Traffic Pacer

HAROLD M. MORRISON, ARTHUR F. UNDERWOOD, and ROBERT L. BIERLEY,
Research Laboratories, General Motors Corporation, Warren, Mich.

This paper deals with the design and evaluation of a traffic pacer system installed on a highway near the General Motors Technical Center. The traffic pacer causes changing speed signs and stop signs between intersections to group traffic so that it may pass through the intersection with a moving start. The control system is intended to increase intersection capacity and reduce delays and trip time.

• ON CONVENTIONAL urban and suburban street systems, the capacity is limited by the performance of the intersections. The traffic pacer is a traffic control system that uses accurate phasing of successive signals along with supplementary speed information for the driver to maximize intersection capacity and thus obtain greatest system capacity. In addition, by controlling their car speed in accordance with the sign information, drivers can avoid the necessity of intersection stops by arriving during the green phase. So that a meaningful evaluation of the traffic pacer system could be made, two systems now in use (a noninterconnected system and an interconnected system) were compared with this unique system for a period of 12 weeks.

The criteria used to compare the three systems were (a) average trip time, average number of stops, and average velocity for the 4-mi experimental testing area; (b) intersection capacity; (c) queue length; safety; (d) and public opinion. All system parameters were kept as constant as possible. A balanced experimental design was utilized to minimize any effect that changing environmental variables might produce.

HISTORY

In 1954, Wolfgang von Stein installed the first traffic funnel in Dusseldorf, Germany. Since then, the popularity of the speed signals and presignals that compose the German Traffic Funnel has grown so that today there are over 200 of these novel traffic control devices throughout Europe. In 1958, Arthur Underwood contacted von Stein, after having driven through the Dusseldorf Traffic Funnel while in Europe. In December 1959, von Stein gave a paper (1) at the Theory of Traffic Flow Symposium held at the General Motors Research Laboratories. Although the actual hardware used in the traffic pacer is different than that used in the German counterpart, the basic control philosophy is the same. So that the traffic control system has a more pleasing connotation to the driver, the name traffic funnel was changed to traffic pacer for the American version.

The German experience has demonstrated that there have been three main improvements attributable to the speed and presignals:

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

The first U.S. traffic pacer installation was placed in operation on Mound Road extending from 11 to 15 Mile Roads in Warren, Mich., on July 31, 1961, to test the pacer's merits. The Macomb County Road Commission owns and operates the pacer system, but the entire project cost and operating expense have been borne by General Motors.

OPERATION OF TRAFFIC PACER

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 should be provided in artery flow. This gap should be large enough to allow the crosstraffic to pass. To accomplish these goals, the traffic pacer employs two extra control elements that are not used in the ordinary interconnected progressive traffic systems: speed signals and pre-intersection stop signals. The latter element shall be referred to as a presignal. These control elements are shown in Figure 1. The elements are from front to back, a speed signal, two presignals with a speed signal mounted in between them, and the normal intersection traffic signal. A telephoto lens has compressed the distance between the elements. 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

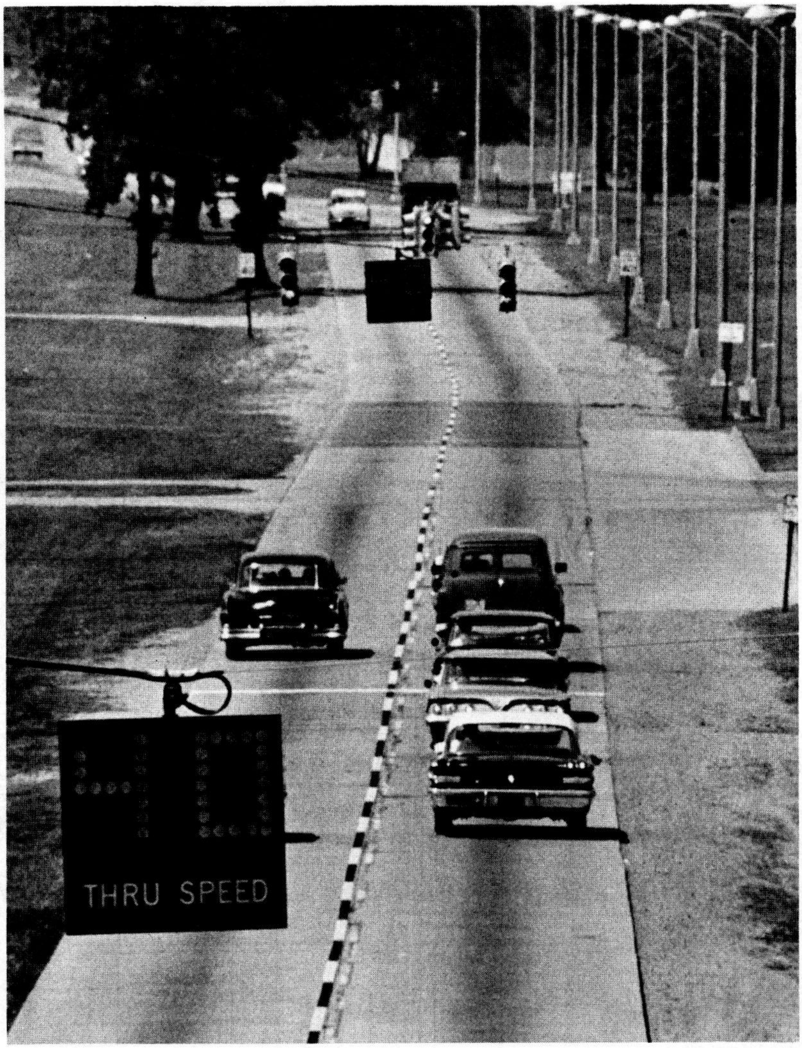


Figure 1. Traffic pacer control elements—speed signal in foreground, speed and presignal in near background, intersection signal in background. Legend changed beneath speed signal to read "Begin Thru Speed Here."

the vehicle's time of passing the signal. In other words, vehicles at the end of the group are told to travel faster than vehicles that have already passed the speed signal, thus concentrating the 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 shaded areas between the two intersections indicate the segment of the time-speed plot that drivers should avoid if they want to arrive at the next intersection during the green light phase. The slope of the lines indicates speeds the 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 that changes from 25 to 30 to 40 mph. The speed and presignal installation has a cycle that changes from amber to red, to 25 to 40 mph. The diagram shows, for example, that a driver leaving intersection 1 at the beginning of the red light interval A will reach intersection 2 at the beginning of its green light interval B by maintaining a 30-mph speed. Similarly, a driver leaving intersection 1 halfway through the light cycle at C will reach intersection 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 1 on the amber signal at D, will reach intersection 2 on its amber signal at E by also maintaining a 40-mph speed.

The purpose of a presignal is to provide a moving start. Even rapidly accelerating vehicles, when starting from a standstill, lose from 3- to 6-sec headway compared with vehicles that have been paced for the intersection signal. By releasing the traffic behind the presignal early, these vehicles that have had to stop for the presignal will arrive at the intersection with a moving start just as the intersection light turns green. Figure 3 shows in a time-space diagram with a 20-sec intersection green how a presignal can increase the capacity of an intersection. In both diagrams, the intersection's traffic signal has a 50-sec cycle consisting of a 20-sec green, a 3-sec amber, and a 27-sec red light interval. In the pacer system, the presignal green is longer than that

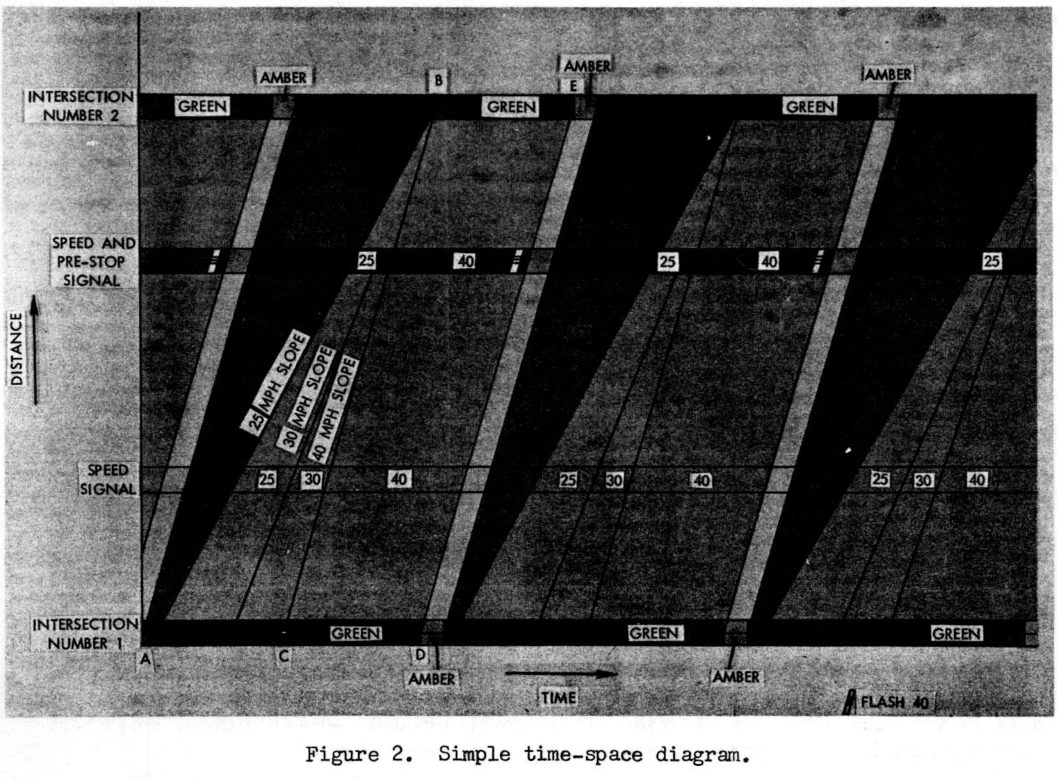


Figure 2. Simple time-space diagram.

