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IMPROVING THE LEVEL OF SERVICE OF A FREEWAY CORRIDOR THROUGH A DYNAMIC INFORMATION AND CONTROL SYSTEM

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OPTIMIZING FREEWAY CORRIDOR
OPERATIONS THROUGH TRAFFIC
SURVEILLANCE, COMMUNICATION AND CONTROL

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ABSTRACT

This report examines five separate techniques which might lead to an improvement in the level of service in a freeway corridor. The techniques were all associated with a dynamic information and control system on the John C. Lodge Freeway in Detroit. The northbound Freeway had a set of metered ramps and information signs used in the afternoon peak period.

The five techniques investigated and the findings are as follows:

1. Reduction of surface street travel times by means of real-time traffic signal control. An attempt was made to reduce travel times on streets indicated as alternate routes by the information signs. The signal timing plans were based on historical volume counts, expected travel times and current sign states. A reduction in overall travel time was obtained only for the second hour in the four-hour peak period. The increases were probably due to equipment malfunction and a paucity of data.

2. Revision of ramp metering calculations. The calculations were based on vehicular storage obtained from measured volume and occupancy at detector stations. It was found that vehicles slow down in passing merging areas between the stations. Hence new formulae to calculate storage were derived. It was also found that in the absence of information signs, Freeway travel times did not increase.

3. Ramp metering hardware changes to increase obedience. The ramp signals were reduced to two aspects with loop detectors just upstream and downstream to detect the passage of a vehicle. It was found that obedience was greatest with an increased length of upstream loop detector and when information from an upstream queue detector was taken into account.

4. Revision of metering strategy to try to prevent the build-up of congestion at bottlenecks. It was found that the downstream Freeway detector station used in determining metering rates should allow for only through traffic when a lane reduction occurs.

5. Diversion of Traffic from Intersections which may be blocked by ramp queues. Two ramp queues were studied and it was found that variable-message signs may be able to achieve some diversion only if a large majority of motorists passed such a sign and if most of the motorists were willing to take an alternate route.

TABLE OF CONTENTS

LIST OF FIGURES

APPENDIX A FIGURES

APPENDIX B FIGURES

APPENDIX E FIGURES

APPENDIX G FIGURES

LIST OF TABLES

Appendix F

SUMMARY OF FINDINGS

This report examines five separate techniques which might lead to an improvement in the level of service in a freeway corridor. The techniques are all associated with a dynamic information and control system on the John C. Lodge Freeway Corridor in Detroit.

A 6.1 mile section of the northbound Lodge Freeway had eight ramps which were metered during the four-hour afternoon peak period. Metering rates were determined on the basis of an assumed allowable vehicle storage between detector stations; these were approximately midway between ramps. Since queues could build up on the ramps associated with ramp metering there was a set of 27 variable message signs. These indicated to proceed to the nearest ramp when the queue length was less than a critical value. Otherwise, they indicated to continue on the network of alternate routes to the next downstream ramp. On rare occasions, diversion (by means of the signs) may have been suggested past all metered ramps to a ninth ramp where normally Freeway demand did not exceed capacity.

THE FIVE TECHNIQUES INVESTIGATED AND THE FINDINGS

1. Reduction of Surface Street Travel Times by Means of Real-Time Traffic Signal Control

As mentioned, diversion on surface streets is suggested whenever the ramp queue length exceeds a critical value. This is equivalent to a comparison between total travel times on the freeway and ramp and travel time on the surface street; a viable alternative. The aim of this technique was to reduce surface street travel time so that ramp queues would be reduced and overall travel time also reduced.

Twenty-seven intersections were selected for real-time computer control. Relay equipment and leased communication lines effectively connected the intersection signal controllers to the Control Center where they were tied into the computer. Signal timing plans were prepared based on historical volume counts and travel time runs. Provision was made to adjust the split of green time every 15 minutes and the offset every five minutes.

The effectiveness of computer control was based on a combination of aerial photography, ground counts, and moving vehicle travel time studies before and after the operation. In the first hour of a four-hour peak period, there was an overall increase of 15% in total travel time on the surface street network for a fixed amount of travel. In the third hour there was also an increase, one percent, and only in the second hour was there a decrease, six percent. No result was obtained for the fourth hour because the onset of darkness terminated aerial data collection. A paucity of data and equipment malfunctions probably caused the two increases.

Considering only the links on the alternate route network where progression was obtained, a 33% increase in average speed was obtained during the second hour with a 14% increase in the third and busiest hour of the peak period. Also, there was a significant reduction (from 52% to 40%) in the probability of having to stop at a controlled intersection and the average stopped time was reduced by 48%.

No estimate has been derived of the likely reduction in overall total travel time due to any diversion from the ramp queues. It is considered this should be done only after a future project involving only one alternate route and where likelihood of equipment malfunctioning has been minimized.

2. Revision of Ramp Metering Calculations

The method of metering involved allowing onto the Freeway at each ramp only so many vehicles each minute that an assumed critical Freeway storage of vehicles would not be exceeded. This meant that the current storage had to be measured accurately. To determine storage, volume and occupancy were each measured at the detector stations upstream and downstream from an entry ramp. These values led to an estimate of a value of total travel in the previous minute and a value of average speed between stations. The quotient was the storage in the previous minute. The calculation was dependent on the average detected length of vehicles and on the assumption that vehicles did not slow down between stations.

A combination of aerial photography and a moving vehicle travel time study, together with the computer's records from detectors, were also used in this study. It was found that the average vehicle length required recalibration and that the proportion of trucks affected the average vehicle length. It was also found that vehicles did slow down between detector stations. Therefore, a new formula to calculate storage was derived and this takes into account the slowing down tendency.

As a further section to this study, the moving vehicle runs were continued after the cessation of operation of the control and information system. It was found that there were no significant differences in Freeway travel times with and without the operation of the system. The suggestion is therefore made that motorists can find normal faster routes without information signs which are more valuable when there is unusual congestion.

3. Ramp Metering Hardware Changes to Increase Obedience

At the beginning of this project in 1969, three-aspect signals were used together with a pair of loop detectors upstream from the signal to give a detected length of 30 feet behind the signal. However, the amber period was sufficient to allow two or more vehicles to enter when the system operation desired only one.

The first change was to remove the amber aspect and place the signals between the loops. Detection at the downstream loop was used to return the signal to red to prevent the passage of more than one vehicle. However, the upstream detected length was reduced to only eight feet. Therefore, many vehicles were not detected at the presence loop. In turn, this caused the signal to remain red until the first waiting vehicle thought the signals had failed. As a result, violations at one test ramp actually increased by an average 115 per day to 142 per day because groups of vehicles passed the signals on a very short green period.

The next change increased the detected length to 14 feet. Violations at the test ramp were reduced to an average of 110 per day.

It was considered that a further improvement could be made if information from the upstream queue detector were utilized. An algorithm to do this was devised and the violations were reduced to an average of 94 per day. This final hardware configuration was considered satisfactory, although a new design probably should have a still longer upstream detected length of about 20 feet for optimum performance.

4. Revision of Metering Strategy to Try to Prevent the Build-up of Congestion at Bottlenecks

A good example of a potential bottleneck was available on the Lodge Freeway with an additional lane between the Davison entry ramp and the Linwood exit ramp. The metering calculations for Davison were based on the usual measurements at the downstream station, Oakman, with the extra lane. It was found by a license plate study that 40% of the traffic in the extra lane was proceeding on the Freeway beyond the next exit ramp. The likelihood of Freeway congestion would therefore be reduced if the storage calculations included only 40% of the traffic in the extra lane at Oakman but considered that there were only three downstream lanes.

5. Diversion of Traffic from Intersections Which May be Blocked by Ramp Queues

Two ramp queues which have a tendency to block intersections because of high demand are at the Davison Expressway and at West Grand Boulevard. This study measured the potential of signs to divert traffic to bypass blocked intersections.

Visual routing observation was used for traffic proceeding from the three Davison signs to the Lodge Freeway entrance. A license plate was recorded to establish the extent of driver obedience to the variable-message sign on West Grand Boulevard. It was found that none of the signs were effective in preventing congestion at either ramp entrance. In the case of the West Grand Boulevard sign, only 21% of ramp users were found to pass it. Therefore, the possibility exists that other signs possibly near other primary traffic generators could have achieved a reasonable amount of diversion. For the Davison signs, earlier reports have shown more obedience. Hence, if the particular streets to take the diverted traffic had been more attractive to motorists, it is likely that considerable diversion would have occurred.

CHAPTER 1
INTRODUCTION

The metering of entrance ramps to freeways is now being used in many urban areas to restrict vehicular entry during rush hours. The purpose of ramp metering is to maintain freeway output at the highest possible level (capacity) by preventing or minimizing freeway congestion which may lead to the blockage of freeway flow. With reasonable storage room on the entry ramps, the average travel time should be reduced.

The John C. Lodge Freeway in Detroit, Michigan has been one of several freeway corridors where the technique of ramp metering has been developed. Other major research projects have been carried out in Chicago (1)*, Houston (2), Los Angeles (3) and New York (4). The Lodge Freeway project as part of the National Cooperative Highway Research Program has also resulted in a number of reports, and in particular three deal with ramp metering to varying degrees (5), (6), (7). The research agencies were the Texas Transportation Institute (TTI) and the Highway Safety Research Institute (HSRI).

It is possible for further reductions in travel time to occur if some drivers arriving at a congested, metered ramp are diverted downstream. Although this may happen spontaneously, it has been shown that better results are obtained when variable-message information signs indicate to motorists the appropriate paths for diversion. The development of variable signs has been reported on by researchers working in Chicago (8) and also on the Lodge Freeway Corridor in Detroit (6), (9), (10).

Even with ramp metering and information signs in operation, additional improvements can be suggested to further reduce corridor travel times. This report considers the following types of improvements:

1. Reduction of surface street travel times by means of real-time traffic signal control.
2. Revision of metering calculations to improve accuracy.
3. Reduction of metering disobedience to improve safety and merging operations and maintain effective surveillance control.
4. Revision of metering strategy to try to prevent the build-up of congestion at bottlenecks.
5. Diversion of traffic from intersections which may be blocked by ramp queues.

During 1970 all of these possible improvements were studied on the John C. Lodge Freeway Corridor for the 2:30 p.m. to 6:30 p.m. afternoon peak period (northbound direction). The specific aims are detailed after a description of the Freeway Corridor and the metering and information sign operation.

THE LODGE FREEWAY CORRIDOR

The Lodge Freeway Corridor section is shown in Figure 1. This section of Freeway itself is below ground level and extends for a distance of 6.1 miles from West Grand Boulevard to Meyers Road. There are nine northbound entry ramps, eight of them metered from 2:30 p.m. to 6:30 p.m. on weekdays. The last downstream ramp (at Wyoming Road) is not metered.

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*Numbers in parentheses refer to references at the end of Part One of this report.

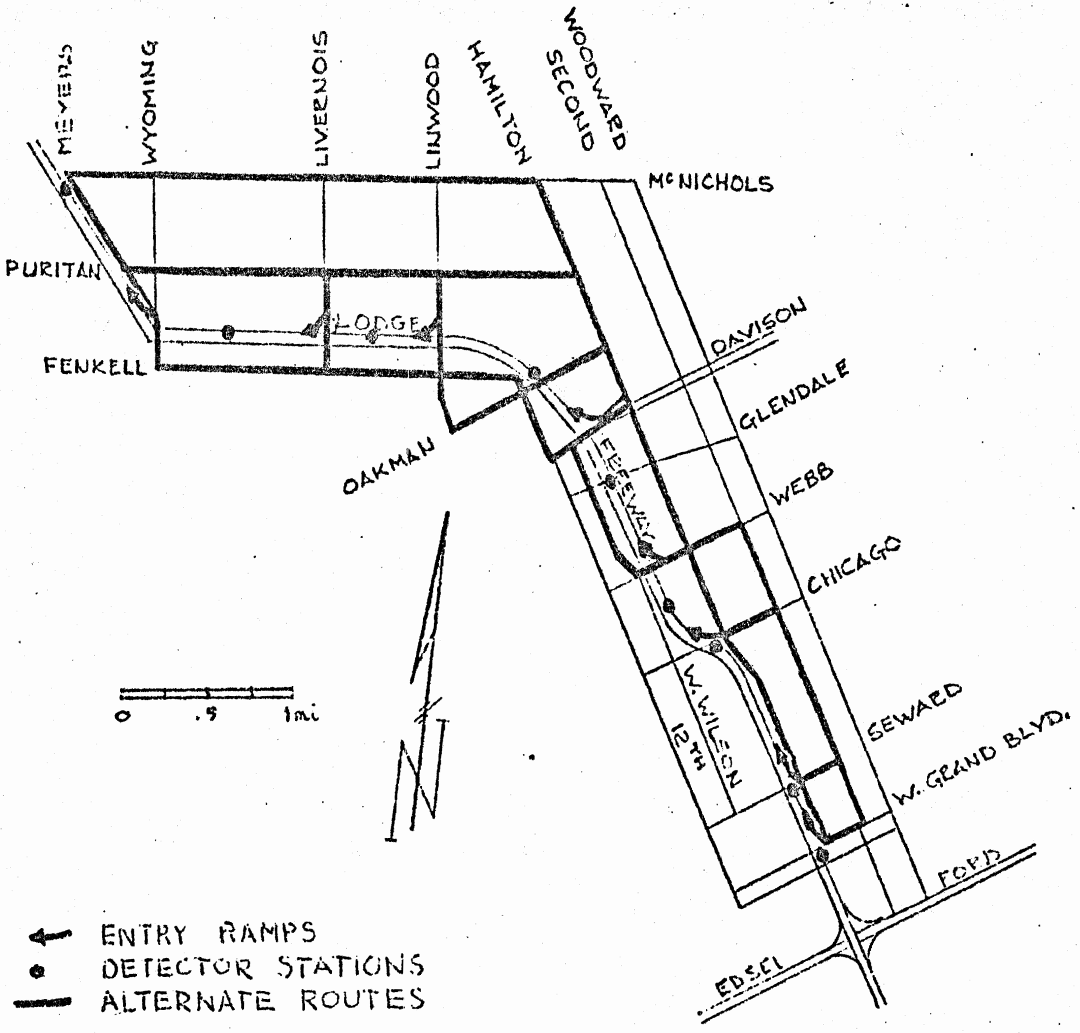


FIGURE 1
LODGE FREEWAY CORRIDOR

There are also ten off-ramps, as shown, with the Davison West ramp being the only one with the left side exit.

The study section is a typical three-lane urban freeway except at two locations where it broadens into four lanes (between the West Grand Boulevard entry ramp and the Hamilton-Chicago exit ramp and between the Davison entry ramp and the Linwood exit ramp). Entering vehicles to this fourth lane therefore do not have to merge immediately. Between 2:30 p.m. and 6:30 p.m. on weekdays, there are about 100,000 vehicle-miles of travel on the Freeway section with a total travel time of about 3,000 vehicle-hours.

The posted speed limit on the Freeway is 55 miles per hour and there is a posted minimum speed limit of 45 miles per hour. There are no substandard horizontal curves nor are there any steep vertical curves. The only significant rise is a short, three percent grade at the Davison overpass.

There are nine Freeway detector stations located so that there is a station upstream and downstream of each entry ramp (with the exception being there is no station between the two Livernois entry ramps). The detectors are all on overhead bridges and they are all positioned on the downstream side of overpasses. During 1970, the station at Muirland was moved to Greenlawn, and the one at Tuller was moved to Dexter. The only effect of this was to slightly change the lengths of two subsections. Otherwise, the detector stations are unchanged as reported previously (10).

Each detector station consists of a sonic detector mounted over each lane. The detector amplifiers are connected by means of telephone line to the input interface of the IBM 1800 computer at the Control Center at the Herman Kiefer Hospital. Full details of the installation are given in Appendix A. Loop detectors, also connected to the computer, are installed on all on- and off-ramps in the section of Freeway under study. The full set of detectors makes a complete cordon around the 3.2 mile study area allowing for input and output calculations.

The main alternate route to the Lodge Freeway (also shown in Figure 1) begins on the East Service Drive at West Grand Boulevard and continues on Hamilton Avenue, Oakman Boulevard, Twelfth Street, Fenkell Avenue, Wyoming Avenue and Couzens Drive. The use of this route may be suggested to motorists by signs placed at decision points when corresponding ramps are congested. There are also secondary alternate routes (Figure 1) which are suggested by signs when diversion to these would save travel time or when it is known that the main alternate route itself is congested. The secondary routes are given below.

1. Second Avenue between West Grand Boulevard and Webb Avenue with connections to the main alternate route or the Freeway via Seward Avenue, Chicago Boulevard and Webb Avenue.
2. Woodrow Wilson Avenue, Davison Avenue and Twelfth Street between Webb Avenue and Oakman Boulevard.
3. Davison Expressway from the Lodge Freeway North entry ramp to Woodrow Wilson Avenue.
4. Oakman Boulevard from Twelfth Street and Linwood Avenue to Fenkell Avenue.
5. Hamilton Avenue from Oakman Boulevard and Puritan Avenue to Couzens Drive.
6. Hamilton Avenue from Puritan Avenue and McNichols Road to Couzens Drive.

All of the above streets are reasonably wide thoroughfares with a general speed limit of 30 mph. Most streets have parking restrictions during peak hours and none possess a residential quality to require a limitation on the amount of diverted traffic.

RAMP METERING METHOD

Ramp metering was introduced on the northbound Lodge Freeway in 1967. The purpose was to prevent demand from exceeding capacity, particularly at two or three potential bottleneck positions near the Chicago, Linwood and two Livernois on-ramps. The metering method utilized was described in a previous report on Lodge Freeway research (7). For convenience, a summary of the method is presented here.

At each of the eight metered ramps entry was controlled by a two- or three-aspect traffic signal positioned halfway down the ramp. At the two ramps with the highest traffic volume, West Grand Boulevard and Davison, multiple vehicles were allowed to enter the Freeway (bulk metering strategy) during two equal but variable green periods per minute. An amber aspect followed the green as with any ordinary traffic signal. Multiple entry did not pose any safety problems because of the extra Freeway lane present at both locations. This metering strategy resulted in metering rates ranging from about 10 to 25 vehicles per minute at these two bulk service ramps.

At the other six ramps vehicles were metered so that they entered one at a time during each of a variable number of evenly-spaced green periods per minute. The green period was terminated by a vehicle departing from the signal so that an amber period was unnecessary. The single entry made merging safer as an entering vehicle would only rarely encounter another vehicle waiting at the bottom of the ramp. The range of metering rates available varied between three and twelve vehicles per minute.

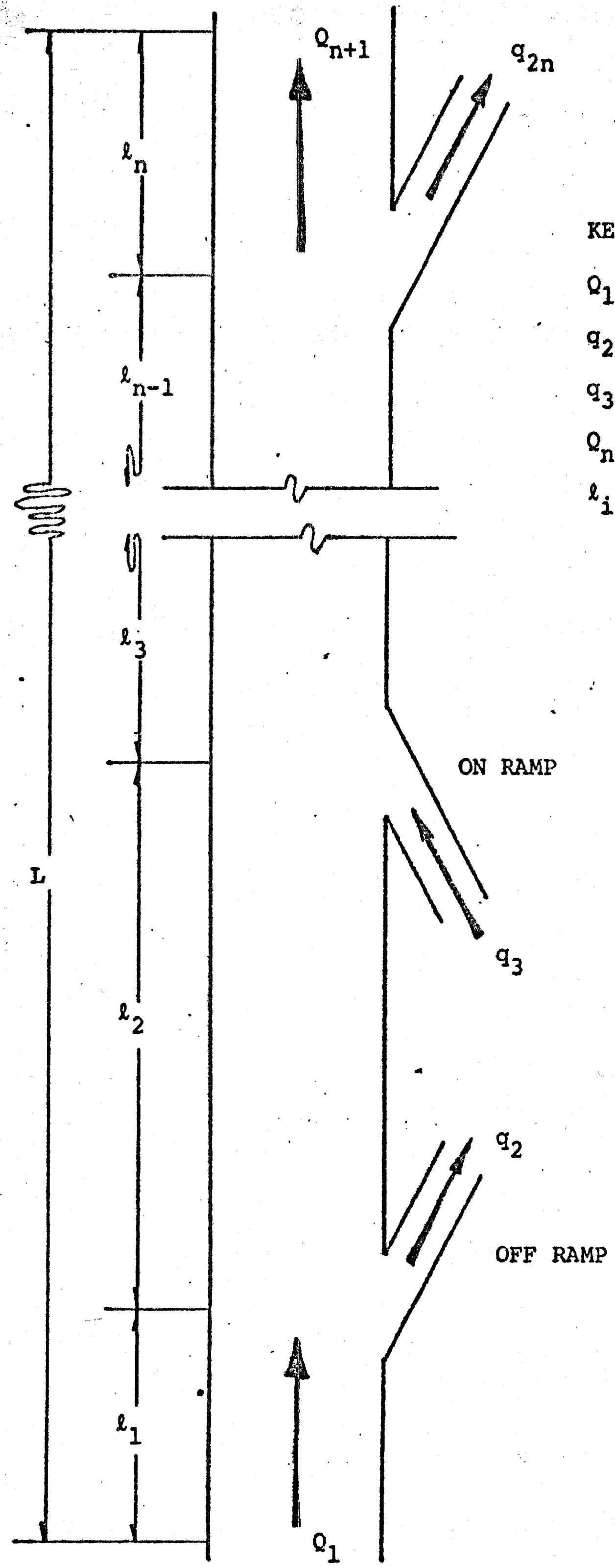
The method of determining the metering rates was essentially the same for all eight ramps. A freeway subsystem was defined as the section of freeway from a detector station upstream of a ramp to the first station downstream. It was determined that a maximum available storage, Sm, exists for each subsystem. If, over a period of one minute, the actual storage, Si, is known, then the allowable metering rate for the next minute is computed as I = Sm - Si. This rate is, of course, subject to the ranges described above.

Since it was found impractical to compute the actual storage on the basis of a continuous record of input and output, the storage was calculated from the detected occupancy and volume at the two detector stations. Referring to Figure 2, total travel, TT, in the previous minute was calculated as

$$\mathrm{TT} = \frac{1}{2}\left[\sum_{i=1}^{n} \left(\ell_i \sum_{j=1}^{i} q_j\right) - \sum_{i=1}^{n} \left(\ell_{n+1-i} \sum_{j=1}^{i} q_{n+2-j}\right)\right]$$

where ℓ_i are the respective lengths of each part of the subsystem and q_j are signed flows, positive for an input and negative for an output.

Average speed, $\overline{u}$, in the previous minute was defined as the average of the speeds computed at the end points of the subsystem where



KEY

Q_1	FREEWAY INPUT
$q_2, q_4 \ldots$	OFF RAMP VOLUMES
$q_3, q_5 \ldots$	ON RAMP VOLUMES
Q_{n+1}	FREEWAY OUTPUT
ℓ_i	DISTANCE FROM INPUT OR OUTPUT TO NEXT INPUT OR OUTPUT

FIGURE 2

ON-RAMP AND OFF-RAMP LOCATION
FOR TYPICAL FREEWAY SUBSYSTEM

$$\bar{u} = \frac{1}{2}(u_1 + u_{n+1})$$

$$u_1 = \frac{k_1 q_1}{\theta_1} \quad \text{and} \quad u_{n+1} = \frac{k_{n+1} q_{n+1}}{\theta_{n+1}}$$

Here θ_1 and θ_{n+1} are the occupancies at each detector station, that is the fraction of time that a vehicle is underneath one of the detectors. The quotient of occupancy to flow is the average travel time to travel the detected field, which is approximately the length of a vehicle plus eight feet. Hence, k_1 and k_{n+1} are constants representing this length and u_1 and u_{n+1} are the space mean speeds over the period of computation.

Finally, for the one-minute sample,

$$S_i = TT\sqrt{u}$$

This method was improved at the end of 1969 so that, although actual storage (S_i) was calculated in this way to start metering, subsequent calculations were made subject to a check on the actual storage by the change in the algebraic sum of inputs and outputs.

The calculated metering rates were then presented as green periods to waiting motorists, provided a vehicle had been detected at the ramp signal. Particularly at the one-at-a-time metered ramps, this prevented vehicles driving down the ramps at excessive speeds or stopping suddenly. Since the metering rate for the two Livernois ramps was calculated for the same subsystem, the two ramps shared the allowable number of entries.

OPERATION OF INFORMATION SIGNS

For this investigation, there were 27 changeable information signs operating in the locations shown in Figure 3. The signs are of three different designs, the details of which are described in an earlier project report (TrS-4). The purpose and message of all the signs were similar in that they directed motorists to the quicker of two possible routes to the northbound Lodge Freeway. The signs were all located just upstream of decision points and simply directed motorists to turn left or right, enter the Freeway or continue straight ahead, depending on the most advantageous route at that particular time. A summary of the sign operating procedure follows.

The signs indicate paths consistent with each other and thus form groups. Of the total of 27 signs, only 12 independent control operations are necessary (refer to Figure 3):

1. Sign 1.
2. Sign 2.
3. Signs 3, 4, and 5.
4. Signs 6, 7, 8, and 9.
5. Signs 10, 11, 12, and 13.
6. Signs 14, 15, and 16.
7. Sign 17.
8. Signs 18 and 19.
9. Signs 20, 21, and 26.
10. Signs 22, 23, and 27.
11. Sign 24.
12. Sign 25.

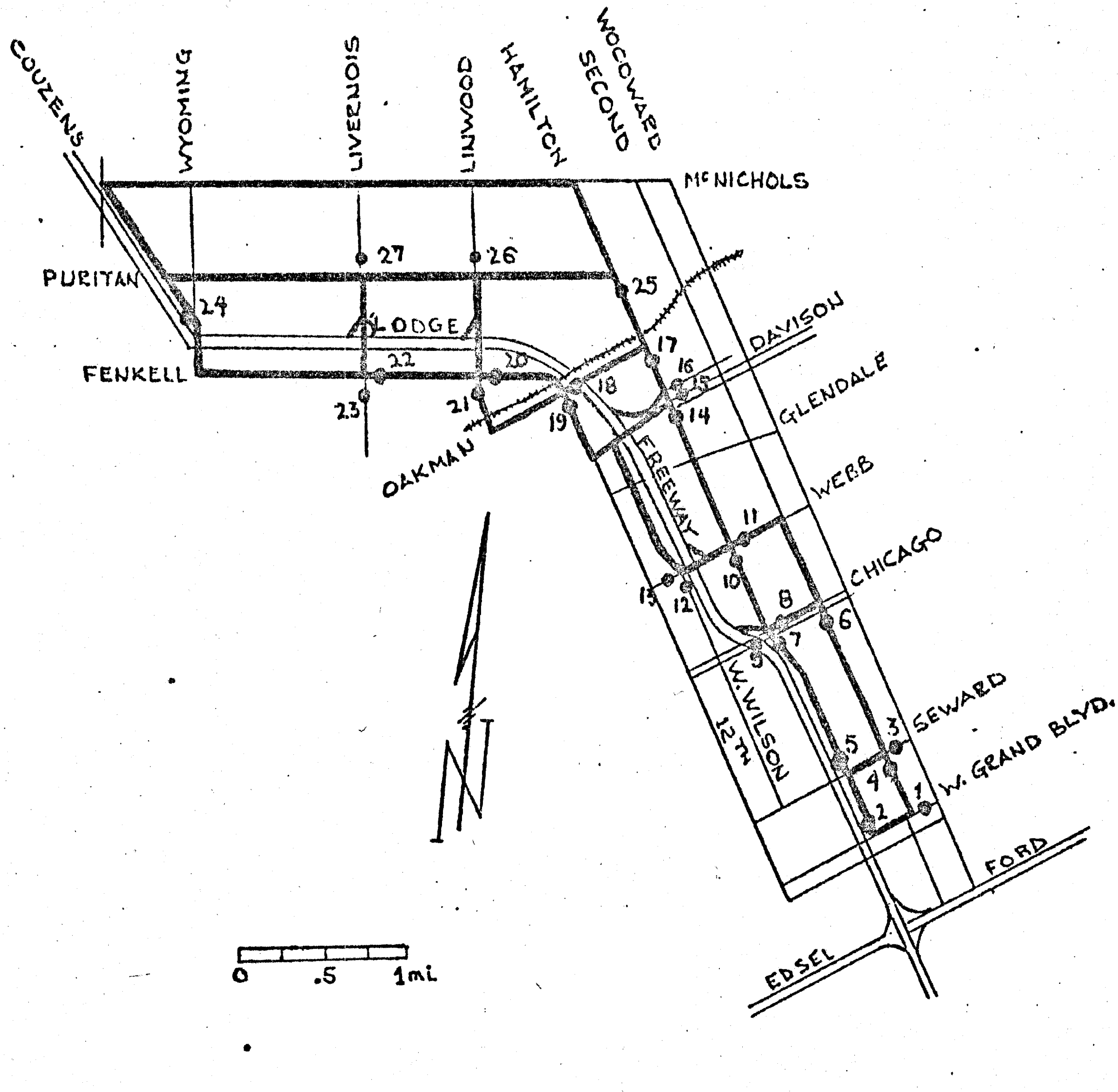


FIGURE 3
DYNAMIC SIGN LOCATIONS

Sign 1 displays the quicker of the two alternate routes to ramps beyond West Grand Boulevard when that ramp is congested. The quicker route is determined from the input to two surface street detectors, one located on the East Service Drive south of Seward and one on Second Avenue.

Sign 17 shows the quickest of three routes via Fenkell Avenue (possibly using the Freeway part of the way), Puritan Avenue or McNichols Road. The appropriate route is determined from the traffic input volume to three surface street detectors, one on each of the three streets. Sign 25 supplements Sign 17 by showing whether Puritan or McNichols represents the quickest route.

Signs 18 and 19 always indicate Twelfth Street unless railway crossing activities are taking place at the Twelfth Street crossing.

The remaining signs in the list effectively cover all approaches to the nine on-ramps in the 6.1 mile Freeway section. The metering should result in the transfer of most of the Freeway congestion to the ramps. Queue detectors at the head of the ramps relay to the Control Center the extent of ramp congestion by measuring the length of the waiting queue. An occupancy level of 20% for over one minute at seven of the metered ramps and 35% for the Davison ramp, activates signs to display messages advising motorists that the corresponding ramp is congested and should be bypassed to the least congested downstream ramp. When a ramp is not congested, the corresponding sign directs motorists to enter the Freeway by way of the ramp. If heavy Freeway congestion could be detected, the upstream ramp or ramps can still indicate congestion even though the occupancy level had not yet been attained. This applies particularly to the Wyoming and Livernois West entry ramps from which diversion would only be desirable in unusual circumstances.

It was found in an earlier study that ramp queue occupancy was not linearly related to queue length but rather that as the queue approached and passed the detectors, the value of occupancy increased more rapidly (33). During the course of the present study, it had been the intention to monitor the actual queue length. This would have resulted in a more accurate determination of the quicker path from each sign. Instead of using a constant level of ramp congestion as a criterion, the relative queue lengths of several ramps together with link travel times would have been compared. An initial study showed, however, that the present ramp detectors or others which could have been substituted were too inaccurate to maintain an input-output count on the ramp. Hence, no further action was taken. An alteration of the queue detector positions at some ramps would have corrected some of the counts which were in error because some vehicles could avoid the ramp after passing the detector or join the ramp after missing the detector. Unfortunately, even this change would not have led to sufficient accuracy.

SPECIFIC AIMS OF RESEARCH

The aims of this research project all have the same general objective, to reduce travel time on the freeway, on the ramps and on the surface streets of the corridor without, of course, sacrificing safety.

REDUCTION OF SURFACE STREET TRAVEL TIMES BY MEANS OF REAL-TIME TRAFFIC SIGNAL CONTROL

As described in the previous section, the information signs direct motorists to the nearest freeway on-ramp until a ramp queue builds up so that the critical occupancy is reached at that ramp queue detector. The signs then point to an alternate route to other downstream ramps since this route is expected to be quicker. With reasonable obedience to the signs, the demand for the critical ramp should be reduced. It can be expected that the queue detector occupancy will thus be reduced and after some time, the signs revert to indicating immediate freeway entrance via the nearest ramp. Thus an equilibrium detector occupancy or queue length has a tendency to form.

This sign control strategy is based on an assumed known and constant alternate route travel time. An allowance can be made for a variable travel time by time of day. With only a few surface street detectors, however, it is not feasible to also adjust this time according to current traffic conditions. Nevertheless, and having this more preferable method, alternate surface route travel times can be improved by adjustments to signal timings. As a result, overall surface street travel times should have been reduced and, in particular, the alternate route travel time should have been more competitive with the Freeway. This should lead to a reduction in the equilibrium ramp queue length and hence ramp queue delay.

REVISION OF RAMP METERING CALCULATIONS

The principal assumptions in the present ramp metering calculations are the method of averaging two space-mean-speeds to obtain an overall average speed for a subsystem and the use of an empirical value for the constant in the speed-occupancy-volume equation. Firstly, it is quite likely that vehicles slow down between detector stations which are usually some distance from a ramp. Secondly, the constants are based only on assumed average length of vehicle and this average length could easily change during the course of the peak period. A change in the proportion of trucks would bring about such an effect.

Before the investigation commenced, some consideration had been given to incorporating the ramp queue lengths into the metering algorithm. Such a change in the overall method of metering was not pursued in the end because of the difficulty in monitoring queue length as described above. Attention was therefore focused on the assumptions in the current metering strategy which does not necessarily have any basic flaws.

RAMP METERING EQUIPMENT CHANGES TO INCREASE OBEDIENCE

The purpose of ramp metering as stated above is to regulate the demand for various freeway sections by means of an ordinary stop-and-go traffic signal. High obedience to these traffic signals is necessary for the concept to operate properly. Motorists are required to stop at ramp signals just as they are at intersection signals. However, enforcement at ramp signals rarely occurs. Therefore, the system should be designed to command the respect and attention of all drivers. At the beginning of 1970, this was accomplished by utilizing warning signs, regulatory signs and pavement markings.

Ramp metering itself was accomplished by electronic detection of the presence of a vehicle, cycling the signal controller through the duration called for as reflected by conditions on the Freeway, changing the signal to green and then changing it back to red before a second vehicle passed. The sensing device used was an in-pavement loop detector. Since the location (even the existence) of the loop is probably a mystery to most motorists, effective forms of traffic control had to be employed to position each succeeding vehicle in a zone not larger in size than a standard automobile.

REVISION OF METERING STRATEGY TO TRY TO PREVENT THE BUILD-UP OF CONGESTION AT BOTTLENECKS

Three potentially serious areas of congestion were identified with the study section of the northbound Lodge Freeway. Two of these occur at the Chicago and Linwood exit ramps where the Freeway decreases from four to three lanes. The third is in the vicinity of the Livernois ramps and is caused because of merging difficulties with high Freeway volumes. The four-lane sections of Freeway each commence with very high on-ramp volumes at both the West Grand Boulevard and Davison ramps. Downstream from these locations, there are detector stations covering each of the four lanes.

The method of metering considers only the immediate upstream and downstream stations to determine the metering rate. With an extra lane, there will be no merging difficulty and usually no capacity problem. Further downstream, however, a lane is dropped at an exit ramp. Since these exit ramps do not carry particularly high volumes, most of the traffic in the fourth lane must merge into the third lane.

In considering a possible revision in the metering strategy, it did not seem necessary to base calculations on the first downstream three-lane detector station. Instead, if the vehicles in the fourth lane could be identified as to which were about to exit and which would continue on the Freeway, the ultimate merging requirement could be met at the four-lane station. The aim in this task was to study the traffic at the Oakman detector station downstream from the Davison ramp. The reason for choosing this subsystem was that the Davison ramp queue might increase to the extent that it would block a lane of the Davison Expressway.

DIVERSION OF TRAFFIC FROM INTERSECTIONS WHICH MAY BE BLOCKED BY RAMP QUEUES

There are two ramp queues which, if they become extended, could easily block passing traffic. These are at the West Grand Boulevard and the Davison ramps. Despite the information signs, it was conceivable that these ramp queues might continue to increase, at least on a short term basis. If nothing could be done about the ramp queues, at least the possibility existed that some surface street traffic could be diverted to prevent an interaction of the two traffic streams. Since additional signs would actually have been required to accomplish this, the aim here was merely to study the potential of each individual existing sign to divert surface street traffic from these points of congestion.

CHAPTER 2
RESEARCH APPROACH

REDUCTION OF SURFACE STREET TRAVEL TIMES BY MEANS OF REAL-TIME TRAFFIC SIGNAL CONTROL

There are about 60 signalized intersection controllers in the study section of the Lodge Freeway Corridor (Figure 4). Each controller corresponds to a single intersection except for the pairs of intersections on the Service Drive at the same cross street. For this purpose, the intersection of Webb and Woodrow Wilson forms a pair with Webb and the East Service Drive. Fifty-two of the controllers are in the City of Detroit, while eight are located in the City of Highland Park.

