SIMULATION OF GARLAND, TEXAS, VEHICULAR TRAFFIC USING CURRENT AND COMPUTED OPTIMAL TRAFFIC SETTINGS

Frank P. Testa
Mark Handelman

Surface Transportation Systems Department
Federal Systems Division
INTERNATIONAL BUSINESS MACHINES CORPORATION

Abstract

This paper presents results of a study utilizing computer simulation of vehicular traffic in the downtown area of Garland, Texas. A general discrete digital simulation model, the Vehicle Traffic Simulator (VETRAS), developed by IBM Corporation, was used for the simulation. Using data supplied by the City of Garland, traffic patterns for three peak periods of daily operation–A.M., Noon, P.M.–were simulated. Two simulations were run for each period. In the first, intersections were controlled with signal settings currently in use in Garland. In the second, intersections were controlled by signal settings derived via a pattern optimization algorithm. A minimum interference technique was used to compute coordinated signal settings and offsets to maximize arterial and network performance.

The results show that arterial and network performance improves in each of the peak periods using the computed signal settings. Further, there is a direct relationship between volume and relative improvement. Estimated cost benefits for these improvements are also presented.

THE PROBLEM

The city of Garland, Texas is considering the implementation of a real time computer system for control of its vehicular traffic. Traffic signal patterns corresponding to peak periods, weekends, special events, etc., would be generated, using a traffic responsive optimization technique. The system would select and apply the appropriate pattern for a given situation in response to actual traffic demand. Data gathered by the system from online traffic detectors would be used to update the patterns. In addition, the system would monitor and report traffic network performance.

A means was sought to quantify the expected improvements from such a system since actual installation of the necessary hardware and software, even for a limited trial area, would be expensive. It was decided to use digital simulation for evaluation of the improvements possible from the proposed system. The simulation would provide the data necessary for a comparison of the performance of Garland's current traffic signal settings with settings representative of optimized patterns that would be used for computer control during AM, NOON, and PM peak periods.

THE MODEL

The simulations were performed using IBM's Vehicle Traffic Simulator (VETRAS), a general purpose discrete simulation model. VETRAS is written in IBM's General Purpose System Simulator language, GPSS/360, chosen for its ease of programming and timekeeping and statistics gathering features.

VETRAS simulates vehicle traffic moving through a network of streets and intersections. It is designed to be an aid in analysis of traffic control techniques. Some of the statistics gathered by the model are:

a. Average time cars spent in queues

b. Trip times

c. Percentage of cars that did not have to stop for traffic lights

d. Lane utilization.

The user can specify network, vehicle, and control parameters. The main elements of the VETRAS structure are:

a. Geometry

b. Signal control

c. Vehicles.

GEOMETRY

The network geometry consists of lanes and intersections into which the lanes empty. Lanes are grouped into segments composed of adjacent lanes carrying traffic in one direction between two intersections. Intersections are the regions common to two or more intersecting lanes where there is usually some competition for the right of way. The intersection of any two lanes determines a cell. Thus, each intersection is divided into a number of cells equal to the product of the number of intersecting lanes. Routes through the intersection for each approach lane are given as sequences of cells.

All lanes, segments intersections, and cells used to describe a network must be uniquely numbered. Figure 1 shows a sample network and Figure 2 shows a sample intersection.

CONTROL

The movement of vehicles into an intersection is controlled by signal light phases, with one or more phases controlling traffic streams that have simultaneous right of way. VETRAS permits two types of phase control for an intersection--fixed and acutated. A fixed phase is defined by a cycle length, split and offset:

a. Cycle length is the total time for a single sequence of red and green.

b. Split is the percentage of the cycle given to green time.

c. Offset is a percentage of the cycle used for initial synchronization of related phases.

Intersection 1 in Figure 1 is a simple two-phase intersection. Phase one controls the East/West lanes, while phase two controls the North/South lanes.

For intersections under actuated control, one or two sequences of phases (called step sequences) are used. A phase regulator is generated for each sequence. It steps through each phase in turn, setting it green and the others red. The amount of time a given phase remains green may vary, depending on traffic demand.