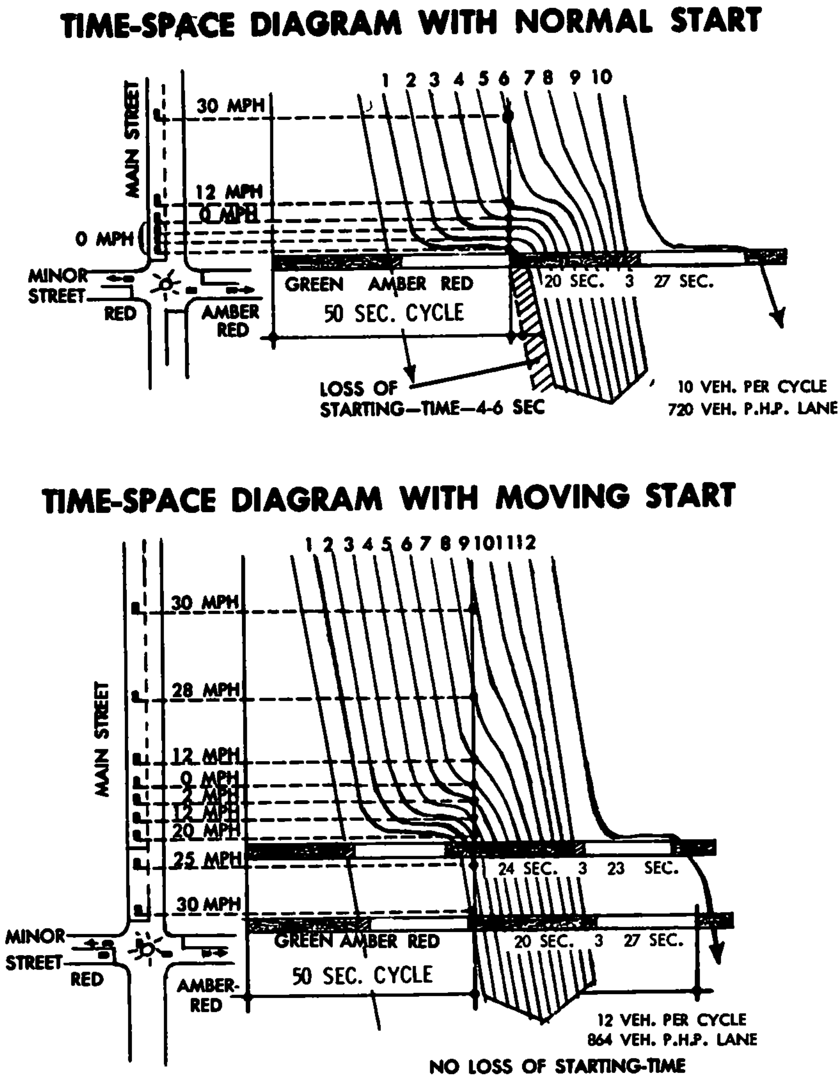


Figure 3. Time-space diagram demonstrating two-car per cycle gain for an intersection with a presignal.

at the intersection (in this example, 24 sec) to provide for acceleration time. In the normal crossing where vehicles stop immediately before the intersection (top), the first four or five vehicles in the group require from 4 to 6 sec to regain the 30-mph speed when accelerating from a standing start, forcing vehicles behind them to slow down as they approach the intersection. In this example, 10 vehicles per cycle are permitted to cross the intersection giving a 720-vehicle per hr per lane capacity. By installing a prestop signal (bottom), however, vehicles that arrive at the intersection during the red light interval are halted before the main intersection. When the prestop signal turns green, the first vehicles in the group can accelerate to the 30-mph maximum speed by the time they reach the intersection, thus eliminating the starting time loss incurred in the normal crossing system. This prestop signal permits 12 vehicles per cycle to cross the intersection, thus increasing the highway's capacity to 865 vehicles per hr per lane.

Figure 4 shows the 4-mi stretch of the pacer system in four 1-mi sections from 11 Mile to 15 Mile. The equipment of the traffic pacer system is located as indicated by the symbols. In all, there are 43 speed signals and 11 pre-intersection stop signals. Details of the pacer system hardware are contained in the Appendix.

EXPERIMENTAL DESIGN FOR TRAFFIC PACER TESTING PROGRAM

There are two types of traffic systems that are in existence on today's signalized arteries. The most common system is the noninterconnected system in which no definite phase relationship exists between successive intersection signals. The noninterconnected system is referred to as the past system. By adding the interconnection feature, the traffic engineer can establish the proper phasing of the succeeding intersection signals, which is coincident with the particular speed between a pair of intersections. This system is popularly known as the progressive system. By adding the properly phased speed signals and the presignals to the progressive system, one creates a traffic pacer system.

Figure 1 shows pacer control elements in operation. To alert the motorist of the experimental test area, roadside signs like those in Figure 5 were installed beyond each intersection. Portions of this sign were blanked out for the progressive and past systems as shown in Figure 6. A roadside sign was placed at the extremities of the system informing the motorist that he was leaving the experimental test area. Speed

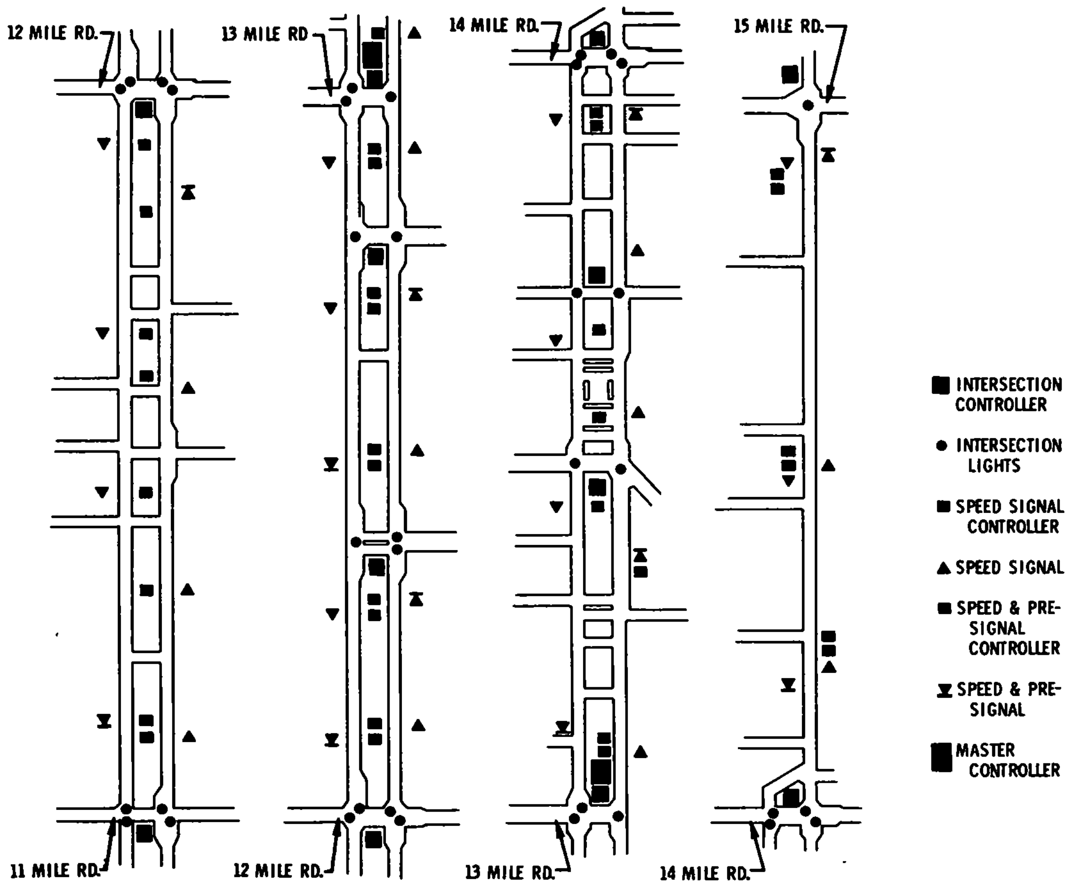


Figure 4. Location of traffic pacer equipment.

signals and presignals were blanked and bagged, respectively, for the operation of the progressive and past systems, as in Figure 7. "Signals Set At" signs were placed above the normal speed limit signs, as in Figure 8, to indicate the progression speed and were removed for the past system. It was a fortuitous circumstance that the progression speed for a 60-sec cycle turned out to be exactly the same as the speed limits that have recently existed on Mound Road.

A comparison of these three traffic systems (past, progressive, and pacer) was the object of the first 12-week testing program. The following performance criteria were used:

1. Average trip time, average velocities, and average number of stops.
2. Intersection capacity.
3. Queue length.
4. Safety.
5. Public opinion.
6. Possible driver economies.

Four professional data takers were provided by the Michigan State Highway Department for the initial 12-week testing program. Trip time and number of stops were recorded by the data takers while driving Mound Road between 11 and 15 Mile Roads. The data takers drove as an "Average Driver" passing about as many cars as passed them. Traffic counts were taken of the number of cars passing an intersection during the green portion of the light cycle. Queues (number of cars waiting for signal) were also recorded at the intersection, and in the case of the pacer system, at the presignal, during the red portion of the cycle. Accident reports and radar checks were recorded by the Warren Police Department during the testing program and compared with previous records. Public acceptance of the pacer system as well as the other two systems was measured by distributing questionnaries to motorists traveling on Mound Road. Also, a small number of fuel economy data were taken.

Figure 5. Roadside sign informing motorist of experimental test area.

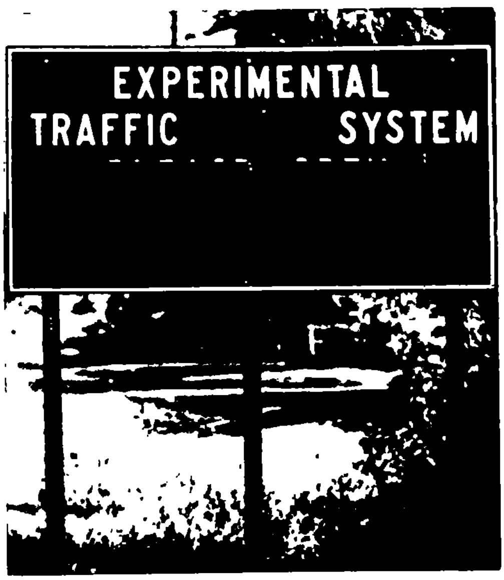


Figure 6. Roadside sign legend with progressive and past systems.

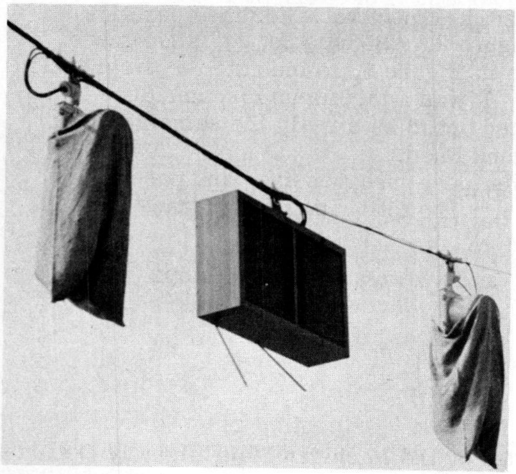


Figure 7. Speed and presignal for progressive and past systems.

Figure 8. Progressive system speed sign.