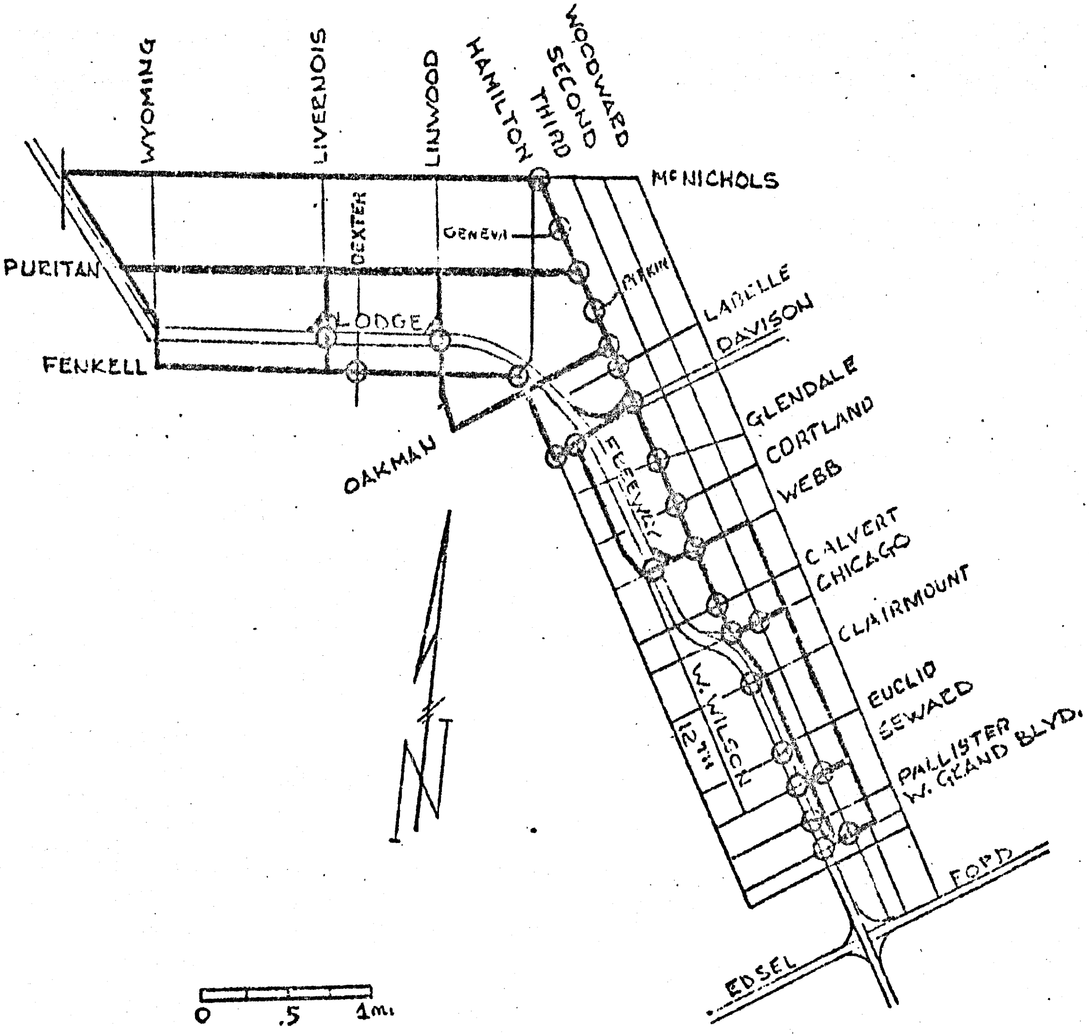
At the beginning of 1970, the signals at intersections south of Webb Avenue were operated from a master controller in the 13th Precinct Detroit Police Department Station. Three timing plans were used, one for the morning peak period, one for all off-peak hours and one for the afternoon peak period. The afternoon peak period, defined by the City of Detroit for special signal control, roughly corresponded to the operational period of experimental signs and signals in the Lodge Corridor. A careful review of the existing timing scheme reached reasonably good signal progression for northbound traffic. A uniform cycle time of 70 seconds was provided on Second Avenue, Third Avenue and the East Service Drive. There was, however, little progression on any of the cross streets with the exception of West Grand Boulevard. The principal weakness of the system was that none of the signal timings was responsive in any way to traffic volume changes within the peak period. Afternoon peak period timings merely differed from the timings established for other periods of the day.

The intersections in the City of Highland Park operated strictly on a fixed, 24-hour plan with a uniform cycle time of 70 seconds. Some improvement in northbound progression was made following an investigation by TTI (5).

The remaining intersections in the northwest section of the Corridor were considered to be isolated intersections. The cycle times were not uniform, being either 60 or 70 seconds in duration and varying by time of day.

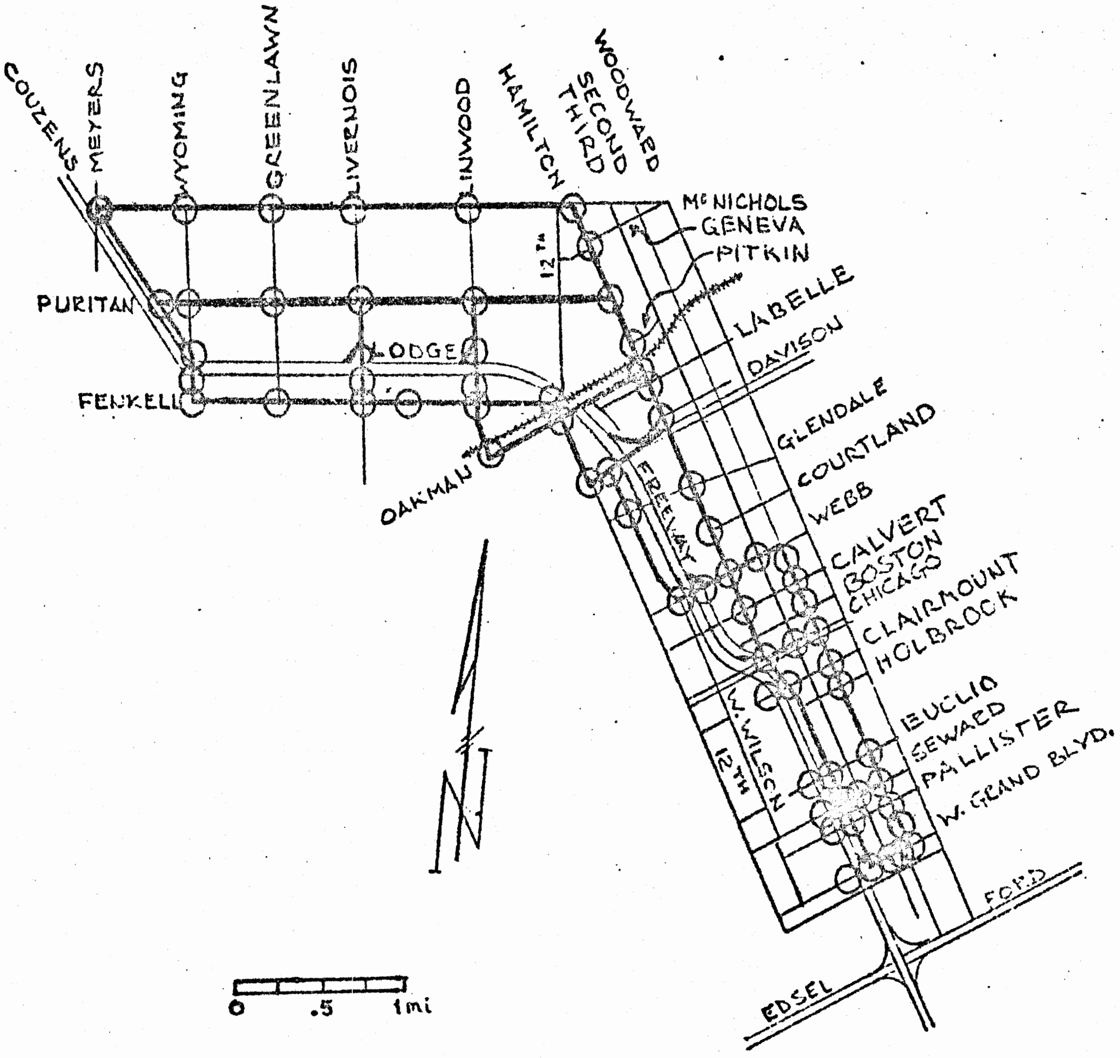
It was decided to develop a scheme of signal control for only 27 of the intersections (Figure 5). About 30 intersections were omitted from consideration mainly because of physical difficulties in arranging for control, time and financial constraints. The intersections selected for control included all of those on Hamilton, the Service Drive and a few on important cross streets (Figure 5). These form a group of 21 intersections. Second Avenue intersections were not included because, with minor cross street traffic, it was considered that it would be difficult to improve on the City of Detroit's plan. An additional six intersections in the northwest section made up the total of 27, although the latter group were still treated as isolated intersections.

Computer control of a network of signalized intersections has been attempted in several cities in recent years, notably Wichita Falls (12), San Jose (13) and Glasgow (14). In each of these, the general object was to minimize the total travel time for



O - Signal Location

FIGURE 4
SIGNALIZED INTERSECTIONS IN SECTION OF
JOHN C. LODGE FREEWAY CORRIDOR UNDER STUDY



O - signal location

FIGURE 5
PROJECT CONTROLLED SIGNALIZED INTERSECTIONS
IN STUDY AREA OF LODGE CORRIDOR

vehicles in the network. This was achieved by setting up timing plans to suit the currently detected traffic volumes. Varying numbers of detectors were used in the different cities to pass volume and speed or occupancy data to the computer.

At first it was considered possible to install sufficient detectors on the affected streets in the Lodge Corridor to enable a similar method to be used. It was planned to install loop detectors at 30 stations, which would have constituted a minimum set for real-time control. However, it became apparent that time and budgetary restraints would prevent no more than a fraction of these from being used. In the end, there were exactly 23 detector stations (Figure 6). These could only be used to check for railway crossing activities and to determine the preferred alternate route for the sign displays. The number was quite insufficient for signal control. Hence, it was decided to develop signal timing plans based on historical volume counts. These were obtained by project and City of Detroit personnel. The figures did appear to be fairly stable from day to day and the timing plans could at least be varied far more often than once per peak period.

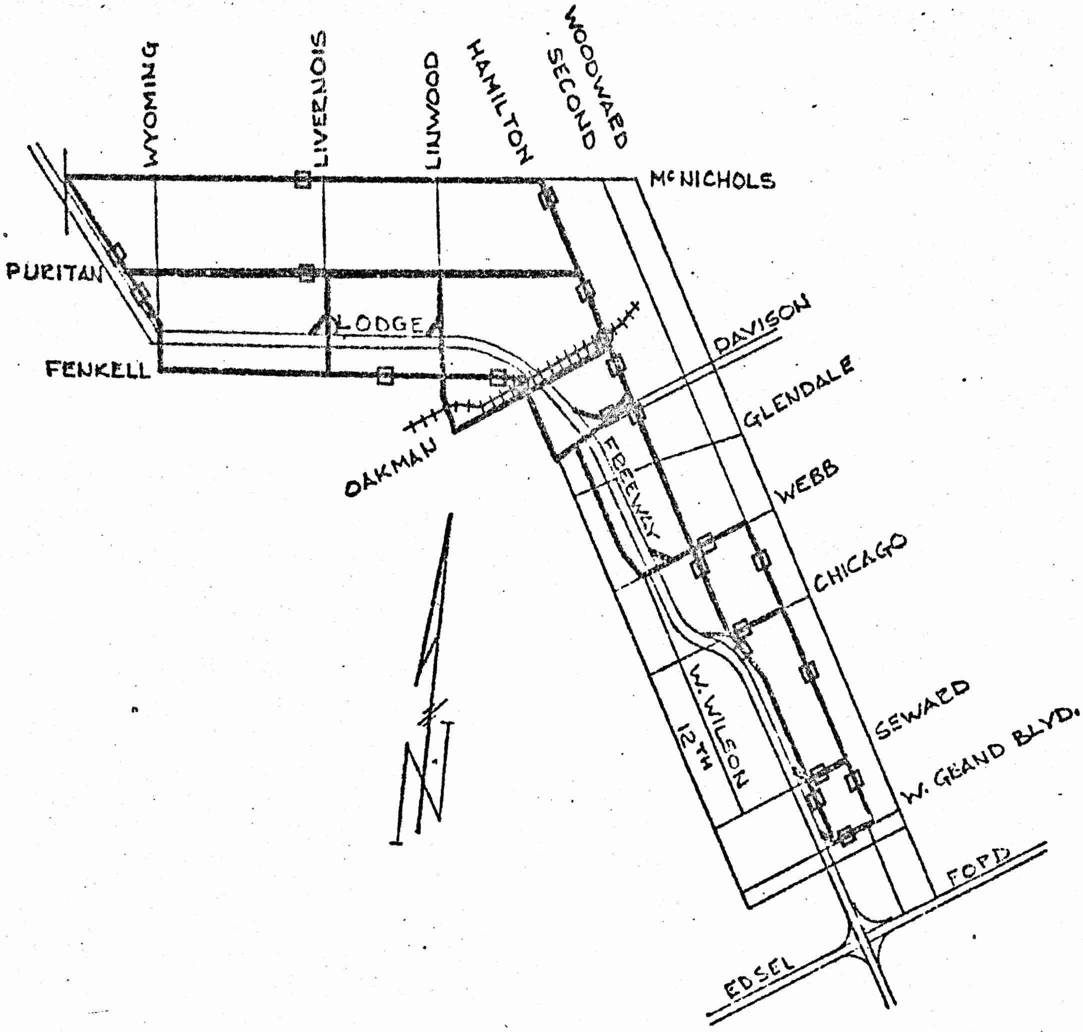
The historical volume counts, together with information on intersection geometry comprise sufficient data to determine the split of green time for each of the 27 intersections. It was decided to recalculate the split every 15 minutes leaving the cycle time unchanged at 70 seconds or 60 seconds. The 15-minute period was considered to be a reasonable period to allow for regular peak-period volume changes and yet ignore short term fluctuations which could not be detected.

Saturation flows for each approach to an intersection were computed from the intersection geometry. Some modifications were made for the effects of bus stops and pedestrian activity. For each phase and 15-minute period, a ratio was formed between the heaviest traffic volume and the corresponding saturation flow. The green time was split in proportion to these ratios from the different phases, subject to the requirement of a safe crossing time for pedestrians, supplied by the City of Detroit. Therefore, the split of green time remained constant over any quarter-hour period and did not change from day to day.

The main group of 21 intersections had a common cycle time of 70 seconds. Progression could therefore be obtained by fixing a suitable value of offset. At the other six intersections, the offset was left unchanged.

In all of the other signal schemes reported, the offset usually favored the direction of heavier flow. For this project, however, an additional object of the computer control was to reduce, if possible, the travel time between choice points on the alternate routes. Wherever these two requirements conflicted, the traffic following the information signs was favored. Because of the limited number of surface street detectors, it was decided to limit offset changes to a minimum of once every five minutes.

There are three closed loops of streets when the Department of Streets and Traffic system is superimposed on the present scheme (Figure 4). There are 12 possible paths to the four ramps shown, depending on the state of the information signs, including the variable message sign at the intersection of West Grand Boulevard and Second Avenue. This particular sign indicates both the appropriate ramp for Freeway access and the surface street--Second Avenue or Service Drive. The closed loops were "broken" as shown in Table 2-1 so that there is no intentional coordination on the links given.



□ --21 Surface Street Detectors

○ --2 Railway Detectors

FIGURE 6

SURFACE STREET DETECTOR LOCATIONS

TABLE 2-1
OFFSET STRATEGIES

POSSIBLE PATHS	SIGN STATES RAMP	SEWARD RAMP	W.G.B. RAMP	2ND OR SERVICE DR. (S.D.)	BROKEN LINKS
1	green	green	green	S.D.	14-13, 12-11, 10-28
2	green	green	red	S.D.	49-24, 12-11, 10-28
3	green	red	green	S.D.	14-13, 49-24, 10-28
4	green	red	red	S.D.	49-24, 50-25, 10-28
5	red	green	green	S.D.	14-13, 12-11, 50-25
6	red	green	red	S.D.	49-24, 12-11, 50-25
7	red	red	green	S.D.	14-13, 49-24, 50-25
8	red	red	red	S.D.	49-24, 50-25, 50-29
9	green	green	red	2nd	48-23, 12-11, 10-28
10	green	red	red	2nd	48-23, 49-24, 10-28
11	red	green	red	2nd	48-23, 12-11, 50-75
12	red	red	red	2nd	48-23, 49-24, 50-25

The remaining links form a continuous open network of north-south or east-west streets. Average travel times for each hour of the day had previously been obtained. The travel times were available as the sum of running and stopped times. It was decided to let the offset be such that a vehicle, entering a link at the beginning of the amber time and moving with a speed corresponding to the running travel time, would arrive at the downstream intersection also at the beginning of amber. Further details of the software methodology are given in Appendix B. Appendix C gives a list of possible splits of green time and the assumed travel times for each hour.

Specifications for the hardware to be placed at each intersection in the control system were prepared by project staff (Appendix C). These specifications, describing in detail what control functions these units must perform, were then sent out for bids. Much of the information needed to plan this task was assembled by discussion with the City and County agencies responsible for traffic signal controllers, as well as by reviewing the literature available.

The Eagle Signal Company supplied the relay assemblies to be placed at each of the controllers. The corresponding assemblies were linked by means of leased Michigan Bell Telephone lines. The assemblies performed the following functions through the computer: disconnecting the local controller's timing, stepping the controller through each interval, varying the time of the interval, and checking the display during main street green to verify that the pulses sent during the previous cycle had been correctly interpreted.

After receipt of the assemblies, the unit was bench-tested to assure proper operation, as well as to confirm that the electrical control logic was correct. Appendix A contains a schematic showing the typical electrical connections from the computer at the Control Center to each of the signal controllers in the field.

With improved signal timing, it is likely that there will be a reduction in travel time on many links for any given traffic flow. A link is simply a street or part of a street connecting two adjacent signalized intersections in one direction. In contrast to travel time savings, there could also be an increased delay to some motorists on certain approaches to some of the intersections. It is expected that the number of motorists experiencing such delay will be small. The overall test will be the change in total travel time for a given amount of travel. Virtually the whole Corridor should be evaluated because of the linkage between adjacent signalized intersections.

The control scheme was to be tested for a reduction in total travel time after its introduction. There could be less travel time or delay, however, if the amount of travel in vehicle-miles is less for a particular day.

The total travel in vehicle-miles can be obtained by means of a sampling technique developed by TTI in a previous project (15). Each of several observers are required to tour several intersections. The traffic volumes on a pair of approaches, if possible by turning movement, are counted. After all approaches have been counted for five cycles, each observer then proceeds to the next intersection on his tour. The measured volumes lead directly to an estimate of the volume leaving a link or sometimes entering a link. If there is more than one visit during the study period, the separate link volumes can be averaged. The observed volumes can also be supplemented by data from machine counts or from loop detectors connected to the computer.

For a given amount of travel, the average speed on each link before and after the introduction of the control scheme determines the extent of any improvement. Two methods of measuring average travel time were available.

In the first method, a 'floating' car travels on a number of selected journeys so that the cars enter most intersections from more than one approach. Four different study paths were devised (Figure 7-10). Where progression is being attempted in one direction, the delays may increase in the opposite direction. The floating car directly measures the average travel time and because of this many replications of the trips should be made.

The second method uses aerial photography in combination with the ground counting described above. From the developed film, all non-parked vehicles on each link can be counted. Since each link can be expected to be photographed about three times per hour with the type of plane available, the vehicles that are counted represent numbers of vehicles on the link at known times during the session. Hence, the total travel time for each hour or the whole session can be estimated. The average journey speed for any link can also be obtained by dividing total travel (as measured above) by total travel time for the same period of time.

REVISION OF RAMP METERING CALCULATIONS

Two separate techniques were available to check the parameters used in the ramp metering calculations. In the first, aerial photography can be used directly to measure storage between the detector stations. The Freeway can be photographed many times during a flight session, so that counted vehicles represent the number of vehicles in each subsystem at known times during the session. Hence, just as for the surface street previously, the total travel time for each

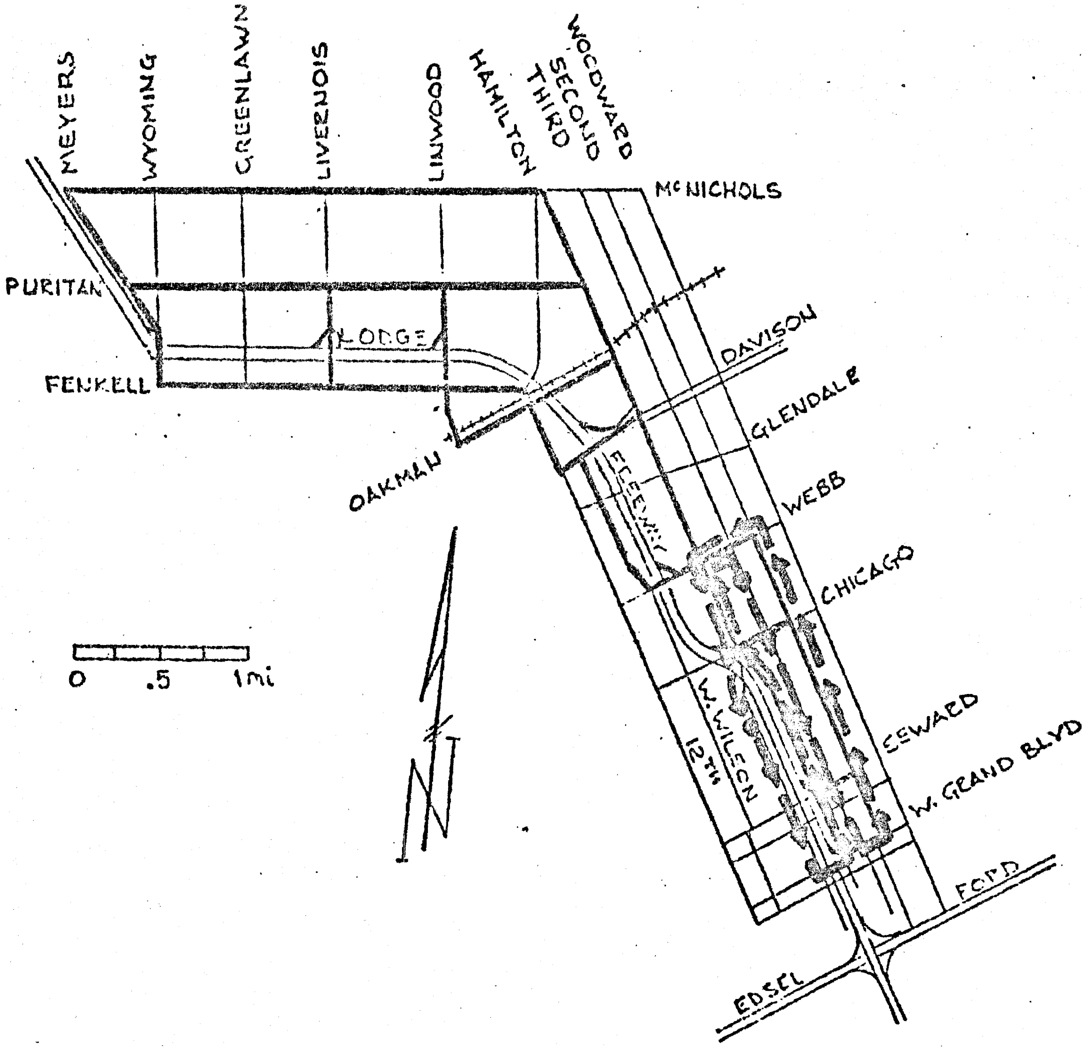


FIGURE 7
FLOATING CAR STUDY PATH 1

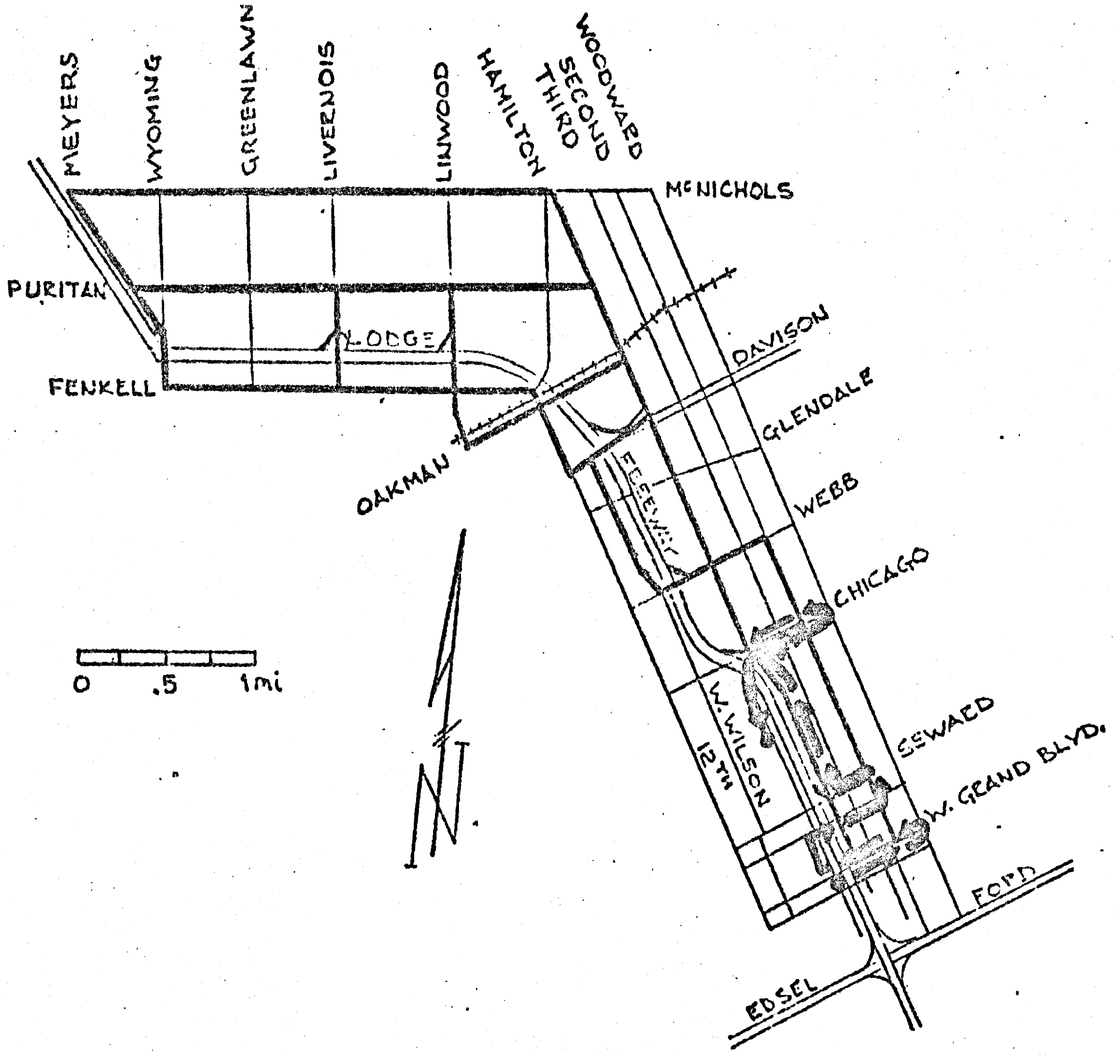


FIGURE 8
FLOATING CAR STUDY PATH 2

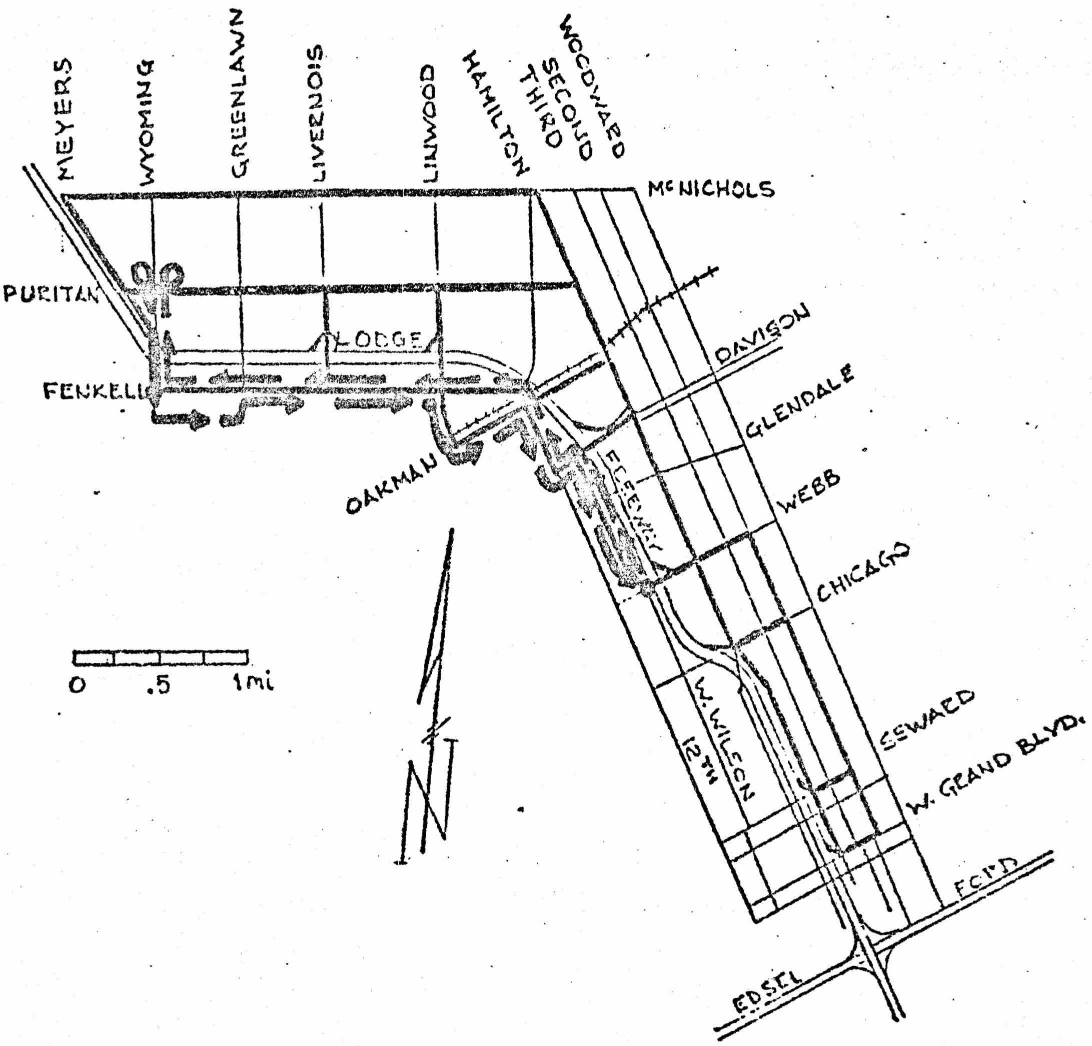


FIGURE 9
FLOATING CAR STUDY PATH 3

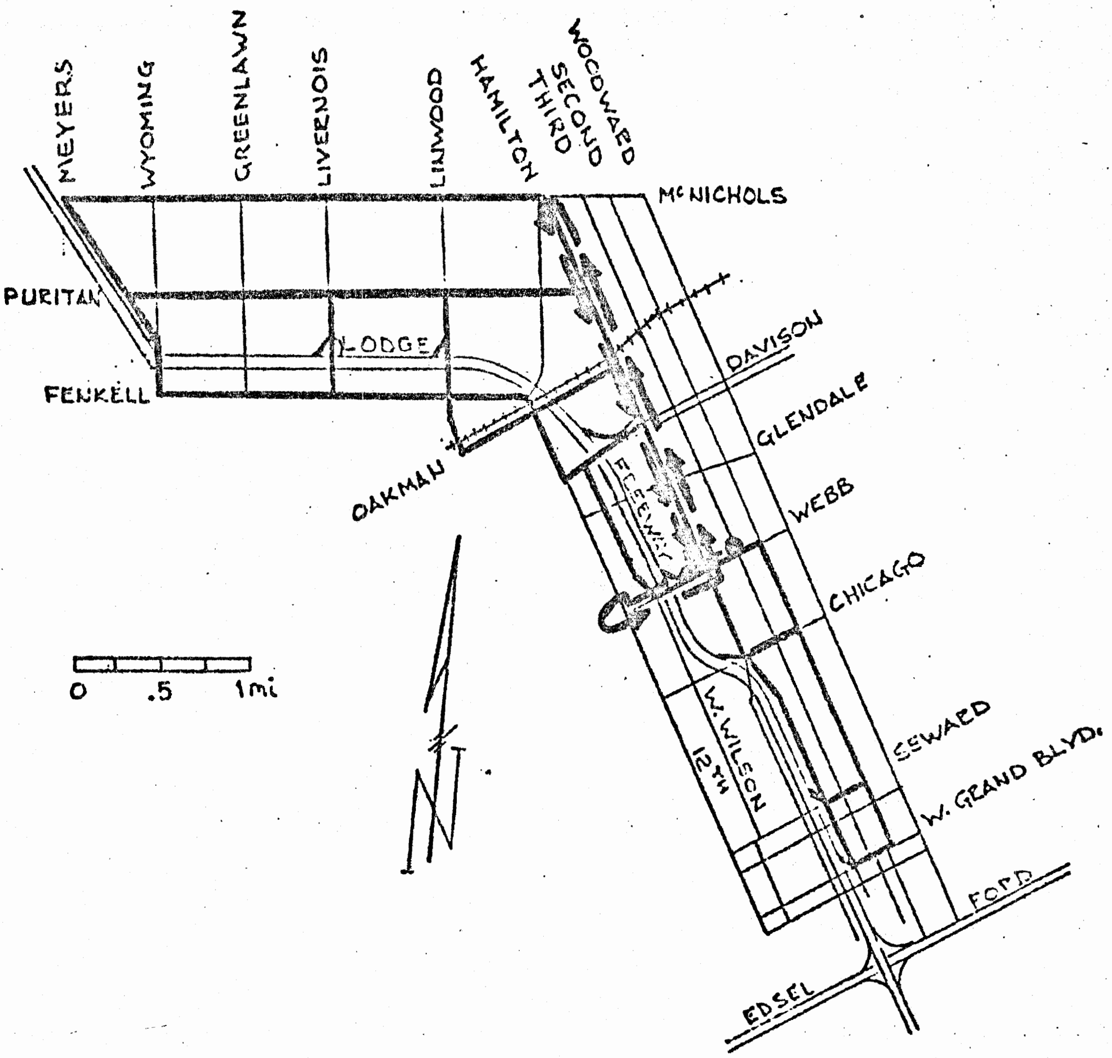


FIGURE 10
FLOATING CAR STUDY PATH 4

hour or the whole session can be obtained. This can be compared with the total travel time over the same period obtained from the computer's records.

In the second method, a 'floating' car is used to directly measure the average travel time between stations: Average speed can be obtained and this divided into total travel from the computer's volume measurements. Total travel time is therefore available in this way, although not completely independently of the computer because of the use of the volume measurements. Fortunately, the volume measurements are easily checked by noting the inputs and outputs on the ramps and volumes at adjacent stations.

The aerial photography can also be used to check the distribution of trucks by lane and time. There could be a pattern of a decreasing proportion of trucks by time of day. If the constant in the computer's speed calculations can also be shown to vary in the same proportion by time of day, then the values should be changed to be a function of the time of day.

RAMP METERING—HARDWARE CHANGES TO INCREASE OBEDIENCE

To insure high obedience to the ramp signals, which is of vital importance to the successful operation of the system, proper and well-designed hardware is essential. This hardware includes ramp signals, and traffic control signs and markings.

The physical arrangement of the various components went through four progressive and distinct changes during 1970. These are shown symbolically in Figure 11. The first configuration consisted of two in-pavement loop detectors, a stop line, and a three-aspect signal. It should be noted here that these two original pavement loops remained in place throughout all subsequent modifications. Their relative position changed, however, as other hardware was moved about them.

The operation of the first configuration was as follows: a vehicle was sensed by either one or both of the presence detectors as it stopped for the red signal. After the signal turned green for 1 1/2 seconds and amber for another 1 1/2 seconds, it returned to red. The lone regulatory sign stating "STOP HERE ON RED," which was mounted on the traffic signal was expected to control the vehicles. However, two successive, eager motorists could pass through on the three seconds of non-red available.

