COMPARISON OF TRAFFIC CIRCULATION ALTERNATIVES THROUGH SIGOP

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Results of analyzing 2 traffic patterns—an existing roadway and traffic signal operation and a proposed traffic flow pattern with optimized signal operation—are presented. Network alternative comparisons are shown for vehicle stop and delay costs, average speeds, and travel conditions. Suggested modifications to the original SIGOP program are also presented. The purpose of the paper is to evaluate the practicability of using SIGOP results as a means of analyzing traffic circulation patterns and traffic signal timing alternatives. Conclusions are that, with minor program modifications required for each network having special traffic characteristics, SIGOP provides the practical results necessary to improve traffic conditions on a grid street system.

•THE COMPUTER continues to play an increasingly important role in the field of transportation technology. SIGOP (traffic signal optimization program), a relatively new application of the computer, assists the traffic engineer in area-wide traffic system analyses (1). The program calculates phase splits and offsets for a given set of input data such that the minimum vehicle stop and delay costs are determined for a grid street network controlled by an interconnected signal system.

This paper explains the authors' experience in applying the program to actual city networks to improve existing traffic circulation efficiency. The principal purpose of using SIGOP in the example cited here, however, was to compare alternative networks—the existing versus a proposed modified street operation system for a moderate-sized East Coast city. This analysis relied heavily on comparative vehicle stop and delay costs and time-space relations in ascertaining the practicability of implementing a "model" signal-timing program.

EXISTING ROADWAY AND TRAFFIC CHARACTERISTICS OF MODEL NETWORK

A portion of the road network of the study area now comprises a rectangular grid system with typical city block dimensions of about 400 by 600 ft; Figure 1 shows the existing road network with the proposed street operation. Major intracity traffic volumes occur on the 5 east-west arterials (Avenues A through E); heavier volumes occur on Avenues A and B. Traffic signals on these main thoroughfares operate in simultaneous progression (0 offsets); arterial movements are allocated approximately 75 sec of green time of a 120-sec cycle. Travel speeds during peak traffic conditions average approximately 20 mph, but delay is common on the north-south cross streets (Streets 1 through 10) because of a lack of signal interconnection and the long waiting period between green signal indications.

A 4- by 14-block section of the model city central business district analyzed contains mostly 2-way streets with 66 signalized intersections. The proposed traffic circulation pattern would have an extensive 1-way street network, as follows:

Direction	Existing Network (miles)	Proposed Network (miles)
1 way	1.6	6.8
2 way	8.5	3.3
Total	10.1	10.1

Avenues C and D would function as a 1-way pair, and all but one north-south cross street would operate 1-way.

SIGOP PROGRAM

An IBM 360 computer was used to run the SIGOP program. However, most computers with a FORTRAN compiler and a main core storage capacity of 300,000 bytes (or 150,000 bytes using the "overlaying" technique) can be used.

The SIGOP package consists of 6 programs—INPUTS, PHASES, OFFSET, OPTMIZ, VALUAT, and OUTPUT. After the input data are verified, phase splits for each intersection are determined based on traffic volumes. Ideal difference in offsets for each network link, based on the time needed to clear the traffic queue, is computed. A traffic simulation is then utilized to evaluate the calculated phase splits and offsets for a network that minimizes delay and stops. The following specific data are included in the output:

1. Cost estimates as a function of vehicle stops and delay;
2. Cycle splits at individual signalized intersections;
3. Intersection offsets of the optimized network; and
4. Time-space diagrams for specified study sections of road.

The SIGOP program analyzed the existing and future networks. A future traffic assignment was made based on land use, roadway characteristics, and origin-destination patterns.

Detailed intersection traffic and roadway inventory characteristics were provided in the analysis. Existing input data included

1. Cycle length, offsets (for existing conditions only), and number of phases;
2. Specific signal phase intervals, such as a delayed beginning of green, advanced beginning of red, all pedestrian time, green time, and amber time;
3. Effective number of approach and discharge traffic lanes;
4. Traffic volumes for all through and turning movements; and
5. Traffic characteristic parameters, such as proportion of trucks, degree of vehicle platooning, and vehicle speeds.

OPERATIONAL MODIFICATIONS TO SIGOP PACKAGE

Several modifications were made to the original SIGOP program so that it would be more responsive to particular conditions of the specific network analyzed. The more pertinent existing program modifications made or proposed in future computer runs based on actual experience of application are summarized below.

1. The SIGOP manual does not specifically state which of several platoons of traffic approaching an intersection should be selected as the main platoon. A policy decision was made to assign the traffic making the through movement as the main platoon approaching from the upstream intersection.