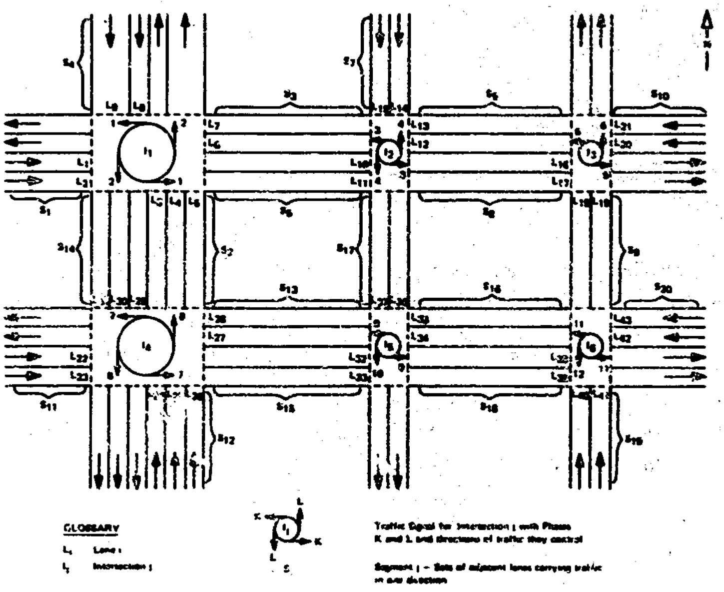

Figure 1. VETRAS Network Geometry

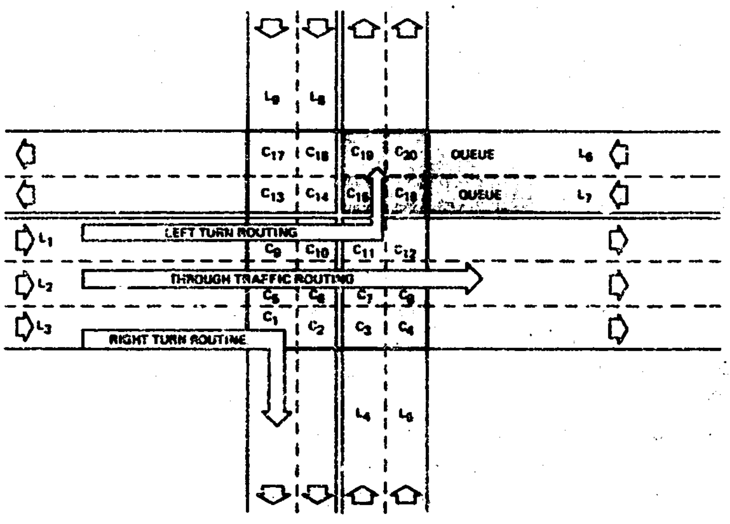

Figure 2. VETRAS Intersection Geometry

Actuated phases are of three types:

a. Main fixed time off

b. Main demand off

c. True actuated.

Main type phases will always turn green when encountered in a step sequence. Fixed time off phases will remain green for a constant time, then turn red. Demand off phases will be green for some minimum time and then remain green until a demand is presented at an intersection access controlled by another phase.

A true actuated phase will turn green when encountered in the step sequence only if a vehicle demand is sensed, and it will stay green some minimum time. If additional demand is detected within some given detect interval at the end of the minimum green time, the phase will remain green for some given additional time. This process is repeated up to some maximum allowable green time.

VEHICLES

Vehicles are input to the network on peripheral lanes. In Figure 1, Lanes 1, 2, 8, 9, 14, 15, etc. represent possible input lanes. Special internal sources and sinks of traffic, such as parking lots, can also be introduced by specifying them as additional input and output locations. For each specified input lane a mean time between arrivals, t_a, and a standard deviation, σ_a, must be supplied. Vehicles are generated at the lane entry points every $t_a + k\sigma_a$, where k is a random variable such that $-.999 \leq k \leq +.999$. When a vehicle is generated, a number of operating characteristics are assigned by the model. These include length, speed, intervehicle gap, and route through the intersection ahead. Routes are assigned on a percentage basis where the percentages of right and left turns are input for each segment.

Each vehicle moves down the lane until it reaches either an intersection or a queue of other vehicles. Vehicles in a queue move up toward an intersection until they are first in the queue, whereupon the vehicle will move into the intersection only if the appropriate phase is green. Figure 3 is an overview of VETRAS.

SIMULATED NETWORK

The city of Garland supplied data describing network geometry, traffic flow and traffic signal settings for twenty-four intersections in the central business district during three peak periods of traffic flow - AM, NOON, PM.

Bandwidth optimization techniques described in a later section were applied to the flow data provided by Garland to develop synchronous signal settings for each of the three peak periods. The signal settings supplied by Garland will be called the current signal settings, and the bandwidth optimization-derived settings the computed signal settings. The latter are of the type used for computer control and are designed to maximize the flow of a traffic network in response to traffic demands.

Two simulations for each of the peak periods were conducted. Current signal settings were used to control traffic in the first simulation while computed signal settings were used in the second. The traffic flow rates input to each pair of peak periods simulations were identical and were derived from the data supplied by the city of Garland.

The portion of Garland, Texas included in this simulation has the following inclusive boundaries:

a. East–First Street

b. West–Garland North Star

c. North–Walnut Street

d. South–Avenue D.

The major arteries in the network included the border streets mentioned above, as well as the following:

a. North-South–Glenbrook Drive and Fifth Street

b. East-West–State Street and West Garland Avenue.

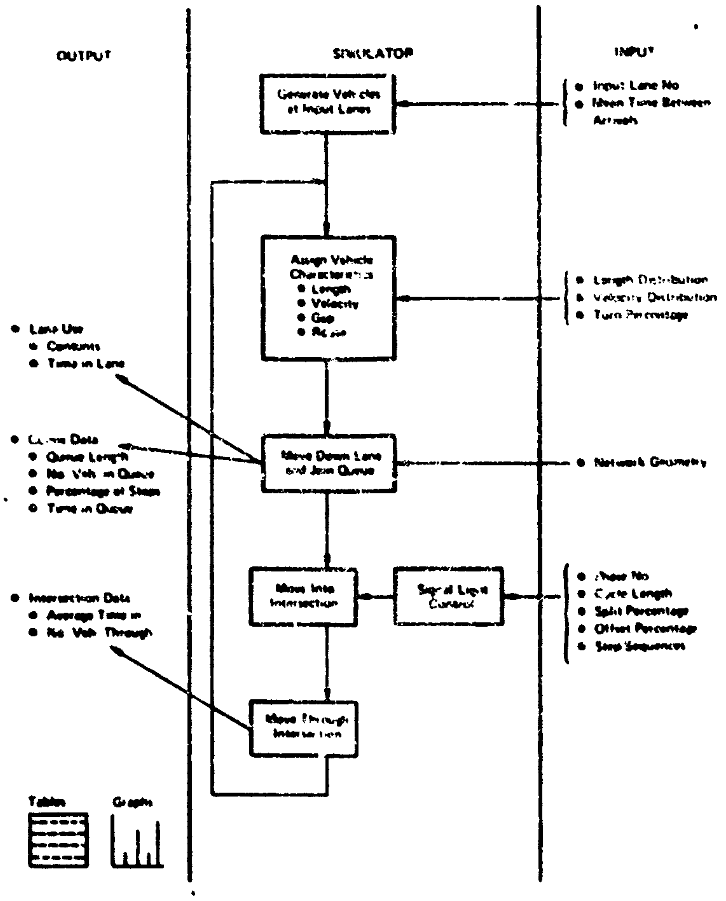

Figure 3. VETRAS Overview

The network is shown in Figure 4. There are 24 signalized intersections currently controlled either by fixed cycle phases, traffic actuated phases, or flashing signals. A single control policy is in force for the entire day, and no arterial progression scheme is currently in use.