The second configuration attempted to prevent this in a number of ways. Firstly, the signal was physically moved upstream beyond the second loop. In addition, the second loop was assigned a different function. With the upstream loop continuing to act as a presence detector, the second loop was utilized as a check out detector. Furthermore, the signal was reduced to only two aspects; green and red. Thus, after a vehicle was detected and had waited its calculated time, the signal turned green. After this vehicle crossed the stop line and traversed the distance (6 feet) between the two loops, it was detected by the second loop. This immediately changed the signal to red, since it was then known that the vehicle had reacted to the green signal and had proceeded to begin its merging maneuver. The physical spacing of the components was such that the next vehicle could not reach the stop line without having a red display. (Note that the signal would remain green until the driver saw it, reacted to it, and accelerated his car down to the second loop.) This flexible arrangement is desirable when the range of perception-reaction times is considered. Also, there was

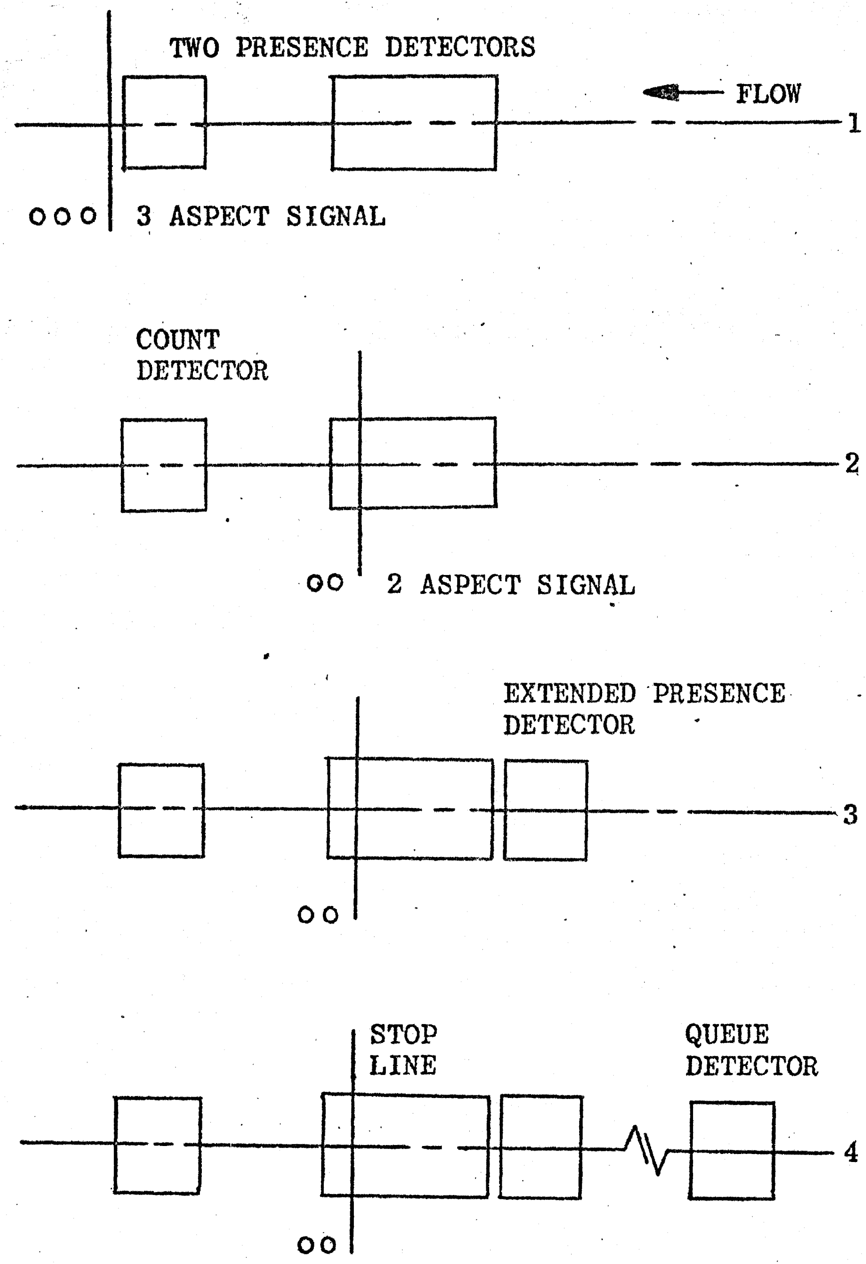


FIGURE 11
EVOLUTION OF RAMP METERING HARDWARE CHANGES

no amber display available to the driver to pass through. Along with these changes, the message on the regulatory sign had been strengthened to be "ON GREEN ONE CAR ONLY" (Figure 12). Channelization markings and rumble strips were added during this modification to encourage vehicles to center themselves on the ramps and to therefore pass directly over the loops. Although this had rarely been a problem in the past, it was felt that this encouraged better obedience to the system as well as giving it the appearance of being more refined and permanent. With the presence of rumble strips on the traveled way, and remembering that vehicles used the on-ramps at night when the system was not operational, a warning sign was erected at the head of the ramps. The message was "FORM ONE LANE" with no arrow which denoted that the center of the pavement should be utilized.

In addition to its previously described function, the second loop was also used as the count detector to record the volume of traffic utilizing that particular ramp. The stop line was placed within the first loop so that any overhang from a vehicle that happened to be stopped beyond the line would not be detected by this downstream loop. By protecting against this occurrence, another problem became apparent. With the reduced presence detection zone upstream of the stop line, some vehicles were not being detected at all. Results of a field study showed that about 95 percent of the vehicles stopped between -3 feet and +12 feet of the signal. Thus, five percent of the vehicles were not being detected.

Since detection of a vehicle's presence is absolutely necessary to start the system operating, this flaw had to be corrected. Thus another modification was made which resulted in the third configuration. The same study had shown that 99 percent of the vehicles stopped between -3 feet and +18 feet of the signal. Therefore, it was decided to add an additional loop having the dimensions of six feet by six feet (see Figure 13). This arrangement then detected all but one percent of the vehicles. One last change was made, which resulted in the fourth and final configuration, in an attempt to overcome even this deficiency.

The existing queue detector was given a second assignment. When the system computer discovered a ramp whose signal had not had a green display once during a one-minute period, and this was combined with a value for occupancy of five percent or greater at the queue detector, the signal was immediately changed to green. Thus, the queue detector acted as a presence detector of sorts. Its primary function is, of course, to measure the presence of a queue; in these cases, however, a much higher threshold for occupancy is required.

The research approach for this task therefore proceeded through four steps, with each modification attempting to overcome minor deficiencies in its predecessor.

FIGURE 12

RAMP METERING CONFIGURATION THREE

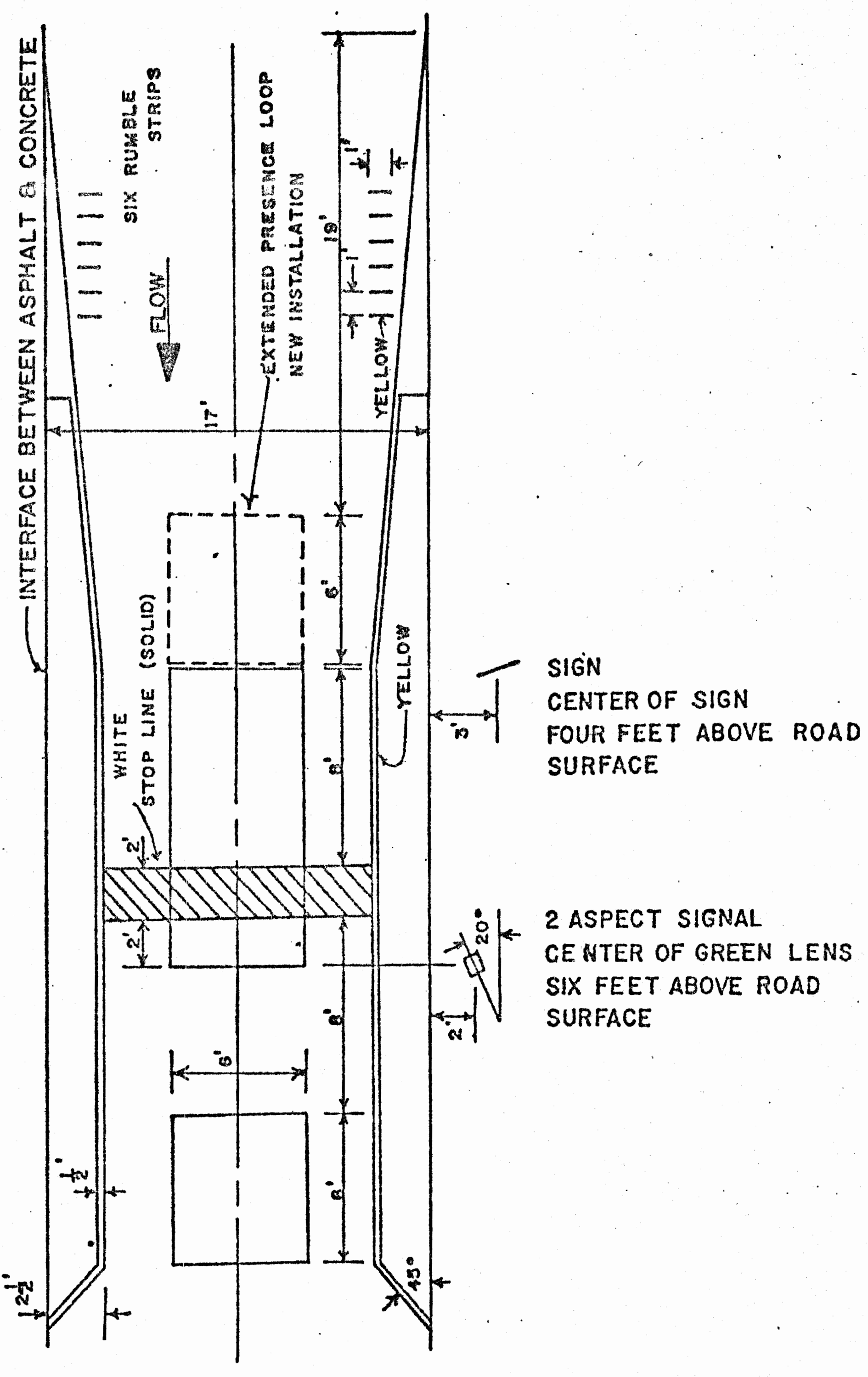


FIGURE 13
THIRD* RAMP METERING CONFIGURATION
(*Refers to Sequence in Figure 11)

REVISION OF METERING STRATEGY TO TRY TO PREVENT THE BUILDUP OF CONGESTION AT BOTTLENECKS

This task is really a study of the traffic passing the Oakman detector station in the shoulder lane and the other three lanes considered together (Figure 14). The traffic in the shoulder lane consists of

1. Davison traffic not leaving at Linwood which has not yet merged,
2. traffic leaving at Linwood which has already prepared itself for exit, and
3. through traffic attempting to gain time by leaving one of the through lanes to later cut back to a through lane.

The traffic in the other three lanes is, of course, complementary to the shoulder lane and contains the Davison traffic which has merged, Linwood exit traffic not yet in the shoulder lane and through traffic.

A license plate study carried out during a typical peak period can be expected to determine the types of traffic in the shoulder lane. Recording stations would be established on the Davison entry ramp, on the Linwood exit ramp and at the Oakman station. Recording license plates in freeway traffic is usually a difficult task because of the speed of the vehicles. Fortunately, just north of the Oakman bridge, there is a small, low platform next to the Freeway shoulder for access to an overhead railway bridge. This is a perfect viewing position for vehicle license plates on the Freeway.

By matching plates between pairs of stations, it will be relatively easy to infer the proportions of through, entering and exiting traffic. A revised method of metering to be developed should take into account only the amount of through traffic in all four lanes.

DIVERSION OF TRAFFIC FROM INTERSECTIONS WHICH MAY BE BLOCKED BY RAMP QUEUES

There are two candidate sites in the Corridor for this study. One, as might be expected from the previous section, is the ramp from Davison to the Lodge Freeway. The other is the intersection of West Grand Boulevard and the East Service Drive where the entry ramp queue often interferes with the flow of traffic. Since the problems differ considerably, they are discussed separately in the remainder of this report.

DIVERSION FROM DAVISON-LODGE INTERCHANGE

The Davison Expressway is, in fact, a limited-access facility, although with a poor geometrical standard. The Expressway ends about 100 yards west of the Lodge Freeway. Just upstream from the Davison exit ramp to the Lodge Freeway North, there is an entry ramp to Davison from Hamilton Avenue (Figure 15). Sometimes ramp queues from the Davison-Lodge interchange extend back onto Davison resulting in hazardous maneuvers in this area.

The four possible sources of traffic which might desire to enter the northbound Lodge from the Davison Expressway are:

1. Westbound Davison Service Drive from southbound Hamilton

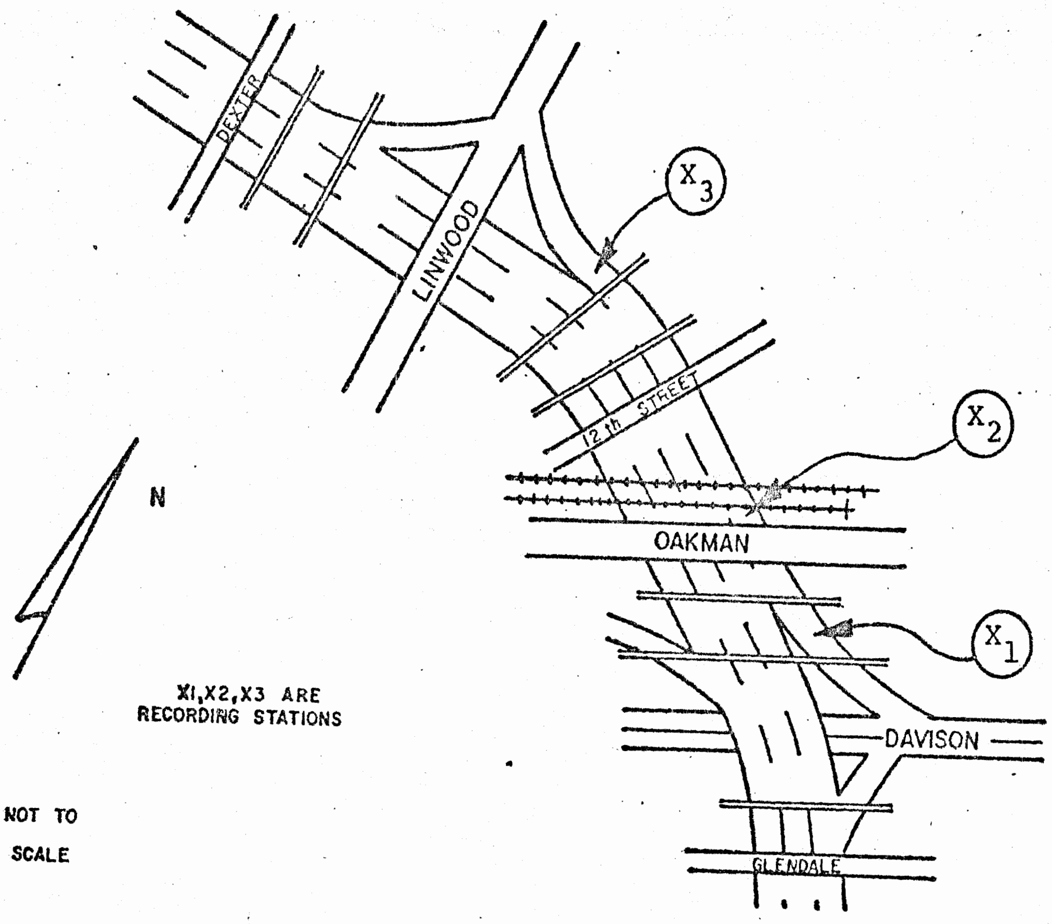


FIGURE 14
LODGE FREEWAY BETWEEN GLENDALE AND DEXTER

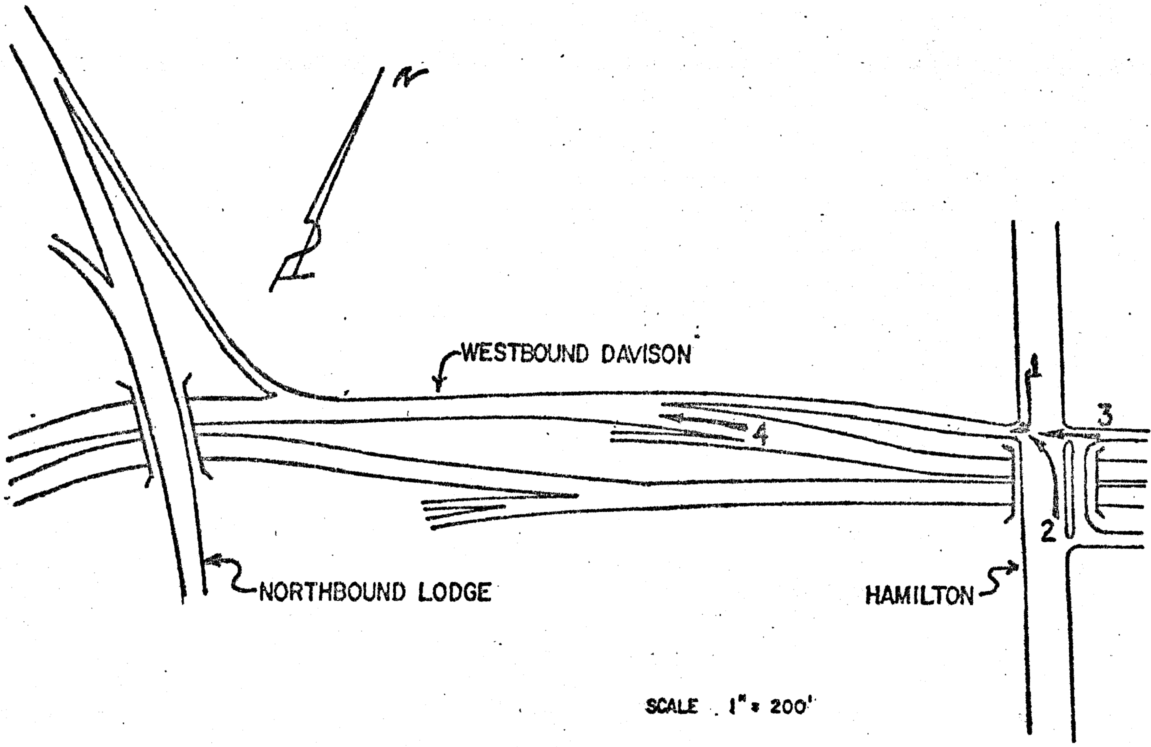


FIGURE 15
LOCAL ORIGINS FOR WESTBOUND DAVISON
AND NORTHBOUND LODGE TRAFFIC

2. Westbound Davison Service Drive from northbound Hamilton.
3. Westbound Davison Service Drive crossing Hamilton.
4. Westbound Davison Expressway.

Except for the first source, the others have the benefit of a changeable message sign which directs traffic along an alternate route whenever the interchange is congested. Thus, if the traffic pattern distributions are known for different displays on the signs, the ability of each individual sign to divert traffic can be inferred. Whether any improvement in the degree of diversion from each could be obtained is beyond the scope of this task. However, it is reasonable to expect some continuing change after a successful period of operation of the real-time traffic signal control scheme already described.

To determine the current traffic patterns, cars can be observed and counted coming from the four origins and going to the two destinations, the Lodge Freeway North or Davison Expressway. The accuracy of the study will be improved by alternating the signs between "red" (congested) and "green" (uncongested) for equal sessions of 15 minutes or a similar convenient period. Credibility, particularly for the Davison traffic, can also be improved by using a slow metering rate to create a ramp queue during red periods and a fast rate to disperse the queue during green periods. Of course, the queue must not be allowed to build back beyond the ramp entrance. Manual controls for metering rates are available at the Control Center where there is also a display device to check queue occupancy.

DIVERSION FROM THE INTERSECTION OF WEST GRAND BOULEVARD AND EAST SERVICE DRIVE

Some of the motorists entering the Service Drive and then the ramp will pass two variable message signs referring to the Freeway, one on westbound West Grand Boulevard between Cass and Second (Figure 16) and the other at the ramp entrance (Figure 17). Other motorists will pass only the latter sign. The former sign can and will advise motorists to use Second Avenue when the Boulevard ramp and the Service Drive are congested. With high obedience to the sign and a reasonable proportion of traffic bound for the Freeway passing it, one could expect a considerable reduction in congestion at the Boulevard and Service Drive intersection. In fact, congestion is still occurring.

A license plate study can be carried out by recording plates passing the sign on the Boulevard, turning into Second and entering the Boulevard and Seward ramps. To simplify the drivers' choices, the Boulevard metering rate can be adjusted manually to alternately create and disperse a queue while the Seward ramp signal should be turned off to guarantee the absence of a queue there. From the Boulevard sign, there are three possible recommended paths to the Freeway:

1. via the Boulevard to Boulevard ramp,
2. via the Boulevard to Seward ramp, and
3. via Second and Seward to Seward ramp.

These sign states to indicate this can be rotated according to a time schedule. For a study carried out on one day only, it is very unlikely that there will be any permanent change in routing patterns because of any unusual sign or signal states. The study should lead to recommendations as to how congestion at the intersection can be further reduced.

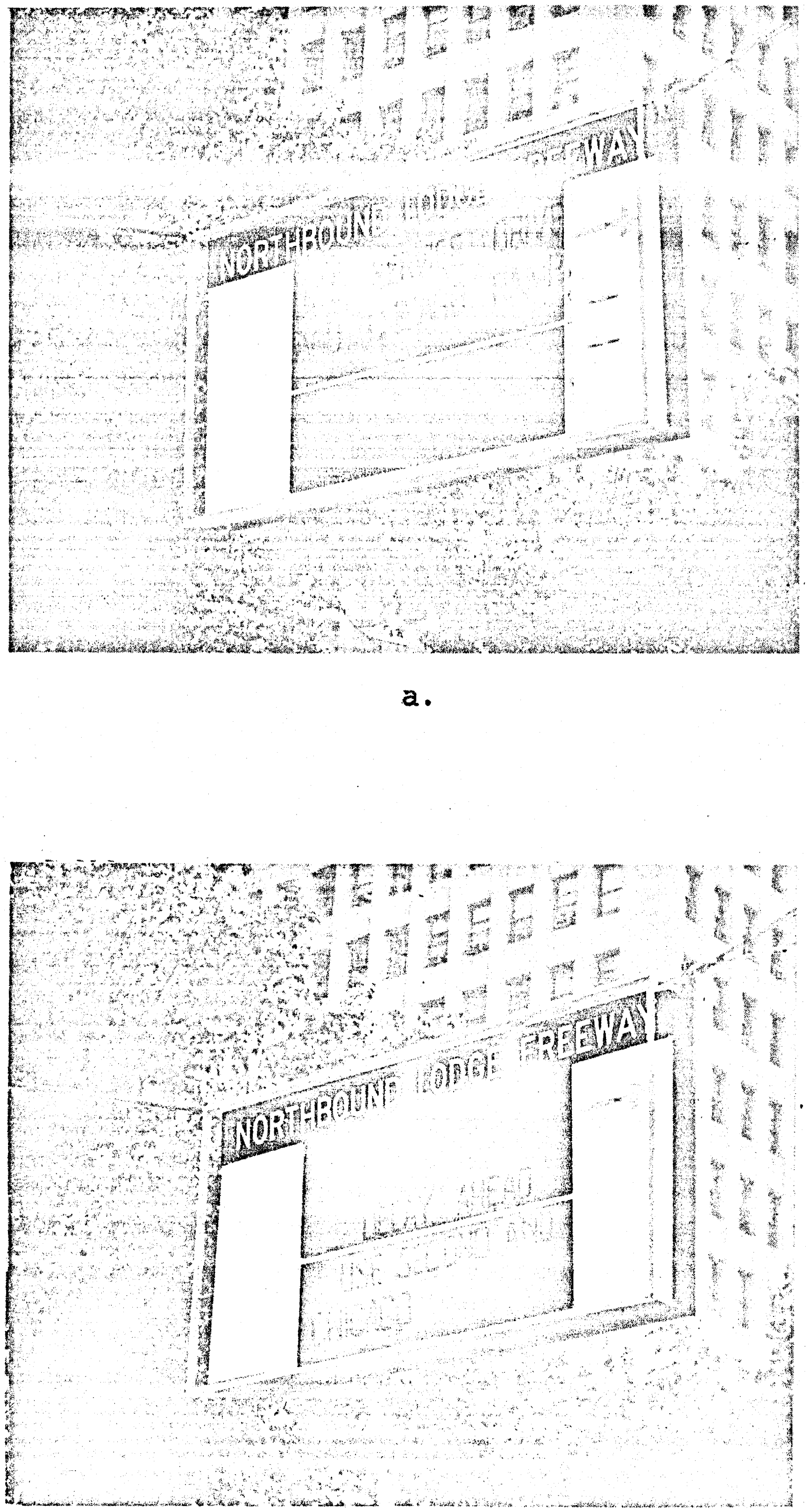


FIGURE 16
VARIABLE MESSAGE SIGN
AT WEST GRAND BOULEVARD AND SECOND AVENUE

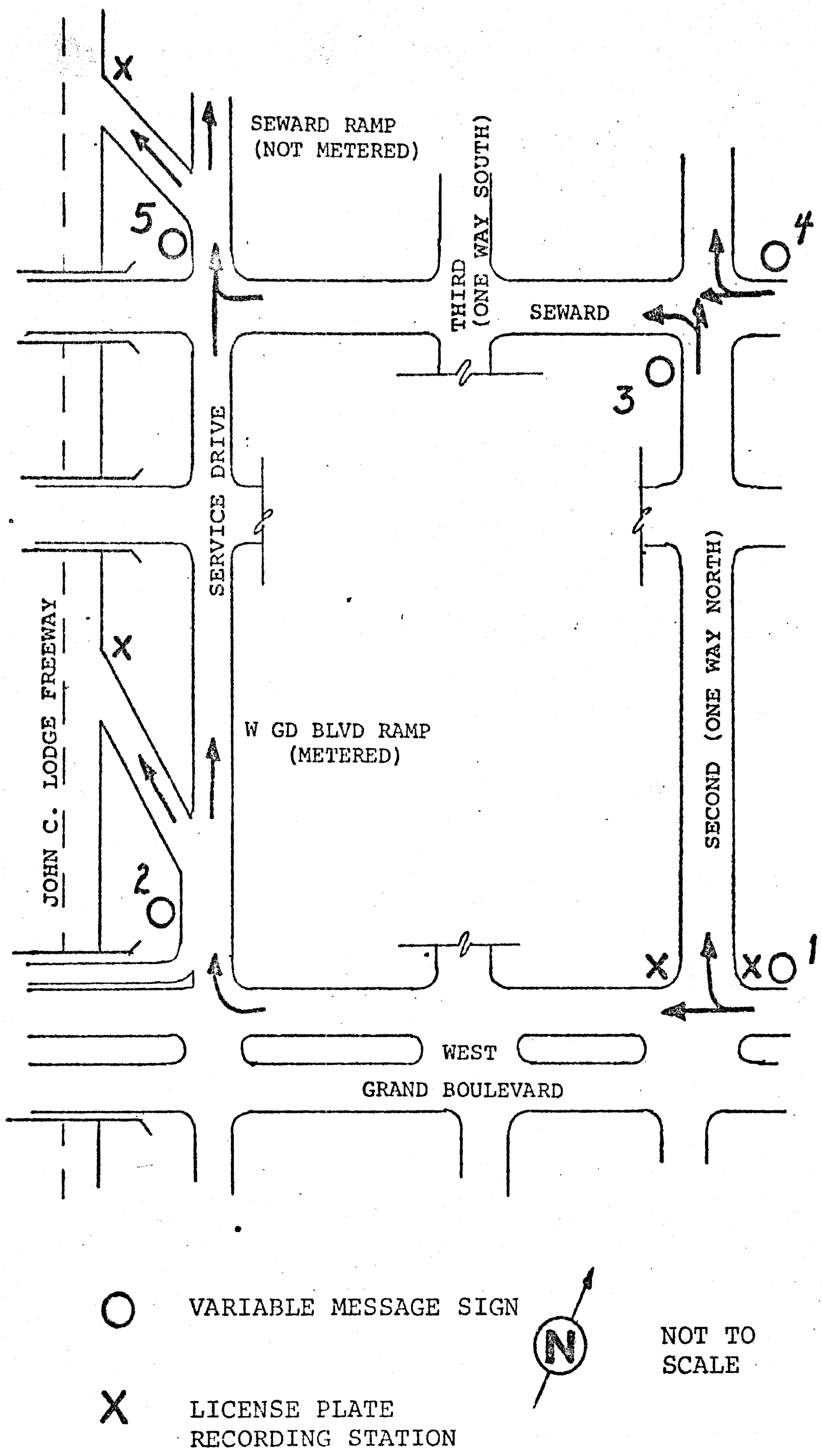


FIGURE 17

AREA BOUNDED BY WEST GRAND BLVD,
LODGE FREEWAY, SEWARD, AND SECOND

CHAPTER 3
FINDINGS

REDUCTION OF SURFACE STREET TRAVEL TIMES BY MEANS OF REAL-TIME TRAFFIC SIGNAL CONTROL

The system became operational on November 19, 1970. With a decision for the completion of field work by December 4, there were in fact only eight days of operation in this period. Excluding the Thanksgiving break, there are only ten week days in this time and on two of these it was decided that maintenance should be carried out following a number of problems with some of the intersection controllers.

The auxiliary typewriter at the Control Center provided a printout of intersections going out and coming back into service. When not under direct control from the computer, these intersections returned to local control. During the eight days of operation, problems arose at as many as 12 intersections. At only one of these was the problem known to be due to a physical defect of the field hardware. The usual problem was a loss of contact through the leased telephone wires. At nearly all of the other intersections control had to be dropped for an interval of one minute but could then be returned to computer control in the next minute. For example, on one day one intersection was dropped for 27 single minutes in a period of just over three hours. Needless to say, the operation of the 27 intersections can hardly be considered satisfactory with the occurrence of an average of more than seven intersection failures per day. This problem is discussed further in the next chapter.

The effectiveness of the control scheme was evaluated by means of "before" and "after" studies using a moving car or cars, aerial photography and ground counts. The four-hour peak period was divided for the purpose of comparison into four one-hour periods. Because of impending darkness, aerial photography was used for only the first three hours. On the other hand, the moving car studies were carried out over the entire study period.

The network studied (Figure 18) has been divided into 85 links using 49 nodes, including the 27 intersections under computer control. Each link was considered as belonging to one of three types. Each link was placed in one of these categories, even when computer control had been lost for some reason.

1. Favored links, F. Where the signal timing plans were developed to favor travel on this link.
2. Affected links, A. Where one or both nodes at the end have signal timing offsets controlled by the computer and the link is not in the category F.
3. Neutral links, N. Where neither node has its signal offset controlled by the computer.

There were 24 links in category F, 31 in A and 30 in N. It should be noted again that the only nodes with signal offset changes by computer were 9 through 14, 16 through 25 and 27 through 31 so that only split was adjusted at nodes 3 through 8.

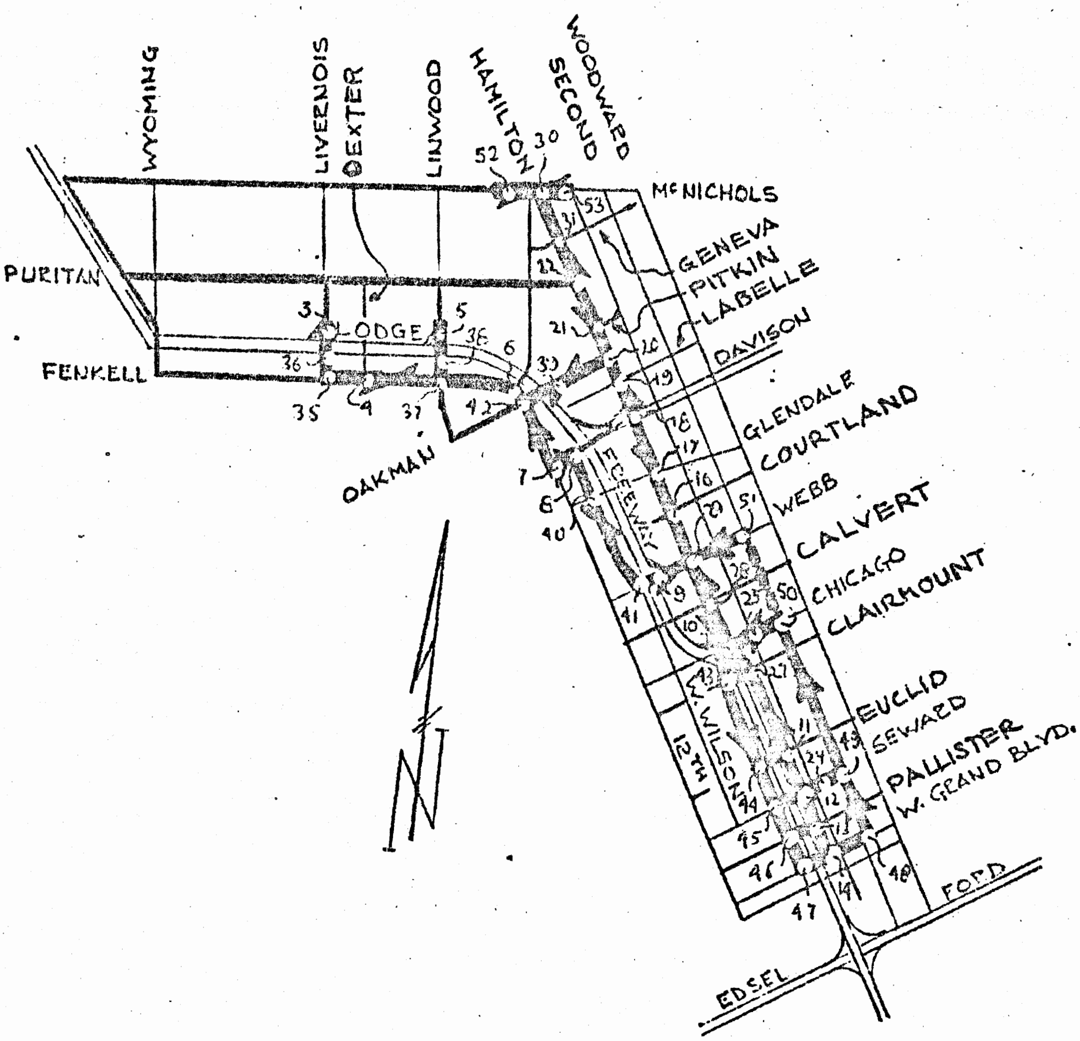


FIGURE 18
NODE-LINK DIAGRAM FOR CORRIDOR ANALYSIS

MOVING VEHICLE STUDY

A University vehicle was available on several days between October 23rd and December 4th. Using two stop watches, the stopped time at each signalized intersection was written directly onto a prepared form, together with the journey time past certain important intersections. A sample form is shown in Appendix F. Altogether, 29 "before" and 22 "after" runs were made with approximately an equal number for each of the four journeys.

The Michigan Department of State Highways (MDSH) made available for one week, commencing November 16th, a vehicle equipped with a speed-delay recorder and a driver and observer. The vehicle was driven over the same routes as the University vehicle. The observer marked the recording chart as the vehicle passed each signalized intersection or other check point. On returning to the office, University personnel transferred the data on the chart to a form similar to that used with the University vehicle. The principal difference was that the journey time was available at every signalized intersection rather than at just a selection. The MDSH team made 19 "before" and 6 "after" runs, again fairly evenly distributed over the four journey types.

The data on the forms from all journeys were transferred to punched cards. A simple program was written to analyze the results. The cumulative journey time was converted to a travel time between a pair of intersections or link. The stopped times were also obtained in terms of links with the stopped time itself referring to the downstream intersection of the link.

In Table 3-1, the number of stops of the floating car has been obtained for comparison with the total number of passes through the intersections. The approaches are all on links which have been separated into the categories F, A and N. Defective links have been merged into the other categories. Also in Table 3-1 are the number of links in each case for which the average stopped time has increased, decreased or remained unchanged and the median changes.

Significance tests were carried out on the number of stops for the F and A links and for each hour. The number of stops was compared with the number of times the vehicle did not stop (i.e., Passes - Stops). Where the null hypothesis, that there was no difference between the "before" and "after" results, has been rejected, the significance level is indicated. Thus there were significant decreases in the percentage of stops for the F links for the first and fourth hours and for the A links for the third hour. Despite these results, other trends emerge. There are increases in the second hour confirmed by the number of links which experienced increased stopped times. Otherwise, all F links exhibited a reduction in stopped times and the likelihood of stopping. With the additional exception of the fourth hour, so did the A links, although to a lesser extent. It is concluded that computer control reduced the probability of stopping for all links with the F links favored with significant reductions, 58% to 32% in the first hour and 52% to 31% in the fourth hour.

The results from The University of Michigan link travel times are much less clear cut (Table 3-2). The rises roughly balance the falls and no significant reduction in travel time can be claimed. The second hour is again unfavorable. The reason for this is not obvious, although, since the number of rises in travel time or stops did not differ significantly from the number of falls, this could be due to chance. The data for the MDSH "after" runs refer to only one day which may not have been typical.

