The Traffic Pacer System

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•MANY ATTEMPTS to solve modern traffic control problems have taken the form of high speed freeways, limited access highways, or multi-lane divided highways which eliminate intersections by grade separation. These forms of traffic control have been aimed at solving high volume traffic problems. According to recent statistics compiled by the Michigan State Highway Department, approximately 12 percent of the existing traffic volume operates on such roads today in Michigan. The bulk of vehicular traffic moves on conventional road networks with intersection conflicts controlled by conventional methods such as stop signs and traffic lights.

Other than the obvious safety advantages of the limited access highway, efficient traffic flow is of prime concern. Smooth efficient traffic flow should also be the goal for signalized streets and arteries. Disturbances in traffic flow have a significant effect down the line of cars on the road (1, 2, 3). If stops or large fluctuations in speed can be reduced, traffic flow should become more stable. The traffic flow will be affected by the concentration of the vehicles on the road (3, p. 139). Furthermore, the flow can be optimized by regulating speed at which traffic moves (4). On conventional urban and suburban street systems, the flow is limited by the performance of the intersections. Existing traffic control systems, such as the progressive or interconnected system, attempt to time successive intersection signals so that uninterrupted flow can be maintained at a particular speed. Although somewhat effective, this system does not give the driver an accurate indication of his temporal position in relation to the beginning or end of the green phase of the cycle, particularly where intersections are widely spaced. This poses problems for traffic merging into the system or for motorists who are stopped or delayed between signalized intersections.

A unique system of vehicular traffic control was first developed in Germany which not only incorporates accurate phasing of successive intersection signals, but provides continuous supplementary speed information for arriving during the green phase of the cycle (5). A modification, called the "Traffic Pacer System," was developed and installed on a suburban roadway and is evaluated in this paper.

HISTORY

One attempt to meet local traffic needs was initiated in 1954, when Wolfgang von Stein installed the first traffic funnel in Dusseldorf, Germany. Since then the popularity of the signals that comprise the German traffic funnel has grown such that today there are more than 200 of these novel traffic control devices throughout Europe. The principles of the traffic funnel were presented formally by Dr. von Stein at a symposium, held at the General Motors Research Laboratories in December 1959, on the theory of traffic flow (6). He theorized that three main improvements should be realized by installation of the speed and pre-signals of the traffic funnel:

1. A 2-car-per-lane-per-cycle increase in capacity,
2. An increase in safety, and
3. A decrease in stops.

The first United States traffic pacer installation was placed in operation on Mound Road, between 11 and 15 Mile Roads, in Macomb County, Mich., on July 31, 1961.

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OPERATION OF THE TRAFFIC PACER

Although the actual hardware used in the traffic pacer system is different from that used in the German counterpart, the basic control philosophy is the same. The object of the traffic pacer is to form compact groups of moving vehicles, timed to arrive at the intersection at the onset of the green phase. As the last car of the artery group of vehicles passes, a time gap in artery flow should be provided large enough to allow the cross traffic to pass. To accomplish this the traffic pacer system employs two extra control elements (Fig. 1) not used in the ordinary interconnected progressive traffic systems: speed signals and pre-intersection stop signals (pre-signals). The elements are, from front to back, a speed signal, two pre-signals with a speed signal mounted between them, and the normal intersection traffic signal. The distance between the speed signal and the intersection traffic signal is approximately 1,500 ft. The indicated speed on the speed signal varies according to the vehicle's time of passing the signal. Vehicles at the end of the group are told to travel faster than vehicles that have already passed the speed signal, resulting in the concentration of vehicles into a more compact group. In every instance, the maximum speed limit shown by the signals is the maximum speed limit of the highway.

Figure 2 is a typical time space diagram showing precisely how this is accomplished. The heavily shaded area between the two intersections indicates the segment of the time-speed plot which drivers should avoid if they want to arrive at the next intersection during the green-light phase. The slopes of the lines indicate the speed which drivers must maintain to keep within the lighter zone, thereby arriving at the next intersection during the green-light phase. The first speed signal has a cycle which changes from 25 to 30 to 40 mph. The pre-signal installation has a cycle which changes from amber

Figure 1. Speed signs and pre-signal.

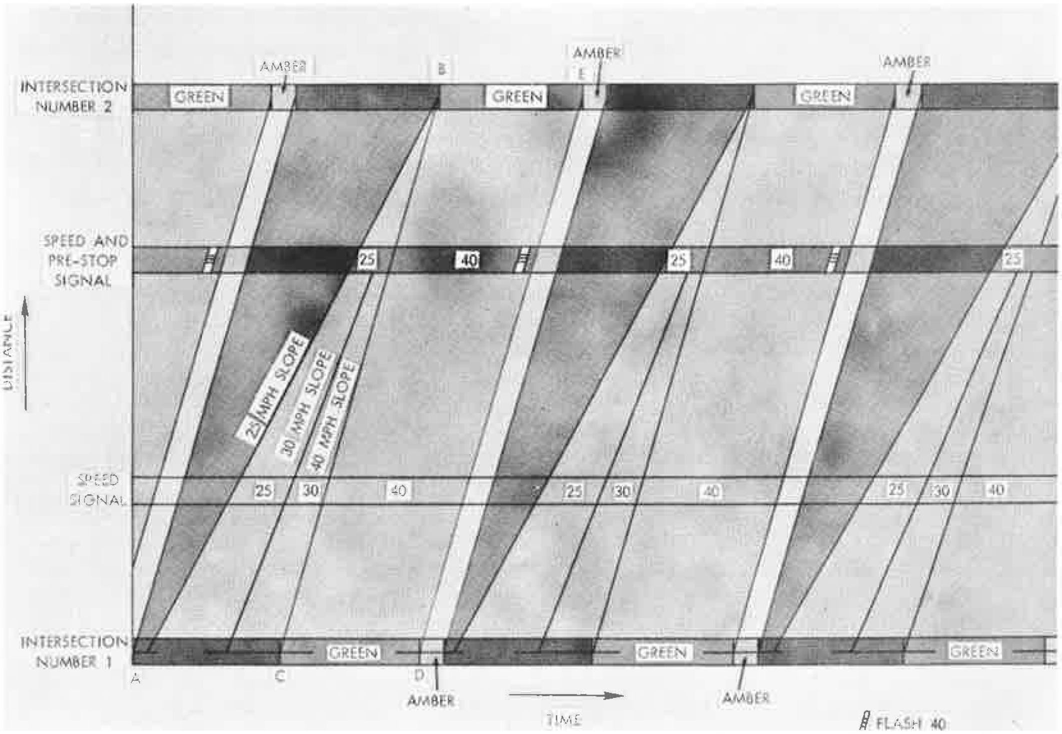

Figure 2. A simple time-space diagram.

to red, and from 25 to 40 mph during the green portion of the cycle. For example, a driver leaving intersection No. 1 at the beginning of the red light interval A will reach intersection No. 2 at the beginning of its green light interval B by maintaining a 25 mph speed. Similarly, a driver leaving intersection No. 1 halfway through the light cycle at C will reach intersection No. 2 at the start of its green light interval at B by maintaining a speed of 40 mph. Finally, the last vehicle of the group leaving intersection No. 1 on the amber signal D will reach intersection No. 2 at its amber signal at E by also maintaining a 40 mph speed.

The purpose of the pre-signal is to provide a moving start for vehicles approaching an intersection. Even rapidly accelerating vehicles, starting from a standstill, lose from 3 to 6 sec headway compared with vehicles that have been paced to the intersection signal. By releasing the traffic queued at the pre-signal early, the vehicles arrive at the intersection with a moving start just as the intersection light turns green. More specific details concerning equipment and its operation, as well as data acquisition, can be obtained from previous literature (5).

EXPERIMENTAL TESTING PROGRAM

The traffic pacer system was compared over a 12-wk testing period in 1961 with two commonly used traffic light installations:

1. "Past System," a simple non-interconnected system in which each intersection signal operates independently of the other intersection signals; and
2. "Progressive System," an interconnected system in which cars proceeding at the speed limit arrive at successive intersections during the green phase of the traffic light cycle.

In this comparison, the cycle length was 60 sec for all three systems, and the progression speed for the progressive and the pacer systems was 40 mph, with the exception of the City of Warren and the 1-mi section of Mound Road between 14 and 15 Mile Roads.

The following performance criteria were compared:

1. Average trip time, average speed, and average number of stops per trip throughout the 4-mi section of roadway;
2. Intersection capacity, the number of cars through an intersection per cycle;
3. Queue length, the number of cars waiting during the red-amber portion of the cycle; and
4. Public opinion.

During the summer of 1962, simplification of the traffic pacer system was examined. Progression speeds and cycle lengths were varied. A fixed single-bulb-type speed sign was compared with the variable multi-bulb configuration previously installed (Fig. 3, 7). Elimination of various components of the system were made in order to test individual and joint contributions to system performance. Table 1 summarizes the system examined, and a more detailed description is given in the Appendix. The same performance data were collected for the summer months of 1961 and 1962 with the exception of public opinion evaluations.