For intersections currently under actuated control, phase time given to an arterial approach may be distributed among straight and turn phases. The turn phases are actuated and will not be given green if there is no demand. For straight phases, the A flow is a main demand off type phase, and the B flow is a main fixed time off phase. These A and B phase type assignments also hold for intersections under two-phase actuated control.

In the simulations using computed signal sets, all main type phases are fixed time off. Any green time not used from the maximum allocated green time of an associated actuated turn phase is given to the main phase during any cycle. In this fashion, total green time allocated to a given direction will be used according to the demand. However, the green time will always terminate after some fixed time interval to preserve the computed offset relationships among phases on an artery.

In addition to the signalized intersections, "dummy" intersections have been included in the network. Dummy intersections have no signal control and serve several purposes in the simulation:

a. Realistic modeling of left turn space

b. Model non-signalized intersections

c. Provide for traffic gains and losses along an artery due to non-modeled intersections.

DERIVATION OF COMPUTED SIGNAL SETTINGS

The current method used for signal control in Garland is based upon one set of fixed time and vehicle-actuated control settings. This method of signal control is not responsive to changing network states. Furthermore, there are no synchronized traffic signals along heavily traveled arteries. As a consequence, when this control discipline was imposed on the simulation of the Garland traffic network, large queues were seen to form at intersections along heavily traveled arteries during peak traffic periods.

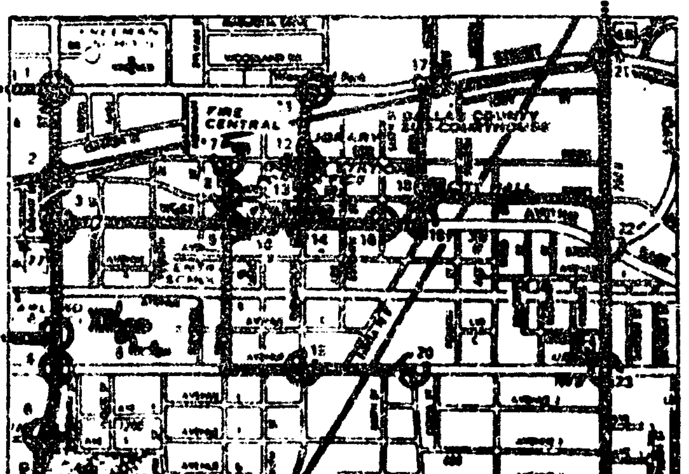

Figure 4. Portion of Map of Garland Showing Network Simulated

To demonstrate possible improvements, a traffic pattern optimization algorithm was used to develop new control strategies. This algorithm is based on the concept of adaptive computer control of traffic signal settings. It provides for optimization of traffic flows within a network based on maximized bandwidth.

Figure 5 shows a time-space diagram for traffic movement along an artery. The horizontal line segments indicate the red times at each intersection and the gaps between them correspond to green times for each signal cycle. The sloping bands represent the bandwidth up and down the artery for a given velocity. A vehicle whose travel trajectory is confined to one of these bands can travel unimpeded the length of the artery in the direction of the band.

The procedure used for bandwidth optimization along an artery can be briefly described as follows: given a base cycle and green times for each intersection, the algorithm determines a maximum bandwidth for a given range of velocities and computes the offsets necessary to coordinate the signals.

In this study, the maximum through-band for each artery was computed by the above procedure for a fixed cycle length of fifty seconds. This was representative of currently used cycle lengths, and analysis of traffic flow data supported its use. The allocation of green splits for all phases of each intersection was computed proportional to directional traffic flows.

The computations for each artery were performed over a velocity range of 30 - 50 mph. The intersections that were included for each artery were selected based on a criteria of major flow contributions in both a North-South or East-West direction. Those intersections which did not provide linkage between major crossing arteries were not used in the bandwidth calculation. Consequently, these intersections

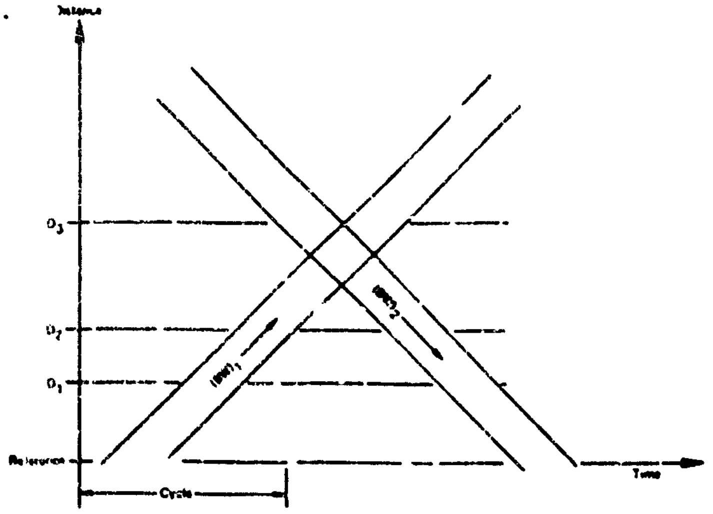

Figure 5. Space-Time Diagram Showing Bandwidth for Arterial Progression in Two Directions

were included as flashers in the traffic simulation for both current and computed signal settings.