TABLE 3-1
STOPPED TIMES FROM U OF M JOURNEYS BEFORE AND AFTER COMPUTER CONTROL OF SIGNALS

FIRST HOUR

Link	No. of Stops						Average Stopped Times[a]		
	"Before"			"After"					
Type	Stops	Passes	%	Stops	Passes	%	Rises	Falls	Unchanged
F	15	26	58	15	47	* 32	5(14)	12(20)	6
A	11	23	48	16	44	N 36	6(15)	8(21)	7
N	3	6	50	4	11	36	0	3(27)	3
Total	29	55	53	35	102	34	11	23	16

SECOND HOUR

Link	No. of Stops						Average Stopped Times[a]		
	"Before"			"After"					
Type	Stops	Passes	%	Stops	Passes	%	Rises	Falls	Unchanged
F	10	26	38	32	53	N 60	11(13)	5(7)	7
A	7	23	30	21	45	N 47	10(14)	3(32)	8
N	4	6	67	3	10	30	0	4(21)	2
Total	21	55	38	56	108	52	21	12	16

THIRD HOUR

Link	No. of Stops						Average Stopped Times[a]		
	"Before"			"After"					
Type	Stops	Passes	%	Stops	Passes	%	Rises	Falls	Unchanged
F	20	34	59	18	39	N 46	5(15)	11(15)	7
A	20	28	71	14	45	** 31	4(14)	10(11)	7
N	0	4	0	0	2	0	0	0	2
Total	40	66	61	32	86	37	9	21	16

FOURTH HOUR

Link	No. of Stops						Average Stopped Times[a]		
	"Before"			"After"					
Type	Stops	Passes	%	Stops	Passes	%	Rises	Falls	Unchanged
F	22	42	52	14	45	* 31	5(16)	13(11)	4
A	14	31	45	18	34	N 53	6(20)	7(23)	5
N	3	4	75	1	4	25	2(38)	11(18)	4
Total	50	96	52	34	96	35	13	31	13

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[a] Median changes (hundreths of a minute) in parentheses
N no significant difference
* significant at 5% level
** significant at 1% level

TABLE 3-2

CHANGES IN LINK TRAVEL TIMES
BEFORE AND AFTER COMPUTER CONTROL OF SIGNALS

(Median changes in hundreths of a minute in parentheses)

LINK	FIRST HOUR			SECOND HOUR			THIRD HOUR			FOURTH HOUR		
TYPE	RISES	FALLS	SAME	RISES	FALLS	SAME	RISES	FALLS	SAME	RISES	FALLS	SAME
F	3 (5)	6 (31)	1	8 (62)	4 (32)	-	5 (47)	7 (90)	-	5 (35)	3 (15)	-
A	7 (17)	6 (21)	-	5 (48)	5 (10)	1	7 (13)	5 (25)	1	7 (60)	4 (84)	-
N	-	1	1	1	1	-	-	2	-	1	1	-
TOTAL	10	13	2	13	10	1	12	14	1	13	8	-

CHANGES IN LINK TRAVEL TIMES FROM M.D.S.H. JOURNEYS

LINK	FIRST HOUR			SECOND HOUR			THIRD HOUR			FOURTH HOUR		
TYPE	RISES	FALLS	SAME	RISES	FALLS	SAME	RISES	FALLS	SAME	RISES	FALLS	SAME
F	-	-	-	6	3	-	2	-	-	-	-	-
A	-	-	-	3	2	-	3	1	-	-	-	-
N	4	3	-	4	-	-	1	1	-	1	-	-
TOTAL	4	3	-	13	5	-	6	2	-	1	-	-

Whether or not the decreased stopped or journey times represent an overall improvement in surface street conditions depends on the amount of travel in vehicle miles on each link. This can be estimated from the ground counts and combined with the results of the aerial photography.

GROUND COUNTS

Another type of summary form was developed for the purpose of recording traffic counts for each turning movement at each signalized intersection. Sometimes the volumes were too heavy to count turning movements, but the total approach volume was still obtained. The counts were again considered to represent the volume on the link forming an approach to an intersection.

The volume approximated could be from the downstream or upstream end of the link. A downstream count came from the traffic entering the intersection whereas an upstream count was obtained by summing the two or three movements leaving an intersection. Provided in the latter case that the movements were counted at the same time, there seemed to be no reason to expect that the two estimates would differ significantly. Hence, both upstream and downstream count were considered to be independent samples and were combined for the estimate of link volume.

Where one or more samples were available in an hour, the hourly volume was estimated. These hourly volumes were to be combined with the data from particular days of aerial photography and floating car studies. The "before" days selected were November 12 and 17 and the "after" days, November 19 and 24. Therefore, if a link was missed during a particular hour of one of these days, a value based on an historical volume table (Appendix F) was determined. If no samples at all were obtained for the link at the time required, the historical volume was used for each hour. On the other hand, if estimated hourly volumes could be made for any of the other hours, then the historical volume was adjusted in the ratio

$$\frac{\text{Sum of estimated hourly volumes for other hours}}{\text{Sum of historical volumes for these hours}}$$

in order to account in some way for daily demand deviations from historical volumes. In this way, an estimate of hourly volumes was obtained for each link, each hour, and each day. These values were converted to vehicle miles by multiplying the length of the link.

AERIAL PHOTOGRAPHY

Aerial photography is a technique which should yield a considerable quantity of data for a whole network in a relatively short time. However, suitable weather is essential and, in fact, on only five days were the conditions satisfactory. Flights were made on November 6, 12 and 17, the "before" period, and on November 24 and December 2, the "after" period.

The airplane was flown at a height of about 4,000 feet over the two paths, Number 1 and Number 2, shown in Figure 19. The photographer used a Hasselblad camera loaded with fast black-and-white film. Photographs were taken to provide, if possible, a complete coverage of the network, including the approaches to all computer-controlled intersections. A log was kept of the time (of day) that each photograph was taken. Throughout the flight session

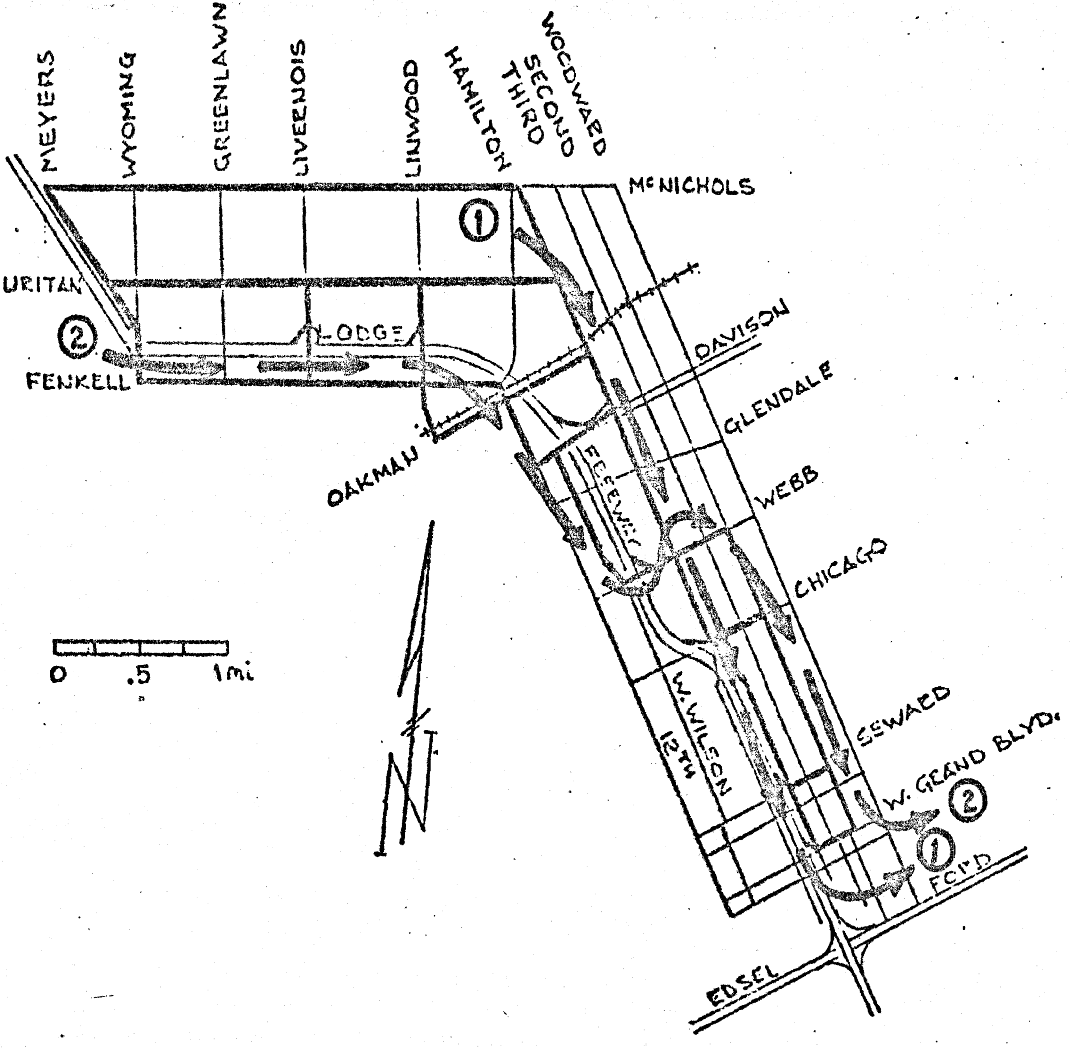

FIGURE 19
AERIAL PHOTOGRAPHY FLIGHT PATHS

the pilot completed each path alternately, commencing with Number 1. Because of impending darkness, all sessions, which commenced at about 2:30 p.m., had to be terminated at about 5:00 p.m.

The films were developed and the negatives examined under a viewer providing a magnification of about 18 times. Forms had been prepared to enter the number of vehicles on each link of the network and each remaining approach to the computer-controlled intersections. The links and approaches were named in approximately the order that successive photographs would cover. The time of day was also entered from the flight log.

The speed and maneuvers of the plane and the photographic requirements led to about three passes over any link per hour. Sometimes part of a link was obscured by tall buildings. On the other hand, well-separated and therefore independent photographs of the same link were sometimes available from the same flight line. A typical photograph has been reproduced in Figure 20. The total travel time on any link, l, for each one-hour period (commencing on the half-hour) is given by

$$TTT_l = \frac{1}{N_l} \Sigma N_i \text{ (vehicle hours)}$$

where N_i is the number of non-parked vehicles counted from the i^{th} photograph for the hour.

N_l is the number of photographs of the link read for the hour.

Total travel time or total delay for cross street traffic is also relevant on the approaches (other than links) in assessing the effectiveness of the computer control of intersections. From the photographs, the number of stopped, but non-parked vehicles on the approaches has also been obtained. The total travel time for the approach, a, for each one-hour period is given by

$$TTT_a = \frac{1}{N_a} \Sigma Q_i \text{ (vehicle hours)}$$

where Q_i is the number of vehicles queued on the approach counted from the i^{th} photograph for the hour

N_a is the number of photographs of the approach read for the hour.

On the first flight (November 6), the pilot acquainted himself with the flight paths and some trial photographs were taken. There were complete photographic sessions on the other four days, thereby providing two sets of data in the "before" period and two in the "after" period.

The results are summarized in Table 3-3 where the total travel times have been summed over the links and approaches. The number of links and approaches about which data are available on each day is given for each of the three hours.

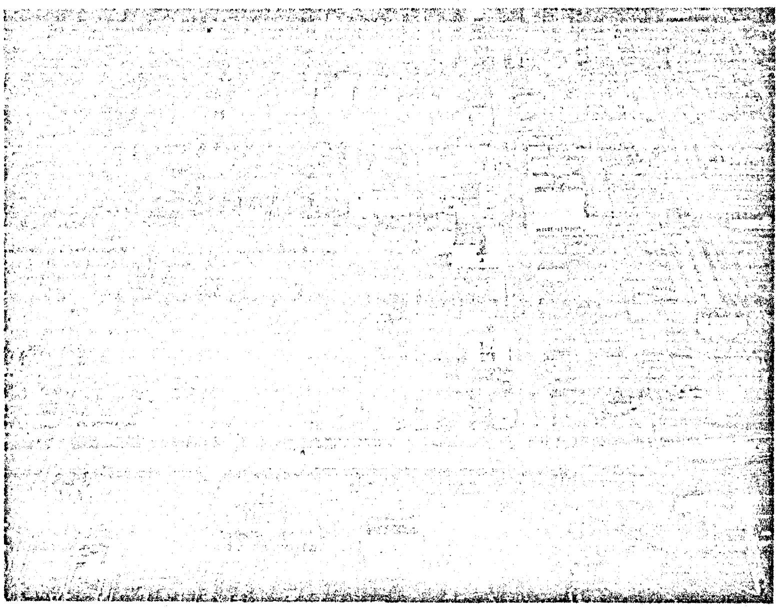

FIGURE 20.

SAMPLE AERIAL PHOTOGRAPH

TABLE 3-3
TOTAL LINK TRAVEL TIME AND APPROACH DELAY*

DATE	FIRST HOUR		SECOND HOUR		THIRD HOUR	
	Links 47	Approaches 11	Links 45	Approaches 17	Links 70	Approaches 18
"Before" Studies:						
Nov. 12			430	44	660	60
Nov. 17	299	26	328	13		
"After" Studies:						
Nov. 24	374	27	425	37	778	115
Dec. 2	316	34	274	30	517	40

*Data obtained from aerial photographic studies.

The table shows considerable variation between the days. There is on the average a decrease in the link travel times for the second and third hours and an increase for the first hour. Despite an increase in the approach delays, these are of smaller magnitude so that in the second hour there is still an overall decrease.

It would be premature, however, to draw conclusions of the effectiveness of computer-controlled signals without checking the amount of travel on each day. Changes in total travel from day to day may well have caused the variation in total travel time and delay. Although the aim of the control is to produce an overall reduction in total travel time for a given amount of travel, it is more interesting to examine each link and each hour of the day separately to find where there have been particular increases or decreases. The floating car studies can be combined with the aerial photography results since the product of total travel and average travel time is also total travel time.

EFFECTIVENESS OF THE SIGNAL CONTROL SCHEME

The days on which total travel estimates were available were November 12, 17, 19, 24 and December 2, with the last three days representing the "after" conditions. Aerial photography results were available on all days except November 19, while floating car results were available on November 17 and 19. Thus, up to six total travel and total travel time estimates are available for each peak-period hour. Usually, however, these were only three or four estimates because of partial coverage, and for the fourth hour (1730-1829) there is no usable data at all. Hence, the effectiveness of control will be based on the first three hours.

SPEED CHANGES BY INDIVIDUAL LINK

Total travel and total travel time values were obtained "before" and "after" for each link in each hour. The ratio of the two quantities is average speed. Table 3-4 shows the result of comparing corresponding average speeds. The increases or decreases are differences obtained by subtracting the "before" speed from the "after" speed. The median speed increase or decrease is also given.

TABLE 3-4

COMPARISON OF "BEFORE" AND "AFTER" AVERAGE LINK SPEEDS
(Median Speed Changes are in MPH)

TYPE OF LINK	FIRST HOUR		SECOND HOUR		THIRD HOUR		TOTAL LINKS
	Increase	Decrease	Increase	Decrease	Increase	Decrease	
F No.	8	15	15	9	14	10	24
Median Change (MPH)	5.3	12.7	9.2	5.1	10.6	9.7	
A No.	16	12	12	18*	19	12	31
Median Change (MHP)	10.4	9.0	7.0	8.5	7.2	4.0	
N No.	6	22	12	18	10	20	30
Median Change (MPH)	5.7	9.6	8.4	9.4	2.7	9.4	

---

*Plus one unchanged speed.

In each case, the greater median change accompanied the greater number of speed changes. The table shows that the introduction of computer control led to more increases in average speed for the favored and affected links than decreases. Unfortunately, there were more decreases than increases for the neutral links. It should be noted that there are always three links in the Category F which are not favored at a particular time, depending on the information sign states (Table 2-1). Moreover, whenever the signs changed state, the offsets also changed with the signal dwelling at the start of main street green. Sign state changes occurred more often in the first hour session. These could explain some of the decreases in speed which occurred on the F links, particularly in the first hour. The decreases on the N links may be due to the number of these links which were not under computer control for some reason.

CHANGES IN DELAY TO CROSS STREET TRAFFIC

There are 32 approaches not on links to the computer-controlled signals. Volume data was available for 30 of these and, of the 30, aerial photography data had been tabulated for 21 approaches (not more than one approach per intersection). The floating car trips did not pass through any of the intersections on these approaches.

From the aerial photography, total delay had been counted for each approach for each hour and each day of flying. Corresponding approach volumes for each hour and each day were available from the ground counts and historical records. To assess the "before" and "after" differences, corresponding "before" and "after" delays and volumes were added and the quotient of delay to volume obtained both "before" and "after." The quotients are, of course, average delays for the approaches and the results are summarized in Table 3-5. The number of approaches with increasing or decreasing delay are given together with the median increase or decrease.

For each of the three hours, either the majority of approaches had an increasing delay or the median increase exceeded the median decrease. Since the signal timings were designed to reduce travel time on the major routes, some increases in delay on these minor routes are not surprising. Like the study of link travel time, this analysis of the approach delay does not consider the traffic volumes and the overall vehicle hours of delay. The last quantity is probably a more realistic measure of effectiveness and is evaluated for both links and approaches in the next sections.

TABLE 3-5
COMPARISON OF "BEFORE" AND "AFTER" AVERAGE APPROACH DELAYS
(Median Delay Changes in Seconds)

	FIRST HOUR		SECOND HOUR		THIRD HOUR	
	Increase	Decrease	Increase	Decrease	Increase	Decrease
Number	13	8	11	10	9	11*
Median	9.0	27.6	16.3	5.5	37.1	11.2

---

*Plus one unchanged speed.

CHANGES IN NETWORK TOTAL TRAVEL AND TOTAL TRAVEL TIME

Table 3-4 showed that, in any hour, there was a reasonably close division between the links with increasing average speeds and those with decreasing speeds. The question now arises as to whether there was an overall increase or decrease in total travel time for a given amount of travel.

The estimates of total travel for each hour and each day were summed over all links. Corresponding values of total travel time were similarly summed. If, in any hour, a value of total travel time had not been obtained for a link on any day, this link was not counted for the other days during the same hour. A further summation was carried out next with the travel and travel times being combined for all links of the same type. The results are given in Table 3-6.

The table shows considerable differences between the links and hours. In the first hour average speed on the "after" days decreased for two of the three types of links, with an increase, surprisingly, on the affected links. There were increased speeds on both the F and A links in the third hour. Only in the second hour was the result near expectations with increased speeds on the F and N links and a decrease on the A links. The most likely explanation is the variation from day to day, with the "before" data represented on only day for both the first and third hours.

CHANGES IN TOTAL DELAY TO CROSS STREET TRAFFIC

In a similar way to the links, the approaches for which data were available were combined for each hour. The corresponding approach total delays and estimated approach volumes were added. Table 3-7 shows the approach delays and volumes for each day.

According to the table, the expected increases in average delay on these 'isolated' approaches have occurred for all three hours. The delays measured on November 17 are remarkably low just as the total travel times were.

LINK SPEEDS

In Table 3-6, comparisons of average speed were made but only within any particular hour. There is, however, a connection between the hours. Prior to the introduction of computer control, the intersections were all operated by a single timing plan throughout the hours of this study. If it is assumed that there is a relationship between total travel on a link and total travel time or average speed, then the values of these variables for all "before" study hours should agree with the relationship. The values were too erratic for an individual link so links of the same type have been combined. Missing values for any link for any hour led to the exclusion of that link.

Table 3-8 shows values of total travel time, total travel and hence average speed. There were now only 14 F links with complete results, 15 A links, and 10 N links, a total of 39 links. Table 3-6 for each hour differs only in the respect that there were up to 70 links, but some data was missing for 31 of the links.

There was a considerable scatter of the four "before" and six "after" values for each type of link, just as in Table 3-6. Most of the links removed from the calculations were those with faster speeds and these account for almost half the travel. On the basis of a comparison of the remaining links, increases in average speeds were obtained for only the F links in the second hour and for only the A links in the first and third hours.

TABLE 3-6

SUMMARY OF LINK TOTAL TRAVEL AND TOTAL TRAVEL TIME

		FIRST HOUR			SECOND HOUR			THIRD HOUR		
LINK TYPE	DATE	TOTAL TRAVEL (Veh. Mi.)	TOTAL TRAVEL TIME (Veh. Hr.)	AVERAGE SPEED (MPH)	TOTAL TRAVEL (Veh. Mi.)	TOTAL TRAVEL TIME (Veh. Hr.)	AVERAGE SPEED (MPH)	TOTAL TRAVEL (Veh. Mi.)	TOTAL TRAVEL TIME (Veh. Hr.)	AVERAGE SPEED (MPH)
F	Nov. 12				3586	194	18.6	6946	308	22.6
	Nov. 17	1683	72	23.4	3074	119	25.8			
	Nov. 24	1872	96	19.5	3545	164	21.6	7319	318	23.0
	Dec. 2	1835	89	20.6	3449	86	40.6	6888	234	29.4
A	Nov. 12				1601	86	18.6	3415	211	16.2
	Nov. 17	1666	96	17.4	1395	65	21.5			
	Nov. 24	2003	96	20.8	1536	113	13.6	3530	201	17.6
	Dec. 2	1894	80	23.7	1591	76	21.0	3550	152	23.4
N	Nov. 12				2822	150	18.8	3252	141	23.8
	Nov. 17	3150	131	24.0	2659	144	18.4			
	Nov. 24	3204	182	17.6	2797	148	18.9	3024	259	11.7
	Dec. 2	3040	147	20.7	2275	112	20.3	3292	133	24.7
TOTAL	Nov. 12				8009	430	18.6	13613	660	20.7
	Nov. 17	6499	299	21.7	7128	328	21.7			
	Nov. 24	7079	374	19.0	7878	425	18.6	13873	778	17.8
	Dec. 2	6769	316	21.4	7315	274	26.7	13730	519	26.5

TABLE 3-7

SUMMARY OF APPROACH TOTAL DELAY AND VOLUME

	FIRST HOUR			SECOND HOUR			THIRD HOUR		
DATE	Delay (Veh. Hr.)	Volume (Veh.)	Average Delay (Sec.)	Delay (Veh. Hr.)	Volume (Veh.)	Average Delay (Sec.)	Delay (Veh. Hr.)	Volume (Veh.)	Average Delay (Sec.)
Nov. 12				44	7739	20.5	60	8596	25.2
Nov. 17	26	5393	17.3	13	7089	6.7			
Nov. 24	27	6663	14.5	37	9114	14.4	115	6900	41.5
Dec. 2	34	5350	23.1	30	8020	13.5	40	8560	16.7

TABLE 3-8

TOTAL TRAVEL, TOTAL TRAVEL TIME AND AVERAGE SPEED FOR 39 SAMPLE LINKS

		FIRST HOUR			SECOND HOUR			THIRD HOUR		
LINK TYPE	DATE	Total Travel (Veh. Mi.)	Total Travel Time (Veh. Hr.)	Average Speed (MPH)	Total Travel (Veh. Mi.)	Total Travel Time (Veh. Hr.)	Average Speed (MPH)	Total Travel (Veh. Mi.)	Total Travel Time (Veh. Hr.)	Average Speed (MPH)
F	Nov. 12				3039	167	18.2	4060	151	27.0
	Nov. 17	1683	72	23.4	2274	93	24.5			
	Nov. 24	1872	96	19.4	2809	137	20.5	3986	184	21.6
	Dec. 2	1835	89	20.6	2782	86	32.3	4118	135	30.5
A	Nov. 12				1320	73	17.9	1379	67	20.6
	Nov. 17	1129	69	16.4	1134	54	20.9			
	Nov. 24	1457	61	24.0	1257	104	12.0	1560	76	20.4
	Dec. 2	1315	51	25.8	1285	69	18.6	1459	42	35.1
N	Nov. 12				1340	96	13.9	1382	83	16.7
	Nov. 17	1166	67	17.4	1354	83	15.1			
	Nov. 24	1316	84	15.7	1350	115	11.8	1317	171	7.7
	Dec. 2	791	87	9.0	929	81	11.4	989	87	11.3
ALL	Nov. 12				5699	336	17.0	6821	301	22.6
	Nov. 17	3978	208	19.2	4762	235	20.3			
	Nov. 24	4645	241	19.3	5416	356	15.2	6845	431	15.9
	Dec. 2	3941	227	17.4	4996	236	21.2	6566	264	24.9

APPROACH DELAYS

A comparison between hours on approaches was also made by excluding those approaches for which data was not obtained for any hour on any day. The results are given in Table 3-9 for the 14 approaches with complete data.

Because delay is now compared over all three hours, it is clear that there has been little change in average delay for a given volume. The "after" days (especially November 24) were characterized by greater volumes on the approaches. Since average delay in general increases monotonically with volume, the increases can be explained by the higher volumes. Again, there is a considerable scatter in the values of delay.

TABLE 3-9
APPROACH TOTAL DELAY AND VOLUME FOR A STUDY SET OF 14 APPROACHES

	FIRST HOUR			SECOND HOUR			THIRD HOUR		
DATE	Delay (Veh/Hr)	Volume (Veh)	Avg. Delay (Sec)	Delay (Veh/Hr)	Volume (Veh)	Avg. Delay (Sec)	Delay Veh/Hr)	Volume (Veh)	Avg. Delay (Sec)
11/12				17	5289	11.6	20	5386	12.2
11/17	26	5393	17.3	7	5399	4.6			
11/24	27	6663	14.5	28	7014	14.4	62	7226	30.9
12/2	34	5350	23.1	18	5930	10.9	9	6170	5.3

OVERALL EVALUATION

To complete the evaluation of the system of traffic control, the delays at approaches were combined with the travel time measured on the links. The reduced set of 39 links and 14 approaches was retained to enable a comparison between hours to be made. The approach delays were added to the vehicle hours of travel time, noting that no vehicle miles of travel were achieved on the approaches. Hence, the delays or travel times in Table 3-9 have been added to the corresponding total travel times in Table 3-8. Table 3-10 is the result.

TABLE 3-10
TOTAL TRAVEL AND TOTAL TRAVEL TIME ON 39 LINKS AND 14 APPROACHES

	FIRST HOUR		SECOND HOUR		THIRD HOUR	
DATE	Total Travel (Veh/Mi)	Total Travel Time (Veh/Hr)	Total Travel (Veh/Mi)	Total Travel Time (Veh/Hr)	Total Travel (Veh/Mi)	Total Travel Time (Veh/Hr)
"Before"						
11/12			5699	353	6821	321
11/17	3978	234	4762	242		
"After"						
11/24	4645	268	5416	384	6845	493
12/2	3941	261	4996	254	6566	273

There are no apparent decreases in total travel time when the two "after" days are considered together. However, since almost half the measured travel has been excluded from the original assessment in Table 3-6 with approach delays reasonably constant, this result is of less significance. Table 3-6 showed an approximate 8% increase in speed in the second hour and an approximate 3% increase in the third hour with about a 7% decrease in the first. hour.

INTERSECTIONS NOT UNDER COMPUTER CONTROL

Several intersections were not under continuous computer control on the "after" days, November 19 and 24 and December 2. On the first "after" day, intersections 4, 6, 8, 10, 13, 16, 20 and 31 were not under computer control. The list on November 24 comprised intersections 8, 10, 16 and 20, while on the last day 3, 4, 6, 8, 10 and 13 were not functioning correctly.

The likely effect of an intersection not under computer control is that delays may increase on links containing the intersection where progression has been intended and may decrease (or increase) on links not in progression. On the neutral links, the desired split of green time will not be obtained and, as a result, delay could be increased. The types of links were separated into two classes on each "after" day--those containing intersections under and not under computer control, known as non-defective and defective links. Although the object is to compare speeds on the defective and non-defective links, speed is not an absolute quantity but a ratio. Hence, the number of vehicles counted in the aerial photographs was chosen as a suitable quantity for comparison. The test could only be applied, of course, on November 24 and December 2.

Table 3-11 shows the number of vehicles counted from aerial photographs on the two types of links, favored and affected, separated into defective and non-defective groups. There were insufficient data for a comparison of the neutral links.

Contingency tables were formed for each hour to compare "before" and "after" counts for defective and non-defective links. Based on a Chi-square test (1 degree of freedom) at the 0.05 level, there was a significant difference (actually at the 0.01 level) only for the second hour on the favored links. The remaining three tests on the F links and all four tests on the A links showed no significant difference between the defective and non-defective links.

In the one significant result, the "after" speed on the defective links was 23.5 mph compared with 27.3 mph on the "before" days in the second hour, a decrease of 3.8 mph. On the other hand, the "after" speed on the non-defective links showed a decrease of only 0.4 mph from 20.3 mph to 19.9 mph. The defective links accounted for about one-third of the travel on any day and had much higher average speeds. The reason for the increase on the non-defective links is not clear but, as already pointed out, this could be due to the considerable variation between days.

REVISION OF RAMP METERING CALCULATIONS

Aerial photography together with a "floating" car were also used for the purpose of data collection for this study. Since the plane could not fly for much longer than three hours without refueling, it was decided to divide the four-hour peak period into two equal sections and fly each half period on different days. It was intended to fly the later half period, 4:30-6:30 p.m. on April 17 and September 23, with the entire time 2:30-4:30 p.m. to be flown on September 21 and September 29. In fact, weather and mechanical difficulties caused some changes in this plan, but films were obtained on at least one day for all sections of the peak period. The long break from April 17 to September 21 was due to unavailability of the original flying service and it took some time to find another suitable service.

TABLE 3-11

NUMBER OF VEHICLES COUNTED FROM AERIAL PHOTOGRAPHS

FAVORED LINKS

DATE	Defective on November 24 (7)			Defective December 2 (5)	Not Defective (15)		
	1st hour	2nd hour	3rd hour	3rd hour	1st hour	2nd hour	3rd hour
Nov. 12		143	265	211		405	618
Nov. 17	69	133			179	351	
Total	69	276	265		179	756	618
Nov. 24	69	224	162		377	434	383
Dec. 2				63			224

AFFECTED LINKS

DATE	Defective on November 24 (9)			Defective December 2 (4)	Not Defective (20)		
	1st hour	2nd hour	3rd hour	3rd hour	1st hour	2nd hour	3rd hour
Nov. 12		88	190	78		380	452
Nov. 17	101	80			183	255	
Total	101	168	190		183	635	452
Nov. 24	146	120	89		336	408	284
Dec. 2				21			125

On the first flight (April 17), the plane was flown alternately northbound and southbound between Meyers Road and West Grand Boulevard. However, it was found that it was difficult to properly align the plane on northbound flights for photographs of the northbound Freeway. Hence, on subsequent flights, photographs were taken only while the plane was heading south. The direct return journey to the starting point at Meyers Road was used for film reloading and for entries in the flight log.

The film used was high-speed Ektachrome Reversal Film. The films were developed and the transparencies examined under the same viewer as for the surface street study. The plane made between 12 and 16 flights per session over the Freeway and a whole film of 16 exposures was available for the six-mile Freeway section allowing for overlap. A typical photograph is shown in Figure 20.

A form had been prepared to facilitate the transfer of data from the film to punched cards. The Freeway had been divided into eight sections between detector stations and each subsection was subdivided at on-ramps or off-ramps between the stations. The number of vehicles (cars and trucks) in each lane of each subsection were entered together with the number of trucks alone in each lane. The time of day was also written down from the flight log. A sample form is shown in Appendix E.

The same photographs also showed clearly the number of vehicles waiting in a queue on each metered ramp. This data, together with the number of trucks and the time of day, were noted on a separate form also shown in Appendix E.

In the "floating" car method, a car with a driver and observer, both University of Michigan personnel, entered the northbound Freeway upstream from West Grand Boulevard. The observer noted the time of day on passing the West Grand Boulevard detectors and started a stop watch. The moving stop watch was read as the car passed each other detector station, entry ramp and exit ramp. The times were entered on a form. The run ended at the Meyers Road detector, whence the car was driven to the next exit ramp and returned on the southbound Freeway to the starting point for another run. Every effort was made to drive at the mean speed of the traffic with the car usually in the center lane.

Three or four runs were made on each day while the aerial photography was in progress and in addition four trial runs were made on April 15. Later, as a test on the effect of discontinuing ramp metering, further runs were made in December and January, 1971.

ANALYSIS

In the introductory chapter to this report, a method of computing storage in a freeway section for each minute was presented. The sum of the storages over any period of time is also the total travel time over that period. The data collected by the computer from each day's metering can therefore be used to obtain the total travel time over any period within the four hours of metering. Similarly, the storage for a sample time within the period of aerial photography has been obtained by direct counting. Dividing the four-hour period into eight half-hours, the total travel time has been calculated from the computer's records and from the aerial photographs averaging data from the same half-hour periods. The results are shown in Table 3-12.

The table shows, as might be expected, considerable differences in the results from the two methods of calculation. However, there are some consistent patterns. Firstly, the computer's record gives a lower value of total travel time for five of the eight Freeway

TABLE 3-12

TOTAL TRAVEL TIME (VEHICLE HOURS) IN HALF HOUR PERIODS FROM AERIAL PHOTOGRAPHS (A) AND COMPUTER'S RECORDS (B)

Freeway Section

HALF HOUR ENDING	1		2		3		4		5		6		7		8	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1500	20.8	27.1	44.2	80.5	16.8	15.8	53.9	44.0	39.1	31.7	72.1	62.2	43.8	42.8	346.1	366.4
1530	20.8	27.1	44.2	80.5	16.8	15.8	53.9	44.0	39.1	31.7	72.1	62.2	43.8	42.8	346.1	366.4
1600	20.8	27.1	44.2	80.5	16.8	15.8	53.9	44.0	39.1	31.7	72.1	62.2	43.8	42.8	346.1	366.4
1630	24.2	30.9	64.8	96.0	21.0	20.8	65.0	57.4	39.4	40.7	69.7	73.6	42.0	46.7	378.0	434.7
1700	22.0	26.0	86.6	86.6	30.2	24.2	77.7	66.8	65.8	52.3	95.2	79.7	51.2	49.6	489.4	459.2
1730	22.3	26.1	81.5	85.4	30.2	24.2	77.7	66.8	65.8	52.3	95.2	79.7	51.2	49.6	484.7	458.1
1800	19.6	21.8	79.6	79.7	32.7	23.4	78.6	64.9	78.9	53.6	109.1	77.1	56.8	49.2	522.1	443.4
1830	16.3	17.4	87.7	61.8	33.9	23.4	88.2	72.1	80.8	61.2	106.0	67.2	52.1	46.9	538.7	422.3
TOTAL	156.8	203.5	532.8	651.0	199.4	163.4	548.9	460.0	448.0	355.2	691.5	563.9	384.7	370.4	480.0	549.3

(The higher travel time estimate has been underlined) sections, the aerial photographs giving the lower values only for sections 1, 2 and 8. There are exceptions for some half-periods highlighting the second pattern in the results. This is a relative decrease in the total travel time from the computer's records compared with the aerial photographs. The swing is so marked that, for the last half-hour period, only the first section yields a greater value of total travel time from the computer's records.

The differences in Table 3-12 show that the assumed constants in the average speed relationship should be decreased in order to increase the computer's calculated total travel time. Whether the constants should be further modified during the course of a peak period depends on the proportion of trucks in the stream. The proportion of trucks in the entire Freeway section was obtained by weighting the observed proportions for each subsection according to the photographic duration of total travel time for each half-hour. The overall percentages of trucks by time of day are shown in Figure 21.

There is a gradual decrease in the percentage of trucks from about five percent at 3:00 p.m. until 5:00 p.m. when the stream contains only about two percent trucks. To overcome this effect in the computer's calculations, the constant should be decreased for the last two hours of metering. This is equivalent to assuming a decreased average vehicle length which would be the case with a decreased percentage of trucks.

The values of the constants were checked again from the results of the floating car studies. The travel times past each check point were first used for a simple check on the speed measurement methods. To describe the methods, consider the check points shown in Figure 22. Detector stations are at Band E.

Method 1

$$\text{Average Speed} \approx \frac{1}{2}\left[\frac{\text{Distance AC}}{\text{Travel Time AC}} + \frac{\text{Distance DF}}{\text{Travel Time DF}}\right]$$

This value is probably a close approximation to the average speed calculated by the computer.

For the first section (from West Grand Boulevard), there is no station upstream from here so that the first ratio is distance BC to time BC. For the last section (to Meyers Road), there is no station downstream from here so that the second ratio is distance DE to time DE.

Method 2

$$\text{Average Speed} = \frac{\text{Distance BE}}{\text{Travel Time BE}}$$

The algebraic sum of the differences is given in Table 3-13.

Using a t-test of the significance of the differences (from zero) on a null hypothesis that there is no difference in the methods, there are (highly) significant differences for only the second, sixth, and eighth systems. However, it should be noted that the sum or mean of the differences in all cases is positive. This indicates a trend, significant in three cases, for vehicles to slow down between detector stations. With independence, the probability of all eight being positive is only 1 in 256. This is a small probability so the difference in means is considered significant.

TABLE 3-13
ALGEBRAIC SUM OF 21 DIFFERENCES
IN AVERAGE SPEED

Section	(Method 1 - Method 2) (MPH)	Standard Deviation of Differences (MPH)
1	+61.20	8.2
2	+407.65	9.4
3	+106.95	12.8
4	+76.85	24.0
5	+50.20	13.5
6	+458.55	17.1
7	+72.74	14.6
8	+472.25	22.4

The results of the aerial photography and moving vehicle tests suggest that the constant in the equation for average speed should be revised. As given in the introduction,

$$\bar{u} = \frac{1}{2}\left(\frac{k_1 q_1}{\theta_1} + \frac{k_{n+1} q_{n+1}}{\theta_{n+1}}\right)$$

But k_1 and k_{n+1} are simply proportional to the detected length under a sonic detector, equal to the detected field plus the average vehicle length. Assuming that the detected fields are equal from station to station

$$\bar{u} = \frac{\ell}{176}\left(\frac{q_1}{\theta_1} + \frac{q_{n+1}}{\theta_{n+1}}\right)$$

where ℓ is in feet, $\bar{u}$ miles per hour, q in vehicles per minute and θ is a proportion (of occupancy over one minute). Hence

$$\ell = \frac{176\ \bar{u}}{(q_1/\theta_1 + q_{n+1}/\theta_{n+1})}$$

With $\bar{u}$ known from the moving vehicle studies and q and θ from the computer records, estimates of ℓ can be obtained.

