic flow variables which are interrelated under all conditions. The flow of vehicular traffic on a roadway depends not only on the geometrics of the road, but also on the environment (type of roadside developments, roadside appurtenances, signs, etc.) and traffic conditions.

The relationship of Q-K-U is of extreme importance in the determination of capacity of a roadway. To be precise, the capacity of a roadway must be referenced on the basis of each section of a roadway. This location bias characteristic of the Q-K-U relationship is caused by the variability of driver behavior to changing geometric, environmental and traffic conditions. Since the Q-K-U relationship defines a specific roadway capacity as a function of speed, this relationship is an essential factor in the proper operation of a progressive-signal system. The effect of this relationship on the design of the optimal timing plan becomes increasingly critical as the volume increases.

Percentile speed (speed limit) may be feasible for certain hours of the day. The driving behavior of the majority of the motorists are such that even during a very low traffic volume condition, they seem to drive at or little above the speed limit on a roadway assuming the speed limit is based on observed percentile speed and not an arbitrary set up.

TRASOM — TRAFFIC SIGNAL OPTIMIZATION PROGRAM — COMPUTER MODEL

"TRASOM" (Traffic Signal Optimization Program) is a computer model developed by Goodell, Grivas & Assoc., Inc. of Southfield, Michigan, which performs the function of designing optimal signal-timing patterns for either single arterial streets or for a network of arterial streets. This program also determines the traffic performance characteristics for selected timing plans. If it is observed from the traffic survey that a street has considerable variation in demand (volume), and an associated speed condition over its length in the system, it is broken down to two or more parts to obtain variation in progression speed. However, same progression speed is obtained for each section of roadway unless broken down in sections. If, on the other hand, a traffic engineer wants to have a change in progression speed from one link to another, each link shall be coded as a separate section. It is, however, strongly believed by the author that a change in progression speed shall only be affected in one roadway where there is considerable difference in volume rate and operating speeds. Unwarranted change in speed often results in what are known as shock waves in the platoon of traffic, due to sudden acceleration and deceleration, and thus increases rather than decreases congestion. This program also produces a time-space plot by means of a Calcomp plotter.

Another problem often occurs during the implementation stage of a signal system—interference of offset keys with the amber keys and/or the left-turn signal key in the traffic controllers. Historically, traffic engineers prepared a cam chart from the time-space diagrams and, if confronted with such a problem of interference, have the offset key moved from the danger zone. This shifting often cuts down the progression band which may cause failure in traffic operation. A TRASOM model goes through the process of determining all key locations for controllers and all dials in the system for a completely interference-free situation without sacrificing the progression band. This is a laborious process of search and is best suited for computers.

Data Required for TRASOM model

1. *Distance between intersections*—The actual spacings in feet of all traffic signals in the system.
2. *Intersection counts*—Traffic counts at all intersections in the system, with a 24-hour distribution for all days, weather and seasonal conditions.
3. *Lane utilization*—This data provide input for determining the effective number of lanes, which in turn determine the critical lane volume.
4. *Turning movement*—Turning movements for all time periods for all intersections.
5. *Roadway capacity*—Roadway capacity and assumed level of service provide a check on the development of the speed-volume function.
6. *Speed and volume data at selected sections of roadway*—Speed and volume data for small segments of time are necessary to establish the speed-volume relationship for each roadway.

   The spot-speed checks and corresponding volume counts must be selected so that a wide range of flow (very low to very high near capacity) is covered in the data points.

   Selecting the location for speed-volume data collection is extremely important, since it has to be at a location where existing signals and other means of traffic control devices do not influence the traffic characteristics.
7. *Roadway geometrics*—Detailed data regarding roadway geometrics such as approach width, number of through lanes, turning lanes, etc., are necessary for the operation of TRASOM.
8. *Special features*—Any special features such as multi-phase signals, special left-turn phase, special turning prohibition, etc., can be incorporated in the model.