Procedure

So that weather and any other environmental variables would not affect one system more than another, a balanced design for testing was used. Due to certain time and scheduling restrictions, a completely balanced design could not be used. The three systems (A, pacer system; B, progressive system; C, past system) appeared in the following order during the 12-week testing program: C, A, B, C, B, A, C, A, B, C, B, A. During the experimental testing period, all other traffic control parameters were held constant, such as cycle length, split, offset, and speed limit. The testing periods used were 6:30 to 9:00 AM and 3:00 to 5:30 PM, Monday through Friday. These two time periods included the heaviest volume of traffic each day. System changes were made on each Saturday by the Macomb County Road Commission. Data were taken at the following intersections: 12 Mile and Mound, north and south bound; 13 Mile and Mound, north and south bound; Chicago Road and Mound, north and south bound; 14 Mile and Mound, north and south bound; 15 Mile and Mound, north bound; and 11 Mile and Mound, south bound. An equal number of observations were made at each intersection for all systems. Traffic counts at all intersections were also balanced for time of testing and day of the week in an incomplete randomized block design. For example, data were taken at the same intersection, the same four days of the week, at the same time intervals for all three systems. This was done to eliminate any effect day-to-day variability might have on the results. Randomization and replication are paramount for interpretation of the results of this experiment in any objective sense. The most important assumption concerning this experiment is that the traffic volume not change over the entire testing program.

Due to road construction, system failures and decreased traffic volume during the auto company-union strikes in the area, approximately one week of data were not usable for each of the three systems tested.

Instrumentation and Data Processing

The following instruments were used to collect data on traffic:

1. A portapunch unit, which holds a preperforated IBM card. A stylus was used to punch the number of cars that went through the intersection.

2. A productograph, which records the time of day to 0.1 sec when the operator depresses a button. This instrument was driven from a car battery by a 12-v DC to 110-v AC converter. It was used by the driver of the trip time car to record the time that he had passed an intersection light—accuracy ± 2 sec in 8 min.

3. A fuel metering instrument used to obtain fuel consumption data from the pace car. It uses two calibrated burettes for measuring the amount of fuel that was used in traveling the 4-mi experimental test section—accuracy 0.1 percent.

Pictures of these data-taking instruments are in the Appendix. Figure 9 shows how these instruments were used in each of the data-processing systems.

RESULTS

Consistency Measures

The assumption was made earlier that the traffic volume not change appreciably from the onset to the end of testing. Traffic counts at all intersections were compared on a weekly basis, and no significant change was noted throughout the testing program. The average standard deviations for the total number of cars through an intersection, the number of cars turning right and the number of cars turning left were ± 7, ± 12, and ± 10 percent, respectively. In other words, the actual number of cars through, right, and left differed from the average by less than these amounts 67 percent of the time. The number of cars through each intersection was totaled for each system. The percentages of the total traffic volume for the three systems are as follows: pacer system, 33.8 percent; progressive system, 33.2 percent; and past system, 33.0 percent. Figures 10 and 11 show the traffic flow patterns for the 4-mi experimental testing area during the morning and evening rush periods.

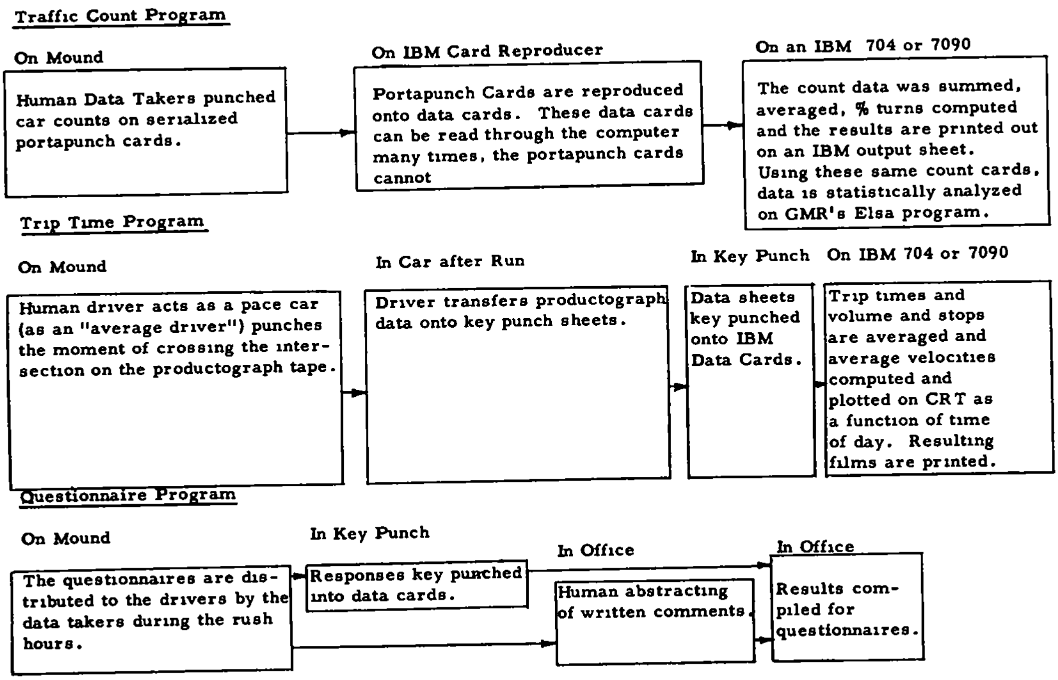


Figure 9. Flow chart of data-processing systems employed for traffic pacer 12-week comparison study with progressive and past systems.

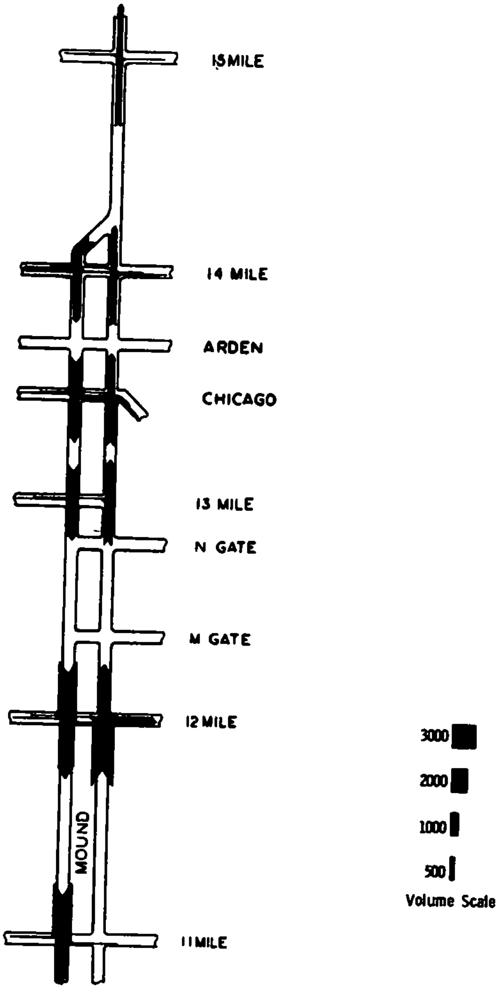


Figure 10. Average traffic volume for 12-week testing period, 6:30 to 9:00 AM.

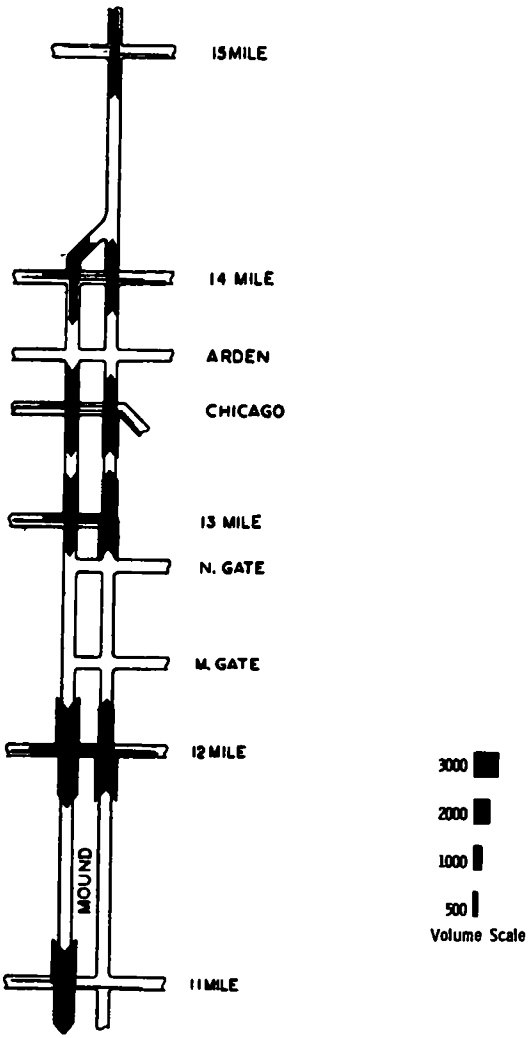


Figure 11. Average traffic volume for 12-week testing period, 3:00 to 5:30 PM.

Trip Times

Frequency of Stops. — While actual trip time data were being taken, the number of complete stops per trip was also recorded. The average number of stops per trip for morning and evening traffic is given in Table 1. A trip is defined as traveling from 11 to 15 Mile Road or 15 to 11 Mile Road, 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. How many miles a motorist can travel before he has to make a complete stop under the three systems is given in Table 2.

An analysis of variance was performed on these data, and the systems were found to be significantly different beyond the 0.05 level of confidence.

Stops may also be thought of as a delay to the driver in traveling from one place to another with a certain amount of displeasure associated with each delay. If one assumes one-half the red cycle as the average delay per stop and compares the three systems on the time delay per trip (4 mi), the results are given in Table 3.

Table 3 only includes the theoretical average time that a car is stopped and does not include the time lost in deceleration or acceleration before and after a stop. Although the average delays are not large, the displeasure associated with them is probably much greater, especially for manually shifted automobiles and trucks.

Continuous records were made of the time taken to travel the 4-mi experimental test area. Average velocities were computed from the time recores and are given in Table 4.

Trip time was significantly less for the pacer and progressive systems when compared with the past system (t's obtained were significant beyond 0.01 level of confidence). No statistically significant differences were found between the pacer and progressive systems. This result is to be expected because even in periods of very light traffic the trip time will be determined by the progression speed which was the same for both pacer and progressive systems; that is, with either of these systems a driver operating above the progression speed would be stopped at some intersection signal and slowed to progression speed.

The frequency of stop data indicates that the additional information given the driver by the pacer system permits more accurate speed control and avoids stops as frequent as those observed with a progressive system.