The 1-mi section of Mound Road between 14 and 15 Mile Roads could not be included in the 1962 testing programs due to heavy construction activity. In addition to these performance measures, mechanical volume counters were employed; intersection arrival time and speed were measured for different offset times between the pre-signal and intersection signal, and accident statistics were compiled for a 12-mo period and compared with pre-pacer accident data.

RESULTS

Summer 1961

During the initial 12-wk testing program, traffic volume counts were taken and the volume was found to be relatively constant for the 3-mo period. The three systems under test, (a) the past system, (b) the progressive system, and (c) the pacer system, appeared in the following order during the 12 weeks: a, c, b, a, b, c, a, c, b, a, b, c. Due to certain time and scheduling restrictions, a completely balanced experimental design could not be incorporated.

Average Trip Time and Speed. —Continuous records were made of the time taken to travel the 4-mi experimental test area. Average speeds were computed from the time records (Table 2). A record of the number of complete stops per trip was also recorded (Table 3). A trip is defined as traveling from 11 to 15 Mile Roads or 15 to 11 Mile Roads, a distance of 4 mi with 8 intersection signals.

The greater number of average stops in the evening is attributable to an increase in the traffic volume. No statistically significant differences in average trip time were found to exist between the pacer and progressive systems; however, both systems showed a significant reduction in trip time when compared with the past system. The frequency of stops indicated that the additional speed information provided by the pacer's system's speed signals permitted more stable speed control when compared with the progressive system.

TABLE 1

SUMMARY OF SYSTEMS UNDER TEST

Phase	Pre-Signals	Speed Signs	Funneling Speeds	Prog. Speed[a] (mph)	Cycle Length (sec)
A	Yes	Yes	Yes	40	60
B	Yes	Yes[b]	Yes	40	60
C	Yes	Yes[b]	Yes	35	70
D	Yes	Yes[b]	Yes	40	66
E	Yes	No	No	40	60
F	No	Yes[b]	Yes	40	60
G	Yes	Yes[b]	No	40	60
H	Yes	Yes[b]	Yes	45	55
K (prog.)	No	No	No	40	60
L (past)	No	No	No	-	60

[a]Speed in front of General Motors Technical Center.
[b]Single-bulb speed signs on southbound lane only.

TABLE 2

AVERAGE TRIP TIME AND SPEED

System	Morning (6:30-9:00 AM)		Evening (3:00-5:30 PM)	
	Avg. Trip Time (sec)	Avg. Speed (mph)	Avg. Trip Time (sec)	Avg. Speed (mph)
Pacer	401.6 ± 24.3[a]	36.6	428.4 ± 41.7	34.3
Progressive	398.4 ± 23.9	36.9	432.7 ± 48.3	33.9
Past	463.8 ± 41.2	31.6	482.9 ± 46.3	30.4

[a]Indicates one standard deviation.

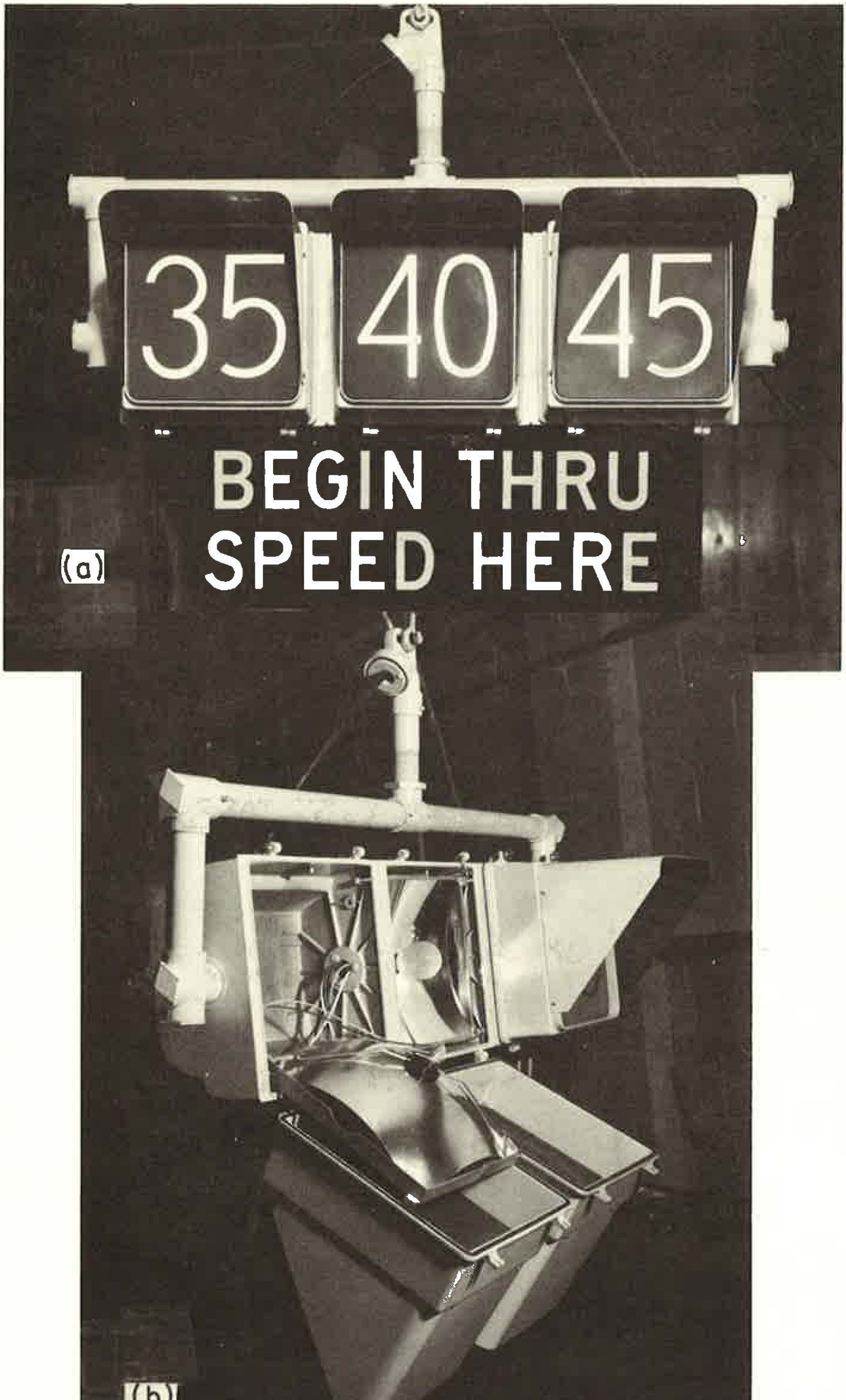

Figure 3. Single-bulb-type speed sign: (a) front view, and (b) assembly.

TABLE 3

AVERAGE NUMBER OF STOPS PER TRIP

System	Avg. No. of Stops	
	Morning (6:30-9:00 AM)	Evening (3:00-5:30 PM)
Pacer	0.23	0.73
Progressive	0.41	1.17
Past	2.35	3.20

TABLE 4

AVERAGE NUMBER OF CARS QUEUED PER LANE PER CYCLE FOR ALL INTERSECTIONS

System	Avg. No. of Cars Queued	
	At Intersection	At Intersection and Pre-Signal
Pacer	0.40	1.79
Progressive	2.50	-
Past	3.14	-

Intersection Capacity. —In an attempt to ascertain any over-all improvement in intersection capacity, all the heavy volume intersections at rush periods were compared. Arbitrarily, the frequency of cycles in which 15 or more cars per lane got through during the green portion of the light cycle, as compared with the total number of cycles were recorded. The average of 25.4 percent of the light cycles allowed this passage under the pacer system as opposed to 19.4 and 17.1 percent under the progressive and past systems, respectively. The 49 percent improvement over the past system and the 31 percent over the progressive system were both statistically significant.

Queue Length. —A tabulation was made of the total number of cars queued per lane per cycle at each intersection for the three systems. The average queue per lane per cycle for all intersections was computed (Table 4). It was hypothesized that some relationship might exist between traffic density and queue length. Figure 4 illustrates this relationship for the three systems. A linear least squares fit, in the general form $y = mx + k$, was performed on the data for traffic densities up to and including 600 cars per lane per hour. Data beyond this point was fit visually.

Public Opinion. —Another comparison was made between the three experimental systems by means of a questionnaire. A total of 600 questionnaires were distributed each week to drivers entering or leaving the experimental test area from 11 to 15 Mile Roads. The drivers were asked to compare the system in operation that week with the system in operation the preceding week. An explanation of each of the three systems under test accompanied each questionnaire.