Once the maximum bandwidths were computed for each artery, a performance index was calculated to determine the best combination of a North-South or East-West artery and all opposing arteries for optimization of network flows.

The arteries chosen for optimization for each of the peak flow periods were as follows:

a. AM–Walnut Street and all North-South

b. Noon–Garland/North Star and all East-West

c. PM–Garland/North Star and all East-West.

Once the arteries for optimization were selected, the offsets computed via the bandwidth calculation were synchronized on a network basis by selecting a reference intersection and adjusting each offset relative to that intersection.

OPERATIONAL CONSIDERATIONS

Data supplied by Garland and computed signal settings were translated to punched cards in a form acceptable to VETRAS and put in a data base on a direct access storage device. VETRAS itself, and a GPSS Output Edit report generator were also resident on direct access data sets. The simulation output was written to a direct access device, later archived to tape. The report generator was used with the simulation output as its data base to produce output reports for analysis and inclusion in the report made to the City of Garland.

No modifications to the VETRAS code were necessary. The majority of presimulation effort was in preparing the Garland data–geometry, traffic, signal control–for input to VETRAS and building the data base. The analysis, input formatting, and the construction and checking of the data base required approximately 1 month.

A total of 10 simulation runs were conducted. The first four simulation runs did not contain signal control. One run was made to check the Garland geometry as described to VETRAS, and three runs were made to check the AM, Noon, and PM peak traffic patterns. Two runs of 15 minutes simulation time were then conducted for each peak period (one with the current signal settings and another with the computed signal settings).

All simulations were run on an IBM System/360 Model 65, using one 2314 disk pack for direct access storage. Simulation of 15 minutes of traffic time required an average of 8 minutes central processor, or CPU time. Figure 6 gives an overall view of the operational process.

SIMULATION RESULTS

Flow volumes into the network and turn percentages at each intersection corresponding to each of the three peak periods, as supplied by Garland, were input. For each peak period, runs were made with the current signal settings and with the computed signal settings derived for that peak period. Simulation runs of 15 minutes were considered sufficient, as data sampling showed the model stabilizing. This is reasonable since the distributions of trip times show mean times of 2 minutes or less.

The histograms of Appendix A show comparisons of certain system performance criteria. For each peak period, distributions of queue waits, queue lengths, and trip times are graphed. The light bars give the distributions under current signal sets, while the dark bars represent distributions under computed signal sets.

Figure 7 shows an example of arterial flow performance comparisons that were plotted for each of the three peak periods. The results of 15 minutes of simulation under current signal settings are plotted against the results of 15 minutes of simulation under computed signal settings. Four quantities are plotted for each artery. They are:

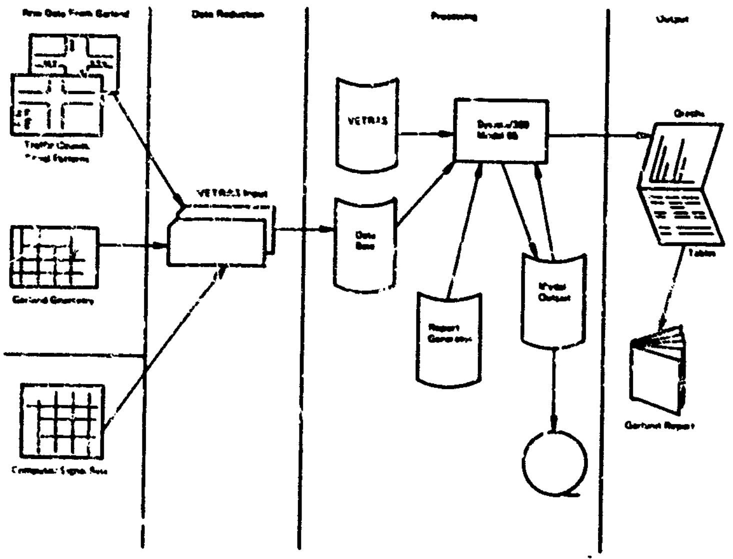

Figure 6. Data Reduction and Simulation Process Overview

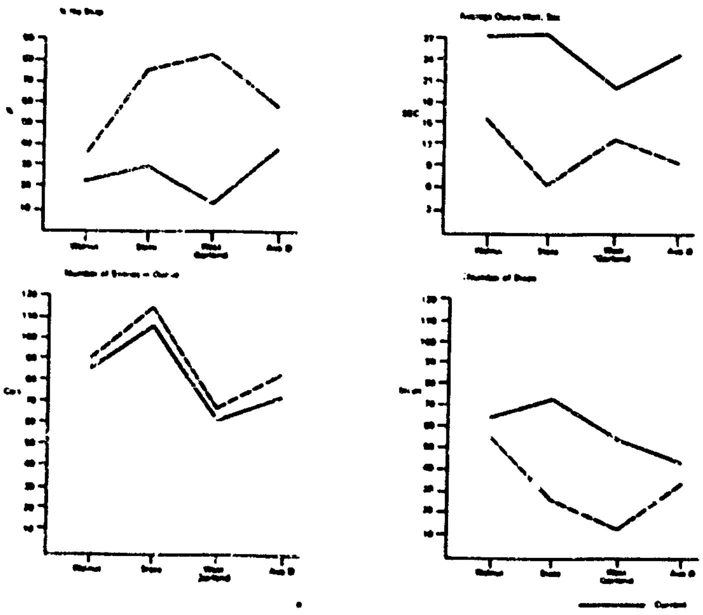

Figure 7. AM Peak, Garland-Northstar Traveling South, 15 Minutes Simulation

a. Percent Queue Zeros–The percent of cars that did not have to stop before entering an intersection.

b. Average Queue Wait–The average time, in seconds, that stopped cars had to wait before entering an intersection.

c. Number of Entries in Queue–The number of cars that have approached an intersection.

d. Number of Stops–The number of cars that had to stop before entering an intersection.