The questionnaire results indicate that drivers feel they are making better time when driving the pacer than either of the other systems. This might suggest that the driver's judgment of time is in-

TABLE 1

AVERAGE NUMBER OF STOPS PER TRIP

System	Avg. No. of Stops	
	AM	PM
Pacer	0.23	0.73
Progressive	0.41	1.17
Past	2.35	3.20

TABLE 2

AVERAGE NUMBER OF MILES TRAVELED BEFORE STOP

System	Avg. No. of Miles Traveled	
	AM	PM
Pacer	17.24	5.46
Progressive	9.71	3.41
Past	1.70	1.25

TABLE 3

TIME DELAY

System	Delay (sec/trip)	
	AM	PM
Pacer	3.45	10.95
Progressive	6.15	17.55
Past	35.25	48.00

TABLE 4

AVERAGE TRIP TIME AND AVERAGE VELOCITY

System	AM			PM		
	Average Trip Time			Average Trip Time		
	Sec.	Std. Dev. Conf. Interval	Avg. Velocity (mph)	Sec.	Std. Dev. Conf. Interval	Avg. Velocity (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]One standard deviation confidence interval.

fluenced more by the amount of time that the vehicle is stopped than by the time the vehicle is in motion.

Some typical plots obtained from the trip time computer program are shown in Figure 12.

Queue Length

A summary was made of the average number of cars queued per cycle at each intersection for the three systems. These averages were then totaled, and a comparison was made between the average number of cars queued per cycle for all the intersections at which data were taken on all three systems. In the case of the pacer system, the number of cars queued per cycle was recorded at both the intersection and at the presignal (see Table 5).

From the standpoint of traffic control, vehicles stopped at a presignal are of less concern than those at an intersection. The greater fraction of green time permits vehicles to accelerate to road speed before the intersection is reached and they do not delay cars behind them.

A t-test was performed on the average queue length at the intersection for the pacer vs progressive, pacer vs past, and progressive vs past system. The average queue length observed under the pacer

TABLE 5

AVERAGE NUMBER OF CARS QUEUED PER CYCLE FOR ALL INTERSECTIONS

System	Cars Queued (Avg. No.)	
	At Intersection	At Intersection and Presignal
Pacer	0.80	3.58
Progressive	4.99	
Past	6.28	

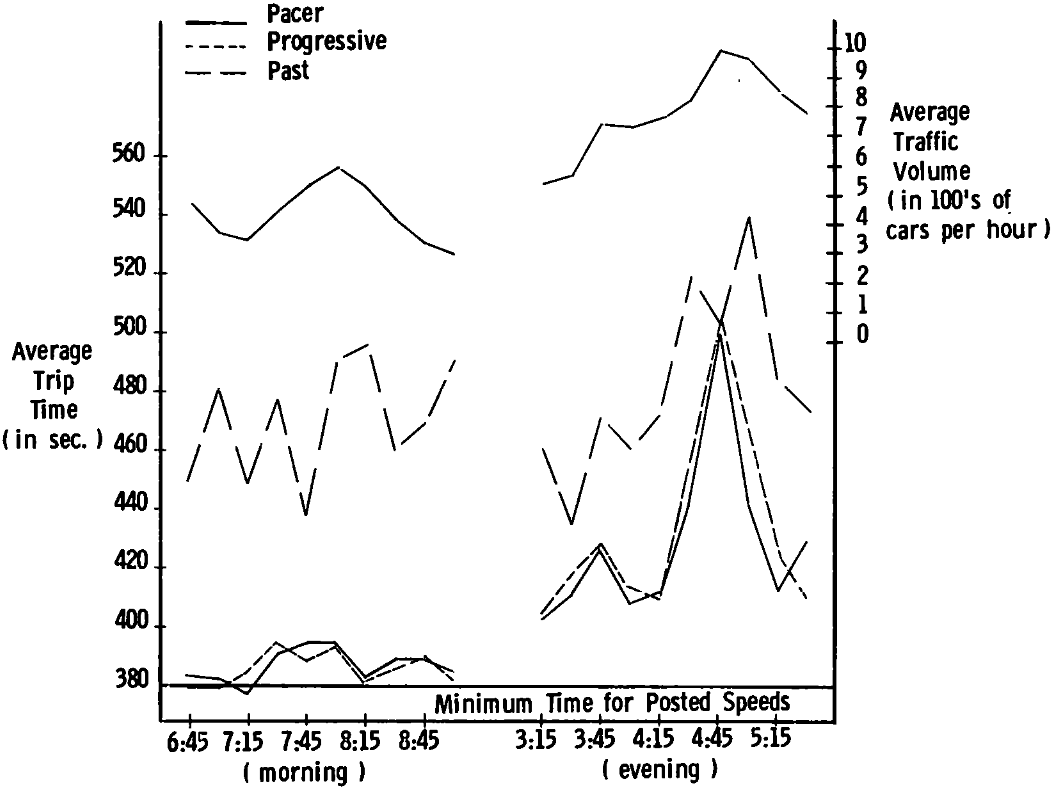


Figure 12. Trip time vs time of day for northbound traffic.

system was significantly less than that with either the progressive or past systems (both beyond 0.01 level of confidence). The average queue observed with the progressive system was not significantly different from that using the past system. After combining the queues at the intersection and at the presignal, the difference between the pacer system and progressive system was significant at the 0.08 level of confidence, and the difference between the pacer and past systems was significant at the 0.02 level.

It was further hypothesized that some relationship might exist between traffic density and queue length (the average number of cars queued at an intersection during the red portion of the cycle). Figure 13 shows 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 up to and including 1,200 cars per hr. Data beyond this point were fit visually. The standard error of estimate (σ_W), which is a measure of goodness of fit, for the straight line fit to the pacer data was $\sigma_W = 0.063$.

The standard error of estimate for the pacer including queues at the presignal was $\sigma_W = 0.259$ and values of $\sigma_W = 0.231$ and $\sigma_W = 0.253$ were obtained for the progressive and past systems, respectively.

A certain amount of error was involved in judging the length of a queue. However, the error is quite small, in the neighborhood of ± 1 car for 15 cars queued and ± 3 cars for 25 cars queued. All counts of 40 or more queues were given the value of 40. Because each data taker counted at the same intersection for each of the three systems, the amount of judgment error should not differ appreciably between the systems.

Intersection Capacity

From the beginning of the 12-week testing period, the authors realized that there

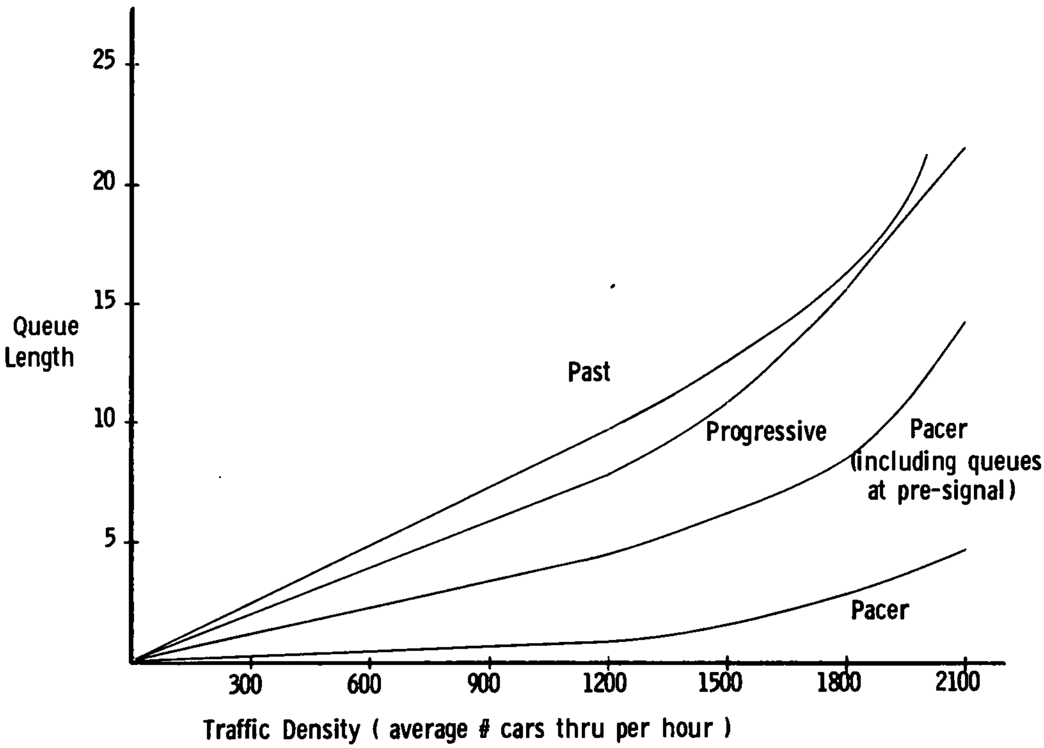


Figure 13. Queue length vs traffic density.

are many variables that might influence the maximum number of cars that can pass through an intersection. These parameters are for all traffic systems as follows:

1. The length of the green phase.
2. The length of the amber phase.
3. The percentage of turns.
4. The length of the turn aprons.
5. The local speed limit.
6. The percentage of trucks in traffic; that is, the average accelerations (plus or minus) and length of the vehicles.
7. The time phasing of the arrival of cars from the last intersection.
8. The sight distances available to the driver as he approaches the intersection.
9. The clarity of signing near the intersection.
10. The time of day.
11. The width of the lanes.
12. The proximity of parked cars.

For the pacer system there are several other parameters:

1. The distance from the presignal to the intersection.
2. The time phasing of the release of drivers from the presignal to the intersection.
3. The time phasings of all speeds shown on all the speed signals with respect to the intersection signal.
4. The time durations of all speeds shown on all speed signals preceding each intersection.
5. The use or the absence of the flashing high speed at the presignal just before the onset of the presignal amber.
6. The actual speeds to be shown on the speed signals.

In the 12-week experiment, the variables for all traffic systems were held constant except 3 and 6, which were monitored for consistency. From one week in which the pacer was operating, to the next week that the pacer was in operation, all the variables for this system were kept constant. Although these six parameters were set by theoretical calculation to be the best for that location, there are undoubtedly some of these initial settings that should be changed to obtain the maximum capacity at each intersection. For example, the distances to the intersection from the presignal were intentionally made different in an attempt to establish the best operational distance. Only a small improvement was expected in capacity. Theoretically, von Stein has predicted an increase of two cars per cycle per lane attributable to the presignals. However, small increases in capacity are worth a great deal when one considers the cost required to obtain an equivalent increase in capacity through the purchase of additional right-of-way and the use of additional concrete.