Results indicated that approximately 65 percent of the people felt that the pacer system was safer, faster, and caused fewer stops than did the progressive or past systems. Twenty-five percent of the responses were neutral and only 10 percent of the responses

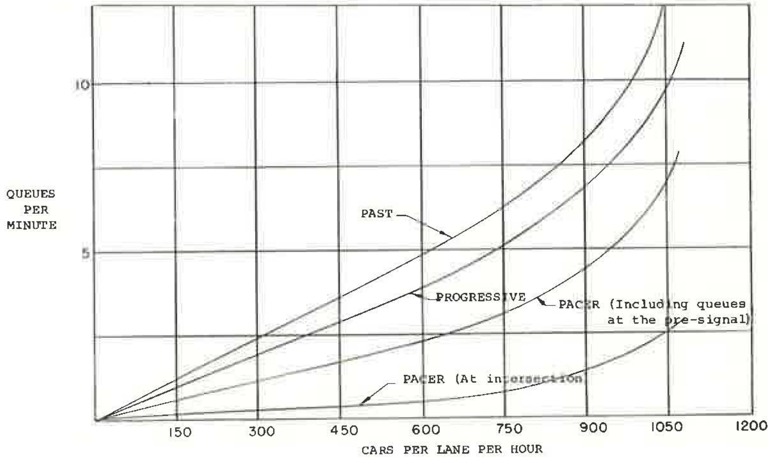

Figure 4. Queues vs traffic density.

rated the pacer system inferior to the other two systems on the three factors mentioned previously. Further results indicated that 75 percent of the respondents would like to see the pacer system installed on other roads. A more complete description of the summarized results of the initial 12-wk testing program can be obtained from the original paper (5).

Summer 1962

Average Trip Time, Speed and Stops. —Figures 5 to 12 show points of individual trip times plotted at the corresponding traffic volume for each of the systems tested. The trip time measurements were taken by a pace car moving in the traffic stream as an "average car"; that is, the car was driven at speeds which, in the opinion of the driver, were representative of the average speed of all the traffic in the stream. The volume count is based on 15-min subtotals, each subtotal being multiplied by 4 to obtain the hourly rate. Counts were taken for two lanes and the total was halved to give cars per lane per hour. For the purpose of comparison, the road section from 11 to 12 Mile Roads was used as a base for volume counts; i.e., a counter in the 11 to 12 northbound section gave the northbound volume data for the complete trip, and a counter in the 12 to 11 southbound section gave the southbound volume data. The starting time for each trip determined which 15-min volume count was to be used as the corresponding volume figure. All data given in Figures 5 to 12 were taken between 6:45 and 8:15 AM and between 3:45 and 5:15 PM; that is, during the heaviest traffic volume periods of the weekday.

Table 5 summarizes the results of Figures 5 to 12. The number of trips made in each direction was approximately the same and Table 5 presents the total of one-way trips, together with the average stops made by the pace car for a one-way trip. The average and theoretical trip times also indicate a one-way trip in either direction. It will be noted that the two-way progression and fixed geometry of the roadway result in fractional theoretical progression speeds. It is clear from Figures 5-12 that the system is operating below capacity at all times; i.e., at no time, for any of the systems tested, was the traffic density (based on 15-min counts) high enough to increase trip time or affect the number of stops.

Because the capacity of the roadway is not reached for the highest number of cars with the highest progression speed, the same average trip time with the higher progression speed (40 and 45 mph) must be due to some drivers dropping back a progression band. Examination of Figure 11 (45 mph progression speed) clearly shows the grouping of the trip times about three separate means, one at the progression speed and the others approximately one and two cycle lengths slower. The increases in trip times are most likely due to the fact that the road users habitually travel at 40 mph. A persistence with the higher progression speed over several months might eventually result in an average shorter trip time. A disadvantage of the higher progression speed and corresponding shorter cycle length is that they produce a loss of efficiency in cross-street traffic and main artery truck traffic.

Intersection Capacity and Queues. —With a 50 percent time split between red and green plus amber, the maximum capacity attainable at an intersection is half the capacity of the roadway itself. Throughout the summer of 1962, counts were made for the 12 Mile intersection, both northbound and southbound. The traffic counts were taken Monday through Friday during the hours of 6:45 to 8:15 AM and 3:45 to 5:15 PM. From both the 1961 and 1962 test programs, it was observed that traffic volume was the highest during these hours of the day. Human traffic counters recorded the total number of cars which went through the intersection during the available green time. Figure 13 shows the relationship between the average queues per minute and the number of cars through the intersection per lane per hour.

All the curves in Figure 13 are visual fits to the data. For all cycle lengths tested, the asymptotic capacity for the intersection seems to be somewhere between 1,050 and 1,200 cars per lane per hour. These curves compare favorably with the queue data in Figure 4. The points, plotted in Figure 13, from the 1961, 60 sec cycle data agree quite well with the curve fit to the 1962, 60 sec cycle data. In comparing various sys-

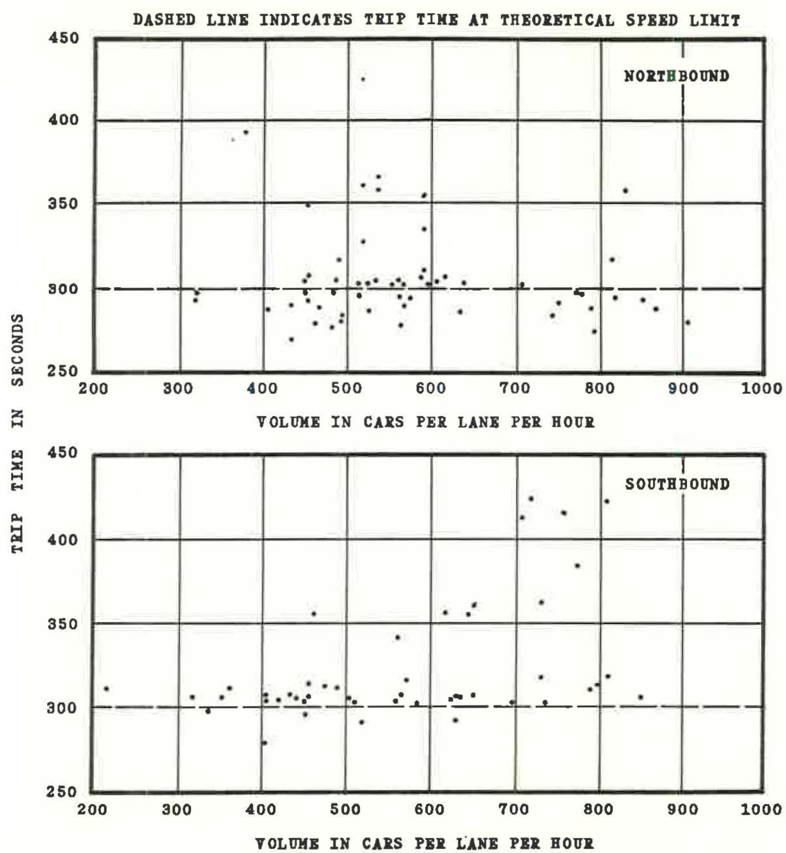

Figure 5. Systems A and B: 60 sec cycle; full pacer system; average stops, 0.62 per trip; average trip time, 318 sec per trip.

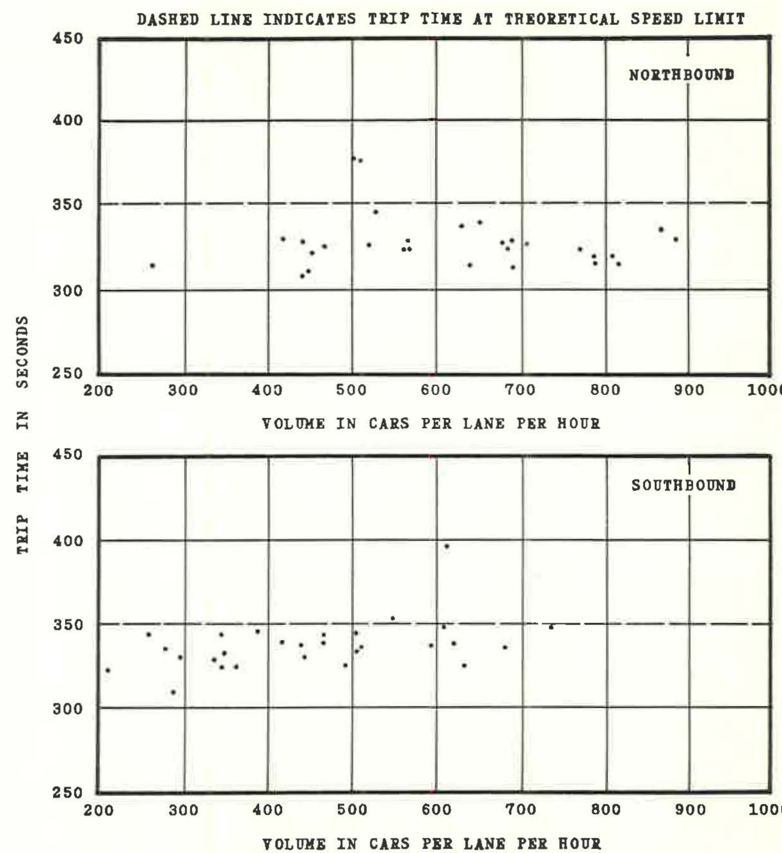

Figure 6. System C: 70 sec cycle; full pacer system; average stops, 0.62 per trip; average trip time, 337 sec per trip.