A study of similar statistics gathered for all arteries indicates queue waits and number of stops are generally lower along an artery under the computed signal sets than under current signal sets. Throughput, as measured by number of entries in the queue, is generally somewhat higher under computed signal sets. The percent of queue zeroes is also higher for computed signal sets.

As might be expected, the computed signal sets also resulted in better overall network performance. Table 1 shows a comparison of several general network statistics taken after 15 minutes of simulation. Note that two queue waits are given. The average queue wait includes cars that did not stop before entering an intersection. The average queue wait includes only cars that had to stop.

A direct relationship between traffic volume and relative improvement in network performance can be seen in Table 1. For the NOON, AM, and PM peaks, which have successively heavier flows, the improvements in each of the measured quantities are successively greater.

The improvements discussed above result from application of the bandwidth optimization algorithm to compute coherent arterial offsets, cycle lengths, and splits as a function of demand. Improvements over current control would also be possible using non-optimizing procedures to compute arterial offsets for current cycle lengths and splits. Altering cycle lengths and splits as a function of time of day would also bring improvements over current performance.

The greatest improvements are, however, expected by using a computer in a traffic responsive mode. The bandwidth optimization algorithm is used to compute offsets and signal sets based on demand, where the demand is automatically sensed and reported to the monitoring computer. The demands are used to update the signal patterns and to select appropriate patterns for use when needed. The demand-monitoring, signal pattern optimization and pattern selection functions performed by the control computer provide a responsive and flexible control system.

Expected improvements for Garland compare favorably with the results of similar analyses conducted for other cities as shown in Table 2.

COST ANALYSIS

The cost to the motoring public during each of the peak periods under control of the current and computed signal settings can be estimated. Figures for the cost computations are taken from the American Association of State Highway Officials report entitled Road User Benefit Analysis for Highway Improvement. This report determines the cost for stopping a vehicle from various speeds, plus the cost of a standing delay.

Table 1. Network Performance Comparison

Item	AM		Noon		PM		Improvement (%)		
	Current	Computed	Current	Computed	Current	Computed	AM	Noon	PM
Throughput (Number of Cars)	1298	1354	1146	1180	1366	1523	4.3	3.0	11.5
Queue Zeros (%)	58.9	66.9	65.8	67.3	57.0	70.4	13.6	2.0	23.0
Average Queue Wait (Seconds)	9.0	5.5	6.9	.8	11.9	4.9	39.0	33.0	63.6
$Average Queue Wait (Seconds)	21.9	16.6	20.2	14.7	27.7	16.6	24.0	27.0	40.0
Average Queue Length (Number of Cars)	2.3	1.9	1.8	1.6	2.75	2.15	17.0	11.0	22.0
Average Trip Time (Minutes)	2.0	1.6	1.6	1.3	2.2	1.6	20.0	18.5	27.0
Number of Stops	2940	2433	1832	1744	3456	2473	17.0	5.0	28.0

Table 2. Improvements Comparison

Item	Garland	San Jose	Wichita Falls
Intersections	26	32	80
Estimated Savings/year ($)	118,830	250,000	4,200,000
Stop Probability Reduction (%)	17	17.8	8

The elements of cost used in the report are based on national averages and are delineated as follows:

Gasoline = $0.32 per gallon

Oil = $0.45 per quart

Tires = $100 per set initial cost

Time = $1.55 per hour.

For a speed of 30 miles per hour, which is the posted speed in the network simulated, the following figures are given:

0.74 ¢ = Cost of a vehicle stop

0.008¢ = Cost per second of idling

0.043¢ = Cost per second of waiting.

Using these figures, a formula for cost per stop is:

0.74¢ + stop time (0.008 + 0.043) = ¢ per stop

where stop time is in seconds. The average queue wait for stopped cars can be used for this figure.

Table 3 presents a summary of estimated costs and savings for each of the peak periods. The formulas used are:

Cost/hour

$$\frac{\text{Cost/stop} \times \text{Number of stops/15 min} \times 4}{100}$$

= $ Cost/hour

Saving/year

Saving/hour x 2 x 260 = $ Saving/year

In the cost per hour formula, the number of stops observed in 15 minutes of simulation is extrapolated linearly to obtain number of stops per hour by multiplying by four. In the saving per year formula a 2-hour peak period is assumed and a 260-day work year (365 - 2x52) is used.

For each of the peak periods, the average time per stop is less under the computed signal sets than under the current signal sets. This results in a lower cost per stop. This difference is most noticeable in the PM peak figures, where the cost per stop is 26 percent less under computed signal settings. In addition, the number of stops during each of the peak periods is less under the computed signal sets. This, combined with the lower cost per stop produces a lower cost per hour. For the PM peak period, there are 28 percent fewer stops under computed settings. There is, however, a 48 percent difference in the cost per hour. Table 4 summarizes the differences in costs for each of the peak periods.