Core Requirement of Model—Size of Network

The TRASOM program is written in Fortan IV and has been developed on an IBM Model 67 computer. The core requirement for the model depends on the size of the network under investigation. One project completed utilizing TRASOM involved a network of 200 signals covering an area of 36 square miles in southeast Oakland County, Michigan. This project required about a 105K core and three direct-access, input-output files. The approximate CPU time used was 160 seconds including preparation of data for the plotting module for one level of demand and seven different cycle lengths.

Same Program Used for Optimizing a Linear Street

The same program can be used for optimizing a linear street with a similar set of input data. Approximately CPU time required for a 20-signal linear street is 20 seconds. This includes solutions for seven different cycle lengths and corresponding data preparation for the plotting module.

TRASOM Model Output Identifies Optimal and Alternative Feasible Timing Plans

The TRASOM model output identifies the optimal and alternative feasible timing plans for a given set of predefined criteria. The selection of optimality is based on the function specified by the analyst.

Other Items Identified by Output Format

The output format identifies the signal numbers, names of cross-streets, distances between intersections, approach volumes, etc., at all the cross-streets for each linear system (see Table 1 and Figures 2 and 3). Table 2 describes a complete signal-timing plan including offsets, splits and left turning phases wherever warranted based on queuing characteristics for left turning traffic. Table 3 shows the statistic of the expected traffic parameters associated with the timing plan described in Table 2. These statistics include expected left-turning-queue length for all approaches, average delay at all approaches, the average number of stopped vehicles at each intersection and average per cent thruput on the main street. These systems performance parameters are obtained analytically for the purpose of system comparison and evaluation only.

OTHER NETWORK OPTIMIZATION PROGRAMS AVAILABLE

There are several other network optimization programs available today which are quite flexible. One of them is SIGOP, developed under contract by the Federal Highway Administration and is available at a very nominal cost.

The costs for utilizing any computer program for design of timing plans is insignificant compared to man-hours which will be necessary to perform the same level and number of plans by hand.

TABLE 1

Name of Linear System ....Southfield
Direction One ....North Bound Traffic
Direction Two ....South Bound Traffic
Time of Traffic ....7:00 a.m. to 8:00
Cycle Length ....80.0 Sec.

	Thru Band Percent	Intersections Lead	Intersections Trail	Suggest Speed		Demand Volume	Feasible Volume	Limiting Inter.
Dir.—1	26.5	5	7	49.2	34	968.	1440.	0
Dir.—2	26.5	7	5	44.4	30	1214.	1342.	0

Signal Number	Distance (Feet)	Street Name	Total Approach Volume/Hour Dir.—1	Dir.—2	X—St.	System Priority (Rank Ordered)
1		Mich. Bell	2032.	2628.	112.	**
	428.					
2		Mt. Vernon	1559.	2550.	286.	**
	2634.					
3		Ten Mile	1656.	2097.	822.	**
	2670.					
4		10.5 Mile	1395.	1682.	113.	**
	2680.					
5		Eleven Mile	1052.	1637.	658.	**
	2208.					
6		Golden Gate	1260.	1577.	42.	**
	3086.					

7		Twelve Mile	1118.	1420.	972.	4
	1990.					
8		Southfield Plaza	1356.	1400.	2.	**
	850.					
9		Webster	1129.	1327.	87.	**
	2560.					
10		Thirteen Mile	1322.	888.	973.	**
	2698.					
11		Beverly	911.	1164.	88.	**
	1330.					
12		Dunelaine	873.	1103.	15.	**
	1327.					
13		Fourteen Mile	904.	722.	507.	1