Table 3-14 shows computed values of ℓ for the three days, September 21, 23, and 29, and for four subsystems. The table does not show a consistent pattern from day to day. For example, if the percentage of trucks decreased sufficiently to decrease the average vehicle length, then the values from the second half of the peak period (September 23) would be significantly lower. Therefore, it seems reasonable to simply tabulate the average and consider them constants over the whole four-hour period. The table also shows a considerable difference between the constants from station to station. The value at section 4 is very low considering that the average vehicle length is about 17.5 feet (31). It would appear that the detectors making up section 4 are either consistently under-reading flow or over-reading occupancy. Because of the differences in the values of ℓ, a restatement of the formula for average speed should be

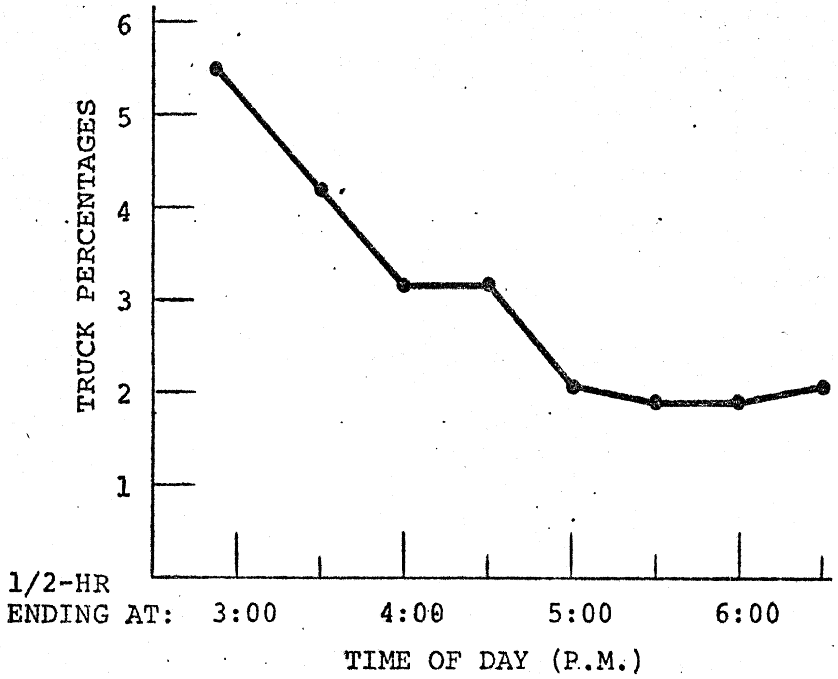

FIGURE 21.
PROPORTION OF TRUCKS BY TIME OF DAY

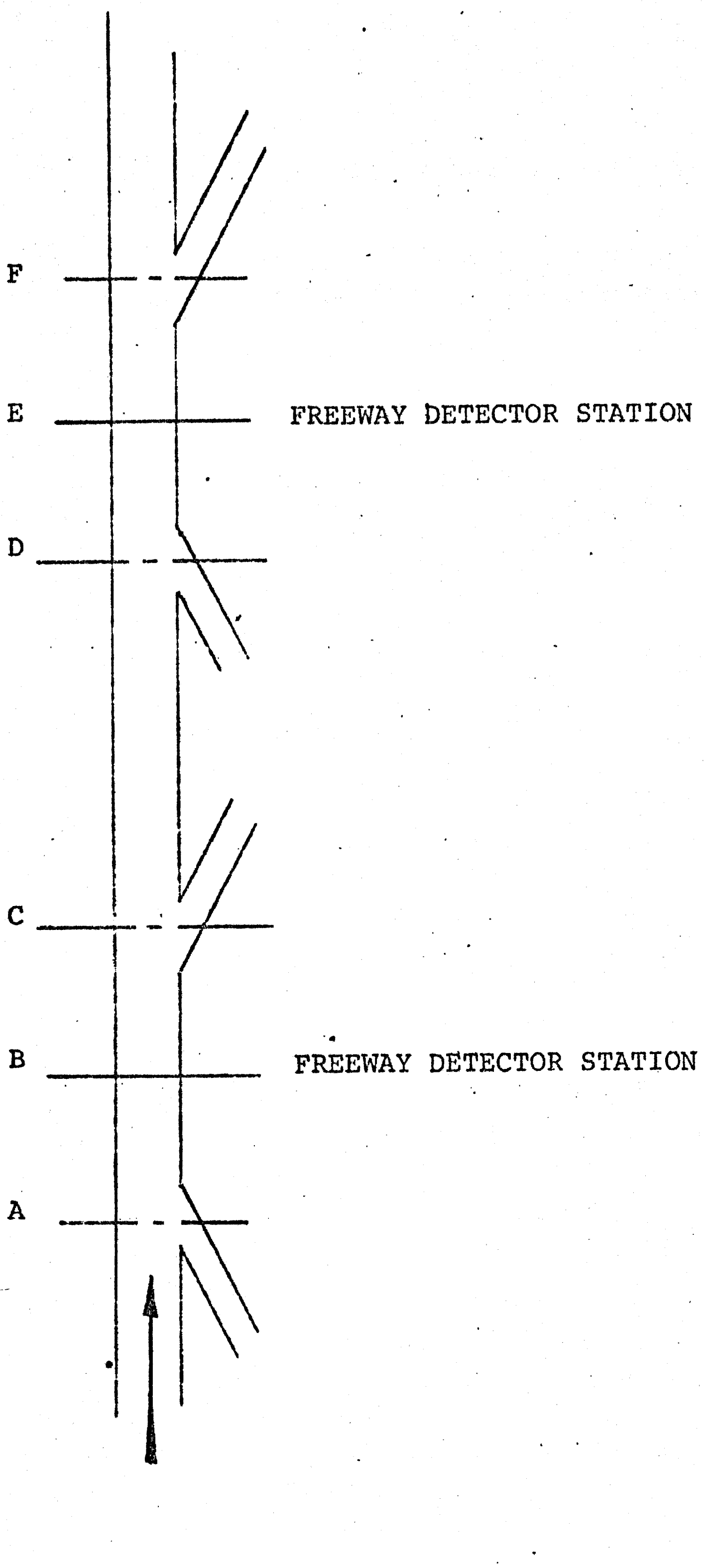

FIGURE 22
FREEWAY SECTION SHOWING METHOD OF
OBTAINING AVERAGE SPEEDS

$$u_1 = \frac{k_{1,n+1}}{176}\left(\frac{q_1}{\theta_1} + \frac{q_{n+1}}{\theta_{n+1}}\right) \cdot$$

where $k_{1,n+1}$ is a constant representing the detector performance bounding a freeway section.

Finally, a check was made to find out the effect, if any, of permanently ceasing ramp metering after December 4, 1971. An analysis of variance was run on trip times (Table 3-15) on the northbound Lodge Freeway from West Grand Boulevard to Meyers Road. Starting times were sorted into four periods and appear as the columns. Rows 1-4 consist of data gathered before December 4, 1970 and rows 5-9 consist of data gathered after December 4. Times are entered in minutes and tenths of minutes. An analysis of variance on the data yielded the results in Table 3-16.

The ratio of the variance estimate for the rows to the variance estimate for the residual is 3.65 with 8 and 12 degrees of freedom, respectively. Consulting tables for Snedecor's F reveals that this result is significant, being slightly higher than the 2.5% level. Thus, the experiment did have a significant effect on trip times on the northbound Lodge. As we would expect, starting time is very significant and the F test gives a level of significance greater than .1%.

TABLE 3-14
COMPUTED VALUES OF ℓ

	September 21	September 23	September 29	Average
3	25.1	20.0	20.9	22.0
4	15.2	15.5	16.7	15.8
7	35.2	27.9	34.5	32.5
8	27.7	26.2	25.4	26.4

TABLE 3-15
FREEWAY TRAVEL TIMES

STARTING TIME	1430-59	1500-59	1600-59	1700-29
"BEFORE"	71	79	116	150
	74	112	135	192
	76	113	147	160
	68	96		155
"AFTER"	85	92	180	201
			111	178
			127	
			110	
			143	

TABLE 3-16
ANALYSIS OF VARIANCE OF FREEWAY TRAVEL TIMES

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	VARIANCE ESTIMATE
COLUMNS	30,331	3	10,110.3
ROWS	4,975	8	621.9
RESIDUAL	2,045	12	170.4
TOTAL	37,351	23	

Unfortunately, there is not much data for the "after" period and the third column is the only one which contains more than two "before" and two "after" times. As an additional measure, a variance ratio test was run comparing the "before" trip times of the 1600-59 column with the "after" times of that column. This test gave a value for F of 3.46 which is not significant on two and four degrees of freedom.

A Student's t test also gave an insignificant result.

In summary, it could not be shown that in the long term travel times increased (or decreased) with the cessation of ramp metering. At first, there were sharp increases in travel times. Thereafter, motorists were probably aware of the increased congestion and reverted to the alternate routes which they perhaps traveled on during the days of ramp metering.

RAMP METERING-HARDWARE CHANGES TO INCREASE OBEDIENCE

To determine how well each of the four separate ramp metering configurations performed, a study on violations to the signal at one of the ramps was undertaken. The Webb on-ramp was chosen as being typical and information was obtained concerning the number of vehicles illegally driving through a red display on the signal. A computer program had previously been prepared to supply data, for each of the 240 minutes in the four-hour control period, on the total number of vehicles utilizing the ramp and the number of these that violated the signal. Thus a listing of ramp metering violators, by minute, was available. In any given minute, the number of violators is equal to the vehicle count minus the green changes on the signal.

Sample days were randomly chosen from each of the following four periods: May 18 to June 19, 1970; July 6 to July 31, 1970; September 1 to September 30, 1970; and October 8 to November 6, 1970. A total of 21 days were compiled and the mean for each period calculated. A Student's t test was performed on the means of the succeeding periods; see Table 3-17 below.

TABLE 3-17

VIOLATIONS AT WEBB RAMP VERSUS CONFIGURATION NUMBER

CONFIGURATION NUMBER	MEAN NUMBER OF VIOLATIONS	SUCCEEDING DIFFERENCE	SIGNIFICANCE LEVEL
1	115.0		
		+27.0	--
2	142.0		
		-32.0	0.05
3	110.0		
		-16.3	--
4	93.7		

The largest number of violations occurred during the time configuration number 2 was active and is directly related to the fact that this configuration had the shortest presence detection zone. There was a statistically significant improvement with the simple increase of this zone as implemented in configuration number 3. There was yet another improvement when the presence zone was increased further by utilizing the queue detector. This fourth configuration proved to be the most successful since it achieved the lowest mean number of violations.

REVISION OF METERING STRATEGY

The study was conducted on two separate days, from 3:00 p.m. to 4:30 p.m. on one day and from 4:30 p.m. to 6:00 p.m. on the next day. These time periods represented the full range of the peak period and almost all of the metering period. Since the travel pattern during this period is work-home trips, it was believed that no bias would be developed by conducting the study on separate days.

Observers equipped with tape recorders were assigned to the three sites. These sites were identified in the following way:*

Station 1 - The Davison On-Ramp
Station 2 - The Oakman Overpass
Station 3 - The Linwood Off-Ramp

The observers were instructed to record the last three digits on the license plate of every vehicle that passed them, starting with a marked University car which returned through the route at approximately half-hour intervals. This divided the study into different runs and reduced the probability of the repetition of numbers for each run. The observers recorded the time at which the marked car passed them and the number of unrecorded license plates for each run.

The data were transferred to coding sheets then punched on data processing cards and a simple program was written to match the license plates at each station for each of the six runs. This resulted in seven groups of license plate totals for each run.

A) Unmatched License Plates at Station 1
B) Unmatched License Plates at Station 2
C) Unmatched License Plates at Station 3
D) Matched License Plates at Stations 1 and 2
E) Matched License Plates at Stations 2 and 3
F) Matched License Plates at Stations 1 and 3
G) Matched License Plates at Stations 1, 2, and 3.

RESULTS OF THE STUDY

Table 3-18 summarizes the groups of matched license plates. The results for the second run on the first day of the study were discarded due to a breakdown of one of the tape recorders during that run. The totals for the fourth and fifth runs were grouped together since these runs were very short and the number of observations were much less than that of the other runs. A Chi-square test of this grouping indicated no significance at the 0.05 level. The runs have simply been indicated as 1, 2, 3 and 4 in Table 3-18.

TABLE 3-18
NUMBERS IN GROUPS OF MATCHED LICENSE PLATES

	STATION							
	A	B	C	D	E	F	G	
RUN	1	2	3	1 & 2	2 & 3	1 & 3	1, 2 & 3	TOTAL
1	191	111	33	94	86	17	98	630
2	192	79	54	107	57	23	114	626
3	176	147	20	126	68	4	56	597
4	176	80	53	58	94	16	56	533
TOTAL	735	417	160	385	305	60	324	2386

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*See Figure 14, Chapter 2.

The four runs represented different periods of traffic volumes during the peak period, the period of heaviest flow occurring during the third run. Group B, plates sighted only at Station 2, represent an undesirable traffic maneuver by using the fourth lane for passing. It was during the third period that this maneuver was most prevalent. Several tables were formed from the matched license plates in order to illustrate the traffic pattern and a Chi-square test was applied to each table. A confidence level of 0.05 was used.

Some of the traffic which enters the Lodge from the Davison ramp does not desire to exit at Linwood and so must merge into the lane adjacent to the auxiliary lane. The ease by which this maneuver was accomplished was examined by comparing groups A and D in the above list of matched license plates. The results are indicated in Table 3-19. The percentage of drivers unable to merge before reaching Oakman, Group D, increased from 33% in the first run to 42% in the third run, then decreased to 25% in the fourth run. This trend showed that it became more difficult for drivers to merge as the traffic volume increased. A Chi-square test on this sample was very significant. Apparently some drivers who later enter Davison desiring to exit at Linwood attempt to save time by merging into a through lane then re-enter the auxiliary lane downstream. The percentage of those drivers who engage in this maneuver is given in Table 3-20. Such maneuvers were not extensive and were diminished considerably during the third run when the volume was heaviest. A Chi-square test on this sample was not significant.

TABLE 3-19
GROUP A COMPARED WITH GROUP D

	GROUPS	
RUN	A	D
1	67% (191)	33% (96)
2	64% (190)	36% (107)
3	58% (176)	42% (126)
4	75% (176)	25% (58)

$\chi^2 = 16.7$ on 3 d.f.
Highly Significant

TABLE 3-20
GROUP F COMPARED WITH GROUP G

	GROUPS	
RUN	F	G
1	15% (17)	85% (98)
2	17% (23)	83% (114)
3	7% (4)	93% (56)
4	22% (16)	78% (56)

$\chi^2 = 6.4$ on 3 d.f.
Not Significant

Table 3-23 compares the Lodge traffic desiring to exit at Linwood which diverged before reaching Oakman with the late divergers. There was no apparent trend in the diverging pattern. The percentage of early diverging traffic ranged from 77% in the third run to 51% in the second run. The low percentage occurring in the second period was quite unusual. A Chi-square test on this sample was highly significant.

TABLE 3-23
GROUP C COMPARED WITH GROUP E

RUN	GROUPS C	GROUPS E
1	28% (33)	72% (86)
2	49% (56)	51% (57)
3	23% (20)	77% (68)
4	36% (53)	64% (96)

$\chi^2 = 17.7$ on 3 d.f.
Highly Significant

Table 3-24 compares Groups C and F with Groups E and G to determine the extent to which the traffic exiting at Linwood uses the auxiliary lane before leaving at Linwood while Groups E and G represent vehicles seen at both Oakman and Linwood. It seems logical that under the heavy traffic flows drivers would diverge early and utilize the auxiliary lane as much as possible. This was demonstrated during the third run where 84% of the exiting traffic diverged early. However, this trend did not follow in the second run. A Chi-square test on this sample was highly significant.

TABLE 3-24
GROUPS C AND F COMBINED COMPARED WITH GROUPS E & G COMBINED

RUN	GROUPS C & F	GROUPS E & G
1	21% (50)	79% (184)
2	31% (77)	69% (171)
3	16% (26)	84% (124)
4	32% (69)	68% (150)

$\chi^2 = 16.6$ on 3 d.f.
Highly Significant

DIVERSION FROM DAVISON-LODGE INTERCHANGE

The study was conducted between the hours of 2:30 p.m. to 6:30 p.m. Three observers were stationed at convenient locations where they could trace vehicles visually from the four sources mentioned below to their local destination. The destinations were:

1. Northbound Lodge Freeway, and
2. Westbound Davison

The observers noted the time at which they began to trace each vehicle for later coordination with the computer record of sign states for the Davison sign. Five-minute volume counts were also taken at the intersection of Hamilton and the westbound Davison Service Drive and for traffic in the shoulder lane of the westbound Davison Expressway.

The study was conducted on three separate days. On the first day, the sign state was allowed to change automatically to reflect the traffic conditions on the Lodge Freeway. However, this resulted in excessive periods of the sign state which diverted traffic from the Lodge entrance ramp at Davison. In order to obtain an adequate sample for both sign states, the metering rate at the Davison on-ramp was changed manually to produce a change in the sign state approximately every fifteen minutes. This was accomplished by establishing the maximum metering rate for fifteen minutes. These manipulations were subject to safety measures. Therefore, regardless of the actual queue length on the ramp, the sign operated normally.

Results

A summary of the results of the study is presented in Table 3-25. The periods during which the signs directed traffic towards the Freeway is designated as green and the periods when traffic is diverted from the Freeway is designated as red. A Chi-square test was conducted for each origin to check the extent to which motorists obeyed the signs. A confidence level of 0.05 was used. The Chi-square test conducted for traffic southbound on Hamilton was highly significant. However, this direction of traffic does not have the benefit of an information sign and decisions were based on driver destination and traffic conditions. For the other three origins, the Chi-square test showed no significance.

DIVERSION FROM WEST GRAND BOULEVARD RAMP

To this end, two studies were conducted in the intersection area in 1970. The first was a license plate study to determine the extent of obedience of drivers passing the sign to various messages displayed on the sign. The second study was of the proportion of ramp users originating from westbound West Grand Boulevard. If the proportions changed in accordance to changes in the sign states of the variable message sign, then it could be inferred that the single sign was insufficient to prevent congestion in the intersection. That is, the amount of traffic using the ramp but not passing the variable message sign would be of such magnitude that congestion still remained.

The license plate study was conducted for a 90-minute period to determine driver response to three recommended routes to the Freeway as displayed on the variable message sign. During the study period the sign states were varied according to the following schedule:

Time Period	Message
3:00 to 3:15 p.m.	Variable message and ramp information signs both indicating the Grand Boulevard ramp.
3:15 to 3:30 p.m.	Variable message sign indicating use of the Seward ramp via the East Service Drive, with the ramp information sign also indicating Seward.
3:30 to 3:45 p.m.	Variable message sign indicating use of the Seward ramp via Second Avenue, with the ramp information sign also indicating Seward.
3:45 to 4:00 p.m.	Same as for 3:00 to 3:15 p.m.
4:00 to 4:15 p.m.	Same as for 3:15 to 3:30 p.m.
4:15 to 4:30 p.m.	Same as for 3:30 to 3:45 p.m.

Since the messages on the ramp information sign are based on ramp congestion and controlled automatically by the computer, the green indication for the Grand Boulevard on-ramp was insured by manually setting maximum metering rates at this ramp. A red indication for this ramp accompanied by a green for Seward was accomplished by setting minimum metering rates at Grand Boulevard. The ramp signal at Seward was turned off throughout to insure the absence of congestion there and a green indication there.

License plate numbers were recorded for the following traffic movements:

(1) Through traffic passing the variable message sign on westbound West Grand Boulevard by lane.
(2) Traffic turning right onto Second Avenue downstream from the variable message sign.
(3) Traffic entering the Grand Boulevard on-ramp.
(4) Traffic entering at the Seward on-ramp.

At the last three locations the observer recorded every license plate number. The number of plates that were missed was noted so that a total volume count could be obtained for the respective locations. Through traffic volumes were so great at the variable message sign that only a sample of license plate numbers could be recorded by the single observer. A second observer at this location counted the vehicles by lane so that the sample size could be obtained. To aid the observers in determining the end of each sign state interval, a control car was sent past each observation station to signal the new study interval.

The license plate numbers were transferred to punch card format and numbers were matched between pairs of stations by computer. The number of plates matched was then expanded to allow for the sampling procedure on West Grand Boulevard and the missed plates at the other locations.

A local origin study of West Grand Boulevard ramp traffic was carried out for the same 90-minute period of a comparable day as the above license plate study. The same sequence of sign states for successive 15-minute intervals was used. As shown in Figure 17, all traffic passing through the intersection and entering the on-ramp passed the ramp information sign. In the study the origins

TABLE 3-25
RESULTS OF DIVERSION FROM DAVISON-LODGE INTERCHANGE

ORIGIN	DESTINATION	SIGN STATE			
		GREEN	RED	TOTAL	
Southbound Hamilton	Lodge	13	27	40	χ^2 = 7.59 on 1 d.f. Significant
	Davison	43	30	73	
	Total	56	57	113	
Northbound Hamilton	Lodge	67	69	136	χ^2 = 0.61 on 1 d.f. Not Significant
	Davison	13	20	33	
	Total	80	89	169	
Davison Service Drive	Lodge	69	89	158	χ^2 = 0.0 on 1 d.f. Not Significant
	Davison	41	62	110	
	Total	117	151	268	
Davison Expressway	Lodge	287	279	566	χ^2 = 0.10 on 1 d.f. Not Significant
	Davison	24	21	45	
	Total	311	300	611	

were distinguished because of the different sides of approach on to the Service Drive and because of the somewhat different opportunities to see the ramp information sign. The local origins were:

1. Right turns from westbound West Grand Boulevard.
2. Through traffic along the Service Drive and left turns from eastbound Grand Boulevard.
3. U-turns from the West Service Drive.

Traffic from the latter two origins would not have passed the variable message sign, and an unspecified proportion of the first origin traffic would also not have passed the sign.

Results

Of the total traffic entering the West Grand Boulevard on-ramp, the license plate study showed that approximately 21% had passed the variable message sign. This meant that even with complete obedience to the sign, only this percentage of ramp traffic could be diverted away from the congested intersection of West Grand Boulevard and the Service Drive.

The actual results for obedience from the license plate study are presented in Table 3-26. The results for the individual lanes at the variable message sign station are combined in the Table. A very low proportion of traffic was found to follow the two signs. When the system favored the West Grand Boulevard on-ramp, 7.5% of the drivers passing the variable message sign diverted to the Seward ramp. When this sign displayed the Seward ramp via the Service Drive, the number diverted increased to 12%, but a third of these diversions did not follow the prescribed route. In general, it appeared that the vast majority of drivers went to the West Grand Boulevard on-ramp regardless of the sign states. Only a relative handful diverted to Seward, and the diversion pattern of these few was so inconsistent that no conclusion can be reached on their obedience to the variable message sign. Since there was very little obedience, it has to be concluded that the variable message sign contributed little to the reduction of congestion at the intersection.

The results of the local origin study are presented in Table 3-27. Similar total volumes were recorded during each of the sets of sign state intervals, and there was a decrease of 27% in the proportion of drivers entering from westbound West Grand Boulevard when the variable message sign indicated Second Avenue as the alternate route. However, the variability of the volume totals for the other origins makes it difficult to attach much significance to this possible evidence of diversion. The only variables in the study were the sign states, and traffic from the other origins would never have seen the variable message sign much less the routing information presented on it. This amount of diversion would also have been inconsistent with the license plate study. Since that study showed that 21% of on-ramp traffic passed the sign, this meant that approximately half of the traffic from westbound West Grand Boulevard passed the sign.

In any event, the local origin study showed that the variable message sign could not greatly reduce the congestion around the West Grand Boulevard on-ramp because of the limited number of drivers who saw it.

TABLE 3-26
EXPANDED MATCHED PLATES PASSING VARIABLE MESSAGE SIGN

RUN	ENTERED WEST GRAND BOULEVARD	ENTERED SEWARD FROM SERVICE DRIVE	ENTERED SEWARD VIA SECOND
System favors West Grand Boulevard ramp	98 (92.5%)	7 (6.6%)	1 (0.9%)
System favors Seward Ramp via Service Drive	102 (87.1%)	10 (8.6%)	5 (4.3%)
System favors Seward Ramp via Second	79 (94.0%)	2 (2.4%)	3 (3.6%)

TABLE 3-27
VOLUME ENTERING FREEWAY AT WEST GRAND BOULEVARD RAMP

RUN	WESTBOUND WEST GRAND BOULEVARD	SERVICE DRIVE & EASTBOUND WEST GRAND BOULEVARD	U-TURNS	TOTAL
System favors West Grand Boulevard Ramp	202 (51.5%)	145 (37%)	44 (11.5%)	391
System favors Seward Ramp Via Service Drive	211 (51%)	178 (43%)	25 (6%)	414
System favors Seward Ramp via Second	169 (43%)	186 (47.5%)	37 (9.5%)	392

REVISION OF METERING STRATEGY TO TRY TO PREDICT THE BUILDUP OF CONGESTION AT BOTTLENECKS

The subsystem which imposes limitations on the metering rate at the Davison on-ramp is that section of the Freeway between the Glendale and Oakman detectors. Figure 23 shows a schematic layout of this section of the Freeway. In computing the storage for this subsystem, the volumes of the three through lanes and the auxiliary lane were added together. However, as seen from the study, the auxiliary lane is utilized by both traffic exiting at Linwood and Lodge through traffic, the usage by through traffic increasing with increasing volume in that section. Based upon this finding, a new metering strategy was proposed for the Davison on-ramp which would more reflect the true storage in this section of the Freeway. Under a possible new metering method, an allowance for the fourth lane should be made for only the movements B and D while the movements C and F should be discounted from the fourth lane. Based on the totals in Table , only 573 out of a total volume of 1431 should be counted. Thus, as an approximation, only 40% of the volume in the auxiliary lane should be included in the storage calculations during the peak period. Although there was some variation in the usage of the auxiliary lane during the peak period, this uniform proportion appears quite adequate in accomplishing the objective of this study. This should result in a reduction in the storage of approximately 12 vehicles per minute but with effectively only three downstream lanes. This would probably result in a reduction of the metering rate at Davison, but should remove the bottleneck caused by the lane reduction.

The method used to record the license plate numbers resulted in few repetitions of numbers during a pass. These repetitions could probably have been eliminated by recording four digits since Michigan license plates consist of three letters followed by three numerals. However, by recording three digits, very few license plates were missed and the percent of recorded license plates was considered vital to the analysis. Ninety-six percent was recorded at Station 1, 78% at Station 2, and 100% at Station 3. The majority of missed license plates occurred at Station 2 and this might have contributed to some of the irregularities of the analysis occurring during the second run. The high speeds and short headways made it difficult to recognize many of the license plates at that station.

However, the results of the study gave enough evidence of the usage of the auxiliary lane during the peak hour. The proportion of through traffic which uses this lane increases with increasing traffic volume. The metering method should therefore be changed to reflect this usage by including only a proportion of the volume of traffic in the auxiliary lane in comparing the storage for that subsystem.

DIVERSION OF TRAFFIC FROM INTERSECTIONS WHICH MAY BE BLOCKED BY RAMP QUEUES

Little, if any, response by drivers intending to enter the Freeway could be found for the various sign states on the Davison signs or variable message sign.

It is difficult to explain the results for the three Davison signs. The purpose of the study was to demonstrate the relative merits of each type of sign to divert traffic away from the ramp entrance. In fact, none of the signs showed any significant

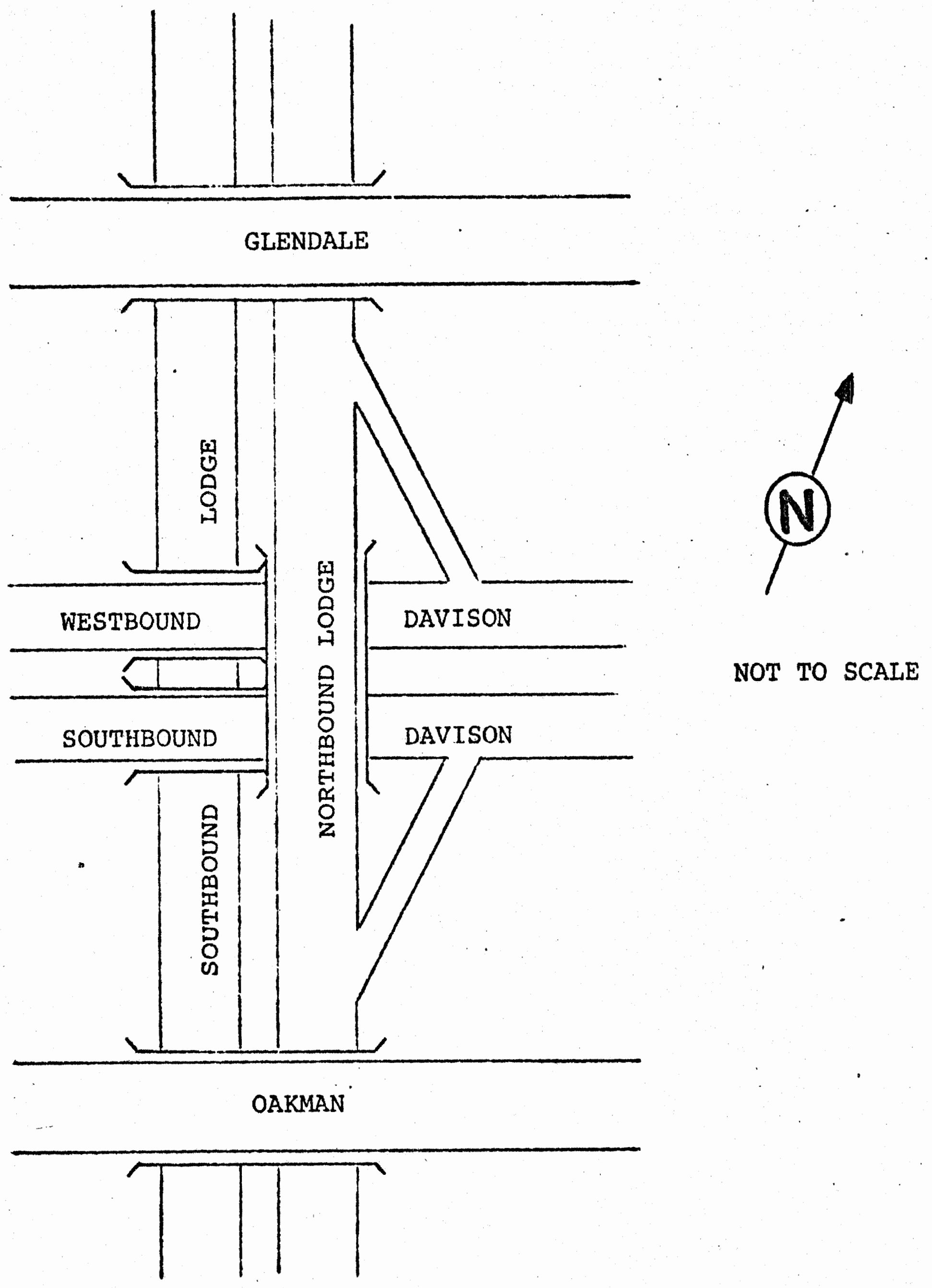

FIGURE 23
FREEWAY SUBSYSTEM FROM GLENDALE TO OAKMAN

divergence at all. It should be noted that the streets to which diversion is suggested, Davison Expressway and Hamilton Avenue, both lead to Twelfth Street if the signs continue to be followed. This street and others nearby have environmental qualities which are not likely to be attractive to motorists.

This result is in sharp contrast with previously reported results (9, 10) which showed considerable obedience to the signs. There is so much more data in the earlier work, that the conclusions in the present study must be rejected. With regard to the merits of the three signs, a driver behavior study (10) showed that the likelihood of seeing the signs was in the order:

1. Blankout sign on Davison Expressway
2. Ramp information sign
3. Trailblazer sign.

Given the sighting of signs, the likelihood of obedience was in the order:

1. Blankout sign
2. Trailblazer sign
3. Ramp information sign.

Thus, the blankout sign was shown to be the most effective. However, it is not as appropriate as the trailblazer sign when traffic is not directed past a ramp entrance. For general applications of variable signs in a freeway corridor, a properly designed trailblazer sign is recommended. A blankout is suitable for diverting traffic past a ramp entrance.

The diversion by the variable message sign on West Grand Boulevard hardly determined an improvement over the Davison signs. This lack of obedience could be explained either by difficulties in reading the sign or inability to cross over in time to the right lane in order to turn at Second Avenue. These explanations are valid for the driver who has never or only infrequently passed this sign since West Grand Boulevard is a busy street and the sign is located too close to Second for many such drivers to respond and make the necessary maneuvers. However, the surveillance effort was directed toward the regular daily users of the Freeway who could have been expected to anticipate the possibility of a turn onto Second and, indeed, not even have had to read the sign word for word to know the recommended route.

It was evident, then, that these regular Freeway users were not using the variable message sign. They may have found the alternative routes either unappealing or not as free from congestion as they anticipated. Or, since the route to the West Grand Boulevard on-ramp is the most direct route to the Freeway, ingrained habits and a tolerance for congestion may have been too much for the research effort to overcome.

These studies also indicate that the variable message sign was seen by only 21% of the ramp users. Limited finances precluded the installation of variable message signs at all feasible locations. Large parking areas had to be excluded in preference to access streets to the on-ramps. However, when permanent facilities are considered for any freeway corridor, consideration must be given to all important access routes to an on-ramp as well as major generators of traffic as large parking lots in the number and placement of variable message signs that seek to divert freeway traffic to alternative routes.

Conclusions

1. The variable message sign on West Grand Boulvard was ineffective in preventing congestion at the intersection of Grand with the East Lodge Service Drive by diverting Freeway users to an alternate route.
2. Despite the location of this sign between the on-ramp and the primary traffic generator in the area, only 21% of the ramp users had passed the sign.
3. Drivers displayed little or no obedience to the various messages presented by the sign.

CHAPTER 4
INTERPRETATION, APPRAISAL AND APPLICATION OF FINDINGS

REDUCTION OF SURFACE STREET TRAVEL TIME BY MEANS OF REAL-TIME SIGNAL CONTROL

An experiment in the application of real-time traffic signals has been described. In terms of an overall evaluation, these resulted in a 19% increase in total travel time for a fixed amount of total travel in the first hour of the four-hour peak period. Similarly in the second hour, there was an 11% decrease in total travel time and only in the third hour was there an increase and this was less than one percent. There was no evaluation of the fourth hour.

These figures suggest that the experiment was a failure in that instead of a reduction in total travel time there was actually an increase. However, this bare fact of two travel time increases masks important benefits that were obtained. Before discussing these, the real reasons for the travel time increases should be sought.

Total travel and total travel time were evaluated on only three days, two "before" days and one "after" day. On the first day, values of the variables were obtained in only the second and third hours. On the second day, they were available for only the first and second hours and on the "after" day for the first three hours. It happened that on the second day, the amount of travel was low and the amount of travel time proportionately lower. Thus, with this apparently unusual day yielding half the "before" information, there is little chance that a reduction in travel time could be obtained. In fact, a slight reduction was obtained for the third hour but the potential for reduction was greatly reduced by the operation of a second factor.

The signal control scheme was based on favoring, by means of the signal offset, 24 links joining nodes or intersections under direct control. Against this, it was expected that 31 other links may have an increased average travel time because of a possibly unfavorable offset. Finally, there were 30 links where the relative offset was unchanged. Because there was much more traffic on the favored links, it was hoped that a travel time decrease there would be greater than any increase on the 31 non-favored links. However, when the system became operational, it was found that at five or more of the intersections, computer control could not be established for some reason. This meant that the proportion of travel on favored links dropped to about one-quarter. There was, instead, an equal amount of travel on defective links where considerable travel time increases could be expected. If only the favored links are considered, a five percent increase in average speed was obtained for the third hour. During this hour, flow conditions are closer to saturation and improvements can be expected to be more difficult to obtain.

Two other favorable results were found. Firstly, there was a significant decrease in the probability of having to stop at a signalized intersection in the network. There was also a marked reduction (48%) in the average travel time through an intersection (Table 3-2). The second favorable result was that there was no apparent increase in the delay on computer-controlled intersection approaches for side street traffic.

On the debit side, both The University of Michigan and State Highway Department travel time runs showed an increase in times for a majority of the links. However, the University evaluation disregarded the time of the runs and so times at different stages of the afternoon peak period would have been compared. The State Highway Department "after" runs were carried out on only one day, the first, when a number of the intersections could not be brought under computer control.

A review of the signal control scheme should include an examination of the method of evaluation. There were, to start with, two separate floating car studies. The State Highway Department vehicle was instrumented and the University vehicle was not. The chart produced by the Department's speed-delay recorder gave much more information than the forms completed manually. Since the recorder was a reliable machine in good working order, it can be stated that it would also produce more accurate and consistent results than any method of manual recording. The floating car technique, of course, took a long time to produce only a limited amount of data.

The aerial photography study produced a more comprehensive set of data in a shorter time. With a member of the project's staff as photographer, the cost of each hour's flying was relatively low. If more flying hours had been available, it would have been preferable to cover a set of links more frequently that the two or three times during the experiment. To achieve this, only a portion of the network would have been filmed for one hour and then the plane would have flown over another portion. As it was, the plane attempted to cover the whole network as often as possible during the two or three hour flight.