Table 3. Cost Comparison of Current and Computed Signal Settings

Item	AM		Noon		PM	
	Current	Computed	Current	Computed	Current	Computed
Stops per 15 min	2940	2433	1832	1744	3456	2473
Average Queue Wait (Seconds)	21.9	16.6	20.2	14.7	27.7	16.6
Cost per Stop ($)	1.86	1.59	1.77	1.49	2.15	1.59
Cost per Hour ($)	218	154	130	104	300	157
Saving per Hour ($)	64		26		143	
Saving per Year ($)	32,640		13,260		72,930	
Total Saving per Year ($)			118,830			

Table 4. Relative Cost Benefits of Computed Signal Settings

Item	Difference (%)		
	AM	Noon	PM
Stops per 15 min	17.0	5.0	28.0
Cost per Stop	14.0	16.0	26.0
Cost per Hour	29.0	20.0	48.0

Table 5. Improvement Factor for Current vs Computed Signal Settings

Item	Improvement (%)		
	Noon	AM	PM
Throughput (Cars)	3.0	4.3	11.5
Queue wait	2.0	13.6	23.0
Average queue wait	33.0	39.0	64.0
Average queue length	11.0	17.0	22.0
Average trip time	18.0	20.0	27.0
Stops	5.0	17.0	28.0

A study of Tables 2 and 3 indicates a relationship between cost and traffic volume. As volume, indicated by stops per 15 minutes, increases, so does the saving per hour. The relationship between volume and improvement is supported by Table 1, where relative improvement in each of the measured statistics increases with an increase in volume, or throughput.

CONCLUSIONS

Simulation results of current versus computed signal control for each of the peak periods demonstrates that use of computer-generated signal settings can significantly improve the performance of Garland's traffic network. This performance improvement is measured in terms of throughput, number of stops, wait times, trip times, and queue statistics. Table 5 shows the improvements for the NOON, AM, and PM peak periods which have successively heavier traffic volumes. The larger volumes of traffic in the PM period realize greater relative improvement.

Improvements in network performance also can be translated into estimated costs savings to the motoring public. Using cost figures for stops and delays and potential improvements obtained from the simulation study, yearly cost savings for the three peak periods (i.e., six hours for five days or 25 percent of weekday operation) were estimated as follows:

Period	Saving per Year ($)
AM	36,640
Noon	13,260
PM	72,930
Total	118,830

This estimate does not take into account weekends, which constitute 28 percent of the year, and special events which could present very high traffic volumes. Even more importantly, this estimate does not consider the growing nature of Garland's traffic volume.

In addition to the direct dollar benefits, other community benefits would be accrued in the environmental areas of air and noise pollution and in the enhanced safety, convenience, and comfort of daily travel.