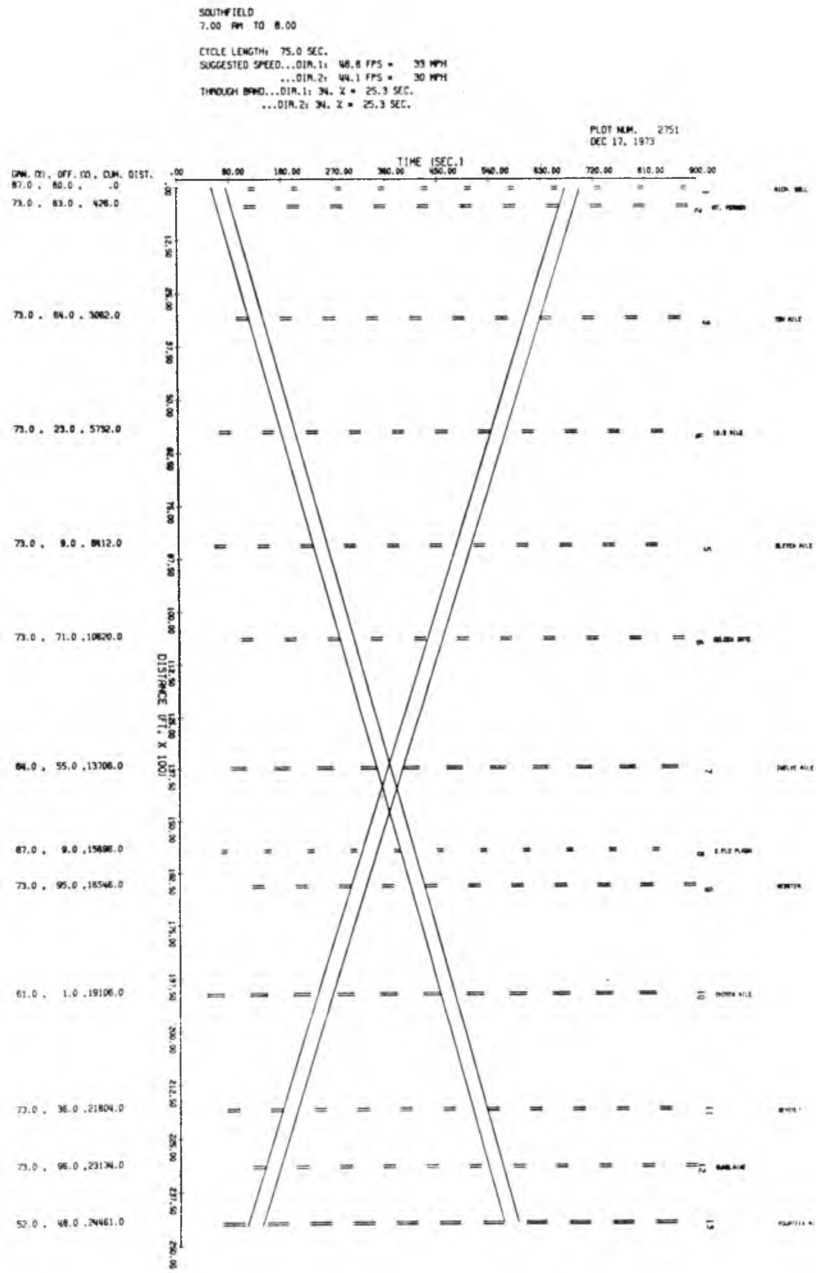
SOUTHFIELD
7.00 AM TO 8.00
CYCLE LENGTH: 75.0 SEC.
SUGGESTED SPEED...DIR.1: 48.8 FPS = 33 MPH
...DIR.2: 44.1 FPS = 30 MPH
THROUGH BAND...DIR.1: 34. % = 25.3 SEC.
...DIR.2: 34. % = 25.3 SEC.
PLOT NUM. 2751
DEC 17, 1973
TIME (SEC.)
DISTANCE (FT. X 100)

Fig. 2.