2. DLANE is an input parameter that measures the number of traffic lanes accommodating the main traffic platoon leaving an intersection. This value is used in determining DRATE, the discharge rate or the rate a queue of vehicles moves through an intersection on a green signal after having been stopped by a red signal, and CRFLO, the critical flow or the maximum observed flow per lane through an intersection for a given phase. Coding DLANE equal to ALANE, the effective number of lanes accommodating the main platoon approaching an intersection improved the determination of DRATE and CRFLO.

3. The SIGOP manual recommends the use of "artificial peripheral links" in the coding of exclusive left turns. This method has 2 disadvantages: (a) The coding procedure is complicated by the appearance of additional links, and (b) the real link loses part of its traffic volume to the artificial link. That loss affects the ideal offset and evaluation of the performance functions (vehicle stops and delays). It is proposed that traffic movements through a 3-phase intersection be "coded" as a 2-phase movement.

Figure 2 (upper portion) shows traffic movements during the signal phase that includes an exclusive left-turn subphase. This is similar in overall traffic aspects to the arrangements that are shown in the lower portion of Figure 2 and provide results just as accurate but use a simpler coding procedure. The lower signal arrangement, with 3 subphases, can be coded simply by assigning ADVAR = S to link A (where ADVAR is the advanced beginning of red) and DEBEG = S (where DEBEG is the delayed beginning of green). The absolute values of the calculated offsets will differ from those calculated by the "artificial link" method but will provide comparable results when related to adjacent intersection offsets. Phasing for the left-turn movement can be easily related to the individual intersection offsets included in the program output.

4. The link-group parameters, LKGP(3), summarize delay and stop costs for 8 different groups of intersections in the optimized network. Inasmuch as it is often desirable to analyze more than 8 separate subgroups of intersections, changes were made in the SIGOP program to allow values from 0 to 99. Ninety-nine subnetwork groups of the total network can, therefore, be analyzed separately.

5. Platoon coherence is the degree to which a group of vehicles moves at uniformly close spacing and speed along a street. The platoon coherence factor, ALPHA, is an important parameter that is often assigned a human judgment value, such as "slightly coherent" or "strongly coherent." It is suggested that ALPHA be assigned a value based on the following mathematical formula:

$$\text{ALPHA} = (\text{VOLYM}/\text{ALANE}) \times (\text{CYCLE}/3{,}600) \div (\text{GREEN}/\text{DISCH})$$

where

VOLYM = total link volume, in vehicles/hour;
ALANE = effective number of approach lanes;
CYCLE = cycle length, in sec;
GREEN = green time, in sec; and
DISCH = minimum average headway of automobiles at one intersection lane, in sec.

In general, platoon coherence is directly related to factors such as traffic volume and roadway capacity; therefore, determining platoon coherence for many street sections is more practical by the recommended formula than by observation in the field.

6. The SIGOP program treats left-turn and right-turn traffic the same with respect to its effect on increasing computer-calculated effective traffic volumes. Similar treatment for left and right turns reduces analysis accuracy because existence of left-turn traffic in a lane will hinder traffic movements over a roadway. A more realistic left-turn traffic hindrance value, LTTHE can be developed by modifying the equivalence factor, EQFAC—a factor that converts commercial or turning vehicles into an equivalent volume of passenger vehicles moving straight through an intersection. The following formula, based on other input data, modifies EQFAC and eliminates the manual approximation of the turning volume hindrance effect:

$$\text{EQFAC} = (1 - \text{FTRUK} + \text{TRUCK} \times \text{FTRUK}) \times (1 - \text{FTRDN} + \text{RIGHT} \times \text{TRNFCR} + \text{LEFT} \times \text{TRNFCL})$$

where

TRNFCR = TRNFC, a turning equivalence factor usually expressed as a value between 1.00 and 2.00;
FTRDN = RIGHT + LEFT;
RIGHT = percentage of right-turn traffic to total traffic; and
LEFT = percentage of left-turn traffic to total traffic.

For 1-lane links,

$$\text{TRNFCL} = (1 + \text{ALPHA}_L) \times (1 + \text{ALPHA}_0) \times \text{TRNFC}$$

where

$ALPHA_L$ = coherence factor of the link proper, usually expressed as a value between 0.00 and 1.00; and

$ALPHA_0$ = coherence factor of the opposite link, usually expressed as a value between 0.00 and 1.00.