Appendix A. NETWORK PERFORMANCE COMPARISON

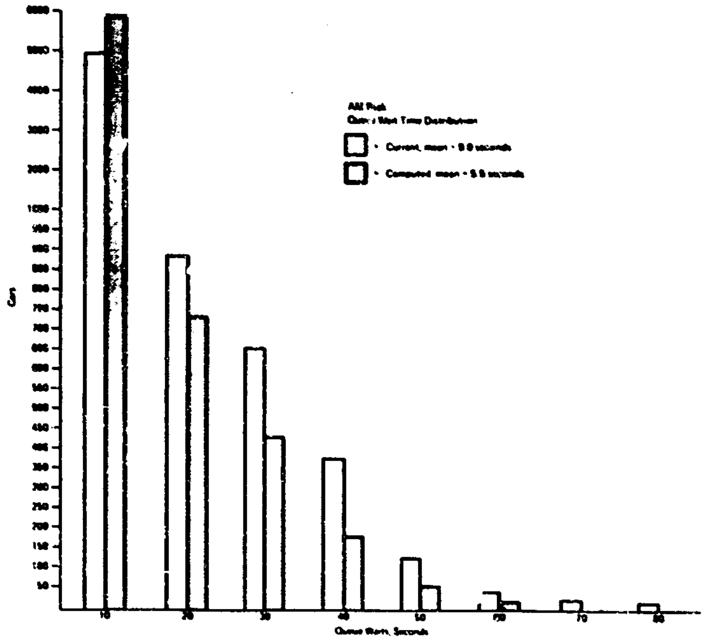

Figure A-1. AM Peak, Queue Wait Time Distribution

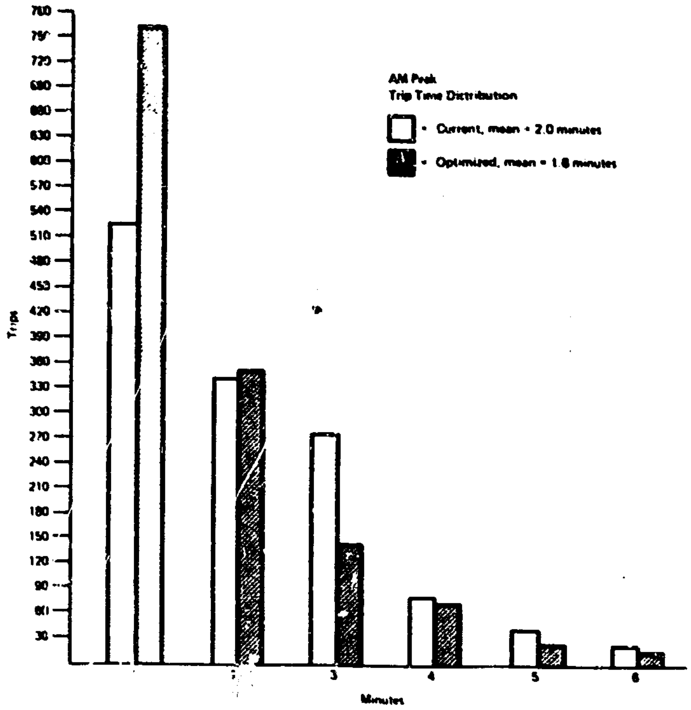

Figure A-3. AM Peak, Trip Time Distribution

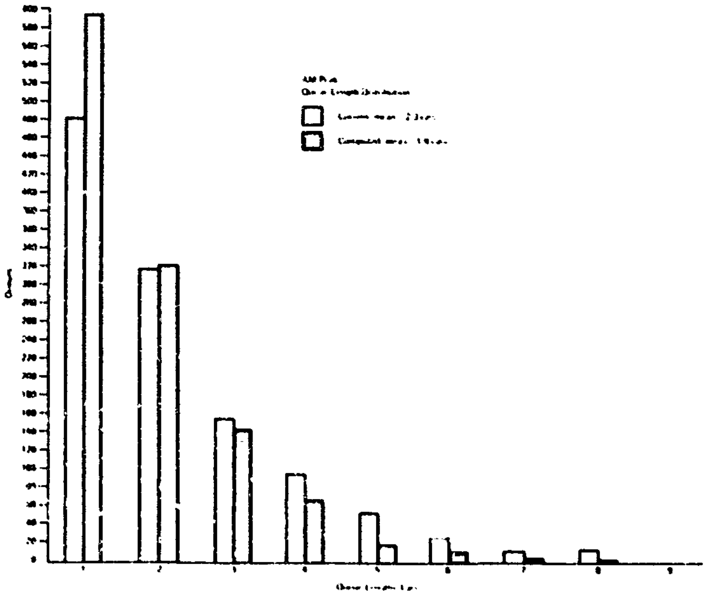

Figure A-2. AM Peak, Queue Length Distribution

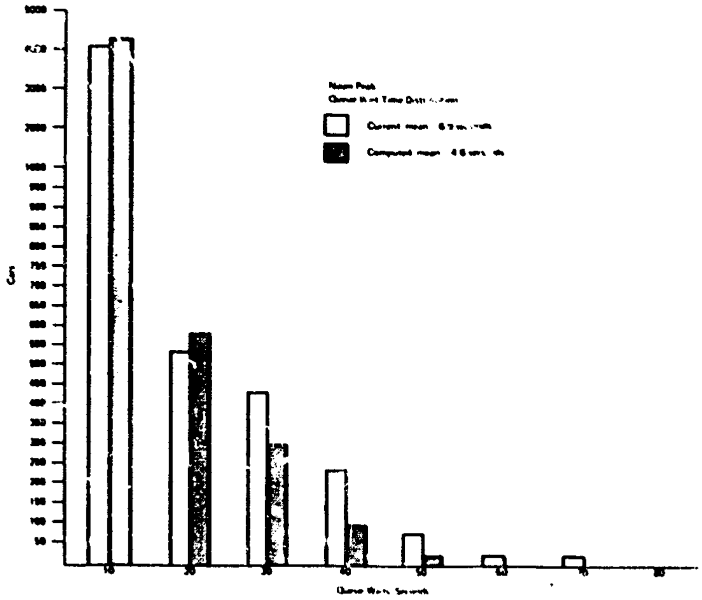

Figure A-4. Noon Peak, Queue Wait Time Distribution