The black-and-white film used was quite satisfactory and the extra expense of color film did not seem to be warranted. Unlike the aerial study of the Freeway where color film was used, the lane position or vehicle type (car or truck) was not required. The principal defect of the aerial photography was the loss of data for some links when a tall building blocked part of a link.

The traffic counting program had perhaps the weakest technique. The results were to back up a set of historical counts (Appendix F) but for more than 50% of the link-hour estimates required, a visit was not made during the hour. This meant a reliance on the historical figures which were themselves somewhat erratic from hour to hour and to some extent from day to day. The choice of a 5-cycle counting period is perhaps preferable to a definite time interval, but an error in counting to five cycles can easily be made. Turning movements were not always obtained but gave additional counting data when available. This was derived combining upstream turning movements to obtain the volume entering a link, a figure apparently just as reliable as the volume leaving. Where there was an intersection of busy two-way streets, the better counting procedure was to rotate the approach counted so that turning movements were almost at the same point of time.

The results would have been more reliable had more data been obtained. In commencing the final analysis, it was expected that three days aerial data would be sufficient although hardly adequate. It turned out that on the day of November 17, the delays were slight and the traffic demand much less than usual. Although there was no obvious reason for this, an extra day of film analysis would have diminished the effects of this unusual day. Many more floating car runs would have been made too, had the opportunity been present. Particular emphasis would have been on the fourth hour of the peak period which had to be eliminated from the evaluation.

The severance of computer control at several of the intersections was a disappointing feature. It was also frustrating that, once trouble developed at an intersection, it was difficult to restore to normal operations. With more time available, it may have been possible to develop more timing plans to cover cases of particular intersections dropping out of the system. As it happened, the delays at such intersections increased above the level before computer control was introduced.

With regard to the signal timing plans in general, it is difficult to see any obvious improvement without a major increase in expense. Other area control schemes based on historical data have been developed (14), but few set out to particularly favor one direction. For an alternative signal timing strategy, the combination method (7) seems to have been successful in the Glasgow (Scotland) experiments. With many more days of evaluation, this method could have been compared with the method used in this project.

The following points summarize the applications and limitations to other projects from this research:

1. Real-time traffic signal control remains as a possible method of reducing travel time on an alternate route to the Freeway.
2. For preference, it should be applied where the alternate route is a single arterial road parallel to the Freeway. In this case, a consistent offset strategy for all intersections could be employed.
3. More than one signal timing strategy should be evaluated.
4. For a short term evaluation, aerial photography should be carried out for not less than four days for each hour of operation and for each control strategy including the existing one.
5. Since control of signals would probably be by telephone line pairs from the Control Center to the field site, extra loop detectors placed on the intersection approaches and extra telephone lines should be leased to increase detection capabilities.
6. Where detectors cannot be provided for all intersections, manual counting will be satisfactory, providing not more than about three intersections are required to be covered by any one observer. Five-cycle counts are a suitable period and counting should be rotated at intersections of two-way streets.
7. Floating car methods should be used to supplement the aerial photography and for long term evaluation. The former method is particularly important when high buildings or dull light will obscure the photographic results.

8. The relay assemblies in this experiment performed very well, but in any future project, particular attention should be given to locating and correcting any intersections going out of computer control.
9. For key intersections out of computer control, alternative timing plans should be developed to minimize adverse effects from the loss of control.

REVISION OF RAMP METERING CALCULATIONS

This investigation has shown that vehicles do show a tendency to slow down between detector stations. On the Lodge Freeway, and probably on other freeways, detectors have been placed well away from entry ramps and positions of congestion so that the conditions measured will not be confused by much lane changing and to represent free-flowing conditions. A moving vehicle study has shown how the tendency to slow down can be allowed for in calculations of average speed and storage from detector data. That is, a constant should be introduced which jointly represents the two detector stations forming the boundaries of a freeway section.

The aerial photography study showed that the proportion of trucks in the stream decreases during the afternoon peak period, and it was possible to show that the average vehicle length had decreased. Since the reduction in the proportion of trucks seemed to cease after about 4:30 p.m., the constant representing the detected lengths (as above) should take two values, one before and one after 4:30 p.m. The need for careful calibration of the volume/occupancy relationship has been strongly demonstrated and this applies to all freeways with metering control.

With regard to evaluation of travel times before and after the cessation of ramp metering, no significant differences were observed after the first four days. However, the ability of motorists to find uncongested routes without the aid of signs has been demonstrated before. This suggests that the real merit of dynamic signs might be to warn motorists of unexpected or unusual delays rather than normal congestion.

RAMP METERING HARDWARE CHANGES TO INCREASE OBEDIENCE

Detection of the presence of a waiting vehicle is essential to the operation of the metering system since the static state of the ramp signal is red. Thus, it remains red until a vehicle is sensed, and the signal cycles through to the green display. Motorists stopping upstream of the detection zone could wait (depending on their patience and the patience of those drivers behind them) for up to three or four minutes. The motorist would then drive through the red display and, quite often, a line of drivers behind him would follow.

As the questionnaire study on this project showed (10), the vast majority of the motorists utilize the northbound Lodge Freeway almost every day during the time the system is operating. Thus, if a signal remained red for a long period of time, the motorist might speculate, through past experience, that something was wrong and that the equipment was probably malfunctioning. Although the individual driver might not know that the maximum red display time is 20 seconds, he may have a subjective idea on the length of the display through his experience and he would, therefore, proceed through the red signal. Also, it should be remembered that there is often pressure on the lead driver to move from the drivers behind. In addition, it is a common social phenomenon for a group to follow the lead if a decision is made by another person; thus there are multiple violations.

CHAPTER 5
CONCLUSIONS

This report has, for the most part, discussed separately the five possible improvements to the level of service of traffic flow in a freeway corridor. Two of the improvements, traffic signal control and the diversion of traffic past intersections possibly blocked by ramp queues, have been concerned with the surface streets of the corridor. The remainder involve the control of traffic entering the freeway and thus attempt to reduce any freeway or ramp congestion.

Improvements to the level of service on surface streets was, in general, not obtained. The following specific conclusions have been reached:

1. The application of real-time traffic signal control resulted in, for the first hour of the four-hour peak period, a 19% increase in total travel time on the surface street network for a fixed amount of travel. In the second hour there was also an increase, 11%, and only in the third hour was there a decrease, 1%. No result was obtained for the fourth hour.
2. The increases were partly due to the inclusion in the "before" measurements of one day out of only two where the average speeds were unusually high. There was also a number of intersections where computer control could not be obtained; this led to a loss of progression on the main alternate route.
3. Considering only the links on the alternate route network where progression could be obtained, a 5% increase in average speed was obtained during the third hour of the peak period. This was a heartening result because congestion is normally at its highest level at this time.
4. There was a significant reduction from 52% to 40% in the probability of having to stop at a controlled intersection and the average stopped time was reduced by 48%.
5. The variable message sign on West Grand Boulevard was ineffective in preventing congestion at the intersection of Grand with the East Lodge Service Drive by diverting freeway users to an alternate route.
6. Despite the location of this sign between the on-ramp and the primary traffic generator in the area, only 21% of the ramp users had passed the sign.
7. Drivers displayed little or no obedience to the various messages presented by the sign.
8. Significant obedience also could not be detected for the three signs on Hamilton Avenue, Davison Service Drive and Davison Expressway to divert traffic away from the Davison ramp. This conclusion does not agree with previous studies (9, 10) of the effectiveness of these signs. Nevertheless, it is considered that the streets to take the diverted traffic (mainly Twelfth Street) are not attractive to motorists.

These conclusions suggest that signs for use with freeway control be carefully designed so that they are seen, understood and obeyed by motorists intending to use the freeway.

Further experimentation is required to justify signal control in a corridor. It is suggested that another site be found where there is only one alternate route to the freeway. The control equipment could be similar to that used in the present project, but better safeguards are needed to minimize the effect on any malfunction for one or more of the intersections. Control on a real-time basis should be attempted to a greater extent with at least one loop detector placed on each link.

Somewhat better results were obtained for the three improvements in ramp metering control. Specifically, the following conclusions have been drawn:

1. Vehicles slow down near merging areas but detector stations placed away from ramps can and should allow for this retardation whenever storage or travel time is being estimated between stations.
2. Normal changes in the proportion of trucks during a peak period affect the average vehicle length measured at detector stations.
3. The permanent cessation of ramp metering and the information system showed that motorists have the ability to find uncongested routes. The value of freeway corridor control is therefore probably greatest in the event of unusual or unexpected delays.
4. Obedience to the ramp signals was quite satisfactory, especially when waiting vehicles could be detected with certainty.
5. The additional lane on the Freeway between Davison and Linwood ramps was used to a considerable extent by through traffic. The method of metering should be modified where there is only a short length of additional lane so that traffic demand does not exceed capacity when the extra lane is dropped.

The method of ramp metering has been still further improved as a result of this project. Given proper calibration of the freeway detectors, it is difficult to imagine a more cost-effective system than this one. Elaborate experiments to actually feed vehicles into gaps in a freeway lane are currently in progress. However, short of automatic vehicle control, there will always be a problem of forcing the cautious driver to accept a particular gap. In this project, the method of metering one vehicle at a time has always operated safely and efficiently, yet for only a fraction of the cost.

APPENDIX A
EQUIPMENT AND PHYSICAL COMPONENTS

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Dynamic traffic control for the John C. Lodge Freeway Corridor was accomplished by means of an ongoing information "feedback" system. Traffic flow for the section of the Freeway Corridor under control was measured by electronic detectors. The data obtained from these devices were continuously received during the four-hour afternoon peak period (2:30 p.m. to 6:30 p.m.) at a control center which housed the electronic digital computing system essential for processing and assessment of the data and control of the in-field equipment. The feedback-control process is depicted in Figure A-1 below.

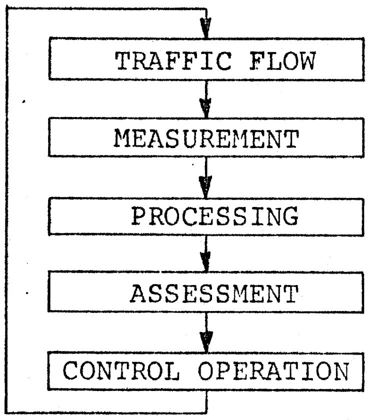


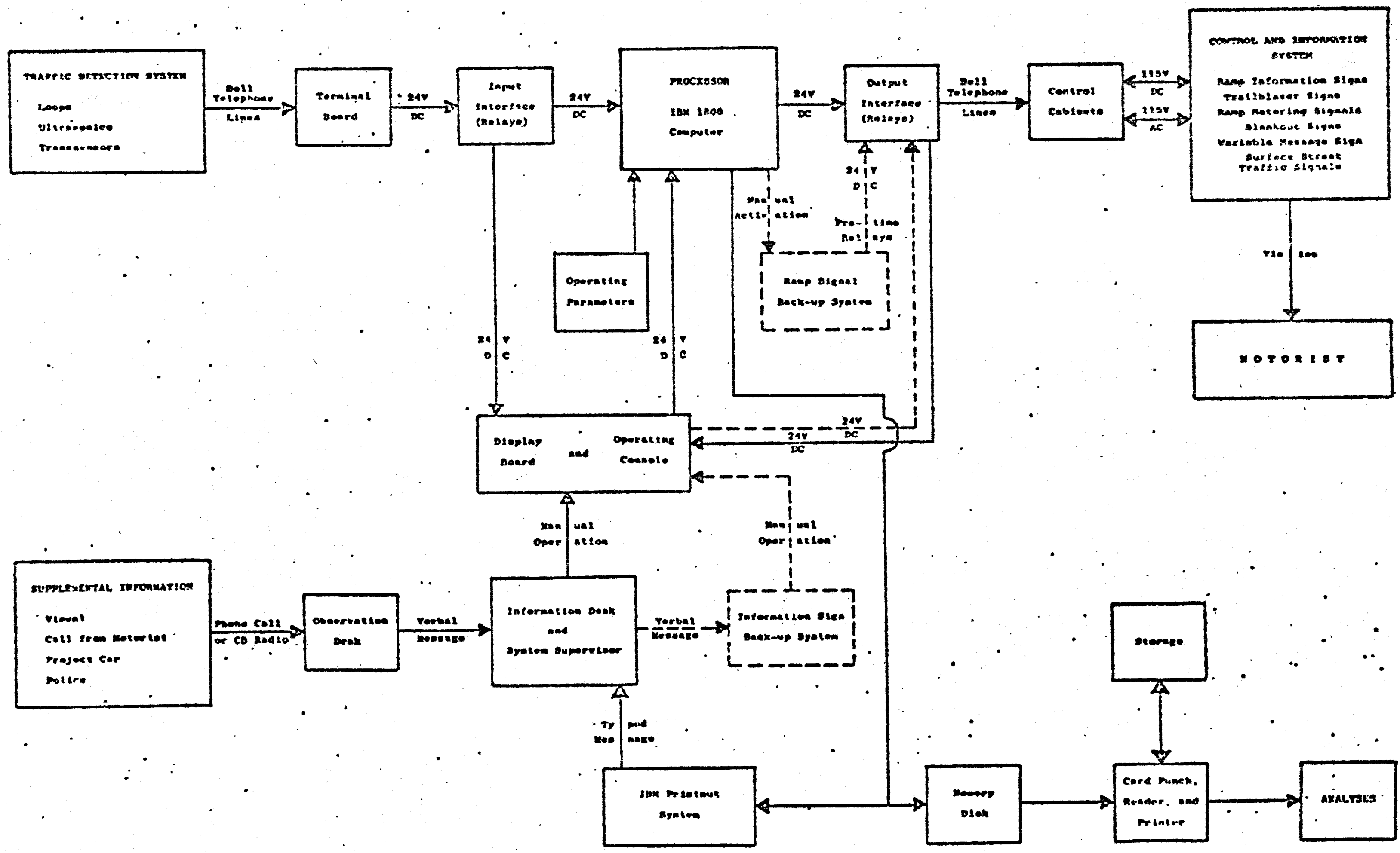
FIGURE A-1
BLOCK DIAGRAM SHOWING REAL-TIME SYSTEM LOGIC

A digital computing system (in this instance an IBM 1800 computer) is both essential and perfect for the real-time control of traffic. As the field system grows in size, such a system can match this growth by appropriate increases in its capability. Also, as new traffic flow theories develop, or as older ones are improved, the assessment function can be updated through programming revisions. Thus, while the computer system is essential to compile and assess the vast quantities of data involved in a real-time freeway control system, it also has the desirable feature of being flexible enough to develop with the control system.

Measurement and control operations in the Lodge Corridor were performed by both field and office equipment. The physical components of the full traffic control and information system are shown in Figure A-2. All aspects, except the traffic signal controllers, are described in greater detail in other reports on this project (TTI final report), (TrS-3), (TrS-4); however, a brief review is presented here for the convenience of the reader.

The traffic detector system was the major source of flow measurement input to the system. Information obtained by these devices was conveyed to the Control Center by means of leased Michigan Bell Telephone lines which connect to an electrical relay interface (switch) (24 volts, DC, double pole, double throw). The interface transforms the electrical impulses carried by the telephone lines into a form usable by the computer and sends the messages to the computer. After processing and assessment by the computer, the appropriate control function was sent out through a

FIGURE A-2
BLOCK DIAGRAM OF PHYSICAL
COMPONENTS OF TRAFFIC CONTROL AND INFORMATION SYSTEM



relay interface, through another set of Michigan Bell Telephone lines, to the control and information equipment in the field. The sign and signal equipment was then switched when necessary and the information passed to motorists by vision messages. This primary process was supported by additional input information (TrS-4) as well as being subject to manual overrides by the system supervisor.

The major installation during this research phase was the intersection signal control equipment. The signal controller equipment was purchased from Eagle Signal Company who offered the most satisfactory bid to specification requirements (see Appendix D). The unit provided by Eagle consisted of three relays mounted on an aluminum panel for ease of installation into the controller cabinet. The assembly also included a labeled terminal strip which facilitated field hookup. These units tied directly into the existing circuitry in each controller unit. Communication between the Control Center and each individual controller was, as in all other instances, accomplished by using leased Michigan Bell Telephone lines. The signals or commands sent over these communication lines were analogous to the commands a policeman would have given if he had been operating the signal manually. Thus, the controller was manipulated by means of a process similar to switching the controller from automatic to manual control. In both these cases, the controller dial continued to rotate but had no regulatory effect on the signal display. The signal was changed by actuating the solenoid which in turn moves the cam.

The status of the signal was continuously monitored during the period it was in main street green. This check provided assurances that the signal was operating properly under computer control. However, if it was discovered that the control was not operating correctly, signal control was immediately returned to the local controller. The accomplishment of this switch of control presented no problem, although a longer than usual main street green phase could at times occur.

A schematic identifying the components necessary for computer control of individual traffic signals is shown in Figure A-3. Note that the three field relays are matched with three office relays. One of these relay sets provided an interface between the communication lines and the controller while the other provided an interface between the computer and the communication lines. The communication lines consisted of two pairs of two conductors. These were routed so as to terminate at one end at the site of the computer (Control Center), while the other end terminated at each individual controller cabinet where they were tied into the relay assemblies by experienced signal controller technicians (in this instance, employees of either the City of Detroit Public Lighting Commission or the Wayne County Road Commission). Staff personnel performed all of the work required at the Control Center. The work was tedious because of the large amounts of electrical wiring required and, therefore, was completed in stages rather than finishing each individual intersection before proceeding to the next. Thus, the relay assemblies and mounting board were built, wired and connected to the terminal strips, then the communication lines were connected to the terminal strips, and finally, the units were tied into the computer. The field work proceeded concurrently. Relays were not installed in the office units during this period as a safety measure to avoid possible activation of the field traffic signals.

Before any installation work began, a prototype system was constructed and tested in the Control Center. A system in

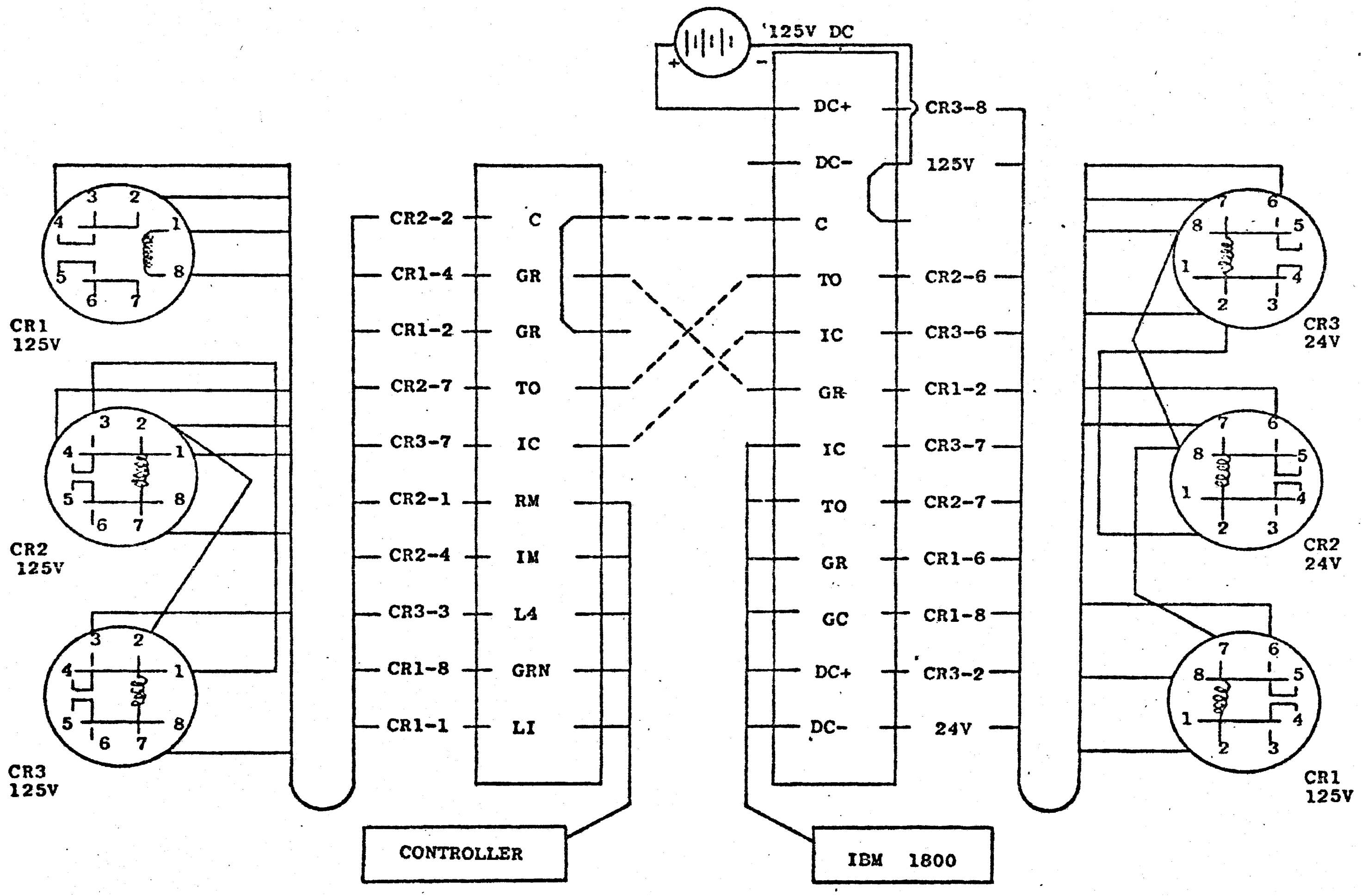


FIGURE A-3
SCHEMATIC OF ELECTRICAL SIGNAL INTERFACE

miniature was constructed which connected the traffic signal controller prototype to the computer which stepped it through the appropriate phases. It operated perfectly. A second test was performed on a group of ten signals after all the field and office work was completed on the entire set of traffic signals. A police officer was present in the field in case of a malfunction. Each individual signal was stepped through a few cycles by commands from the Control Center and each signal operated properly at that time. Despite this 100% trial success, the system operated only 75% successfully during the full operational period. An average of seven signals did not operate properly on each of the eight days the full system was operational. In one case, on the day before the system was turned on, an accident occurred at one intersection and the controller cabinet and pole were hit and physically damaged. The relay assembly was also damaged and was not repaired until six of the eight days the system was on had passed. It did, however, operate perfectly on these last two days. There were 11 other intersections that did not work at one time or another. However, every one of the signals in the entire set did work for some portion of time. Since the 11 did operate properly at times, and the others operated properly all the time, the work completed in the field and at the Control Center was assumed to be correct. The intermittent problem was traced to problems in the switching and relay apparatus of the leased communication lines. The reliability of the communications service was less than desirable. In some cases the problem was intermittent with signals being dropped from computer control for many one-minute intervals over a four-hour period (the highest was 27 separate minutes), while in other cases the control operation worked fine for one-half the period, then would drop out for the other half.

APPENDIX B

PROGRAM METHODOLOGY FOR DATA ACQUISITION AND CONTROL

APPENDIX B
PROGRAM METHODOLOGY FOR DATA ACQUISITION AND CONTROL

OVERVIEW OF CONTROL SOFTWARE

The primary objectives of the software written for this project were as follows:

1. Metering of the eight on-ramps.
2. Control of driver information sign network.
3. Control of surface street signalized intersections in the Freeway Corridor.
4. Data collection from traffic detection devices.
5. On-line system status log.

In order to maintain minimum operator intervention and maximum system reliability, the following features were incorporated into the system.

1. The system periodically interrogated itself for the successful completion of all scheduled tasks. If all tasks were not completed, a system reload was forced.
2. Modification to IBM system software was necessary in order to save all system variables in the event of a reload.
3. A special technique was developed to allow "hands-off" restarting of the system in the event of a normally non-recoverable failure. All system variables were saved and all time dependent functions were resynchronized.
4. A pseudo-calendar technique was employed to ensure that the traffic control system was operated only on weekdays.

Ramp Metering

The ramp metering system was operated between the hours of 2:30 p.m. and 6:30 p.m. For each metered ramp in the system there was an external control which provided selection of one of eight possible modes of operation. These modes were as follows:

1. Storage of real-time (same as Storage number 2, except that it was responsive to the instantaneous dynamic aspects of the traffic pattern).
2. Storage (yielded number of vehicles to be allowed onto Freeway in next minute, based upon the number of vehicles in the subsection).
3. Demand capacity (yielded number of vehicles to be allowed onto Freeway in next minute, computed from upstream flow and downstream occupancy).
4. Fixed historical rates (table look-up).
5. Minimum rates (table look-up).
6. Maximum rates (table look-up).
7. Constant green
8. Off (operationally same as constant green).

After selection of a strategy was made for each ramp, a button was pushed which caused the computer to sense the chosen mode for each ramp. Acceptance of mode selection was dependent upon the operating condition of certain detectors and signals required for that particular mode. If critical hardware for a particular mode was non-operative, then that mode was inhibited. A search was then initiated for the next hardware demanding mode (note that the metering modes were arranged in a hierarchy of responsiveness). Each minute, based upon mode selection and hardware inhibition, the appropriate data were transferred to the two metering subroutines: bulk service or one-at-a-time.

The bulk service subroutine was used at the West Grand Boulevard and Davison on-ramps where the addition of another lane provided extra capacity and allowed for a more gradual merging process. At these two high-service ramps, a 30-second cycle was used. The normal cycle began on green for a minimum of 10 seconds and continued green until the desired number of vehicles had entered the Freeway. The maximum green time for the cycle was set at 25 seconds, leaving a minimum of five seconds for the amber-red cycle (amber was fixed at two seconds).

The one-at-a-time subroutine serviced all of the remaining six on-ramps. These signals were all two-aspect with the exception of the Livernois on-ramp which had an amber phase. This amber phase was hardwired to the beginning of the red phase (1 1/2 seconds) and not functionally controlled by the computer. The normal cycle consisted of 1 1/2 seconds of green and from 3 1/2 to 18 1/2 seconds of red, the maximum cycle length being 20 seconds. The variable red time was computed from the number of vehicles to be metered in the minute and was integrated with respect to demand on a dynamic basis. Violators and vehicles queued but not detected were also taken into account.

In this one-at-a-time subroutine, the signal was changed to green if the computed red time had expired and if a vehicle was waiting in the upstream detector. The signal was switched back to red when the vehicle arrived at the downstream detector after a minimum of 1 1/2 seconds of green time had elapsed. In the storage real-time mode the signal was changed to green if a vehicle was waiting and if either the maximum red time (18 1/2 seconds) had expired or if the real-time storage was less than the computed maximum.

Driver Information Signs

The driver information signs were operated in a dynamic manner during the periods of ramp metering, from 2:30 p.m. to 6:30 p.m. At other times they operated in a static state. These signs were made to indicate the preferable route to the Freeway based upon detection of actual queues on the ramps and determination of potential queues. The latter was determined from reductions in metering rates due to increases in demand for the Freeway and the resulting higher volumes on the Freeway.

The signs were updated every five minutes (to coincide with the signalized intersection logic) based upon the most recently collected minute data. A manual option was provided to inhibit the Freeway-data dependent aspect of the information sign logic. This was necessitated by some incurable detector malfunctions.

Surface Street Intersection Control

Control of each signal was initiated at 2:30 p.m. by a process which waited for the beginning of main street green (MSG). Upon detection of this condition, the computer acquired the signal from local control. In much the same way as a dial change is made in a local controller, the computer extended the MSG phase to synchonize with the pseudo-dial in the computer. This pseudo-dial was based upon time in exactly the same way as is the dial in a local controller. The times for split, offset, and cycle were obtained from historical data for each 15-minute segment of the four-hour metering period. Within this 15-minute segment, based on the status of the information signs, a table look-up was performed every five minutes to find the associated historical offset modification that favored the preferred route to the Freeway. Each offset modification was phased-in with the same extended MSG logic as the dial change described above.

Control was maintained as long as the confirmation pulse was being received from the controller. Upon detection of an out-of-correspondence confirmation pulse, the computer immediately relinquished the signal to local control. Any subsequent sensing of a beginning of MSG from the local controller caused reinitiation of computer control. Any of the above malfunctions precluded a typewriter message.

At 6:30 p.m., all signals still under computer control were systematically released. This was accomplished by relinquishing control at the beginning of MSG, where upon the local controller would automatically resynchronize with its own dial.

Data Collection

The basic data collected from the traffic sensors were volume and occupancy. Volume data was gathered by scanning all detectors every 100 milliseconds for an "end of vehicle" condition. Occupancy was computed by scanning the Freeway and queue detectors every 25 milliseconds for a "vehicle present" condition. All data were collected in one-minute samples and written in a disk file for later analysis. At the end of each minute, the data collected were used on-line for:

1. field equipment malfunction analysis
2. computation of metering parameters
3. determination of information sign states and pursuant intersection signal splits and offsets
4. selectable dynamic information display

On-Line System Status Log

The following information was available on-line in the form of a typewritten log:

1. Metering mode selection change.
2. Internal metering override.
3. Data to disk messages (started, suspended, overlapped).
4. Detectors down or back in service (accompanied by an audible alarm which required operator action to silence).
5. Intersection and ramp signals down or back in service messages (accompanied by an audible alarm which required operator action to silence).
6. Date incrementation.
7. On request--list of all detectors and signals down with elapsed down-time.
8. On request--time of day in hours, minutes and seconds (to the nearest second).

SYSTEM DISCUSSION

Programming

The operating system (Figure B-1) consisted of two major sections: a core-resident area and an overlay area (VC). The core-resident area contained input-output drivers, a common communications area (I/C), a process control monitor, and miscellaneous user- and system-required subroutines. The overlay area allowed for a priority scheduling and virtually unlimited program length. Routines using these areas were manipulated by the following IBM linkage creating subroutines:

CHAIN -	Routine which allowed the user to link two coreloads by overlaying the calling program with the called program
QUEUE -	Routine which allowed for priority scheduling of programs to be subsequently called for execution in the overlay area by the VIAQ routine
VIAQ -	Routine which allowed execution of coreloads based upon their queue priority
LEVEL -	Routine which allowed for priority scheduling of programs in the core-resident area
COUNT - TIMER	Routines which allowed for execution of programs after a specified interval of time has elapsed.

Process Control Software

The following discussion is provided as a preface to the accompanying flowcharts.

Overall system flow - This shows initialization and perpetuation of the system

RSTAR, RESTR (Figure B-2) - The purpose of these coreloads was to enable the system to recover from internal malfunctions automatically without any operator intervention and, more important, without any interruption in the metering and signal-control system.

COLDS (Figure B-3) - The purpose of this coreload was to initialize the system for continuous operation.

COMP (Figure B-4) - This coreload checked all the detectors and made the necessary computations for the metering coreload. Historical metering rates, splits, and offsets were read in when needed.

MTRNG (Figure B-5) - This coreload computed the metering rates, determined dial settings, and controlled the information signs. The metering mode was also determined using detector malfunction information from COMP.

MLINE (Figure B-6) - This coreload did all the communication with the operator, in the form of a typewriter log. Also, the last minute's data was buffered to disk in this coreload.

DROUT (Figure B-6) - This coreload outputted the digital display information as requested through three rotary switches on the display panel.

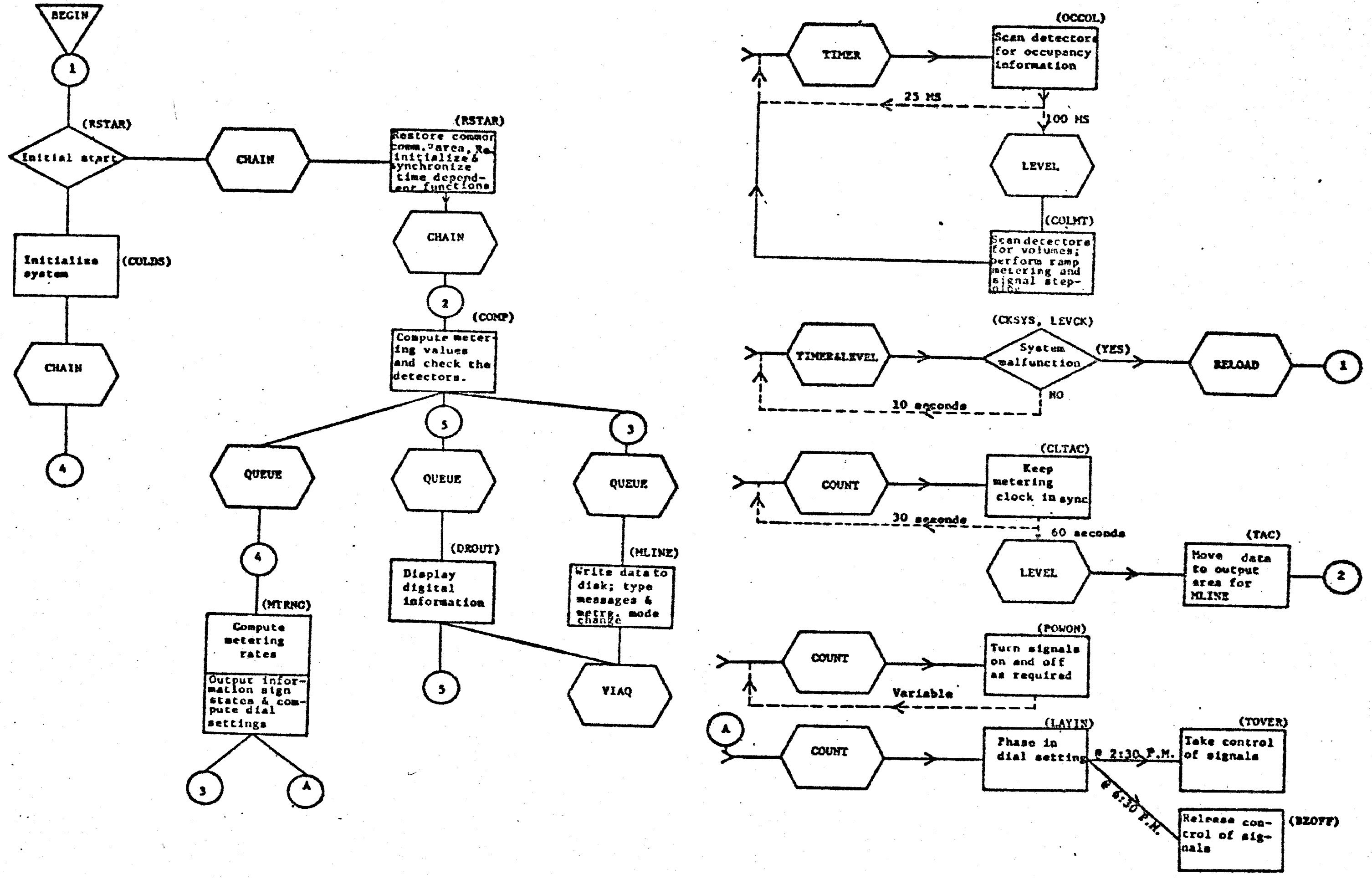


FIGURE B-1
SYSTEM FLOWCHART
(CHAIN, QUEUE, VIAQ, LEVEL AND COUNT TIMER)

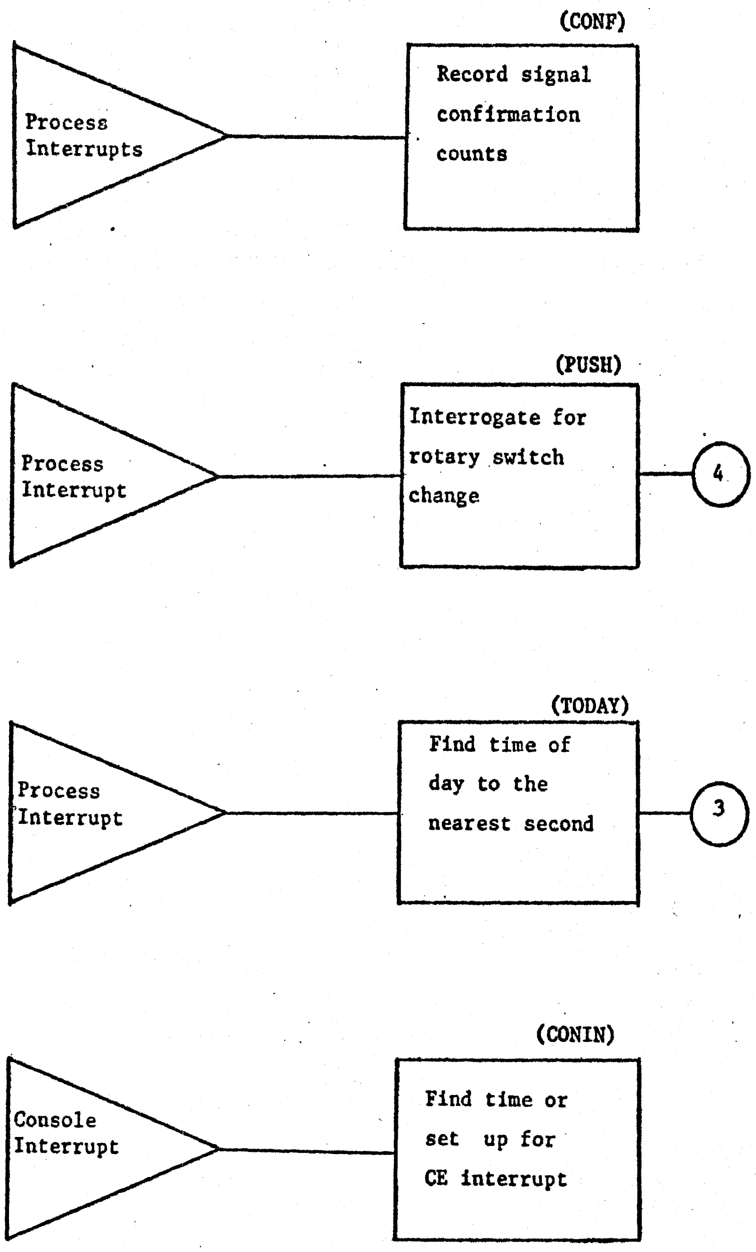


FIGURE B-1 (con't)