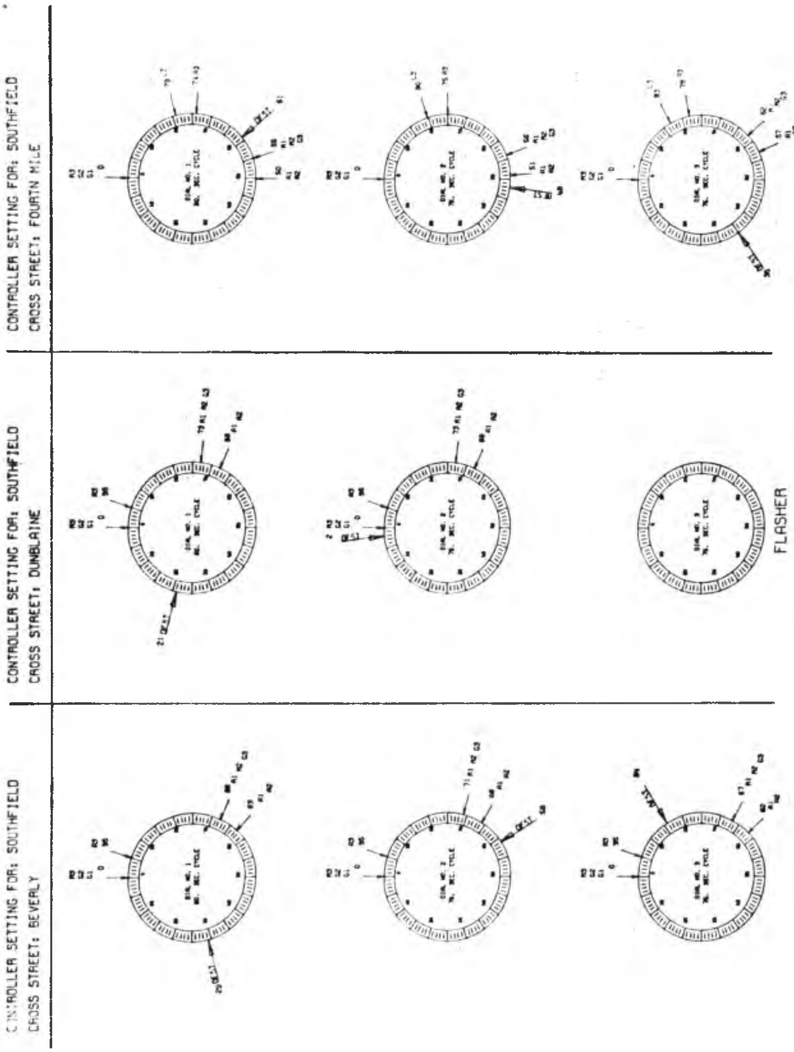
CONTROLLER SETTING FOR: SOUTHFIELD
CROSS STREET: FOURTH MILE
CONTROLLER SETTING FOR: SOUTHFIELD
CROSS STREET: DUNBLAINE
CONTROLLER SETTING FOR: SOUTHFIELD
CROSS STREET: BEVERLY
FLASHER

Fig. 3.

TABLE 2—(SIGNAL TIMING PLAN)

Signal	Selected Offsets		Green Splits				Splits for Turning Movement											
			Direct. 1		Direct. 2		Direct. 1				Direct. 2				Cross St.			
Number	Seconds	Percent	Grn.	Red	Grn.	Red	Grn.	Amb.	Left	Red	Grn.	Amb.	Left	Red	Grn.	Amb.	Left	Red
1	29.0	36.3	70	10	70	10	66	4	0	10	66	4	0	10	6	4	0	70
2	19.0	23.8	60	20	60	20	56	4	0	20	56	4	0	20	13	4	3	60
3	14.0	17.5	60	20	60	20	56	4	0	20	56	4	0	20	11	4	5	60
4	60.0	75.0	60	20	60	20	56	4	0	20	56	4	0	20	16	4	0	60
5	43.0	53.8	58	22	58	22	54	4	0	22	54	4	0	22	14	4	4	58
6	7.0	8.8	60	20	60	20	56	4	0	20	56	4	0	20	16	4	0	60
7	40.0	50.0	51	29	51	29	47	4	0	29	47	4	0	29	20	4	5	51
8	76.0	95.0	70	10	70	10	66	4	0	10	66	4	0	10	6	4	0	70
9	48.0	60.0	60	20	60	20	56	4	0	20	56	4	0	20	16	4	0	60
10	79.0	98.8	49	31	49	31	45	4	0	31	45	4	0	31	21	4	6	49
11	75.0	93.8	60	20	60	20	56	4	0	20	56	4	0	20	16	4	0	60
12	68.0	85.0	60	20	60	20	56	4	0	20	56	4	0	20	16	4	0	60
13	38.0	47.5	42	38	42	38	38	4	0	38	38	4	0	38	23	4	11	42