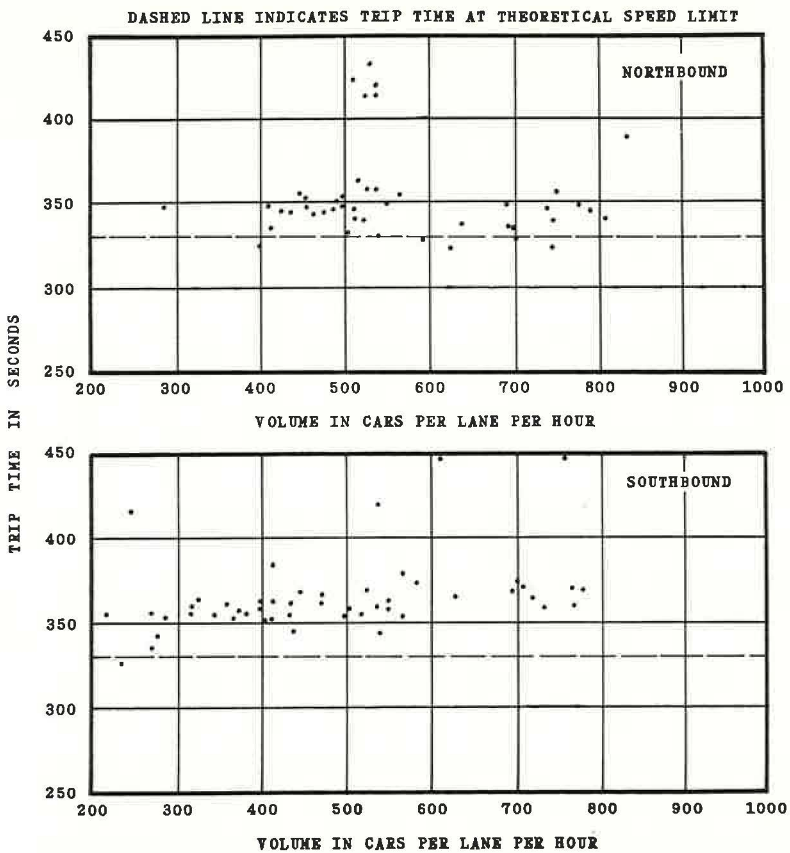

Figure 7. System D: 66 sec cycle; full pacer system; average stops, 1.23 per trip; average trip time, 359 sec per trip.

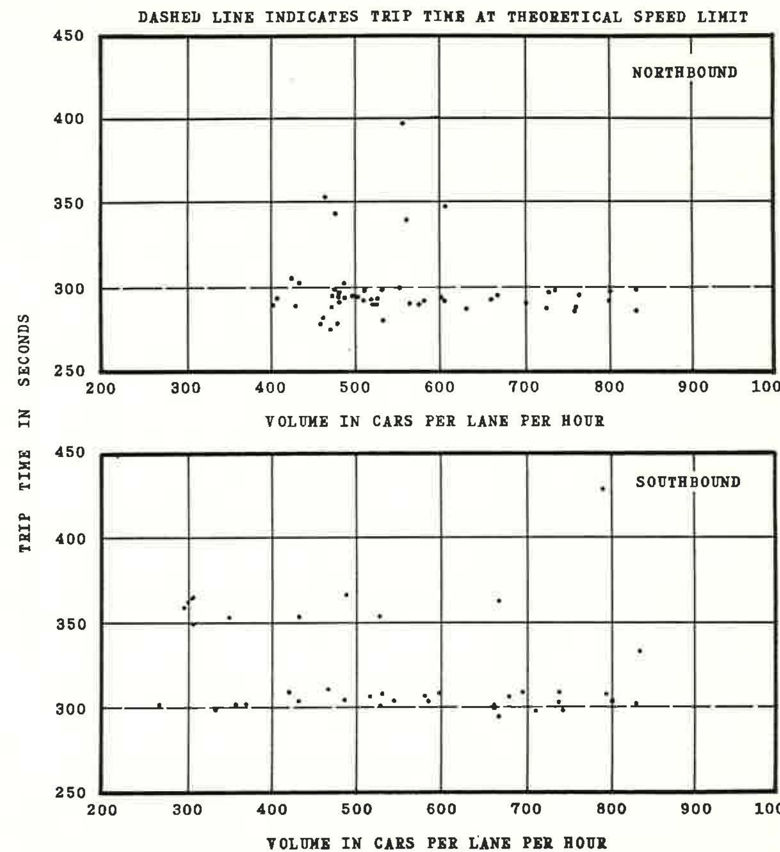

Figure 8. System E: 60 sec cycle; pre-stop only in operation; average stops, 0.57 per trip; average trip time, 315 sec per trip.

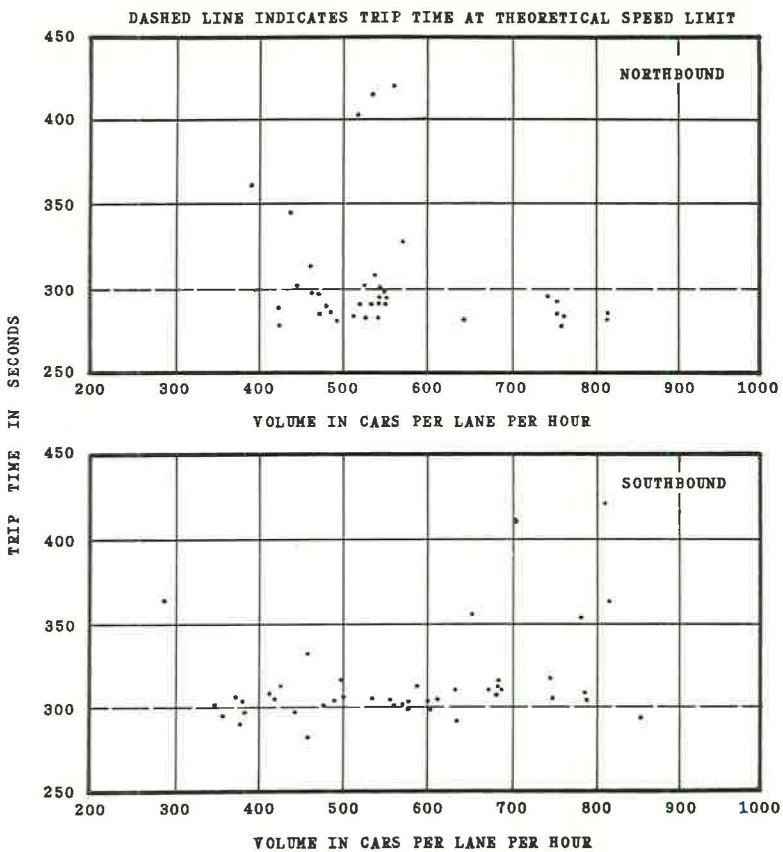

Figure 9. System F: 60 sec cycle; speed signs only in operation; average stops, 0.57 per trip; average trip time, 315 sec per trip.

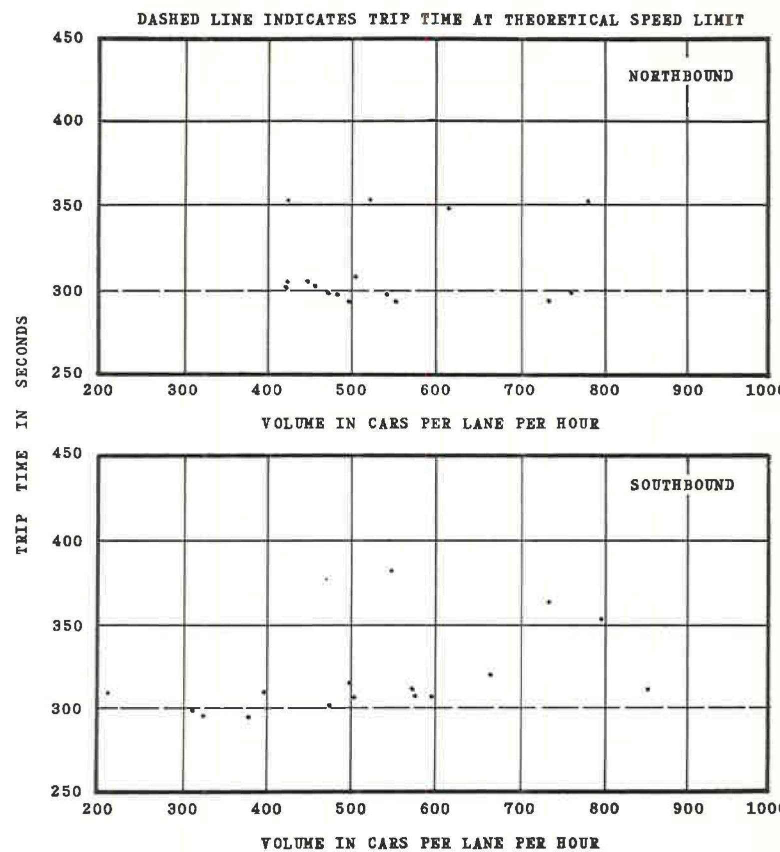

Figure 10. System G: 60 sec cycle; normal pacer except speed signs show only progression speed (no funneling); average stops, 0.54 per trip; average trip time, 320 sec per trip.