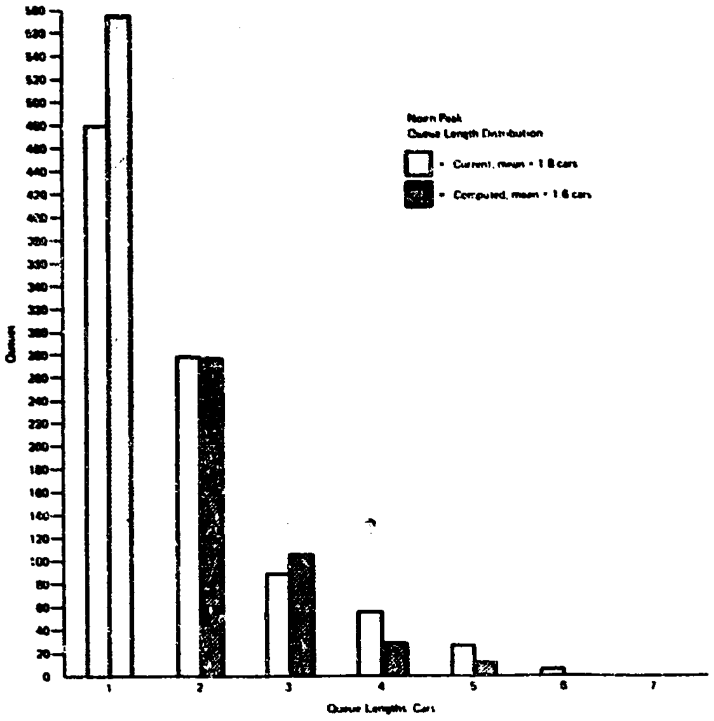

Figure A-5. Noon Peak, Queue Length Distribution

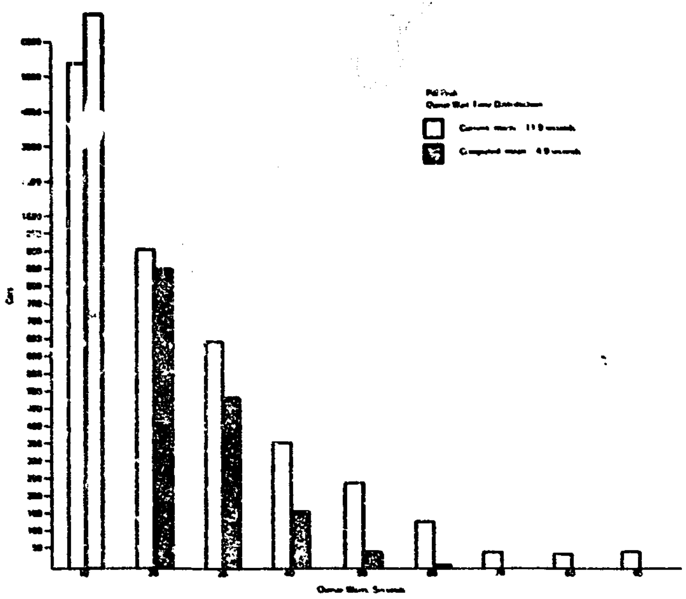

Figure A-7. PM Peak, Queue Wait Time Distribution

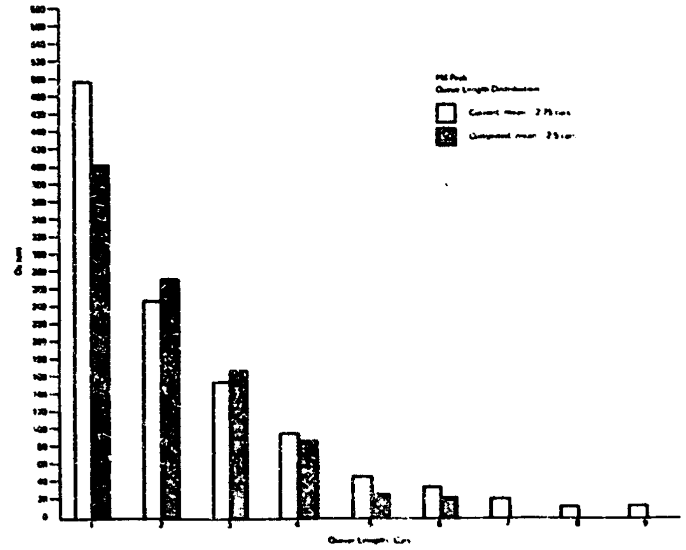

Figure A-8. PM Peak, Queue Length Distribution

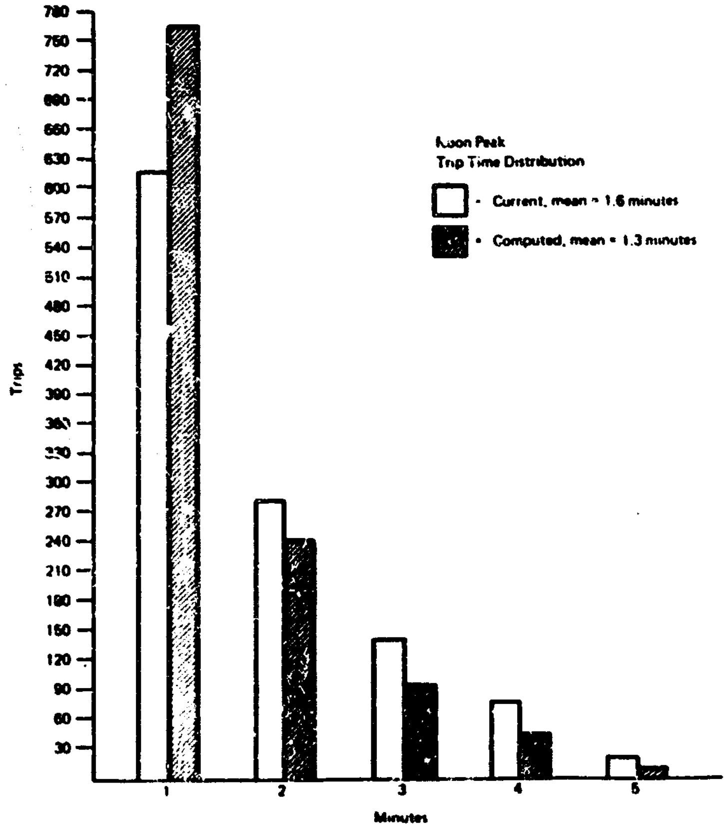

Figure A-6. Noon Peak, Trip Time Distribution

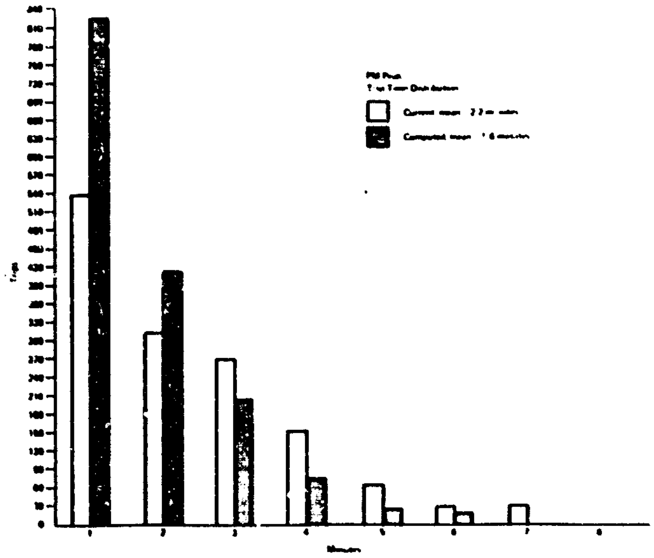

Figure A-9. PM Peak, Trip Time Distribution