TABLE 3—(SYSTEM PERFORMANCE PARAMETERS)

Signal Number	Average Queue Length Per Cycle (Veh.) For Left Turning Only Nor. Leg	Sou. Leg	East Leg	West Leg	Average Delay Per Veh. (Sec.) Nor. Leg	Sou. Leg	East Leg	West Leg	Average Intersection Delay Per Veh.	Average Percent Thruput	Average Number Stopped Vehicles (Dir. 1 + 2) Per Cycle	Progression Speed M.P.H. Dir. 1	Dir. 2
1	0.0	0.0	0.0	0.0	5.16	2.87	6.69	6.69	5.35	84.22	16.14	34	30
2	0.0	0.1	11.7	11.7	4.22	5.63	5.94	5.94	5.43	80.52	18.64	34	30
3	0.1	2.2	14.2	14.2	8.24	5.97	16.19	16.19	11.65	88.74	8.73	34	30
4	0.0	0.0	4.9	4.9	6.07	5.11	1.85	1.85	3.72	85.45	9.92	34	30
5	0.3	0.0	12.7	12.7	7.09	5.02	14.25	14.25	10.15	87.42	7.68	34	30
6	0.1	0.1	0.1	0.1	5.69	4.73	23.42	23.42	14.32	86.50	8.42	34	30
7	3.7	0.3	14.8	14.8	9.38	7.91	12.15	12.15	10.40	90.26	5.35	34	30
8	0.0	0.0	0.0	0.0	1.80	1.74	30.68	30.68	16.22	86.47	8.29	34	30
9	0.0	0.0	0.1	0.1	4.91	4.40	23.46	23.46	14.06	87.99	6.58	34	30
10	0.1	1.7	15.2	15.2	8.78	10.88	12.16	12.16	10.99	90.55	4.71	34	30
11	0.0	0.1	0.2	0.2	4.48	3.91	23.47	23.47	13.83	90.81	4.27	34	30
12	0.0	0.0	0.0	0.0	4.33	3.83	22.83	22.83	13.45	91.21	3.95	34	30
13	0.2	0.1	24.9	24.9	12.12	13.26	8.99	8.99	10.84	95.39	1.72	34	30

System efficiency = 50.44%

HISTORY AND USE OF COMPUTERS AS TRAFFIC CONTROL TOOL

Digital computers became available as a traffic control tool in the 1950's. The first application of digital computers in the control function of area-wide traffic signal systems occurred in Toronto, Canada in 1959. Since then several communities across the country have used the computer-controlled traffic signal system, and a considerable number of urban communities are preparing to go for it now.

Use of First Generation Computer-Controlled Systems

Interpreting and analyzing detected traffic parameters like: speed, volume, occupancy, etc.

Searching from tables of timing patterns previously designed for incremental demand conditions the optimal timing plan for the detected level of demand.

Sending appropriate signals to the controllers for implementing selected timing patterns.

Monitoring the implemented plans.

Accumulating, analyzing and summarizing traffic data for off-line analysis.

Detecting equipment failure and reporting in the form of printed copy and audible alarm, etc.

Use of Second Generation Computer-Controlled Systems

The second generation of computer-controlled traffic signal systems perform on-line design of optimal signal-timing plans for the entire and/or part of a system besides the functions as noted in the first generation system. Figure 4 shows a typical diagram for a computer-controlled traffic signal system. Use of a digital computer as a traffic control tool is relatively recent; however, analog computers have been in use for quite some time. Still, communities with a limited number of signals tend to favor an analog system rather than a digital computer system. Some of the package systems offered by system suppliers today are so compact and easy to operate and maintain that it is worthwhile to use digital computers for even 20 to 30 signals as a system.