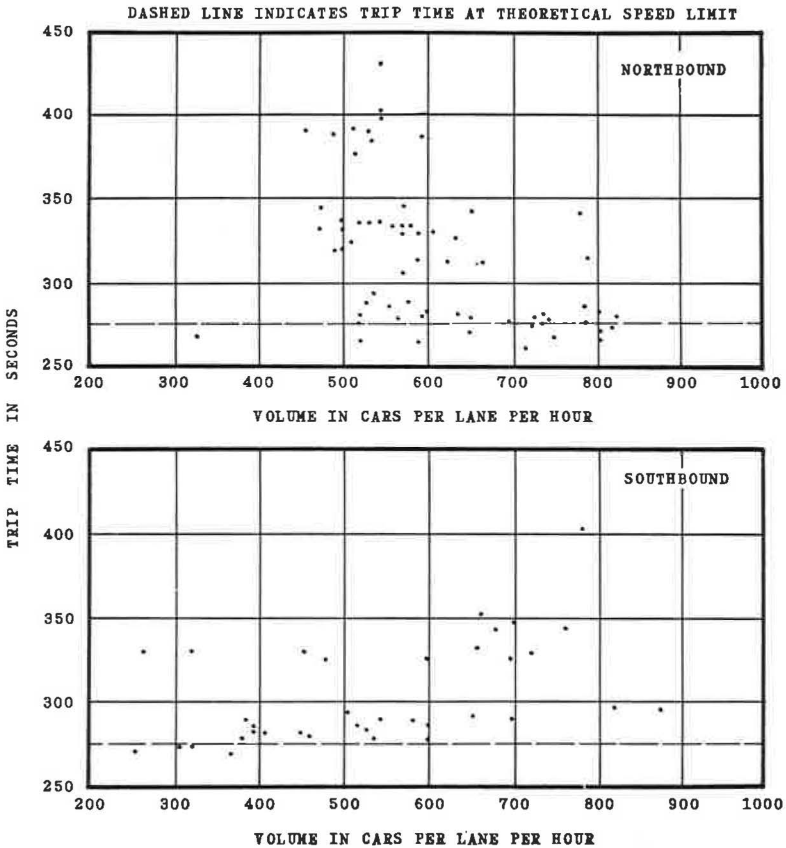

Figure 11. System H: 55 sec cycle; full pacer system; average stops, 0.84 per trip; average trip time, 315 sec per trip.

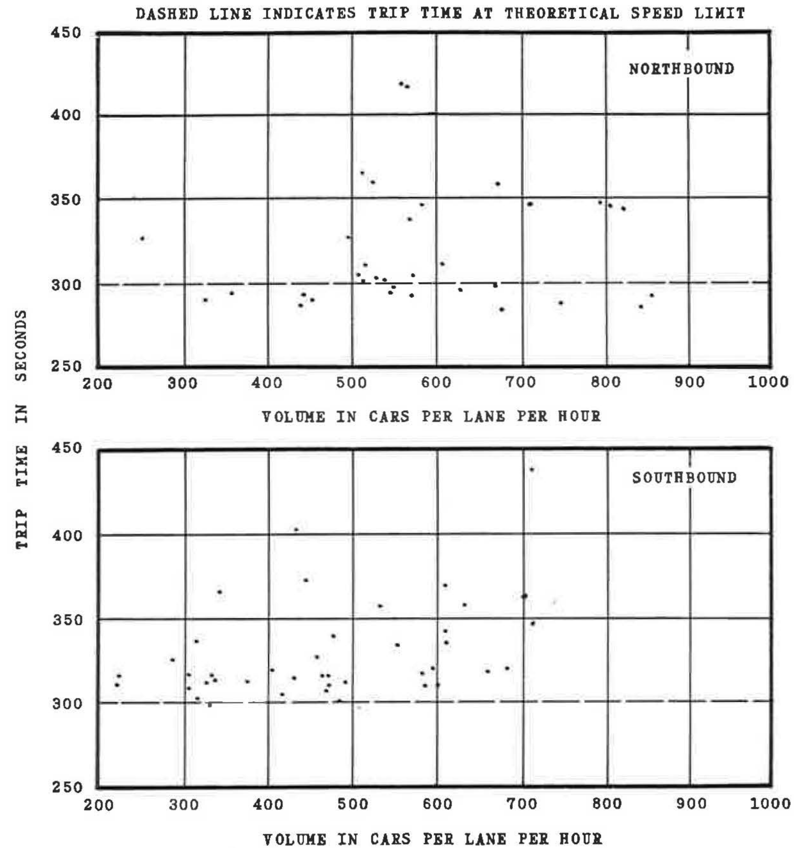

Figure 12. System K: 60 sec cycle; progressive system; average stops, 1.17 per trip; average trip time, 327 sec per trip.

TABLE 5

SUMMARY OF AVERAGE TRIP TIME, SPEED AND STOPS

Phase	No. of Trips	Avg. Stops Per Trip	Avg. Trip Time (sec)	Avg. Speed (mph)	Theo. Trip Time (sec)	Theo. Speed (mph)
A	180	0.62	320	33.8	300	36.0
B	65	0.63	316	34.2	300	36.0
C	59	0.41	337	32.0	349	30.9
D	102	1.23	359	30.1	330	32.7
E	106	0.57	315	34.3	300	36.0
F	100	0.57	315	34.3	300	36.0
G	62	0.54	320	34.7	300	36.0
H	153	0.84	315	34.3	275	39.3
K	96	1.17	327	33.0	300	36.0
L	56	3.33	375	28.8	-	-

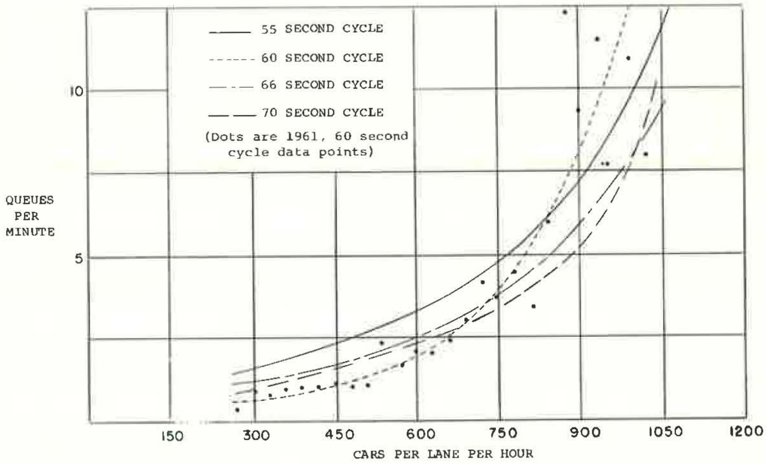

Figure 13. Queues vs traffic density.

tems over a specified time interval, the average number of cars through the intersection per cycle is not a particularly sensitive measure of intersection capacity unless the roadway is near saturation. When a roadway is not saturated, at a particular time interval during the day in which the traffic density is highest, the cars through per cycle are measured for N cycles. By plotting the percent of cycles in which n or more, $n + \Delta n$ or more, $n + 2\Delta n$ or more, etc., cars per lane per second go through the intersection, a comparison of several systems can be made, and the capacity of each system can be approximated by extrapolation.

Figure 14 shows a plot for the 12 Mile intersection over the given morning and afternoon time periods. Each cycle length tested is shown together with the 1961, 60 sec cycle data of the pacer system and the 1962, 60 sec cycle progressive system data. The 55 sec cycle is the most efficient on a car through per second basis.

Because of the small proportion of high volume cycles on Mound Road, the hypothesized 2-car-per-lane-per-cycle increase in capacity could not be adequately tested. A 25 percent increase in the number of cycles in which 15 or more cars per lane got through during the available green was observed for the pacer system over the progressive system. This compares with an increase of 31 percent during the summer of 1961.