In an attempt to ascertain any over-all improvement in intersection capacity, all the heavy volume intersections at rush periods were compared by measuring the frequency of cycles in which some arbitrary maximum car count per cycle or over made it through the intersection during the green. For example, at an intersection during the rush period, the number of times that 30 or more cars got through during the green portion of the cycle was recorded. The results are given in Table 6.

TABLE 6

AVERAGE PERCENT OF LIGHT CYCLES DURING WHICH 30 OR MORE CARS PASSED THROUGH AN AVERAGE INTERSECTION

System	Light Cycle (%)
Pacer	25.4
Progressive	19.4
Past	17.1

The 8.3 percent improvement of the pacer over the past system was statistically significant beyond the 0.01 level of confidence. The pacer's 6 percent improvement over the progressive system was significant at the 0.05 level. No significant difference was obtained between the progressive and past systems.

Results from Questionnaires

Another comparison was made between the three experimental systems in the form

of a questionnaire. A total of 600 questionnaires were distributed by the State data takers each week. The questionnaires were distributed to drivers entering or leaving the experimental test area of 11 to 15 Mile Roads. In order that a true taxpayer's evaluation might be made, the questionnaires were mailed to the Macomb County Road Commission. Each week 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 and the two systems that were to be compared accompanied each questionnaire. A copy of the questionnaire used is in the Appendix. Approximately 1,800 questionnaires were not distributed because of system malfunctions, road construction, and other factors beyond control. A total of 6,000 questionnaires were distributed and 1,350 or 22.5 percent were returned. A basic assumption, as mentioned earlier, is that traffic volume does not change appreciably over the 12-week testing period. To make valid comparisons between the three systems, all other external variables should remain as consistent as possible. To test for consistency, various responses to the questionnaires were analyzed.

Drivers indicated whether they were driving a truck or an automobile, what time of day, how often, and how many miles they normally traveled on the experimental system from 11 to 15 Mile Roads. No statistically significant differences were observed from week to week during the 12-week testing program for responses to all the information listed. In other words, the ratio of cars to trucks remained stable, the distribution of trip lengths and frequencies of travel per week did not change, and the time distribution of traffic also remained constant. Table 7 gives the average frequencies of the listed traffic information.

TABLE 7

QUESTIONNAIRE QUESTIONS AND ANSWERS

Question	Answer: Category	Answer: Percent
What type of vehicle are you driving?	Auto	95.7
	Truck	4.2
	NR	0.1
How often do you normally travel on Mound Road? (times per week)	5 or more	88.3
	2 to 4	8.6
	1 or less	2.7
	NR	0.4
How many miles do you normally travel each morning or evening on Mound Road between the experimental test area of 11 and 15 Mile Road? (mi)	Less than 1	7.2
	1	20.2
	2	20.7
	3	16.5
	4	35.4
At what time interval do you usually travel on Mound Road?[a]	Rush hours (6-9 AM; 3-6 PM)	92.8
	Midday (9AM-3PM)	15.1
	Evening (After 6PM)	21.2

[a]Summation of percentages of response greater than 100 percent due to multiple responses.

As mentioned earlier, the traffic volume and percentage of turns were very consistent over the 12-week testing period. The consistency measures obtained from the questionnaires give further support to the important basic assumption, that the amount and type of traffic remain constant throughout the testing program.

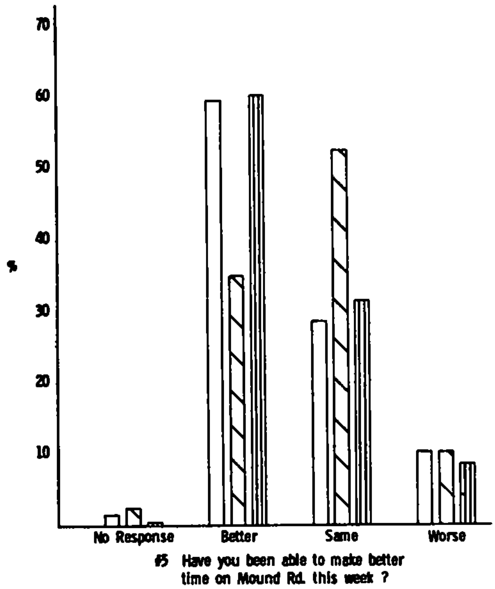


Figure 14.

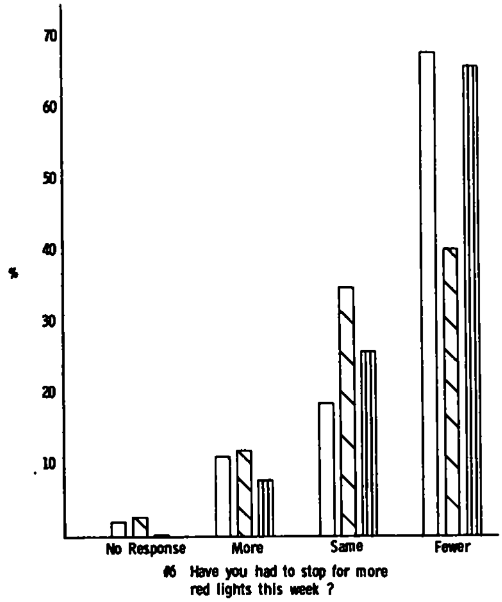
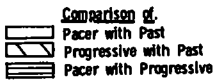


Figure 15.



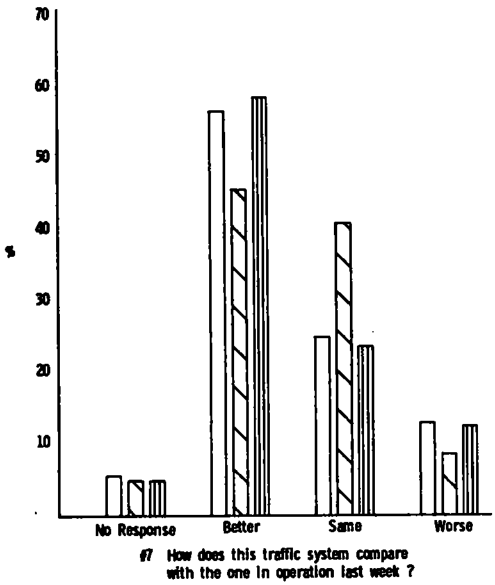


Figure 16.

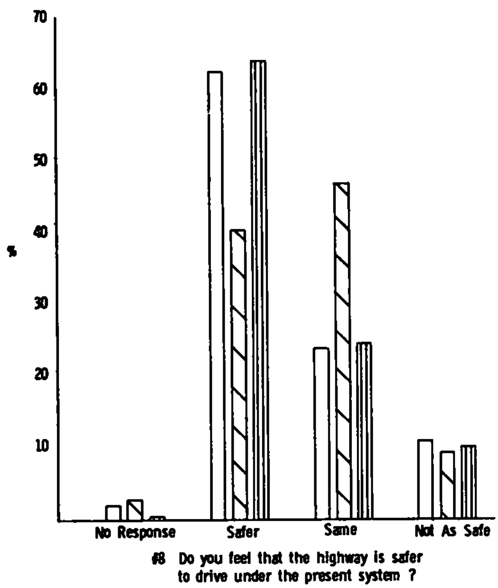


Figure 17.

Basic Comparisons

Responses to questions 5, 6, 7, and 8 are shown in Figures 14 to 17. Each system was compared with the other two systems, and in all cases the pacer system was preferred to either the progressive or past systems. The pacer system was preferred significantly more to the past system than was the progressive system to the past system. However, no significant difference was obtained when comparing the pacer with both the progressive and the past systems; i.e., the pacer system was preferred as much to the progressive system as it was to the past system.

The statistic used to test for differences between the three systems was χ^2. This measures discrepancies between observed and theoretical frequencies and makes probability statements about these discrepancies. The confidence level (probability level) chosen was 0.05. This means that the value of χ^2 obtained from any difference between observed and theoretical frequencies must be high enough so that it could have occurred by chance only 5 times out of 100 occurrences. Whenever a significant difference is noted in the report, it is so beyond the 0.05 level of confidence.

The χ^2 obtained for the comparisons between the pacer-past systems and progressive-past systems on questions 5, 6, and 8 were all significant beyond the 0.01 level of confidence. For question 7 the χ^2 was significant at the 0.055 level of confidence.

In general, the drivers preferred the pacer system to the other systems, felt that they were making better time, fewer stops, and that driving was safer.

No problems were noted concerning the legibility of the overhead speed signs. When motorists were asked if they had trouble maintaining the indicated speeds on the overhead speed sign, approximately ⅓ of them stated that they did have trouble. Of these, about 30 percent said the signs changed too often and too rapidly, suggesting an incomplete understanding of the operation of the system. The responses to what point they should be going the suggested speed with respect to the overhead speed sign (question 11) indicated that over 50 percent of the drivers were following the signs as soon as they could see them or were not sure where to begin the suggested speed, even though the legend under each speed sign read, "Begin Through Speed Here." Of those drivers who had trouble maintaining the speed on the overhead speed sign, about 30 percent stated that other drivers were not cooperating in following the suggested speeds. Another 25 percent gave as their reasons slow moving vehicles, heavy traffic, and cars turning onto cross-streets from Mound Road. Again, these percentages did not change significantly from the start of testing to the end of testing.

When the drivers were asked if they would like to see the pacer system installed on other roads, 74.5 percent said "yes," 20.4 said "no," and 5.1 gave no response. The attitude of the drivers to this question did not change significantly from the first week of testing to the last week of testing as indicated in Table 8.

TABLE 8

ANSWERS TO QUESTION ON APPROVAL OF PACER SYSTEM INSTALLATION ON OTHER ROADS

Week	Response (percent)		
	None	Yes	No
Second	8.2	74.9	16.9
Sixth	7.7	75.4	16.9
Eighth	3.6	71.4	25.0
Twelfth	1.1	76.1	22.8

The main reason for not wanting the pacer system installed on other roads was that it would increase taxes. As mentioned earlier, the questionnaires were mailed to the Macomb County Road Commission. The drivers possibly thought that the Commission was paying for the installation, and hence the County was undertaking an experimental

project with taxpayers' money. The other reasons for not wanting other installations varied from preferring the progressive system to not liking the presignals to being a distracting influence from the driving task.