New Mini Computers

In recent years the manufacturers of digital computers have developed mini computers with a memory capacity from 4^K. This enabled the system designers to put together compact small systems. The communication system consists of controller and computer interface units,

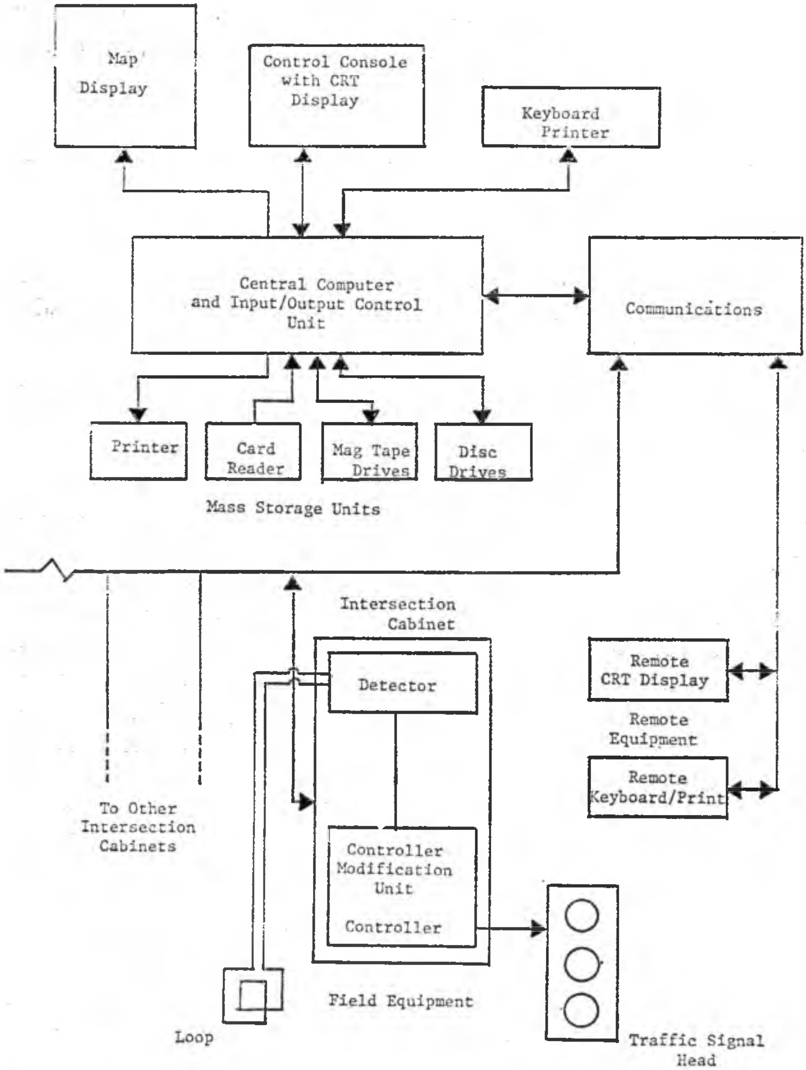

Fig. 4. System Block Diagram.

and communication interconnection. The interface units are mostly solid state and are purchase items. The interconnection can be either owned lines or leased telephone lines. Type of multiplexing used through a communication line may be either frequency-division multiplexing or time-division multiplexing, both having advantages and disadvantages.

The computer and peripheral equipment may be as simple as an 8^K central processor, secondary storage, teletype and map display to any level of sophistication as may be desired.

The Software Package Must Be Efficient

The software package for a real-time system varies from simple control programs and selection routine to a very sophisticated software package like a UTCS* package.