System Simplification

In the simplification of the system (Table 1), phases B, E, F, and G were evaluations of a single-bulb-type speed display (southbound only), pre-signals only, speed signs only, and a full pacer system with no funneling action, respectively. All four of these phases were based on a 60 sec cycle and a 40 mph progression speed. Phase B

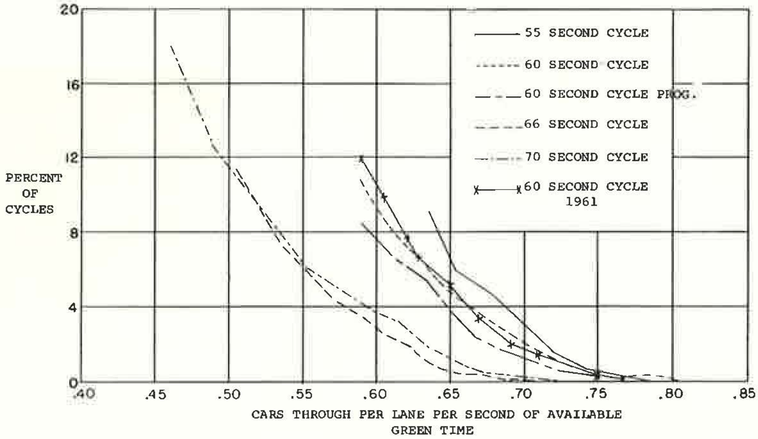

Figure 14. Intersection capacity.

is worthy of further comment. Although the speed display window of the single-bulb-type sign is much smaller than the multi-bulb sign, no impairment in efficiency was noted. The motorist is requested to comply with the indicated speed from the location of the display. Thus, if he is closer to it before he can read it, it is possible that better compliance to the system is achieved. A disadvantage of the single-bulb-type display is the limited number of funneling speeds that can be displayed. This presents no problem if only one progression speed is in use at all times. The cost and maintenance of the single-bulb-type speed sign is much less than the multi-bulb sign.

In phases E and F, the partial effect of the pre-signals and speed signs were examined. Table 5 and Figures 8-10 indicate a similarity between phases E, F, and G and the complete pacer system. The advantages of E, F, or G, as well as the complete pacer system, over the progressive system were in the fewer number of stops made. A 50 percent reduction was achieved. There were 12 mandatory stop points with the pre-signals in operation as compared to 7 with the progressive system (Phase K), yet the number of stops were halved (Table 5). The pre-signal is primarily useful within a small range of traffic densities close to road capacity. The pre-signal operation can break down at excessive traffic densities and can be an annoyance to light traffic. It is suggested that for the present level of traffic on Mound Road, pre-signals might be omitted or used as speed signs.

Intersection Arrival Time and Speed

The capacity of intersections will be increased if the stream of cars is moving as the light turns green, provided that the front of the "stream packet" is close enough to the intersection (6, 8). Because the leader of the stream packet is proceeding toward a red light as he leaves the pre-signal, his behavior is important to the efficiency of the system.

Figure 15 shows the "Traffic Signal Time Loss Meter" which was designed and built at the General Motors Research Laboratories. By installing two lengths of "Tape-Switch" on the roadway a known distance apart and just inside the intersection, the meter measured the arrival time and speed of the first motorist after onset of the green. Experiments were carried out at the 12 Mile and Mound Road intersection (northbound) with the corresponding pre-signal set back 846 ft from the intersection.

Figures 16 to 18 show individual arrival times and speeds for pre-signal time offsets of 13, 16.5 and 19.2 sec., respectively. These curves are a visual fit to the mean arrival speeds of Table 6. The present standard offset for the 60 sec. cycle is 17 sec. All the curves were based on the behavior of the first motorist leaving the pre-signal, whether he stopped or came through with a rolling start. Cycles in which cars were already stopped at the intersection or in which left turns into the roadway between the pre-signal and the intersection were made were deleted.

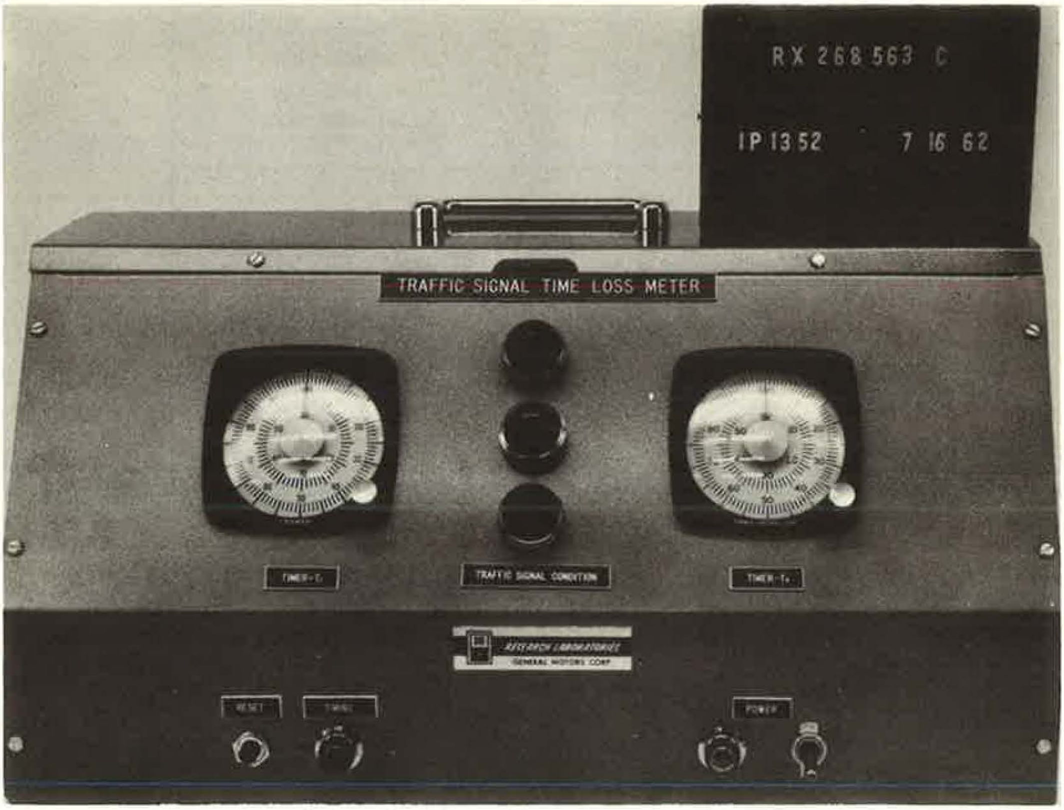

Figure 15. Traffic signal time loss meter.

Table 6 gives the arrival speed and time to the nearest second for the three time offsets. The mean speed is given for all cars arriving in the same 1-sec time interval. Table 7 gives the normalized arrival time to a 100 car base and the weighted mean arrival times for the three time offsets.

Pre-Signal Placement

It was considered that work carried out on driver responses to the amber phase of the traffic signal would give a relative measure of a motorist's behavior to a red light at the beginning of the cycle (9). The data from the drivers' responses gave an estimate of the probability of stopping for vehicles as a function of their distance from the intersection at the onset of the amber phase of the traffic signal. Similarly, if the motorist has to travel a distance of L ft from the pre-signal to the intersection, his motion must be such that at some distance, S, from the intersection the red to green light change must occur, or he will start braking. Dividing the motion into an acceleration period and a constant speed period, his position at a particular time is given by:

$$S = L - (\tfrac{1}{2} a t_1^2 + v t_2) \qquad (1a)$$

in which

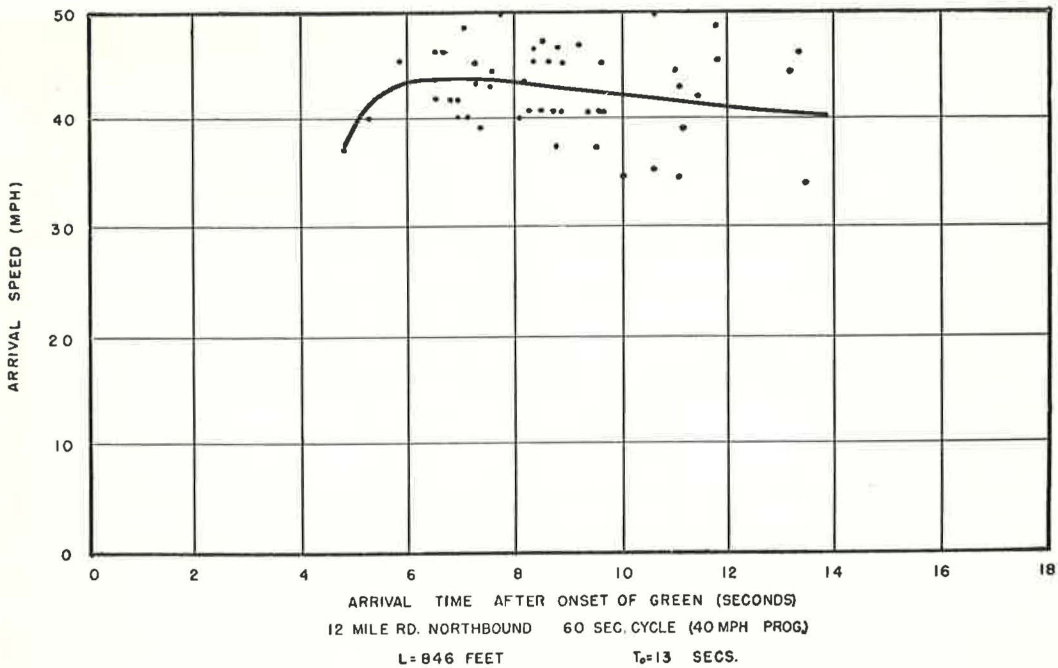

Figure 16. Arrival time and speed for pre-signal offset of 13 sec.