For multilane links,

$$TRNFCL = (1 + ALPHA_0) \times TRNFC$$

7. Some overall changes were made in the 6 programs constituting SIGOP to effect greater computer operational efficiency. For example, the INPUTS program was divided, making a total of programs in the entire package. The PHASES program was rewritten to use the green-cycle ratio extensively in computations of the signal phase split.

RESULTS OF COMPUTER RUN

Data output from the SIGOP program provided important findings concerning cycle length, efficiency of signal operation, signal progression, and travel times.

Cycle Lengths

Estimates of optimized vehicle delay and stops for the 2 most heavily traveled streets (Avenues A and B) and total optimized network are given in Table 1. A general trend can be seen because, as the cycle length decreases, delay also decreases, whereas the number of stops increases. This suggests that, with a shorter cycle length, a vehicle is stopped a shorter overall length of time but is stopped more frequently.

The SIGOP program aided in the determinination that the existing 120-sec cycle length is not so efficient as a shorter cycle length would be. The most efficient cycle lengths for Avenues A and B are 105 and 90 sec respectively, whereas the total network operates most efficiently at 60 sec. The shorter cycle length necessary to efficiently accommodate the low traffic volumes on the numerous side streets explains the 60-sec cycle length for the total network. A 90-sec cycle length was, therefore, recommended for the following reasons:

1. Traffic operation efficiency on the numerous side streets was somewhat sacrificed to provide an acceptable level of efficiency on Avenues A and B, which have peak-hour traffic volumes equaling roadway capacity; and
2. The 90-sec cycle length time-space diagrams for the principal streets provided acceptable traffic patterns.

Optimization of Signal Operation

Data output of the SIGOP program provided the basis for the conclusion that greater efficiency in traffic flow would be achieved by the optimization of the operation of the networks' traffic signals. Results of SIGOP also helped substantiate the improvement in traffic operation anticipated with the proposed 1-way street network. A sample printout of offsets for an optimized network is given in Table 2. The relative degree of improvement resulting in traffic operation is calculated by estimating the delay and number of vehicle stops at each intersection for a given time period for each alternative network. Costs of $2.50/hour of vehicle-delay and $1.00/100 vehicle stops were assigned to these parameters.

Table 3 gives estimated vehicle stop and delay costs for a 1-hour time period for 3 street and signal operating conditions. A reduction in cost from $1,780 to $1,460 should result from the optimization of the traffic signal operation of the existing system. Optimizing signal operation and implementing the proposed street operation pattern (conversion of many 2-way streets to 1-way) should further reduce total delay and stop costs to $1,160. The additional capacity resulting from 1-way operation explains this additional savings.

Figure 1. SIGOP model network.

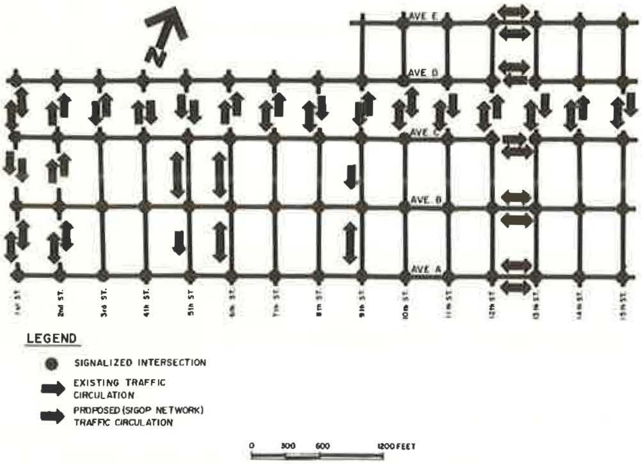


Figure 2. Analysis of exclusive left-turn lane coding.

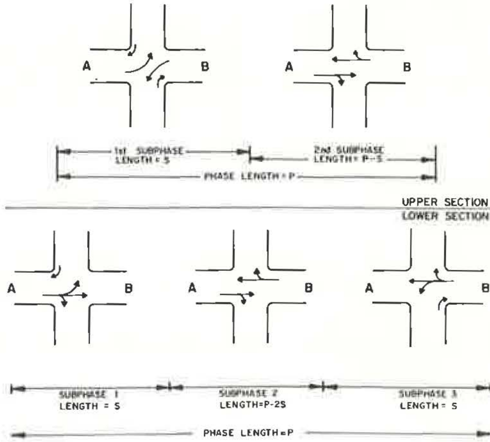


Table 1. Vehicle stop and delay estimates for different cycle lengths on optimized Avenues A and B and total network.