A comparison was made between truck drivers' and auto drivers' opinions concerning the pacer system. Approximately the same percentage of truck drivers had trouble maintaining the indicated speed as did the auto drivers. There were no significant differences between the truck and auto drivers' opinions concerning installation of the pacer system on other roads. Questions 5, 6, 7, and 8 were combined and responses were listed in the categories favorable, neutral, or unfavorable. Results for the auto-truck comparison are shown in Figure 18. Truck drivers prefer the pacer to the past system significantly more than do auto drivers. Both auto and truck drivers prefer the pacer system to the progressive system about equally (no statistically significant difference). However, auto drivers significantly prefer the progressive system to the past system more than do the truck drivers. This last finding may be due to the importance that truck drivers ascribe to the presignals, possibly indicated by their significantly greater preference for the pacer system over the past system. The pre-

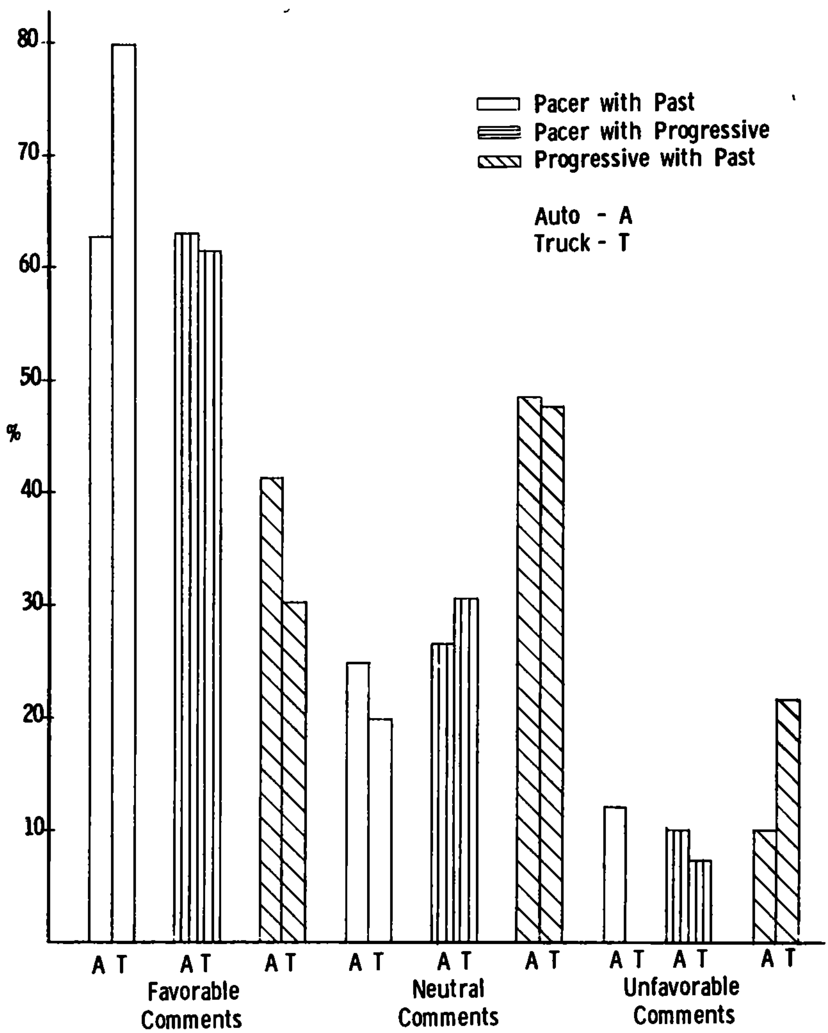


Figure 18. Comparisons among systems.

signals give the truck driver a chance to pick up speed so he can be moving when the intersection light turns green. If a truck driver is stopped while traveling on the progressive system, this advantage is lost.

In any type of public opinion research, it may be asked how different the results would have been if everyone had been questioned and not just a sample from the total population driving on Mound Road. By computing the sampling tolerance at the 0.95 confidence level, it was found that for observed percentages of 50 percent, the results would not change more than ± 3.57 percent and for percentages in the neighborhood of 10 or 90 percent the results would not change more than ± 2.14 percent if all Mound Road drivers had been questioned.

User Economies

Because drivers make fewer stops using the pacer system, and because a great deal of gasoline is consumed in accelerating, it might be expected that vehicles driven on the pacer system should experience better fuel consumption. To test this hypothesis in an abbreviated experiment, one driver was selected to drive the pace car three successive mornings on the three different traffic systems. The vehicle used was a 1961 passenger car. The temperature outside on the three days was $55^\circ \pm 5^\circ$ and the fuel temperature was $75^\circ \pm 5^\circ$ for the three days of the test. The trips were made both north and south to cancel out the effects of wind. Table 9 shows the results of this abbreviated test.

The transitive nature of the data is immediately apparent; i.e., there is an increasing improvement as one observes the data in the order past, progressive, and pacer. However, because of the small number of observations, the only observed statistical difference was between the pacer and past systems for mean fuel consumption.

Although it has not been tested, it might be expected that brake wear should also be significantly reduced by the pacer system because of the fewer stops that the drivers are encountering.

Safety

Possibly the only true criteria for safety is number of accidents. Because accidents are such relatively rare events, a true estimate of safety would take much more time than the four weeks in which the pacer system was operating. On the other hand, some inferences can be made about safety. Because the pacer creates large gaps in the traffic stream, entering a busy artery from a nonsignalized cross-street is easier to accomplish. Also, at busy pedestrian intersections, a vehicle-pedestrian accident should be less likely to occur if the vehicles stop at the distant presignal. From the measures of queue length, the pacer system reduced the average number of cars waiting at an intersection by 87 percent over the past system and by 84 percent over the progressive system. Because fewer cars are waiting at an intersection, the chance for intersection accidents may be reduced. As was pointed out in the questionnaire results (see Fig. 17), 64 percent of the motorists thought that the pacer was safer than either the past or progressive systems, 24 percent thought that the pacer was about the same as the other two systems, and only 11 percent thought that the pacer was not as safe.

From verbal reports of the drivers of the experimental pace car and from observations made by the Warren Police Department, it was felt that fewer lane changes were being made. This may be attributable to no advantage being gained by going over the speed limit and passing other cars. Radar checks were made before and after the installation of the pacer system and although the average speed of traffic was only slightly slower, the variability of automobile speeds was greatly reduced when the pacer system was in operation. The 85th percentile speed before installation of the pacer system was 47.5 mph and was reduced to 44.7 mph after the installation. This means that traffic was more uniform and that speeding was not as prevalent. No accidents were attributable to system changes.

TABLE 9

COMPARISON OF FUEL CONSUMPTION FOR THE THREE SYSTEMS

System	No. of Runs	Relative Fuel Consumed (pacer = 1.0)	Avg. Time of Trips (sec)	Avg. No. of Stops per 4 Mi	Date, Day, and Time
Pacer	6	1.00	414.7	0.333	10/20/61 Friday a.m.
Progressive	9	1.05	424.2	0.667	10/23/61 Monday a.m.
Past	8	1.12	440.8	1.88	10/24/61 Tuesday a.m.

Future Testing of Pacer System

In the next twelve months, a variety of experiments will be conducted in two main areas: capacity and system simplification. The system will be refined to meet the specific needs of the Mound Road test area. Additional data will be taken on the same performance criteria and compared with the results of the present experiment.

SUMMARY AND CONCLUSIONS

Results from the initial 12-week testing program comparing the three systems (A, traffic pacer system; B, progressive interconnected system; and C, noninterconnected system) are as follows: Traffic volume was constant over the entire testing period. Significantly fewer stops were made under system A, higher average speeds could be maintained, and trip times were less for systems A and B than for system C. The intersection capacity was increased, inasmuch as high volume traffic counts on an average were 8.3 percent more frequent for A than C and 6 percent more frequent than B. The average number of cars queued under system A was 44 percent less than system C and 27 percent less than B. System A had equivalent safety, and results from the questionnaires indicated that approximately 65 percent of the people felt that A was safer and faster, and caused fewer stops than B or C. Also, 75 percent of the respondents would like to see system A installed on other roads.

Future research will be conducted so that capacity and system simplification may be explored to a greater extent.

ACKNOWLEDGMENTS

The authors wish to thank the members of the Macomb County Road Commission for their continual cooperative spirit and diligent work in the construction and maintenance of the pacer system and, in particular, their assistant engineer, Warren Anderson. They express their thanks also to the Michigan State Highway Department, whose Research Group, headed by Edward Gervais, supplied guidance in the Pacer design and whose Survey Group, headed by Julius Negri, supplied the data-taking personnel. At the General Motors Research Laboratories, there were many contributors to the success of the project: Herbert Bauer for his design of the speed signal, Fred Becker and Norman Brainard for their help in the electrical design of the system, James Dallemand for his statistical assistance, George Cole for his comprehensive "trip time" program, and to Joseph Bidwell for his continuing interest and direction of the project. Also, they express their thanks to the Detroit Edison Company and the Michigan Bell Telephone Company for their continuing cooperative spirit and assistance in the design

and installation of the traffic pacer system. The Warren Police are also to be thanked for their cooperation in reporting accidents and speed checks through the direction of Inspector Charles Rabideau.

REFERENCE

1. Herman, R.C., "Theory of Traffic Flow." Elsevier (1961).

Appendix

TRAFFIC PACER HARDWARE

For purposes of testing the traffic pacer control concept, the pacer hardware was designed and installed to be flexible. The specifications for the traffic pacer speed signal equipment called for the following:

1. Six independently selected cycle lengths.
2. Five independently selected offsets.
3. Four independently selected splits and number sequences (the split and number sequences are tied together).

In general, each speed signal or speed and presignal had its own controller. The controllers were mounted on a pole in pairs of double cabinets, one double cabinet for the northbound direction and one double cabinet for the southbound direction, as shown in Figure 19. This dual controller arrangement allowed for independent selection of the northbound and southbound speed number sequence. If two speed signals had been operated from one controller, a split or offset change could cause a lighting sequence change, requiring nonstandard equipment to be built. Hence, the single controller per speed signal resulted in a more flexible design. When the testing period is over, the lighting sequence can be frozen, and any sequence changes that result from offset or split changes can be resolved in favor of the best compromise. In fact, it would be possible, and much less expensive, to operate the speed signal from the intersection controller.

The pacer system was designed to be fail safe. In each intersection controller, a timer terminates the cross-street green with a pre-emptive cross-street amber, if the camshaft does not index ahead to the cross-street amber position when actuated by the dial key. The entire traffic pacer system is interconnected with telephone lines.

Figure 20 shows in schematic form the fail safe circuitry that ties the pacer system intersection controllers together. If the contacts are broken in any of the locations A, B, or C (intersection controllers), all the local controllers are switched to local Edison power from the power that had been supplied the intersection controller by the local amplifier. The local amplifier supplies a voltage to the controller synchronous drive motor, the frequency of which is slaved to the frequency of the master. It is the output of the local intersection amplifier that holds in a fail safe relay, the contacts of which are used to complete the series circuit. Thus, if any of the intersection controllers were to stop running on master frequency, this event would be detected, and the local failed intersection would continue servicing traffic on a 60-sec cycle obtained from local intersection power. If this situation were to occur, the speed signals adjacent to the failed intersection would not be in phase with the failed intersection. Hence, the master control sends a shut-down function to all the speed signals and establishes the presignals in an amber flashing condition. If the failure occurred at a speed signal or presignal and not at an intersection, the local speed signal would be blanked and the presignal would establish an amber flashing condition. Figure 21 shows the master control for the pacer system.