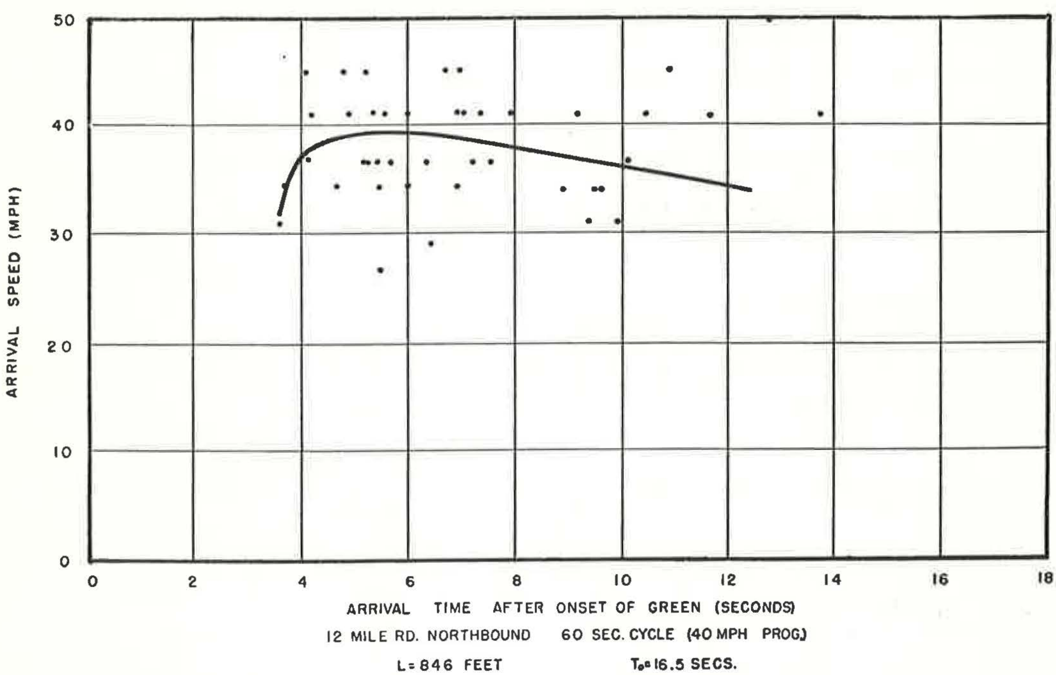

Figure 17. Arrival time and speed for pre-signal offset of 16.5 sec.

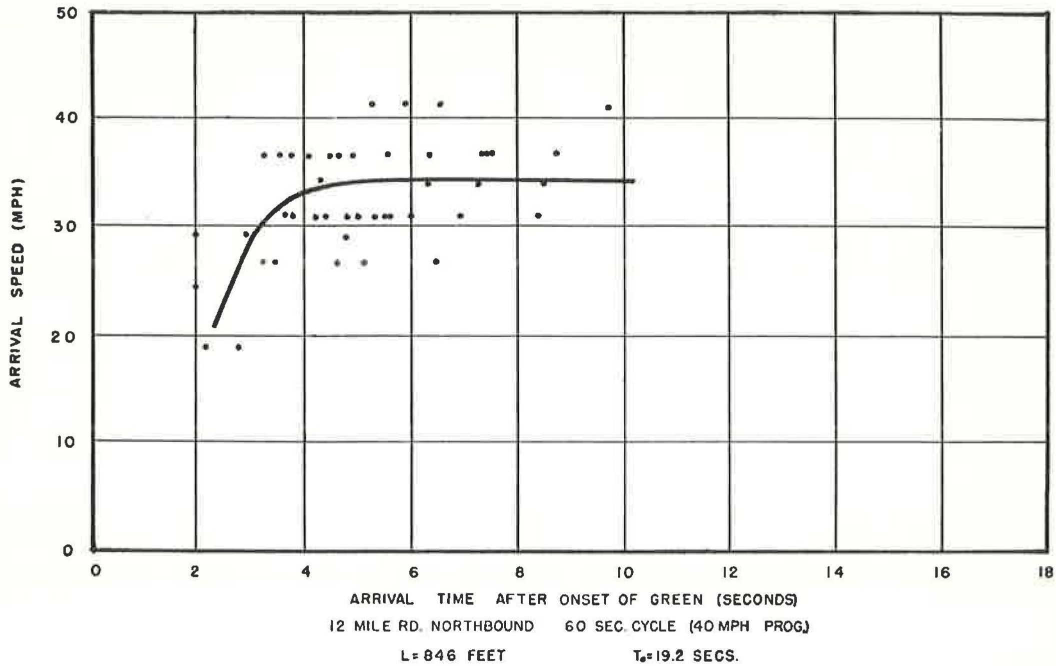

Figure 18. Arrival time and speed for pre-signal offset of 19.2 sec.

a = acceleration in ft/sq sec,
t_1 = time spent accelerating in sec,
v = velocity attained at end of acceleration in fps,
t_2 = time spent at constant speed in sec,
L = distance from pre-signal to intersection in ft, and
$(t_1 + t_2)$ = time after pre-signal release in sec.

If a position of 260 ft from the intersection is taken as the edge of the dilemma zone for 90 percent of the drivers at 40 mph, (9), the following relationship can be obtained at $(t_1 + t_2)$ sec:

$$L - (\tfrac{1}{2} a t_1^2 + v t_2) = 260 \qquad (1b)$$

and time offset = $(t_1 + t_2)$ sec. It is assumed that the motorists starts from rest on the pre-signal release. However, if he is moving toward the pre-signal at the progression speed, he will experience a dilemma zone and a subsequent loss in time at the pre-signal. This time loss

TABLE 6

ARRIVAL TIME AND SPEED OF FIRST CAR

Green Time (sec)	Time Offset					
	13 Sec		16.5 Sec		19.2 Sec	
	No. of Cars	Mean Arrival Speed	No. of Cars	Mean Arrival Speed	No. of Cars	Mean Arrival Speed
0-1	0	-	0	-	0	-
0-2	0	-	0	-	0	-
2-3	0	-	0	-	5	24
3-4	0	-	1	33	8	32
4-5	1	37	6	41	11	33
5-6	2	43	10	37	9	34
6-7	8	44	7	38	5	34
7-8	10	44	6	38	5	36
8-9	14	43	2	36	3	34
9-10	6	42	5	34	1	41
After 10	12	42	6	41	0	-

TABLE 7

ARRIVAL TIME (NORMALIZED TO 100 CARS)

Green Time (sec)	Time Offset		
	13 Sec	16.5 Sec	19.2 Sec
0-1	0	0	0
1-2	0	0	0
2-3	0	0	11
3-4	0	3	17
4-5	2	17	23
5-6	5	26	20
6-7	20	19	10
7-8	23	16	10
8-9	35	6	7
9-10	15	13	2
Weighted Average Arrival Time (sec)	8.3	7	5.7

TABLE 8

OPTIMUM PRE-SIGNAL PLACEMENT

Progression Speed (mph)	Acceleration Rate (ft per sq sec) 4		5		6	
	L (ft)	t (sec)	L (ft)	t (sec)	L (ft)	t (sec)
30	285	7.5	263	6.0	248	5.0
35	371	8.75	338	7.0	318	5.83
40	460	10.0	420	8.0	393	6.67
45	572	11.25	521	9.0	488	7.5
50	691	12.5	629	10.0	587	8.33

compensates for the acceleration time of the stationary start.

Thus, Eq. 1b gives a relationship by which pre-signal time offsets can be approximated. If the time offset ($t_1 + t_2$) is set to a motorist who accelerates at 6 ft per sq sec to the speed limit, the smallest reasonable offset is readily determined; i.e., for 12 Mile Road (northbound) where L = 846 ft, $846 - [1/26 t_1^2 + (6 t_1)\, t_2] = 260$ and (6 ft per sq sec) (t_1 sec) = (40) mph = 58.7 fps, $t_1 = 9.8$ sec and $t_2 = [846 - 260 - 1/26\,(9.8)^2] / [6\,(9.8)] = 298/58.7 = 5.1$ sec. Thus, a time offset of 14.9 sec is a reasonable minimum. The actual time loss in this instance (green time before arrival) would be $t = s/v = 260/58.7 = 4.4$ sec.