It is important to recognize that a computer-controlled traffic signal system becomes successful only when the software package which controls the controllers and designs the timing patterns are efficient. The first-generation type, computer-controlled systems consist of selecting optimal timing patterns from stored data. They are quite simple and may prove to be quite efficient for smaller systems.

The UTCS software package covers most aspects of computer-control systems quite comprehensively and is available at a nominal cost. This package, however, requires a larger central processor unit as compared to some of the commercial software packages supplied by system contractors. The UTCS package is quite comprehensive and can be tailored to specific needs by persons having proper know-how. It is unfortunate that there have been so many efforts expended to date by individual commercial houses to develop similar computer programs in the field of computer-control systems. Most of them are similar in function and no significant improvements have been made in terms of traffic control capability. The effort was concentrated towards coming up with a computer package which requires minimal CPU memory and is simple to work.

Investigate Monetary and Nonmonetary Consequences

The feasibility of a computer controlled traffic signal system should investigate both monetary and nonmonetary consequences for a local municipality, roadway users and non-users. In the light of the energy crisis, the significance of a computer-controlled signal system is more meaningful. Granted, there will be a change in the gradient of the ever increasing highway-travel-demand curve, still minization of delay, number stops, etc., have more benefit now than ever before. A recent study performed by the author in the Detroit metropolitan area indicated that there is considerable saving in gasoline driving on thru-roadways (without stopping) which have a progessive timing pattern as

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* Urban Traffic Control System. Developed under contract by the Federal Highway Administration.

TABLE 4A COSTS OF COMPUTER-CONTROLLED SIGNAL SYSTEM

City	No. of Intersect. in the Sys.	Capital Costs in Dollars	Annual Maint. Costs in Dollars	Estimated Annual Savings in Dollars	Time to Surpass Capital Outlay
Toronto	864	5,000,000	297,000	20,000,000	< 6 months
San Jose	59	1,000,000	Not Available	264,000	< 6 years
Wichita Falls	77	128,000	11	450,000	< 6 months
West London	100	1,540,000	103,600	Not Available	

TABLE 4B REDUCTIONS IN SYSTEM PERFORMANCE DATA

City	No. of Intersect. in the Sys.	Percent Reduction: Delay	Stops	Accidents	Travel Time
Toronto	864	20	53	13	44
San Jose	59	12	7	Not Available	Not Available
Wichita Falls	77	18	8	9	Not Available
West London	100	18	Not Available	18	9
New York	433	30	30	Not Available	20-40

opposed to a signal system which allows speed changes along its route and the motorists stops due to non-existence of a progressive timing plan or unfeasible timing plan implemented.

Costs of Computer-Controlled Systems Highly Variable

Costs of computer-controlled traffic signal systems vary considerably depending on the nature and specifications of individual projects.

Some system contractors can offer a complete system package for 20 to 25 signals for $125,000 to $135,000—the same system may cost as high as $200,000 with others for use of some sophisticated hardware. Tables 4A and 4B indicate costs and benefits estimated for four-computer-controlled systems[1]. The savings are based on the cost of a vehicle stop of 0.74 of a cent, vehicle idling cost of .008 of a cent per second and 0.043 of a cent for each second of the driver's time ($1.55 per hour). Each accident was estimated at $500. These cost rates are probably quite conservative in light of today's costs level.

CONCLUSION

Increasing traffic congestion and delay on our roadway system warrants emphasis in the traffic control aspects to increase the productivity of our existing roadway facilities. Application of computers in the design, operation and control of signal systems provides effective and efficient means for roadway traffic control. Substantial benefits can be derived by using computers in generating feasible and optimal timing patterns for a fixed-time-interconnected system.

A digital computer-controlled signal system, as exists today, can vary from as small as 20—30 to 700—800 intersections. The software and hardware technology is available. Emphasis has been largely on the control aspects of such a system rather than performance. There are considerable cost savings by using digital computers both in fixed-time and real-time signal systems.

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[1] Source of data—the Federal Highway Administration Publication "Selecting Digital Computer Signal Systems."