Cycle Length (sec)	Delay[a]			Stops[b]			Cost[c]		
	A	B	Network	A	B	Network	A	B	Network
120	31	114	371	2,950	13,280	38,230	107	418	1,310
105	31	106	334	2,620	13,450	39,270	104	400	1,228
90	30	100	304	3,560	13,040	40,480	111	380	1,165
75	31	93	263	4,160	20,140	46,170	119	434	1,119
60	36	88	241	5,460	21,340	48,700	143	433	1,089

[a]Total hourly vehicle-hours of delay due to traffic waiting at signalized intersections.
[b]Total number of hourly vehicle stops due to traffic stopping at signalized intersections.
[c]Total hourly cost due to delay ($2.50/hour of vehicle delay) and stops ($1.00/100 vehicle stops).

Table 2. Sample printout of optimized offsets, 90-sec cycle.

Inter-section[a]	Offset[b]	Inter-section	Offset	Inter-section	Offset	Inter-section	Offset	Inter-section	Offset	Inter-section	Offset
112	0.0	123	0.94	219	0.63	315	0.49	326	0.89	422	0.09
113	0.99	124	0.96	220	0.60	316	0.53	412	0.32	423	0.16
114	0.98	125	0.97	221	0.60	317	0.59	413	0.41	424	0.26
115	0.98	126	0.99	222	0.60	318	0.60	414	0.45	425	0.36
116	0.97	212	0.60	223	0.60	319	0.58	415	0.48	426	0.47
117	0.96	213	0.57	224	0.59	320	0.54	416	0.54	512	0.64
118	0.95	214	0.61	225	0.60	321	0.41	417	0.58	513	0.74
119	0.94	215	0.57	226	0.62	322	0.40	418	0.64	514	0.72
120	0.95	216	0.60	312	0.54	323	0.33	419	0.70	515	0.85
121	0.94	217	0.61	313	0.52	324	0.19	420	0.79	516	0.71
122	0.94	218	0.58	314	0.51	325	0.05	421	0.90	517	0.58

[a]Avenues are numbered serially as follows: A, 100's; B, 200's; C, 300's; D, 400's; and E, 500's.
[b]Optimized offsets expressed as a percentage of cycle length.

Table 3. Stop, delay, and cost estimates for street operation alternatives.

Street Operation	Traffic Signal Operation	Cycle Length (sec)	Stops	Delay	Cost
Existing	Existing	120	49,810	510	1,780
Existing	Optimized	120	40,870	420	1,460
Proposed 1-way	Optimized	90	40,480	300	1,160

Figure 3. Existing timing relations on Avenue D.

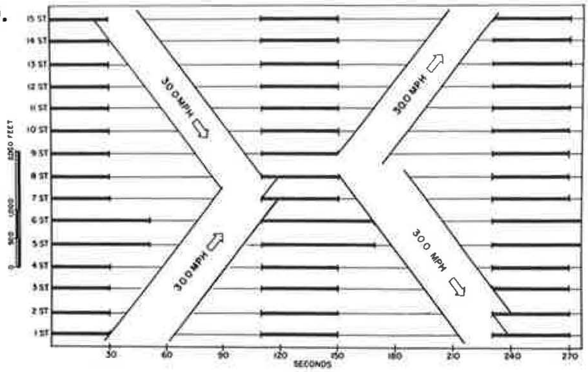


Figure 4. Proposed timing relations on Avenue D.

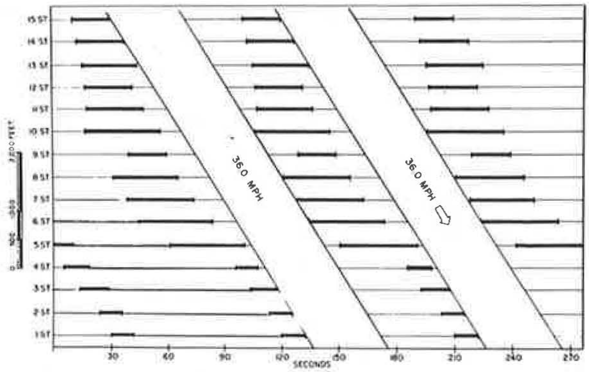


Figure 5. Existing and proposed timing relations on Fifth Street.