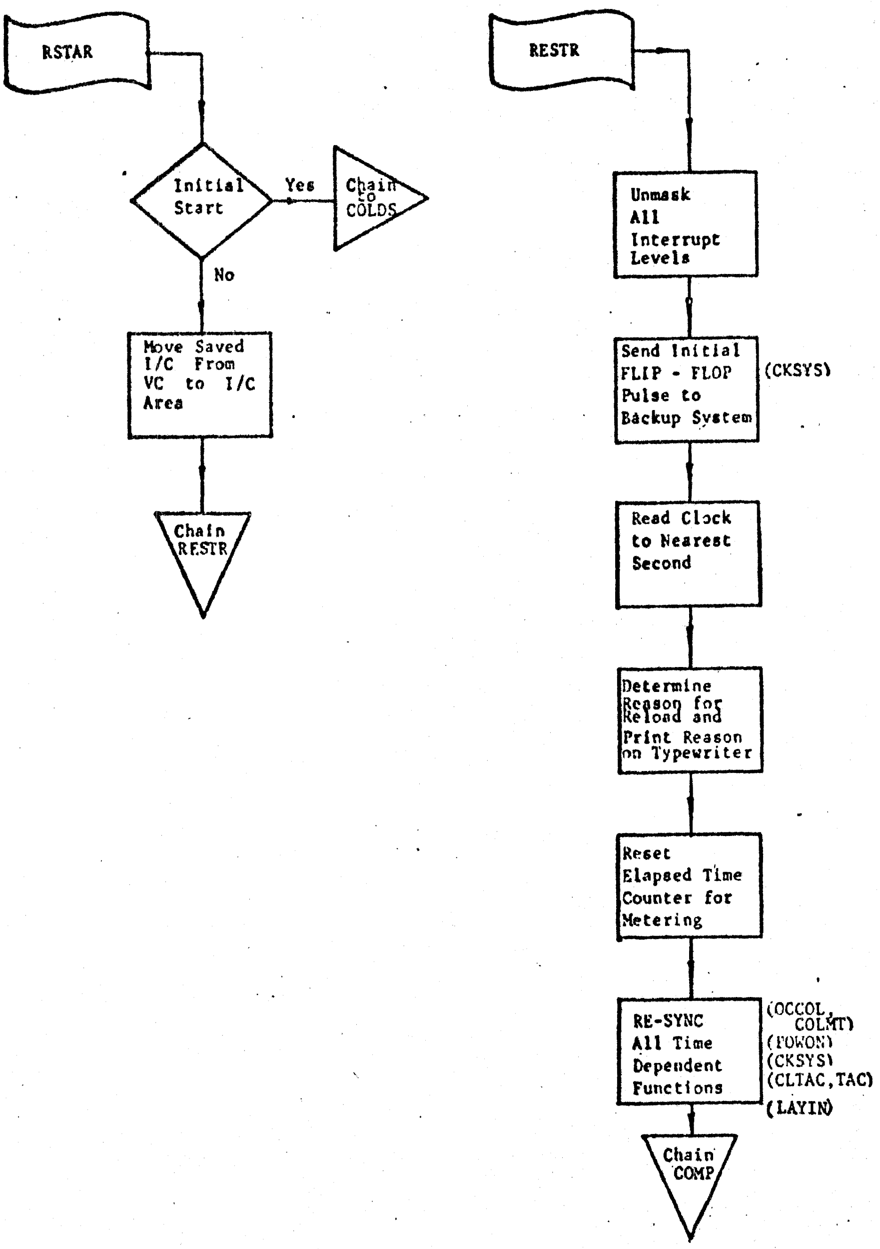


FIGURE B-2
RESTART CORELOADS

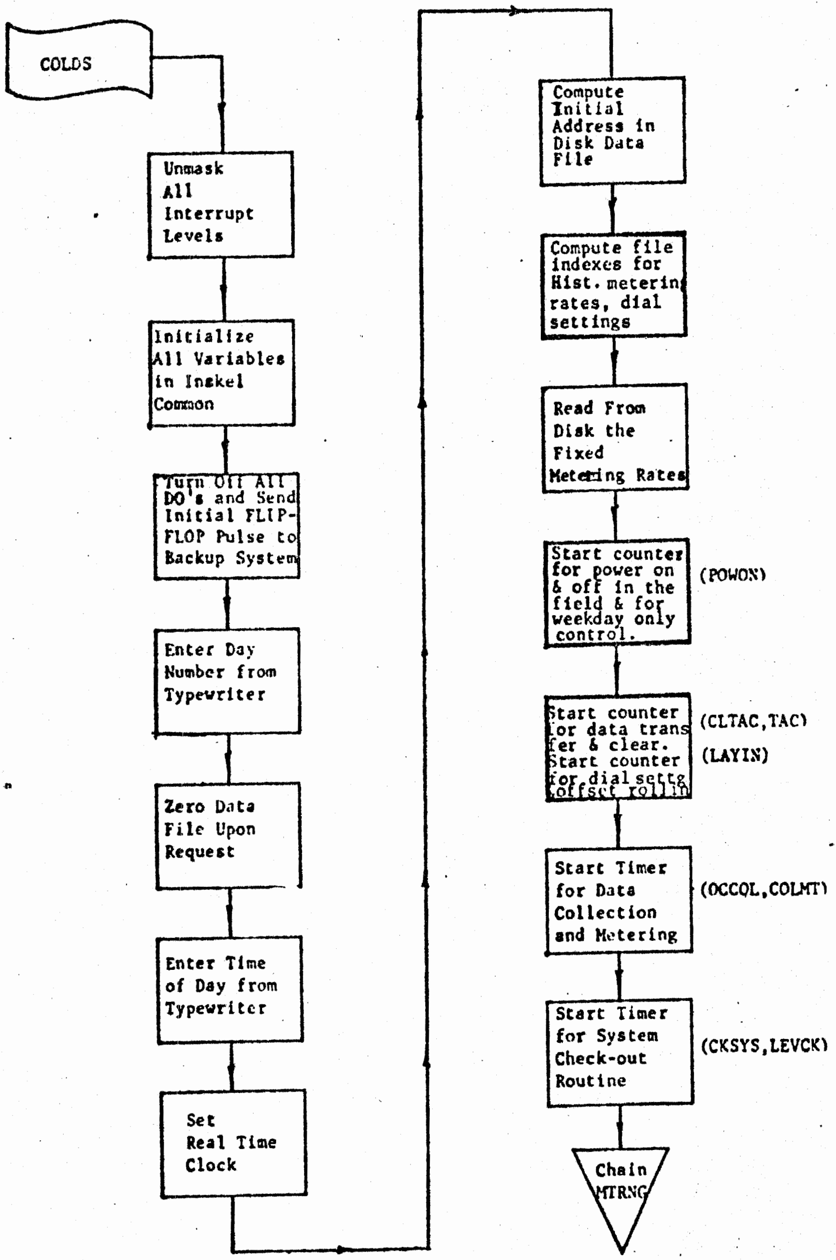


FIGURE B-3
INITIALIZATION CORELOAD
(COLD START)

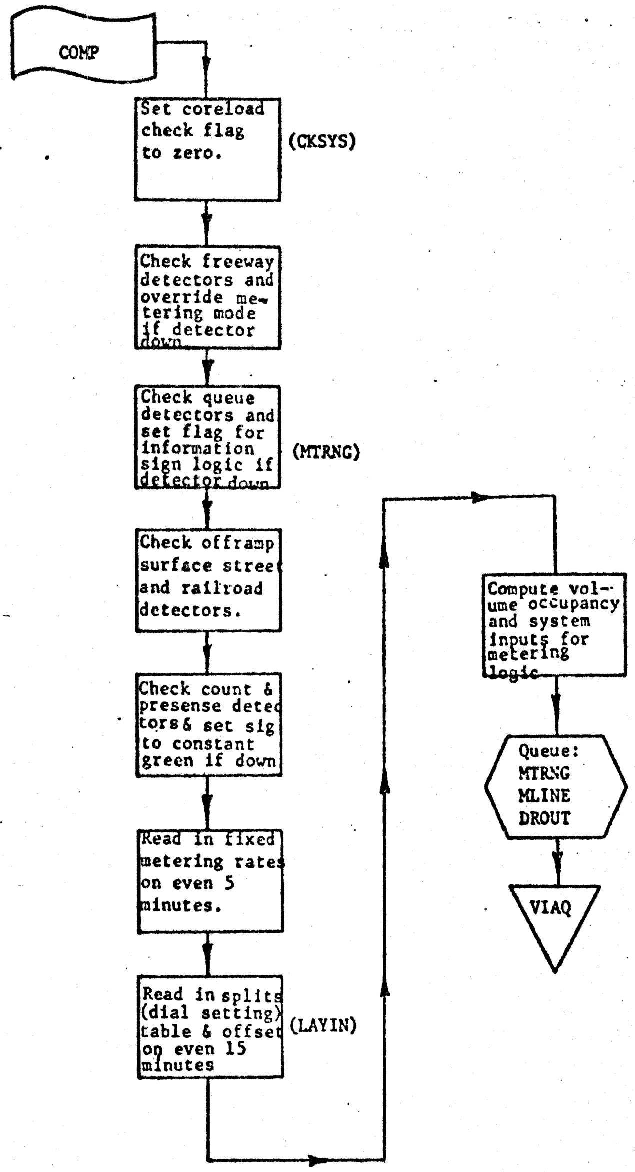


FIGURE B-4
SYSTEM CHECK-OUT
ROUTINES (COMP)

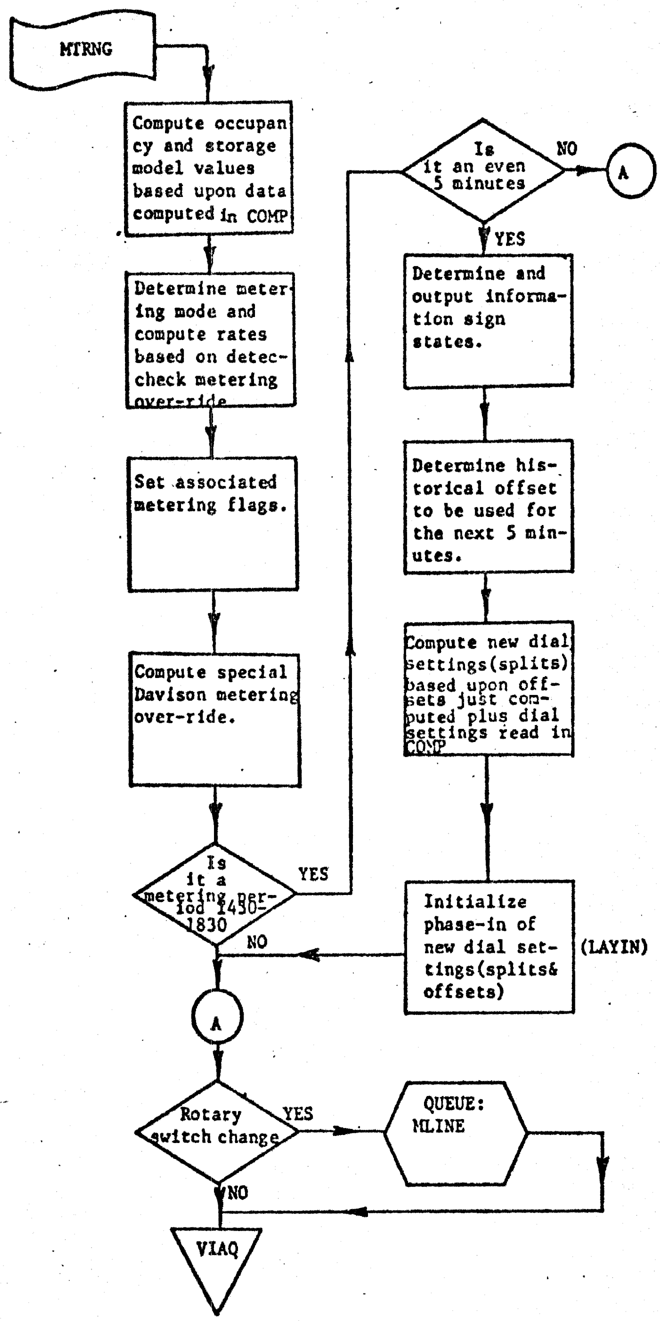


FIGURE B-5
METERING RATE COMPUTATION
CORELOAD (MTRNG)

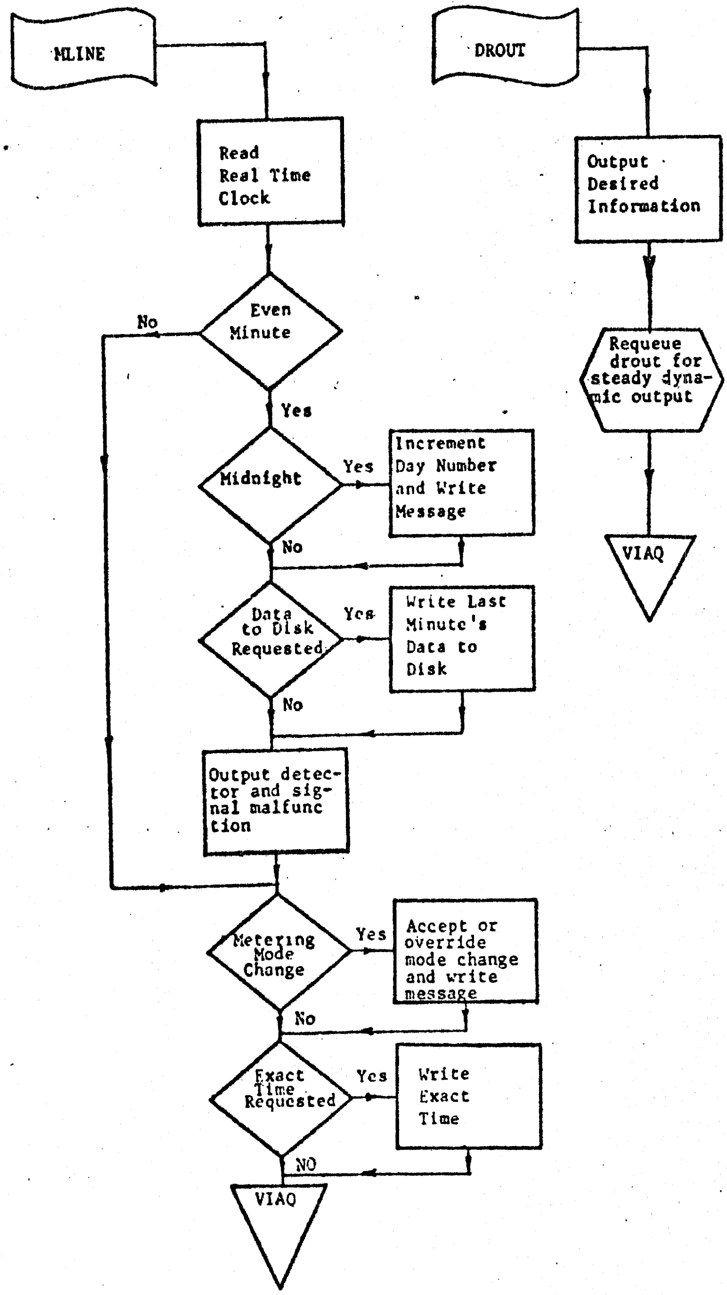


FIGURE B-6
MESSAGE AND DATA
OUTPUT CORELOADS (MLINE)

CKSYS,
LEVCK (Figure B-7) - These routines checked for successful completion of all scheduled tasks during the previous period. If all tasks were not completed, then a system reload was forced on the assumption of an internal malfunction.

OCCOL (Figure B-8) - This routine collected occupancy information.

COLMT (Figure B-9) - This routine collected volume information, performed ramp metering, and performed signal dial stepping.

M1ATM
M1SPC (Figure B-10)
TWOCY (Figure B-11) - These routines were used by - COLMT - for the logic for ramp signal control at the three-aspect one-at-a-time, and bulk service ramps, respectively.

CLTAC,
TAC (Figure B-12) - These routines controlled the transfer of data from the previous minute to an output buffer for later transfer to disk by - MLINE - Also, - CLTAC - synchronized all time dependent functions.

POWON (Figure B-13) - This routine controlled the time at which the metering and signalized intersection control system was actuated in the field.

LAYIN (Figure B-14) - This routine phased-in the dial-settings as determined in - MTRNG -. At 2:30 p.m. - TOVER - was called. At 6:30 p.m. - BZOFF - was called.

TOVER (Figure B-15) - This routine systematically took control of the intersection signals.

BZOFF (Figure B-16) - This routine systematically relinquished control of the intersection signals.

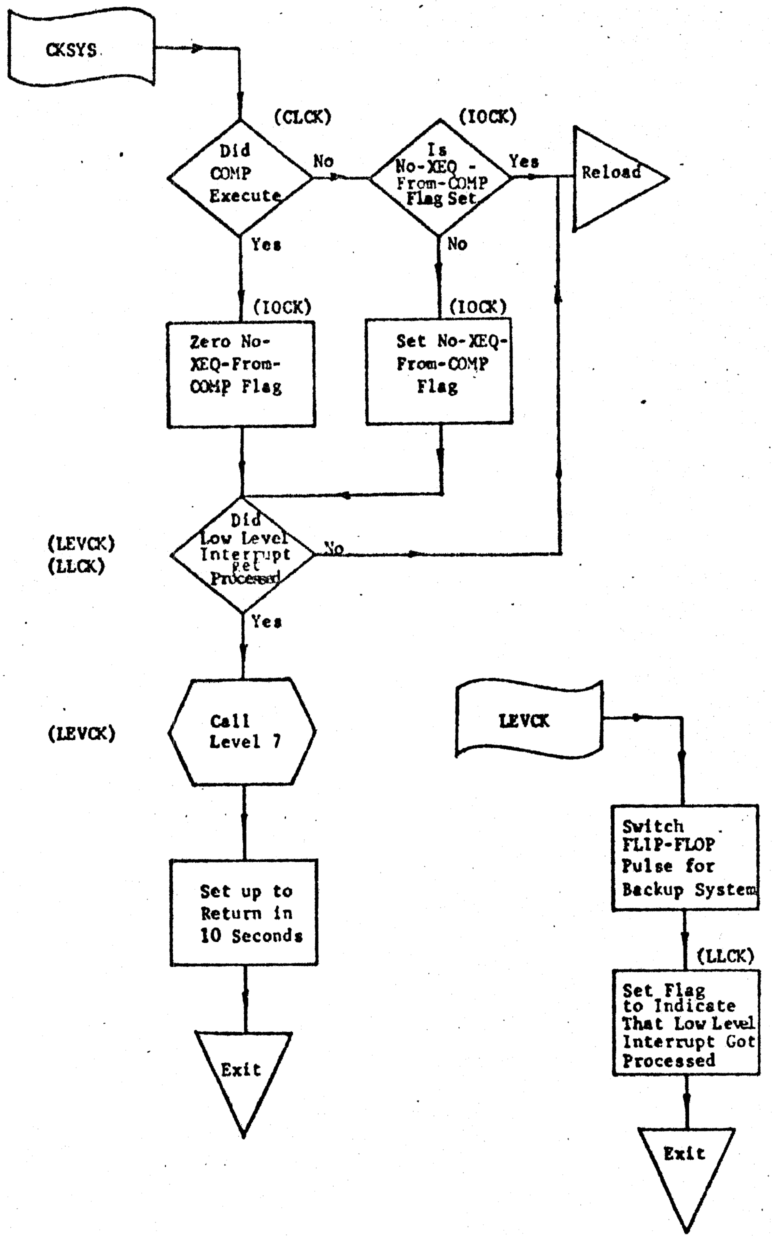


FIGURE B-7
SYSTEM CHECK-OUT
ROUTINES

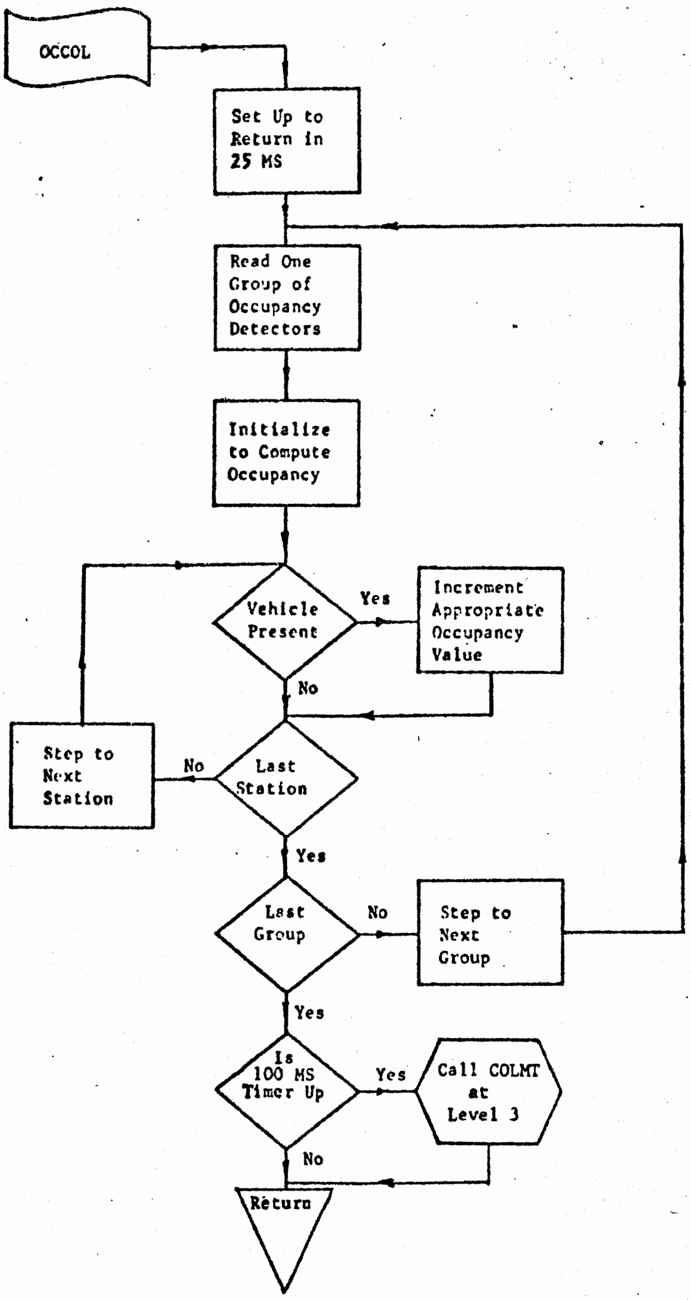


FIGURE B-8
METERING AND DATA COLLECTION
ROUTINES (OCCOL)

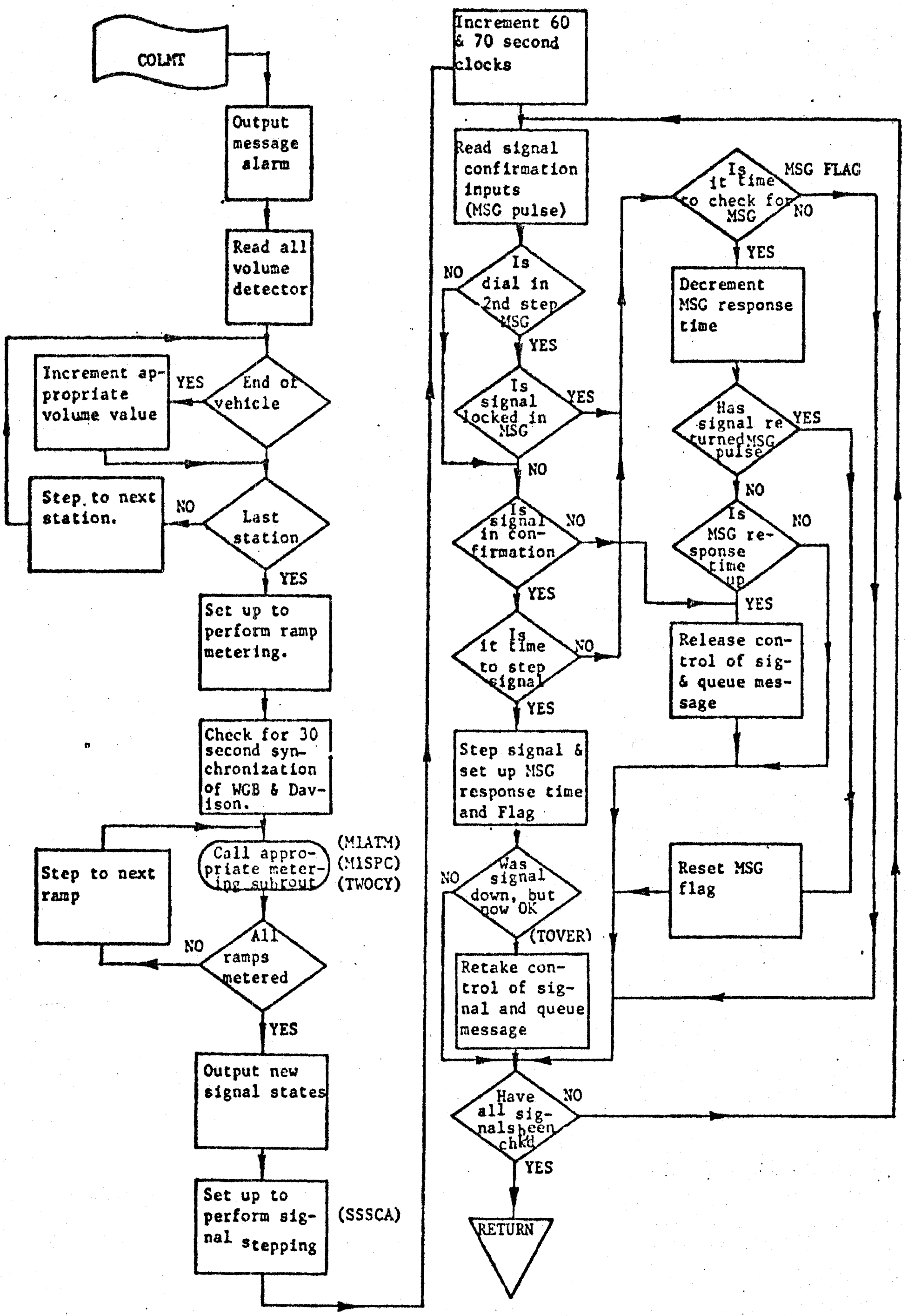


FIGURE B-9
METERING, VOLUME COLLECTION
AND SIGNAL CONTROL ROUTINE (COLMT)

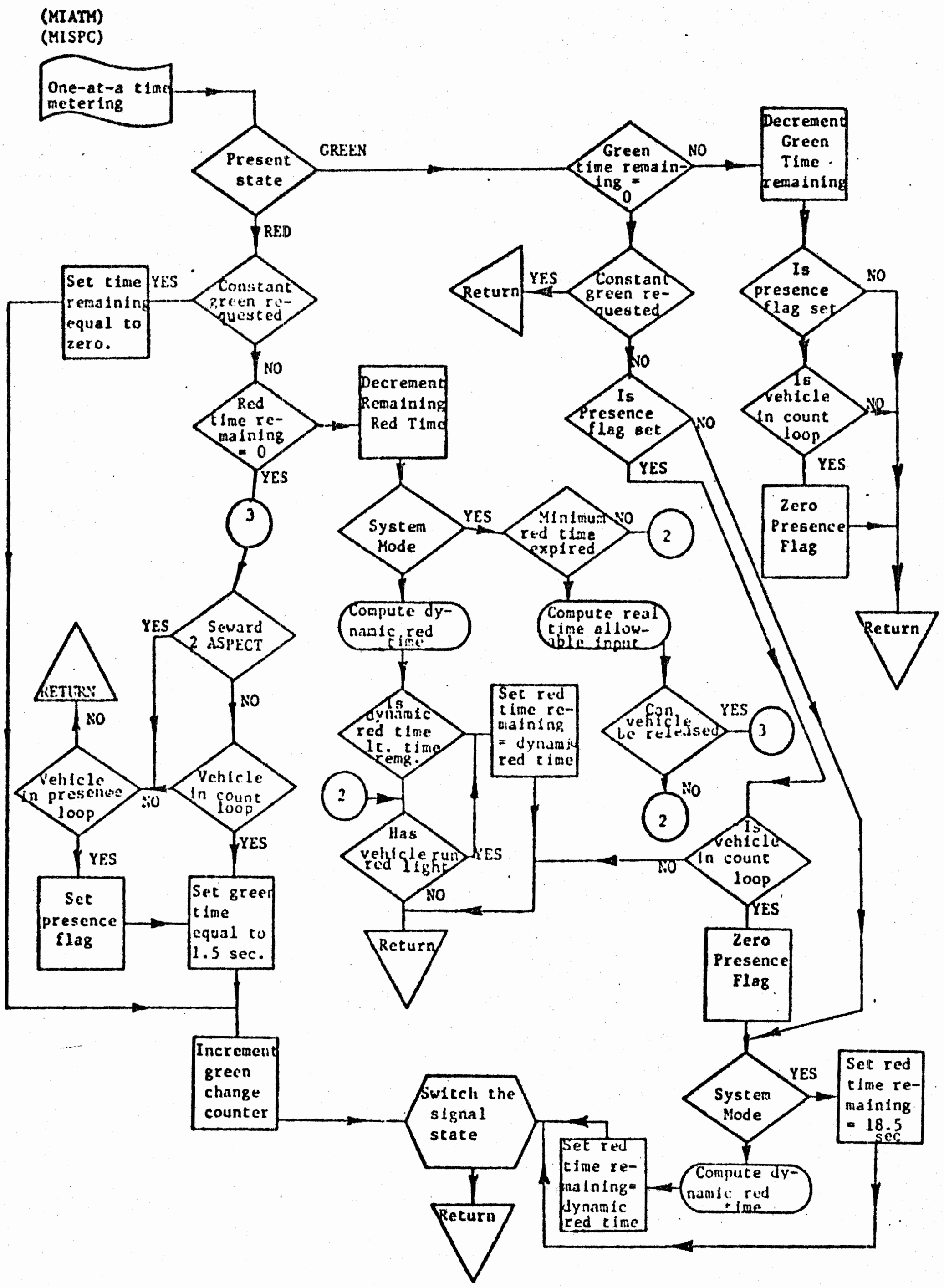


FIGURE B-10
METERING SUBROUTINES FOR
ONE-AT-A-TIME METERING
(MIATM, MISPC)

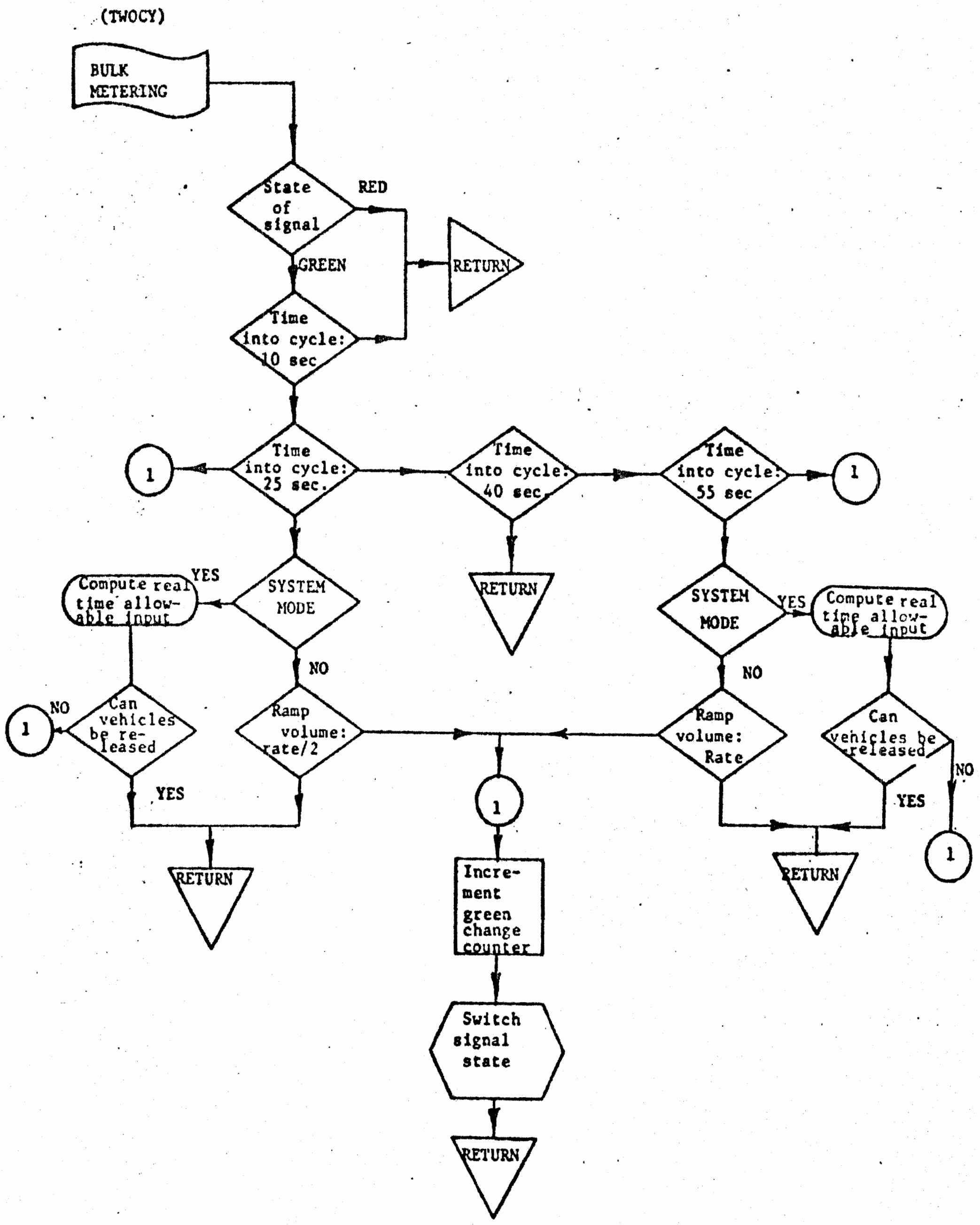


FIGURE B-11
METERING SUBROUTINE FOR
BULK METERING (TWOCY)

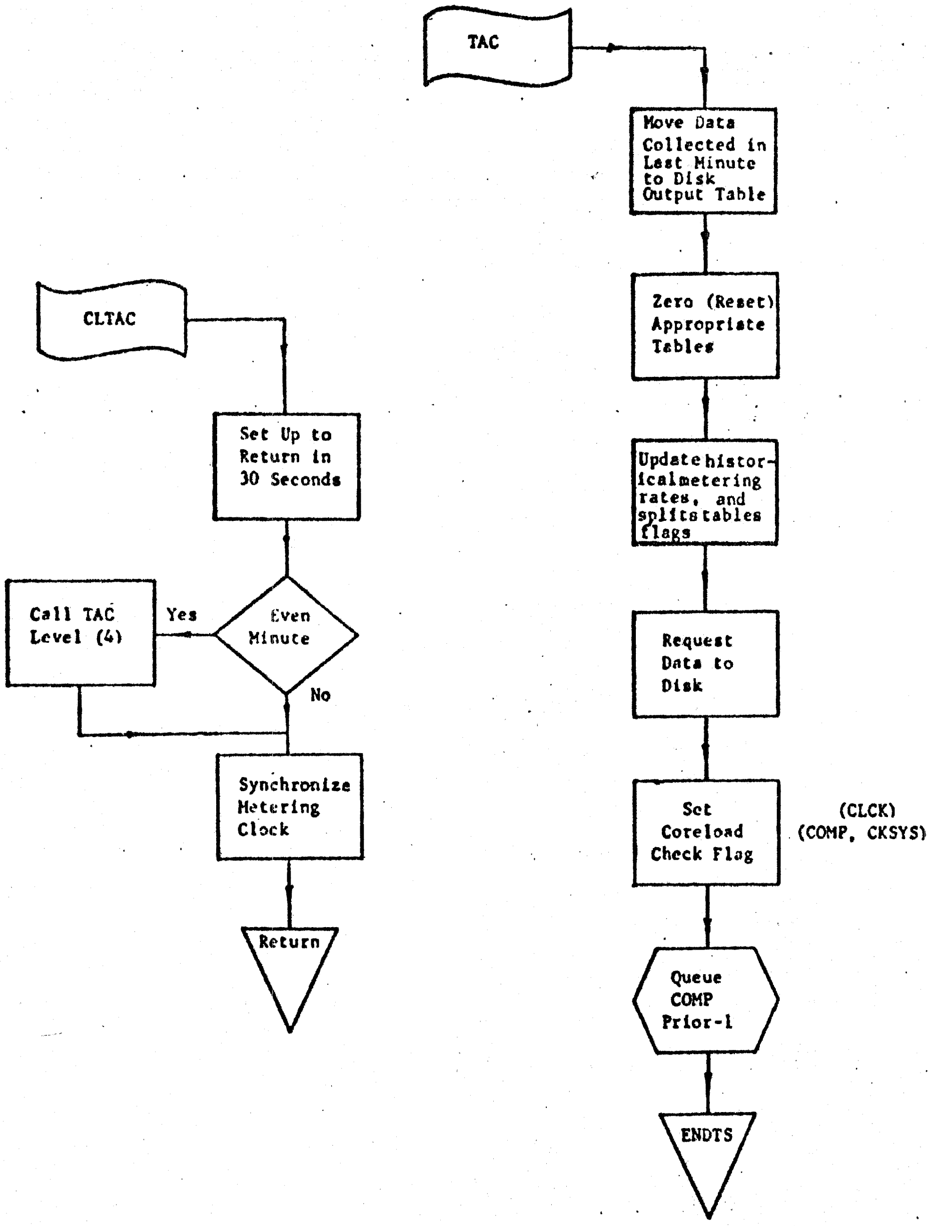


FIGURE B-12
DATA TRANSFERRING ROUTINES
(CLTAC, TAC)