For any new installation of a pacer type system, optimum placement of pre-signals and offset times can be determined for any desired speed limit. If the lead car of a platoon has to slow down because the light has not changed, the impact can be felt down the line of cars, reducing any capacity advantage that the pre-signal provides. Ideally, the system should be designed so that for some upper limit of acceleration (6 ft per sq sec), the traffic signal will change to green just as the lead car reaches the progression speed, i.e., the end of the acceleration period.

TABLE 9

ACCIDENTS ON VAN DYKE (11-14 MILE)

Period	No.
Jan. 1-Dec. 31, 1958	138
Jan. 1-Dec. 31, 1959	187
Jan. 1-Dec. 31, 1960	228
Jan. 1-Sept. 30, 1961	177
Oct. 1-Dec. 31, 1961	74
Jan. 1-Sept. 30, 1962	251

TABLE 10

ACCIDENTS IN WARREN (ALL CITY)

Period	No.
Jan. 1-Dec. 31, 1958	2,072
Jan. 1-Dec. 31, 1959	2,831
Jan. 1-Dec. 31, 1960	3,421
Jan. 1-Sept. 30, 1961	2,401
Oct. 1-Dec. 31, 1961	949
Jan. 1-Sept. 30, 1962	2,993

TABLE 11

ACCIDENTS ON MOUND ROAD (11-14 MILE)

Period	No.
Jan. 1-Dec. 31, 1958	51
Jan. 1-Dec. 31, 1959	111
Jan. 1-Dec. 31, 1960	138
Jan. 1-Sept. 30, 1961	66
Oct. 1-Dec. 31, 1961, Pacer	29
Jan. 1-Sept. 30, 1962, Pacer	80

Table 8 shows the optimum placement, L, of pre-signals from the intersection and the corresponding offset time, t, for three acceleration rates and five progression speeds. The dilemma zones for 90 percent of the drivers for the progression speeds of 30, 35, 40, 45, and 50 mph are 173, 216, 260, 319, and 379 ft, respectively. It, therefore, appears that somewhat shorter pre-signal to intersection distances than were used in the traffic pacer installation are desirable.

Accident Statistics

The analysis of accident data for the purpose of comparing two kinds of traffic systems is difficult. There are no two sections of roadway on which the geometry is the same and the number of cars using the road is identical. If the same road is used over different time periods, the weather has an important effect on how many accidents will occur.

The following accident data has been collected from Warren Police Department records and includes accidents of every degree of severity. In each case there was generally property damage to at least one vehicle. Personal injuries are not differentiated from property damage accidents but are included in the totals.

Tables 9 to 11 show the accident totals for the entire City of Warren, Van Dyke be-

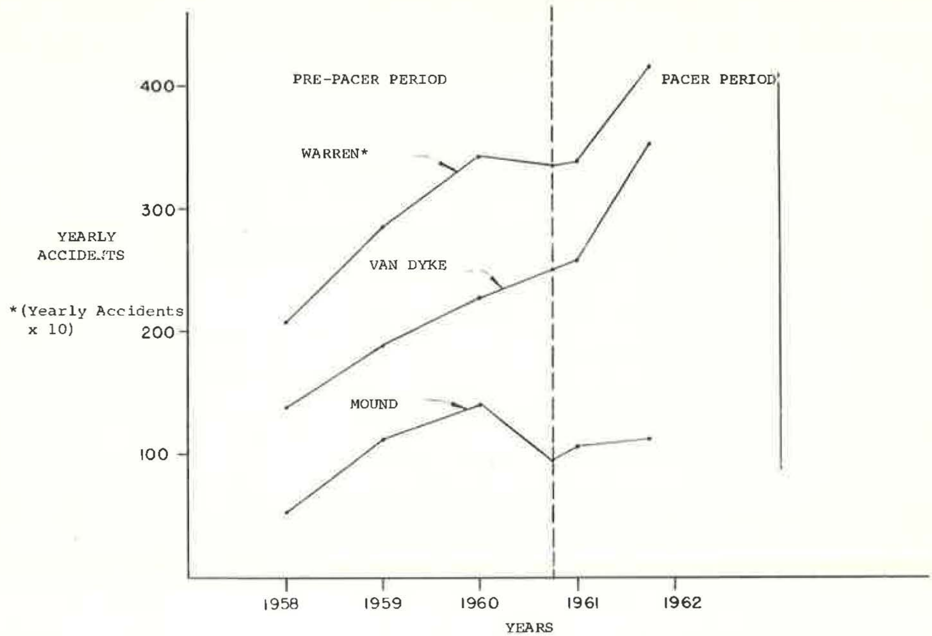

Figure 19. Accident statistics.

tween 11 and 14 Mile Roads (the adjacent parallel road 1 mi east of Mound Road) and the test section of Mound Road (11 to 14 Mile Roads). The year 1961 is split into the first 9 mo and the last 3 mo in each table so that comparisons could be made with the pacer system which was in continuous use from Oct. 15, 1961. The data from Tables 9 to 11 are plotted in Figure 19. The incomplete year totals are given projected yearly totals for easier comparison.

The percentage increase in accidents during the pacer period, for Warren, Van Dyke, and Mound were 24.7, 41.8, and 19.8 percent, respectively. The increase in accident rate from Mound during this 1-yr period was approximately 20 percent less than that for the City of Warren and 53 percent less than that for Van Dyke Road. Statistical significance cannot be assigned to these differences because of the insufficient data.

SUMMARY AND CONCLUSIONS

During the 15 mo of testing, results indicated that the pacer system significantly decreased the number of stops when compared with two conventionally used systems of traffic control. Although increases in intersection capacity were observed during the operation of the pacer system, the hypothesized 2-car-per-lane-per-cycle increase was not realized. This does not necessarily reflect on the pacer system but may be due to the lack of peak volume periods of any appreciable duration. Although accident statistics were in general agreement with the original hypothesis, additional long-term data are needed to reach a valid conclusion.

The pacer system, depending on its application, can be significantly simplified without any loss in efficiency. For example, the variable multi-bulb speed sign can be replaced by a more economical and dependable fixed single-bulb type. Possibly an even more economical way of presenting speed information to the driver can be developed. Pre-signals can be eliminated for low and moderate volume traffic densities. The funneling action of speed signs can be eliminated if cost and system simplicity are prime considerations. Optimum placement of pre-signals has also been determined so that intersection delays can be minimized.

APPLICATIONS

The traffic pacer system has many potential uses in traffic control. A few of the more obvious uses are:

1. The placement of two or three speed signs near the end of an expressway or freeway to funnel traffic into the surface street progressive system;
2. Speed signals before small towns so that motorists will be able to adjust to the existing local traffic system;
3. The use of pre-signals before school crossings at major intersections;
4. The proper timing of pre-signals to eliminate the dilemma zone the motorist faces when he is confronted by an amber light. If the motorist makes it through the pre-signal, even on the amber, he will make the intersection signal on the green, assuming no loss in car speed;
5. The use of speed signs and pre-signals to regulate traffic flow through tunnels;
6. Placement of speed signs on the approaches to isolated intersections.

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Appendix

1962 PACER TEST PROGRAM

The following is a detailed description of the traffic systems tested (Table 1):

Phase A—Cycle length, 60 sec; progression speed, 40 mph; pacer system with large multi-bulb signals in both north and southbound lanes.

Phase B—Cycle length, 60 sec; progression speed, 40 mph; pacer system with 8-in. high numerals ½ in. wide in southbound lane, northbound lane signs as A.

All other phases of test program will have speed signs as phase B. Display uses a 12-in. square, crosshatched amber lens, with single "Verteray" 67-w frosted bulb.

Phase C—Cycle length, 70 sec; progression speed, 35 mph.

Phase D—Cycle length, 66 sec; progression speed, 40 mph.

Phase E—Cycle length, 60 sec; progression speed, 40 mph; pre-signals only (speed signs shut down).

Phase F—Cycle length, 60 sec; progression speed, 40 mph; speed signs only (pre-signals shut down).

Phase G—Cycle length, 60 sec; progression speed, 40 mph; pre-signals and speed signs in operation but showing progression speed only at progression time, i.e., no funneling for early vehicles.

Phase H—Cycle length, 55 sec; progression speed, 45 mph; with pacer system in full operation including funneling speeds. This phase involved changing most of the road side speed limits and was cleared through the Macomb County Road Commission prior to operation.

Phase K—Cycle length, 60 sec; progression speed, 40 mph; progressive system with pre-signal lights turned sideways and all speed display signs turned off.

Phase L—Cycle length, 60 sec; arbitrary speeds between any adjacent intersection signals; past system with pre-signal lights turned sideways and all speed display signs turned off. Time offsets were picked from a table of random numbers. Stops and trip times were taken from 1961 test program.