The speed signal used in the pacer system is a multibulb signal, with small relays used to perform the switching of the numerals in the signal. Figure 22 shows a close-

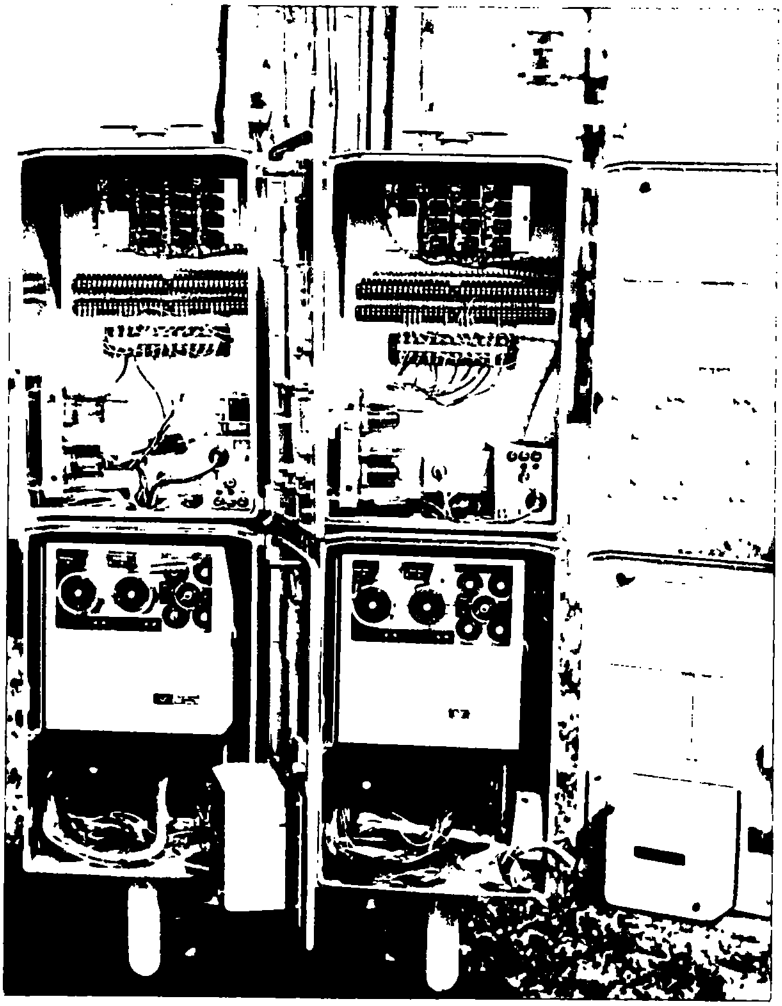


Figure 19. Typical mounting of speed signal controller double cabinets. Conventional controller contained in lower cabinet, and terminal strips for wiring speed number sequence contained in upper cabinet. Right cabinet pair controls northbound speed signal; left cabinet pair controls southbound speed and presignal.

up view of the front of the speed signal, and Figure 23 shows the front "Koolshade" screen lowered and one of the digits removed, and turned to show the relays. The relays are mounted in about a 2-cps natural frequency suspension system to avoid the sharp high frequency vibrations in the horizontal direction created by the actuation and release of the relays. Such high frequency vibrations were fatiguing the bulb filaments. These small relays only switch the numerals displayed after the controller has broken the power. The power in the local controller is not applied to the new numeral configuration until the small relays in the speed signal are changed to thier new configuration. General Motors report 350 contains a discussion on the actual bulbs lit for each numeral and the clarity of the signal under various lighting conditions.

NOTES:

1. A, B and C are contacts on failure alarm relays with each local controller.
2. Current relay senses breaks in fail-safe line and open-failure alarm contacts.
3. Voltage relay senses shorts on fail-safe line.

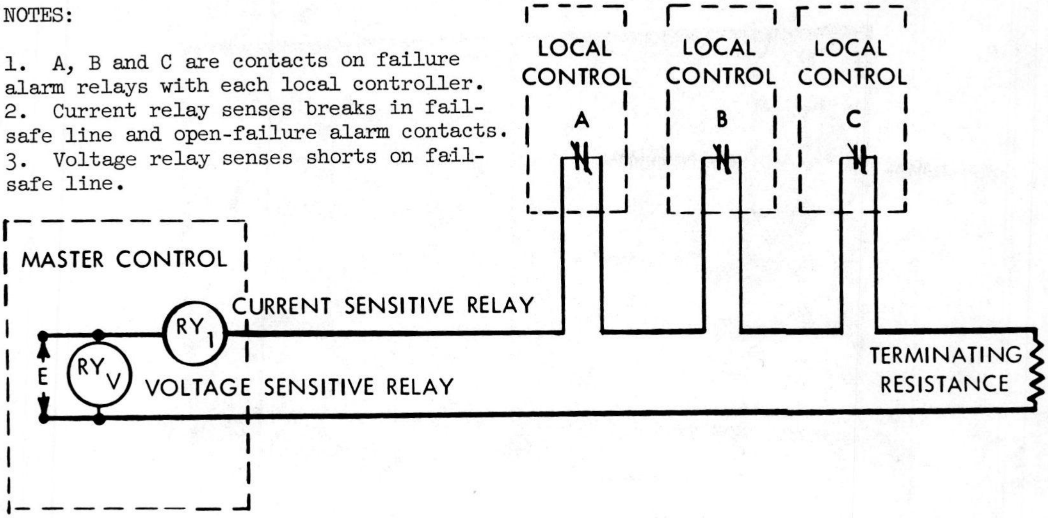


Figure 20. Failure alarm circuit.

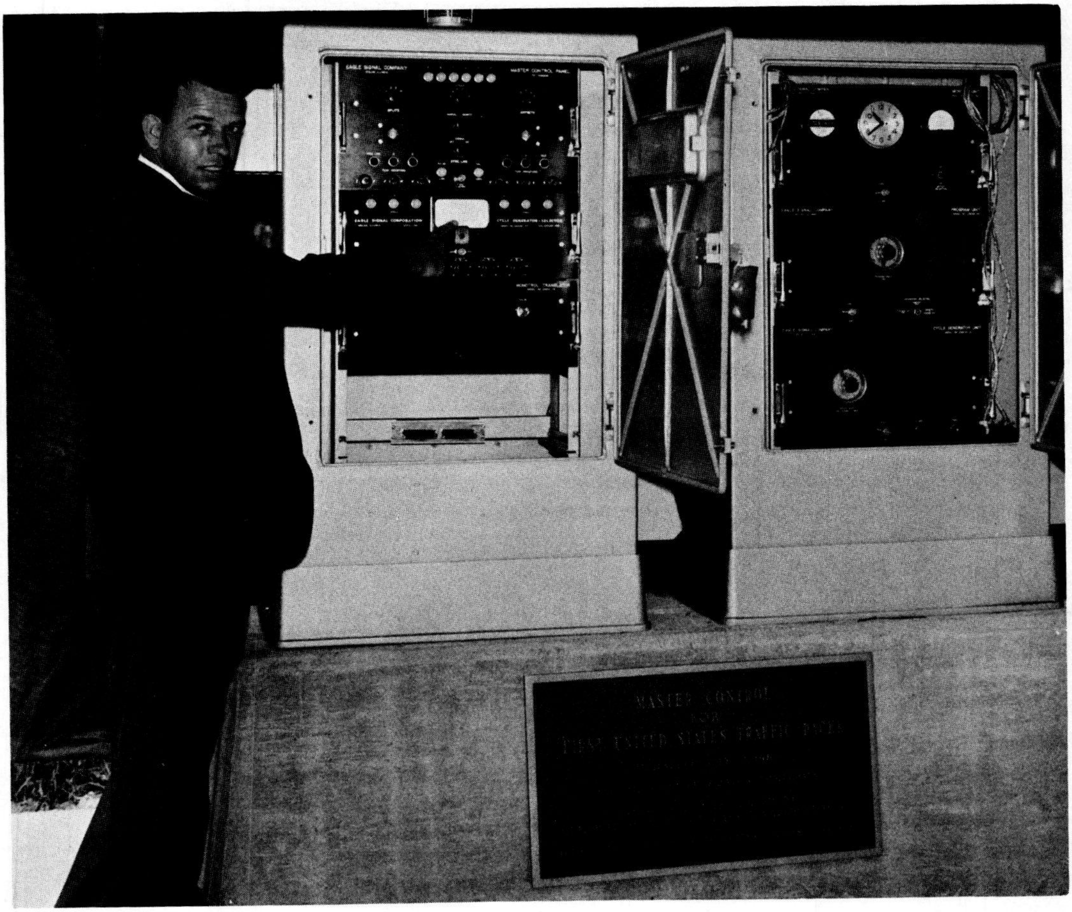


Figure 21. Pacer system master control.

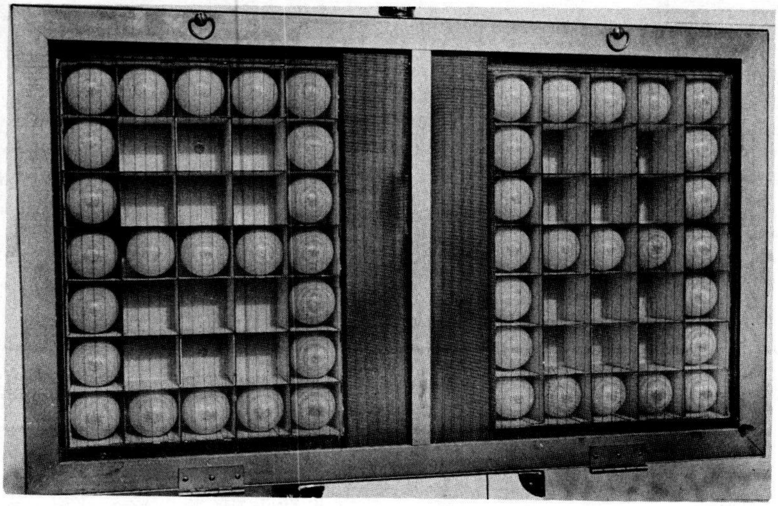


Figure 22. Close-up of speed signal.