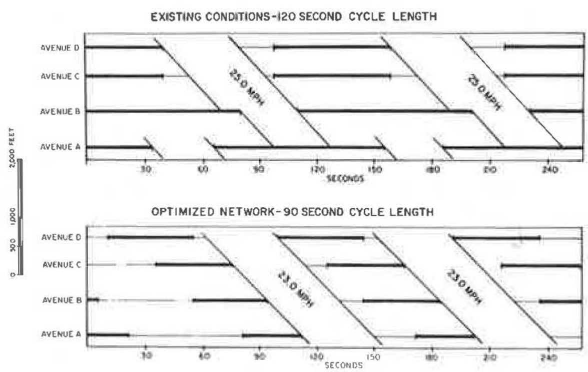
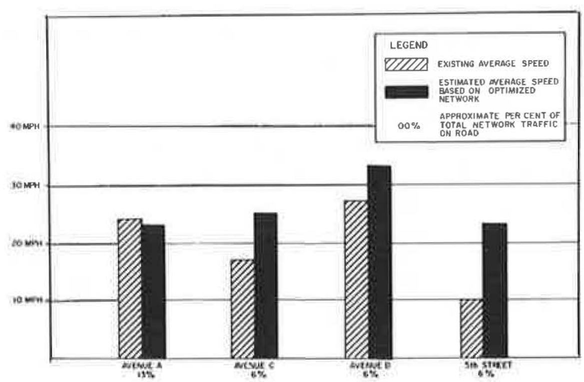


Figure 6. Existing and proposed average speed estimates.



Implementation of the proposed traffic circulation patterns, plus optimization of traffic circulation operation, should result in a 33 percent reduction in vehicle stop and delay costs. Eighteen percent of the savings is attributed to conversion to 1-way operation of many streets. A disadvantage of 1-way operation is that an increase in total vehicle-miles traveled of approximately 6 percent should result. However, the increase in average vehicle speeds on the proposed traffic network should result in an overall reduction of approximately 7 percent in total network travel time.

Signal Progression

Cross-street progression should be improved by the utilization of a general progression (versus a perfect linear progression) on the east-west arterials and by the development of cycle splits and progression responsive to cross-street traffic as well as the heavier arterial traffic. SIGOP printouts of time-space diagrams provided a convenient means of determining whether the most efficient signal operation calculated also produced realistic traffic-flow patterns that would improve the quality of driving.

Figures 3 and 4 depict the time-space relations for an existing 2-way arterial and its proposed 1-way operation respectively. One-way operation not only results in an increase in roadway capacity of about 25 percent but also provides a satisfactory progression that is currently not available.

Figure 5 shows existing and proposed time-space relations of a major cross street. Improved traffic flow in this street is reflected in the proposed 23-mph progression resulting after optimization of the network's signal operation.

Various output results were developed by varying different input parameters weighing the importance of vehicle delay to stops and of critical flow to total flow. Although progression on Avenues A and B remained relatively constant for the different parameters used in the input data, there were substanial differences on the less traveled Avenues C and D. The most efficient network did not achieve satisfactory progression on Avenues C and D. A less efficient network with adequate progression on those 2 arterials was selected as the system to be recommended for implementation because it is anticipated that good 1-way progression on Avenues C and D would be more beneficial to the other arterials in the total network.

Travel Times

Figure 6 shows existing and anticipated vehicle speeds for several key roads in the network. Avenue A should maintain simultaneous signal operation but have the cycle length reduced from 120 to 90 sec. Average speeds should remain the same or be reduced slightly. Avenues C and D, to be changed from 2-way to 1-way operation, should have significant increases in average speed.

Average speeds, after implementation of the proposed changes, will not improve on some of the cross streets. However, improvements should result on the more heavily traveled roads such as Fifth Street. This is achieved at the expense of some other lesser traveled side streets that will likely have speeds for the proposed network slower that those that now exist.

CONCLUSION

The principal deficiency in the SIGOP program, as it related to the specific network analyzed, is that capacity constraint resulting from traffic opposing left turns and conflecting opposing traffic is not accounted for in the computer analysis. This factor has to be estimated manually and, in this case, resulted in a stop and a delay cost adjustment from the computer printout value of $1,460 to $1,780. Furthermore, offsets of the optimized network will likely be somewhat different if this capacity restraint is incorporated into the program as part of the input data.

Coding the SIGOP input data requires considerable work, the amount of time being proportional to the number of signalized intersections coded. To eliminate coding errors and specific problems that develop with each network analyzed often requires several computer runs. This can be overcome with more application of the program, however.

Results obtained from the SIGOP program are valuable to enable the traffic engineer to better understand signal network operations. It saves many man-hours of work not feasible without a computer application of this type. As is the case with most computer work, however, human judgment must be applied in all interpretations of the printouts.

REFERENCES

1. SIGOP: Traffic Signal Optimization Program. Traffic Research Corporation, New York, 1966.
2. SIGOP Traffic Signal Optimization Program Users Manual. Peat, Marwick, Livingston and Company, New York, 1968.