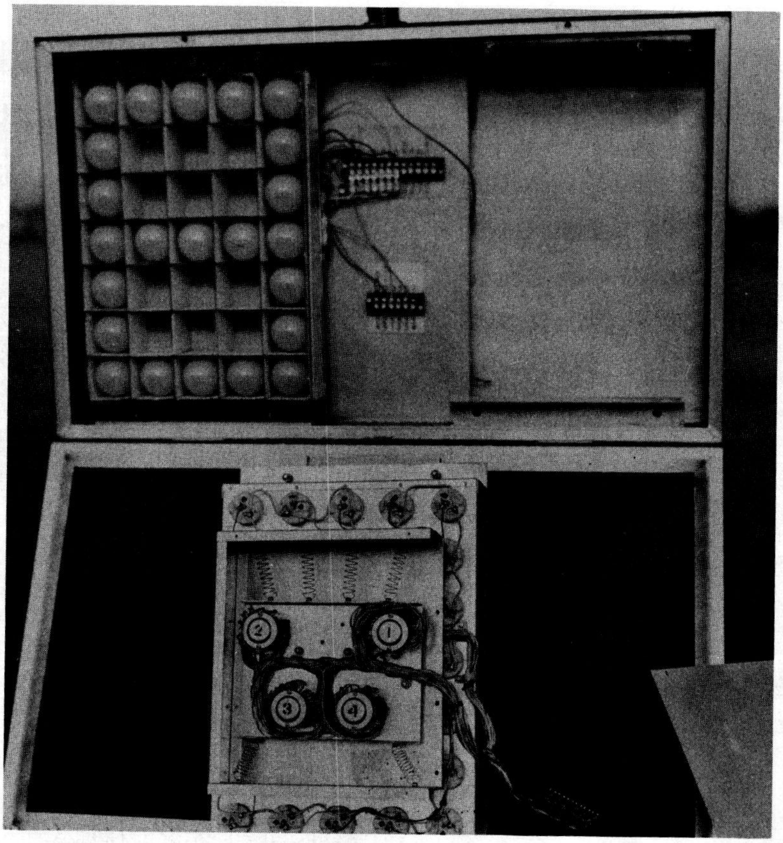


Figure 23. Close-up of interior of speed signal with right digit removed to show switching relays and their suspension.

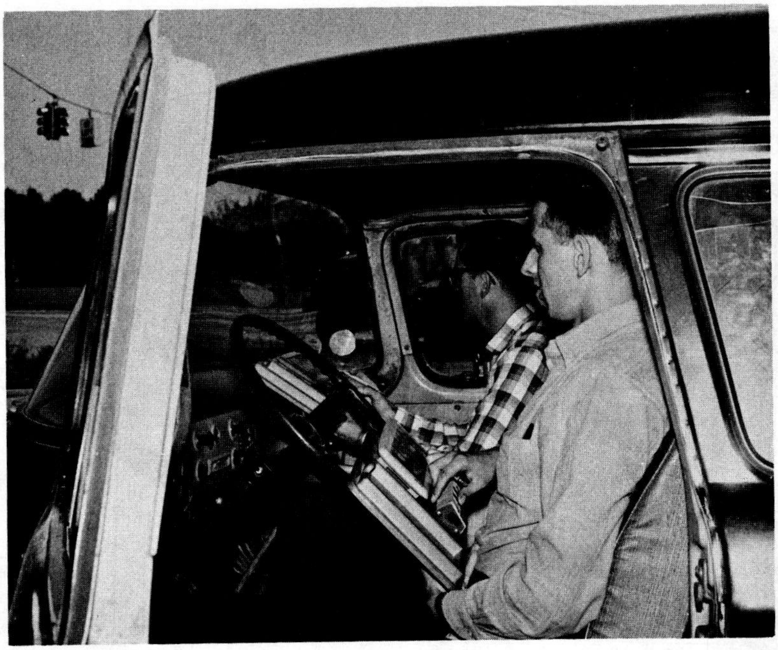


Figure 24. Operation of portapunch unit.

Figure 25. Productograph.

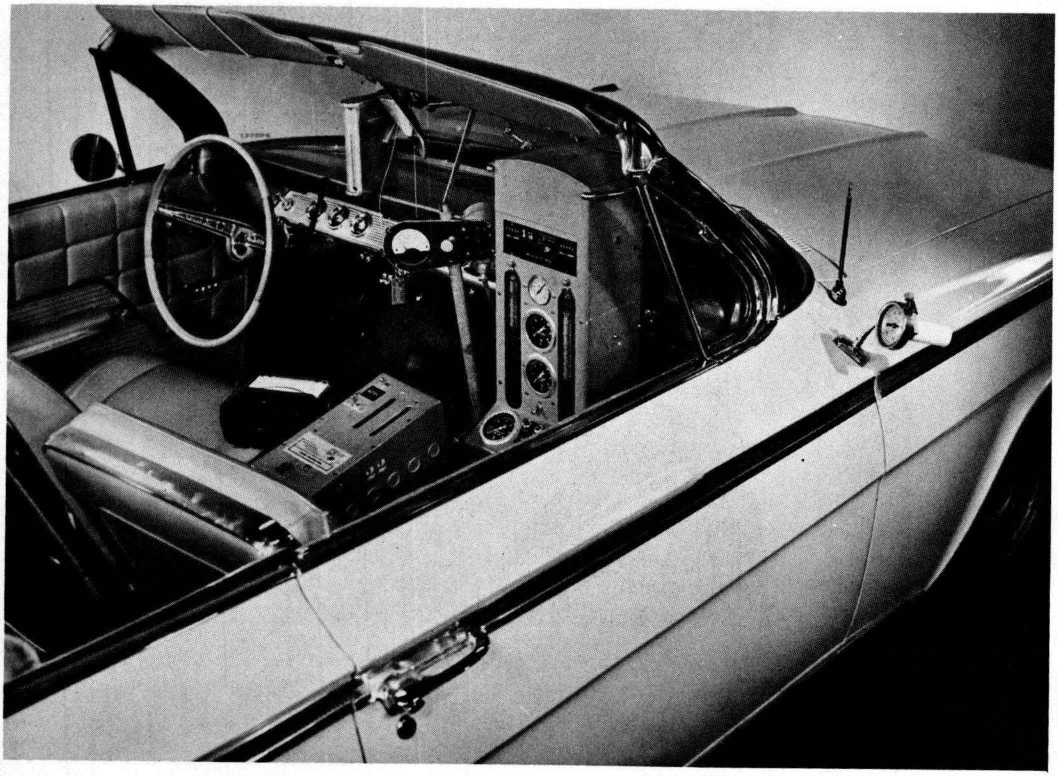


Figure 26. Fuel meter.

SAMPLE QUESTIONNAIRE

Three different traffic control systems are being tested on Mound Road between Eleven and Fifteen Mile Roads.

THE ORDINARY SYSTEM

The system used on most of the highways and streets.

THE PROGRESSIVE SYSTEM

The system in which the traffic signals are set at the posted speed.

THE PACER SYSTEM

The system in which overhead speed signs indicate the speed to travel in order to make the next traffic signal.

The system in operation this week is the ____________________. The system in operation last week was the ________________________. Please compare these two systems by answering the questionnaire provided.

How many miles do you normally travel each morning or evening on Mound Road between the experimental test area of 11 Mile Road to 15 Mile Road?

LESS THAN 1 MILE____ 1 MILE____ 2 MILES____ 3 MILES____ 4 MILES____

Please return this sheet with the questionnaire provided.

PLEASE DISREGARD IF YOU HAVE ALREADY
FILLED OUT A QUESTIONNAIRE THIS WEEK

We would be very interested in your opinions of the experimental traffic systems being tested on Mound Road between 11 and 15 Mile Roads. Please answer the questions below and return them in the postage-free envelope as soon as possible.

THANK YOU

1. Have you ever filled out a similar questionnaire on the traffic system in use this week?

YES____ NO____

2. What type of vehicle are you driving?

AUTO____ TRUCK____

3. How often do you normally travel on Mound Road?

5 OR MORE TIMES/WEEK____ 2--4 TIMES/WEEK____

ONCE OR LESS/WEEK____

4. At what time intervals do you usually travel on Mound Road?

6--9 AM____ 9 AM--3 PM____ 3--6 PM____

AFTER 6 PM____

5. Have you been able to make better time on Mound Road, within the experimental test area of 11 to 15 Mile Road, this week? (________to________) *

BETTER____ ABOUT THE SAME____ WORSE____

6. Have you had to stop for more red lights this week? (________ to________) *

MORE____ ABOUT THE SAME____ FEWER____

7. How does this traffic signal system compare with the one in operation last week? (________to________) *

BETTER____ ABOUT THE SAME____ WORSE____

8. Do you feel that the highway is safer to drive under the present system?

SAFER____ SAME AS BEFORE____ NOT AS SAFE____

* The actual week of system test was specified in the ( ).

*
9. Do you have any trouble reading the overhead traffic speed sign?

YES____ NO____ If YES, please explain.

10. Do you have any trouble maintaining the indicated speed on the changing overhead speed sign?

YES____ NO____ If YES, please explain.

11. At what point with respect to the overhead speed sign do you feel you should be going the suggested speed?

12. Would you like to see other main roads equipped with the present Traffic Pacer System?

YES____ NO____ If NO, please explain.

13. Do you have any comments or suggestions about the traffic signal system in use this week on Mound Road?

THANK YOU FOR YOUR COOPERATION

*Questions 9, 10, 11, and 12 were not included on the questionnaires the weeks in which the Progressive and Past Systems were in operation.

Discussion

H.J. KLAR, Chief Traffic Engineer, New Jersey Bureau of Traffic Safety, Trenton—Although the authors' efforts to increase the traffic capacity of a signalized intersection are commendable, the writer would like to raise a few questions.

1. Is the rear-end collision potential being increased by funneling vehicles through the main intersection at very close spacings?
2. Is the number of accidents increased when the accidents at both the main intersection and the presignalized location are added?
3. Will the obedience to traffic signals be lessened by the introduction of the presignal at a nonintersection (midblock) location?
4. Could not large compliance by motorists be obtained if the proper speed of progression were continuously displayed, thereby avoiding the possible negative aspects of questions 2 and 3?

In a brief verbal discussion with one of the authors he indicated that, though the posted speed limit was 40 mph, the 85 percentile speeds measured approximated 48 mph. If this is so, the writer believes this information should have been presented with the paper because it is a strong indication why motorists did not realize and hence did not react favorably when the signals were offset for a progressive movement at 40 mph. In other words, their normal operating speeds were higher than the speed of the signal progression and hence they were slowed or stopped by red signals in most instances and did not feel that the signals were in progression.

In the writer's work, establishment of the speed of progression as close as possible to the 80 to 90 percentile speed of traffic regardless of the speed limit has been attempted. In this way, it has been possible in many instances to get the speed limit raised so that it more nearly fits traffic conditions.