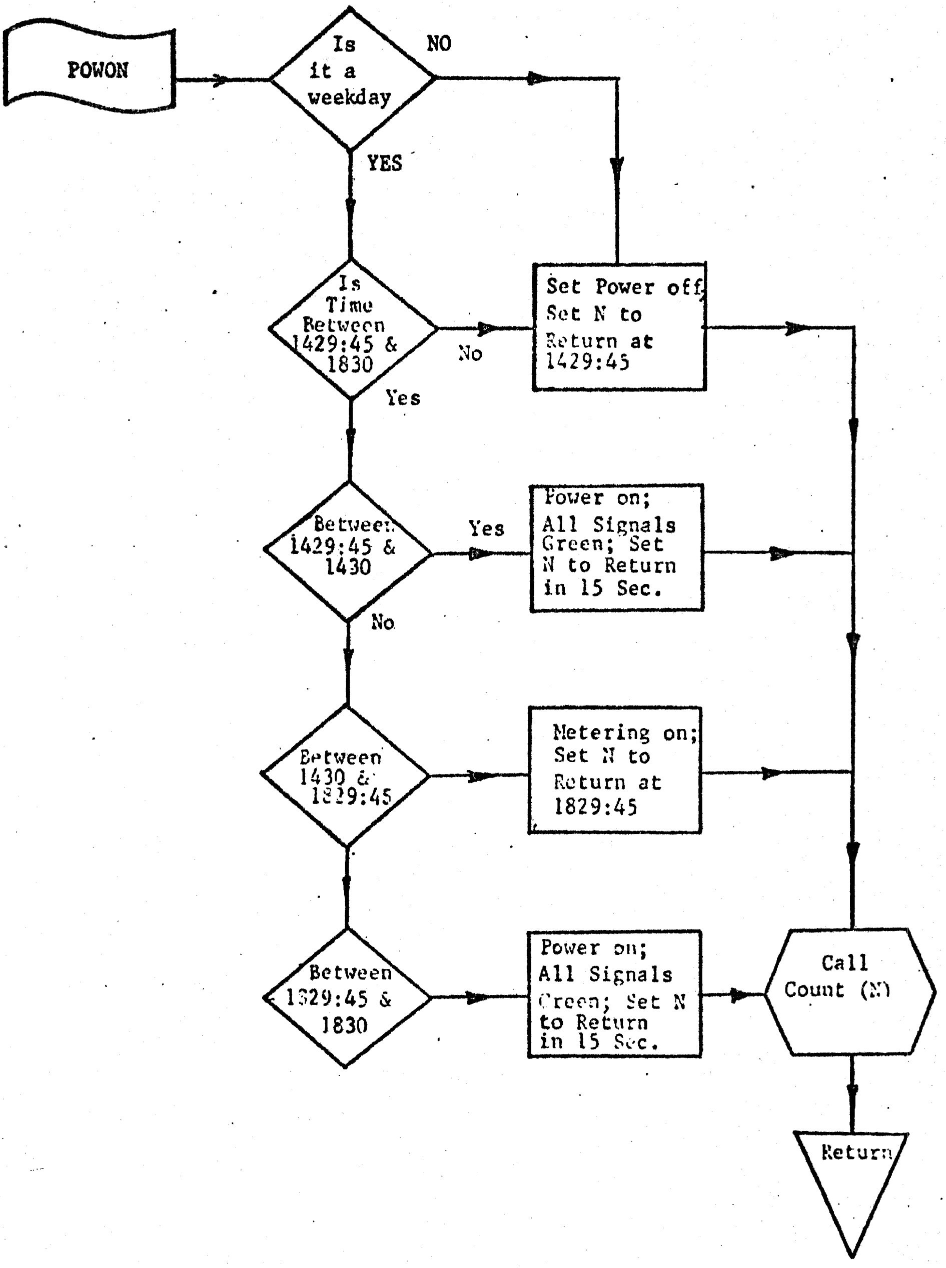


FIGURE B-13
POWER ON/OFF ROUTINE
(POWON)

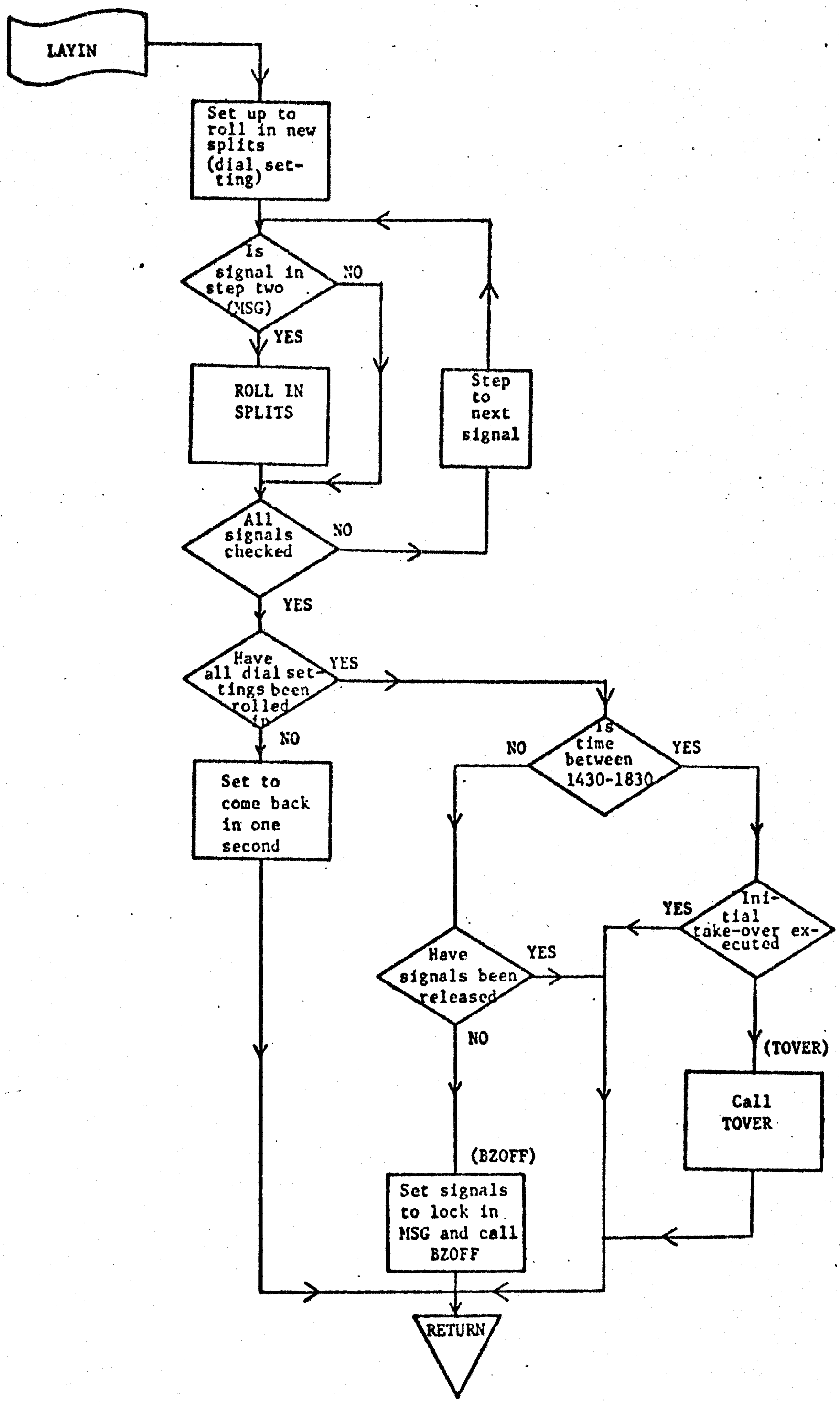


FIGURE B-14
DIAL-SETTING (SPLITS)
PHASE-IN ROUTINE (LAYIN)

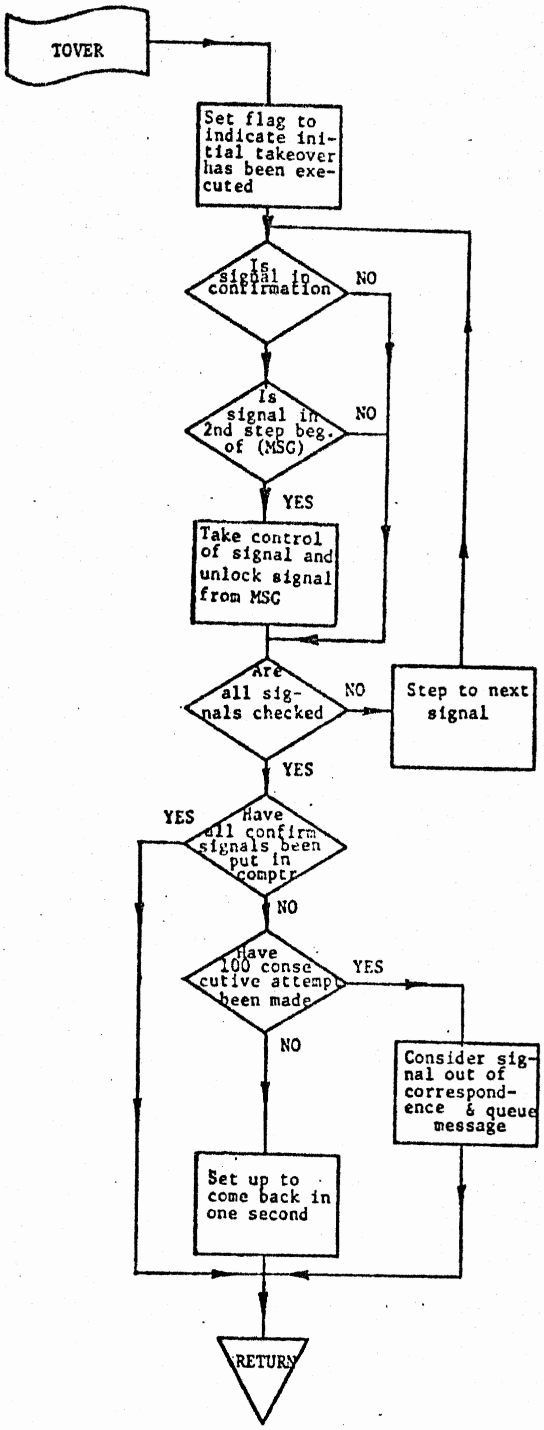


FIGURE B-15
ROUTINE WHICH TAKES CONTROL
OF SIGNALS (TOVER)

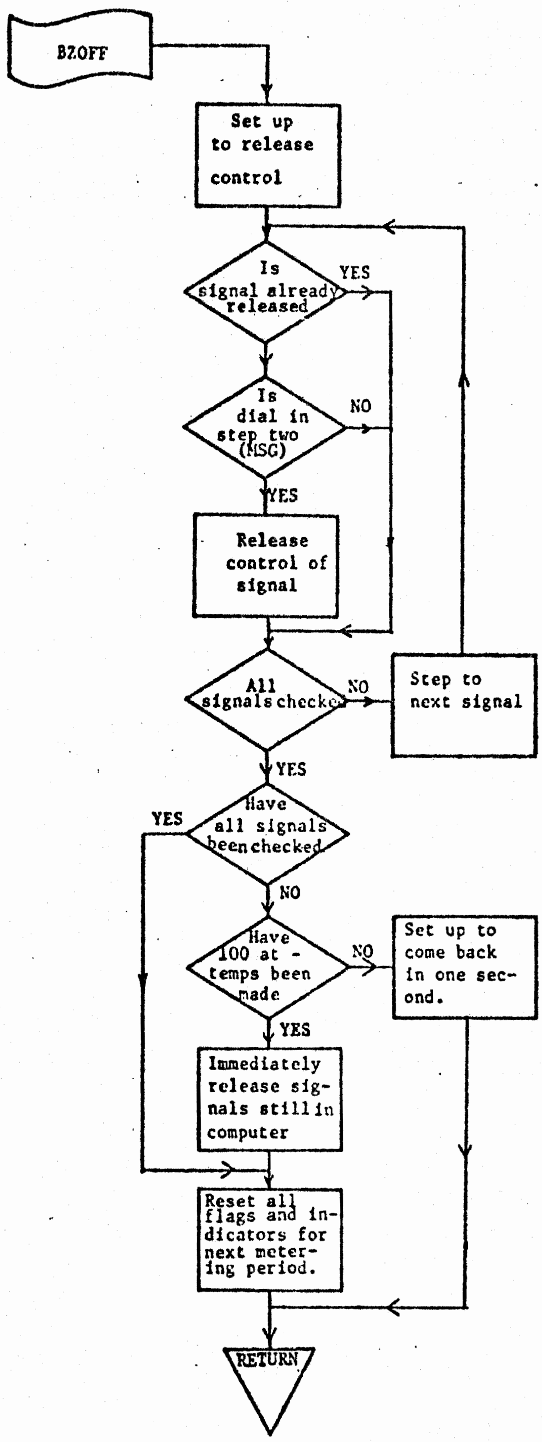


FIGURE B-16
ROUTINE FOR RELINQUISHING CONTROL
OF SIGNAL CONTROLLERS (BZOFF)

APPENDIX C
A SUMMARY OF SIGNAL TIMING PLANS

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A SUMMARY OF SIGNAL TIMING PLANS

INTERSECTION		CYCLE	MAIN STREET GREEN DURATION	
NUMBER	LOCATION	LENGTH (sec.)	MINIMUM (Sec.)	MAXIMUM (Sec.)
3	Lodge & Livernois	70	43.5	43.5
4	Dayton & Fenkell	60	24.1	32.7
5	Lodge & Linwood	60	12.2	19.3
6	Fenkell & Twelfth	60	36.5	45.0
7	Davison & Twelfth	70	35.5	35.5
8	Davison & W. Wilson	70	44.6	47.0
9	Lodge & Webb	70	36.5	37.3
10	Chicago & Hamilton	70	27.7	39.5
11	Lodge & Euclid	70	20.2	39.5
12	Lodge & Seward	70	35.0	46.0
13	Lodge & Pallister	70	38.3	46.9
14	Lodge & West Grand Boulevard	70	32.1	40.3
16	Cortland & Hamilton	70	49.0	49.0
17	Glendale & Hamilton	70	31.8	46.3
18	Davison & Hamilton	70	28.8	42.9
19	LaBelle & Hamilton	70	35.9	49.0
20	Oakman & Hamilton	70	44.4	49.0
21	Pitkin & Hamilton	70	43.4	43.4
22	Puritan & Hamilton	70	38.6	45.1
23	West Grand Boulevard & Third	70	31.5	41.3
24	Seward & Third	70	24.3	37.0
25	Chicago & Third	70	31.5	47.5
27	Lodge & Clairmont	70	29.9	42.6
28	Calvert & Hamilton	70	35.5	45.5
29	Webb & Hamilton	70	37.9	45.7
30	McNichols & Hamilton	70	17.5	21.0
31	Geneva & Hamilton	70	50.5	50.5

APPENDIX D
FUNCTIONAL SPECIFICATIONS FOR THE SUPPLY OF EQUIPMENT FOR COMPUTER CONTROL OF TRAFFIC SIGNALS

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FUNCTIONAL SPECIFICATIONS FOR THE SUPPLY OF EQUIPMENT FOR COMPUTER CONTROL OF TRAFFIC SIGNALS

Purpose

During 1969, The University of Michigan arranged for the erection of 26 variable-message guide signs and for a number of detectors to be placed on alternate routes in the northbound John C. Lodge Freeway Corridor in the City of Detroit. The detectors measure traffic volume and frequently occupancy and these data are communicated to a computer. From this information the computer determines ramp metering rates for the next minute. The variable-message guide signs are actuated from the computer so that motorists are shown the quickest route to the northern end of the Freeway Corridor from any point within it.

Our goal is to have the computer generate an appropriate set of signal timings to the local traffic signal controllers in the Corridor as early as February 15, 1970. The set of timings will be such that total travel time in the Corridor for all users will be minimized subject to certain constraints. Since many motorists desire to travel north on the Freeway during the afternoon peak period, it can be expected that the signal timings will favor the peak flow direction and reduce the overall travel time. The detectors on the surface streets indicate the level of congestion on the alternate routes. The signal timings for the peak period will be adjusted to allow for increased congestion.

The purpose of these specifications is to describe the functioning of the system needed to accomplish this control and to solicit bids on 57 assemblies that will be needed.

Controller Locations

There are 54 pre-timed traffic signal controllers on the alternate routes. Twenty-two of these controllers are located at the southern end of the Freeway Corridor and are interconnected to a master controller located in the 13th Precinct Police Station in the City of Detroit. Seven controllers are located in the City of Highland Park. The remaining 25 controllers are in the City of Detroit and some of these are operated by the Wayne County Road Commission.

Control Center Facilities

An IBM 1800 digital computer is located at the Control Center in the Herman Kiefer Hospital. This computer will soon have 24,000 bytes of core storage. The powerful Multi-Programming Executive System will permit the computer to cope with the tasks of receiving information from the detectors and with operating the ramp metering, the variable signs, and the signal controllers. The 1800 Vehicular Traffic Control System program prepared by IBM will be used as much as possible in the development of control programs for the planned configuration. Adequate digital inputs and outputs will be provided.

The University of Michigan will provide an appropriate interface at the Control Center. This device will communicate appropriate signals between the computer and the local traffic controllers via leased Michigan Bell Telephone Company lines.

Leased Telephone Service

Two pairs of direct current telephone cables protected by lightning arresting devices will be leased for communication between the Control Center and each traffic signal controller.

Controller Assembly Functions

To accomplish the desired control, several functions are required at each local controller and the successful bidder must provide a hardware assembly to be mounted within each control cabinet to fulfill all of these functions.

1. Disconnect Pre-Timed Dial from the Signal Circuits. Upon actuation of a signal requesting this function, disconnection will occur at the beginning of the main street green phase. Some of the controllers have more than one dial and the disconnection will be required for the dial currently in use. This function is similar to that frequently used in switching from automatic to manual control. The necessary circuitry for manual control is already present in each of the local controllers.
2. Advance Controller Drum. Upon receipt of a signal from the computer, the drum will advance to the next sequential signal display. This function is similar to that used in manual control.
3. Monitor Controller Operation. A signal will be sent from the assembly to the computer via the telephone lines whenever the traffic signal is in main street green. This function will enable the computer to remain aware of the state of the controller.
4. Return of Control to Controller. If the computer senses that a controller has not responded to its commands, the control must be returned to the specified pre-timed dial for that time. In returning to this mode of operation, the local signal displays must follow a normal phasing sequence. Clearance intervals shall be at least the standard ones. The return to local control must be achieved within one cycle length.

With these functions, the computer will disconnect the local controller's timing circuit, step the controller through each interval, vary the time of the interval, and check the display during main street green to verify that the pulses sent during the previous cycle have been correctly interpreted.

It is essential that the assemblies provide operation of the controllers which is at least as reliable as the present system. The assemblies must insure that control reverts to the pre-timed control whenever the computer detects an anomaly or when the computer loses communication with the controller.

Assembly Requirements

The assembly must be designed so that it can be easily attached inside of the control cabinet, either on the door or the sides. The assembly must operate satisfactorily throughout the normal variety of weather conditions encountered in the Detroit area. Provision will be made on the assembly itself for the easy termination of the telephone lines. The assembly will also provide leads of sufficient quality and length so that they may be terminated at the controller terminal strip. The assembly must be encased for protection against dust and dirt to insure its proper operation.

Summary of Equipment Required and Work to be Done

The successful bidder will provide:

1. 54 assemblies (one for each of the controllers)
2. 3 spare assemblies for a total of 57 assemblies.

The University of Michigan will be responsible for:

1. The necessary Bell Telephone service
2. A 125 volt power supply at the Control Center with sufficient current to operate all equipment simultaneously (with suitable fuses)
3. The connections at the Control Center between the telephone lines and the interface, the connections between the interface and the computer input and output devices, and the connection of the power supply
4. The complementary assembly (interface) that will be installed at the Control Center.

Coordination between the successful bidder and the University must be carefully effected to assure proper operation of the system.

Electrical Requirements

All assembly components must be approved by Underwriters Laboratories.

Guarantee

The successful bidder shall guarantee satisfactory performance (excluding physical damage) of all of the assemblies for a period of nine (9) calendar months from the date of delivery. The successful bidder must deliver any replacement assemblies to the National Proving Ground, 8801 John C. Lodge, Detroit, Michigan 48202, at his own expense. This delivery must be accomplished within four days of receiving notification by the University. The University will promptly return any assemblies found defective.

In the event of physical damage to an assembly, the University will pay the unit cost of each additional assembly required and for shipping of same. This delivery must also be accomplished within four days of receipt of notification by the manufacturer.

Delivery

Delivery of the entire lot must be completed within sixty (60) days of notification of acceptance. It is anticipated that notification will take place by December 1, 1969. The quoted price shall include delivery to the National Proving Ground (address above).

Bids

Bidders are to bid to supply 57 assemblies. The total possible current load from all assemblies, and any special equipment or telephone line requirements for the Control Center not described in the specifications must be stated. Within fourteen (14) days of notification of acceptance, a prototype assembly is to be forwarded to the National Proving Ground. Within a further seven (7) days, the University will notify the manufacturer of its approval of the prototype or the nature of the failure of the assembly to meet the specifications. The University will assist the manufacturer by providing prompt testing and information to the manufacturer. The manufacturer will complete delivery of equipment within the required original sixty (60) day period.

The bids should be submitted in duplicate with both copies sent to the Principal Investigator, Professor Donald E. Cleveland, Highway Safety Research Institute, Baxter Road and Huron Parkway, Ann Arbor, Michigan, 48105. One copy of the bid should be addressed to The University of Michigan Purchasing Department. The bid must be received no later than 9:00 a.m. on November 26, 1969.

APPENDIX E
SAMPLE FIELD AND ANALYSIS SHEETS

Lodge Freeway Corridor Journey No. 2

Date Driver

Starting Time Trip No. Observer

Turn	Timing Point or Intersection	3-4	5-7 S.T.	8-11 J.T.	12	13-14	
	West Grand Blvd. at WEST SERVICE DRIVE	47					
	EAST SERVICE DRIVE	14					
	Third	23					
	SECOND	48					
U	Before Woodward	–					
	SECOND	48					
	Third	23					
	EAST SERVICE DRIVE	14					
	WEST SERVICE DRIVE	47					
right	Poe	–					
	Pallister	–					
	WEST SERVICE DRIVE	46					
	East Service Drive	13					
	Third	–					
left	SECOND	–					
left	SEWARD	49					
	Third	24					
right	EAST SERVICE DRIVE	12					
	Euclid	11					
	Clairmount	27					
right	CHICAGO	10					
	Third	25					
	SECOND	50					
U	Before Woodward	–					
	SECOND	50					
	Third	25					
left	HAMILTON	10					
	CONTROL CENTER DRIVEWAY	–					

FIGURE E-1
MOVING VEHICLE STUDY FIELD SHEET

STORAGE ESTIMATES
FROM AERIAL PHOTOGRAPHY

Month		Day	
1	2	3	4

Flight Path No. 2
Flight Line I.D. No:
Time Period:

Description			Link		Vehicles	Frame
On	From	To	56-78	9-12	13-15	No.
Fenkell	Livernois	Dexter	35-04			
Fenkell	Dexter	Livernois	04-35			
Livernois	Fenkell	S.S.D.	35-36			
Livernois	S.S.D.	Fenkell	36-35			
Livernois	S.S.D.	N.S.D.	36-03			
Livernois	N.S.D.	S.S.D.	03-36			
Fenkell	Dexter	Linwood	04-37			
Fenkell	Linwood	Dexter	37-04			
Fenkell	12th	Linwood	06-37			
Fenkell	Linwood	12th	37-06			
Linwood	Fenkell	S.S.D.	37-38			
Linwood	S.S.D.	Fenkell	38-37			
Linwood	S.S.D.	N.S.D.	38-05			
Linwood	N.S.D.	S.S.D.	05-38			
12th	Fenkell	Oakman	06-42			
12th	Oakman	Fenkell	42-06			
12th	Davison	Oakman	07-42			
Davison	12th	W. Wilson	07-08			
W. Wilson	Davison	Glendale	08-40			
W. Wilson	Glendale	Davison	40-08			
W. Wilson	Glendale	Webb	40-41			
W. Wilson	Webb	Glendale	41-40			
Second	Chicago	Webb	50-51			
Second	Seward	Chicago	49-50			
		Seward	48-49			

FIGURE E-2
SURFACE STREET AERIAL PHOTO ANALYSIS LINKS

FROM AERIAL PHOTOGRAPHY

Flight Path No. 1
Flight Line I.D. No.:
Time Period:
Summarized by:

Month		Day	
1	2	3	4

Approaches: EB = 1, SB = 2, WB = 3, NB = 4

Intersection	No.Appr.		Time	No.in Q	Appr.	Time	No.in Q
	5-6	7	8-11	12-13	14	15-18	19-20
McNichols & Hamilton	30	2					
Geneva & Hamilton	31	1			3		
Puritan & Hamilton	22	1			3		
Pitkin & Hamilton	21	3					
Labelle & Hamilton	19	1			3		
Dav. N.S.D. & Hamilton	18	3					
Glendale & Hamilton	17	1			3		
Cortland & Hamilton	16	1			3		
Calvert & Hamilton	28	1			3		
Chicago & Hamilton	10	1					
Clairmount & E.S.D.	27	3					
Euclid & E.S.D.	11	3					
W.Grand Blvd. & Third	23	2					
Seward & Third	24	2					
Chicago & Third	25	2					
Livernois & N.S.D.	03	3			2		
Dexter & Fenkell	04	2			4		
Linwood & N.S.D.	05	3			2		
Fenkell & 12th	06	3					
Davison & 12th	07	3			4		
Webb & Freeway	09	4					

FIGURE E-3.
AERIAL PHOTO ANALYSIS: SURFACE STREET APPROACHES

LODGE FREEWAY OPERATIONS STUDY:
AERIAL PHOTO ANALYSIS FREEWAY DENSITY AND TRAFFIC COMPOSITION

1 OF 2

Month		Day	
1	2	3	4

FLIGHT LINE ID. NO.: ____________

FRAMES PER FLIGHT LINE: ____________

TIME PERIOD: ____________

SUBSECTION ID. NUMBER		TIME				NUMBER OF VEHICLES PER SUB-SECTION PER LANE																FRAME ID. NO.
						LANE 1				LANE 2				LANE 3				LANE 4				
						TOTAL VEHICLES		TRUCKS		TOTAL VEHICLES		TRUCKS		TOTAL VEHICLES		TRUCKS		TOTAL VEHICLES		TRUCKS		
5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	

FIGURE E-4.
LODGE FREEWAY OPERATIONS STUDY
AERIAL PHOTO ANALYSIS: MAIN CORRIDOR
TRAFFIC DENSITY AND TRAFFIC COMPOSITION

LODGE FREEWAY OPERATIONS STUDY:
AERIAL PHOTO ANALYSIS RAMP QUEUES

2 OF 2

Month		Day	
1	2	3	4

FLIGHT LINE I.D. NO.: ____________

FRAMES PER FLIGHT LINE ____________

TIME PERIOD ____________

RAMP	NUMBER	TIME				TOTAL VEHICLES		TRUCKS		FRAME I.D. NO.
5	6	7	8	9	10	11	12	13	14	

FIGURE E-4 (con't)

LODGE FREEWAY OPERATIONS STUDY
AERIAL PHOTO ANALYSIS: ON-RAMP DENSITY AND TRAFFIC COMPOSITION

Month		Day	
1	2	3	4

Flight Line ID. No.: ____________

Frames per Flight Line: __________

Time Period: ____________________

RAMP NO.	ID. NUMBER	TIME				Number of Vehicles per Ramp			
						TOTAL VEHICLES		TRUCKS	
5	6	7	8	9	10	11	12	13	14

FIGURE E-5
AERIAL PHOTO ANALYSIS ON-RAMP DENSITY AND TRAFFIC COMPOSITION

APPENDIX F
TABLES OF HISTORICAL VOLUMES

TABLE F-1

HISTORICAL SURFACE STREET VOLUMES

Link	2:30-3:30	3:30-4:30	4:30-5:30	5:30-6:30
36-03	1618	2112	2016	1530
35-04	421	415	510	353
37-04	369	625	1155	444
38-05	797	1084	973	895
37-06	524	403	398	244
42-06	462	755	817	598
40-08	301	301	769	156
41-09	428	412	469	329
29-09	493	527	651	539
27-10	798	1765	1686	871
25-10	647	1240	770	412
28-10	299	306	297	256
12-11	280	699	922	408
44-11	298	313	243	149
13-12	806	837	1328	581
14-13	812	963	1024	527
46-13	451	608	579	304
23-14	2137	2508	2771	1857
29-16	441	707	1403	790
17-16	451	413	542	296
16-17	695	820	1268	670
18-17	564	515	548	425

TABLE F-1 (con't)

17-18	817	973	1430	715
19-18	630	609	818	537
18-19	450	880	1347	686
20-19	360	742	549	403
	757	936	1548	843
	438	484	615	337
21-20	626	513	541	458
20-21	589	1078	1466	743
22-21	438	601	534	585
21-22	748	1098	1668	773
31-22	451	417	426	374
48-23	1206	1341	1765	1023
49-24	281	395	454	265
24-12	383	367	438	312
50-25	489	825	938	445
10-25	445	579	638	370
14-23	1935	2021	1249	1783
11-27	647	787	1317	973
43-27	502	397	502	386
10-28	617	660	1079	883
29-28	380	361	469	310
09-29	251	230	238	194
51-29	232	281	292	151
16-29	447	421	438	335
31-30	458	577	1232	566
52-30	412	506	905	543
53-30	1046	893	1680	1219

TABLE F-1 (con't)

22-31	676	988	1443	679
30-31	658	440	757	461
36-35	1594	1771	1857	1610
04-35	595	812	825	768
20-39	456	425	623	456
42-39	525	737	804	710
23-48	1290	1568	1922	1124
48-49	1041	1565	2779	1462
49-50	1246	1545	1557	1355
25-50	424	437	443	592
05-38	481	488	420	337
37-38	483	579	690	486
10-43	534	504	414	338
27-43	447	447	390	330
03-36	1476	1504	1222	1066
35-36	1646	2077	1955	1604
47-14	1490	1417	1536	936
46-47	1008	1411	1690	1150
07-08	1797	1924	2860	1373
50-51	1143	1443	2267	1869
14-47	1397	1995	2319	1558
12-45	273	307	324	190
11-44	224	301	254	165
43-44	584	481	348	341
09-41	601	542	524	514
39-42	561	540	804	527
04-37	356	350	418	241
38-37	459	523	503	332

TABLE F-1 (con't)

06-37	337	557	634	477
06-42	565	265	288	239
07-42	653	584	1036	664
08-40	260	222	381	274
45-46	320	685	575	216
44-45	370	425	410	236
41-40	236	453	453	391
40-41	230	220	285	237

TABLE F-2

HISTORICAL SURFACE STREET VOLUMES

INTERSECTION NUMBER	APPROACH DIRECTION	2:30-3:30	3:30-4:30	4:30-5:30	5:30-6:30
03	South	1357	1543	1316	1265
03	West	566	392	199	303
04	South	246	344	485	299
04	North	412	676	804	399
05	South	384	424	331	374
05	West	693	?	665	724
06	West	180	123	214	190
07	West	1406	1464	1912	1038
07	North	700	623	1086	676
09	North	296	176	131	156
10	East	332	455	464	321
11	West	214	290	243	149
14	North	874	769	847	782
16	East	29	41	62	56
16	West	58	63	101	90
17	East	287	270	314	231
17	West	383	355	398	220
18	West	472	508	626	516
19	East	31	75	65	34
19	West	120	360	337	197
21	West	50	143	103	38
22	East	211	189	388	224
22	West	193	255	167	94

TABLE F-2 (con't)

23	South	1319	1651	1087	1531
24	South	603	669	586	451
25	South	711	950	775	380
27	West	453	519	557	431
28	East	186	163	243	132
	West	154	139	179	133
	South	523	311	595	414

APPENDIX G
PROJECT PUBLICITY

Detroit Free Press

THE SECOND FRONT PAGE

Page 3, Section A

Thursday, January 7, 1971

TV Experiment on Lodge Freeway Ends

BY LEE WINFREY
Free Press Staff Writer

After 10 years of experiments that cost an estimated $1 million, traffic research on the John Lodge Freeway is over.

The television cameras that monitored the roadway are turned off. The green arrows and red Xs don't flash any more. The glowing numbers that used to suggest the proper speed have been extinguished.

The Lodge has sunk back into harsh reality, once again just another overcrowded conduit where every driver must shift for himself.

As a result of all the money and time, not one of the experimental devices tried on the Lodge has been permanently adopted into the system.

MOTORISTS who are still chugging through the Davison interchange in low gear may be startled to hear that researchers consider the program a success even though it has led to nothing new.

Among those applauding the research, which often made the Lodge an avenue of surprises, are Alger F. Malo, city director of streets and traffic, and Harold Cooper, traffic engineer for the state Highway Department.

Here is how they look at the program:

- The TV cameras were good. They spotted accidents and jams and helped clear up clogged spots quickly.

The only trouble is that the cameras, installed experimentally over a three-mile stretch from W. Grand Blvd. to Davison, are too expensive to install over the whole route. Cooper estimates that it would cost about $750,000 to cover the Lodge from Cobo Hall north to Eight Mile.

- The green arrows and red Xs were good, too. Motorists obeyed them and thereby made better time.

The problem is that the arrows and Xs depend on the TV cameras to figure out when they should be turned on. So since the cameras are coming down, the arrows and Xs are going out, too, except to indicate road maintenance work.

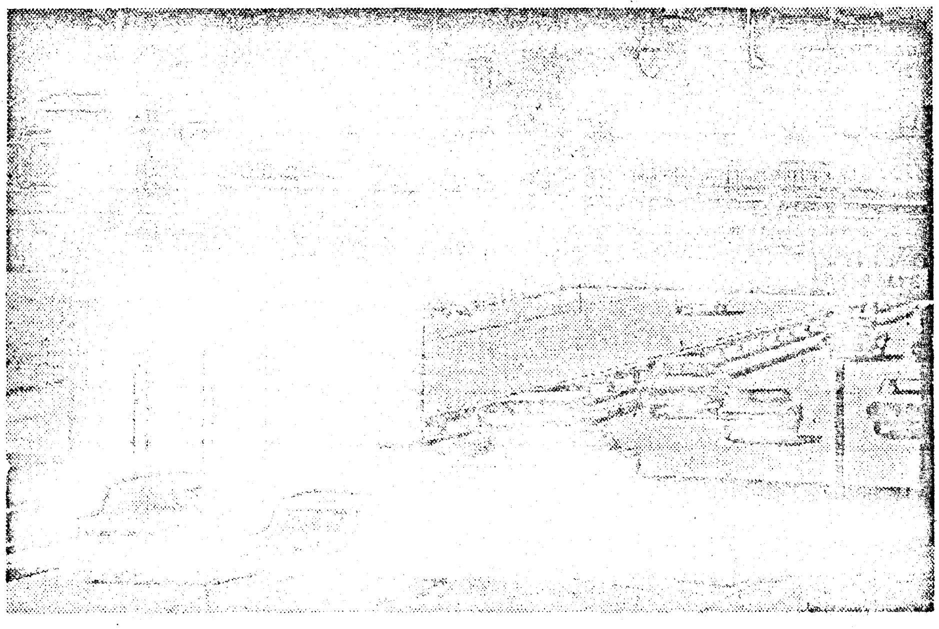
- The lights, which flashed on with suggested speeds, were a failure. Motorists hated them.

DRIVERS PULSING along at two miles an hour as they approached a jackknifed trailer truck customarily collapsed into suicidal depression or flew into blind rage when informed that they could drive 35 if they wished. They never understood that the 35 meant the speed that they could expect to make a little farther down the road.

The last of the great experiments on the Lodge ended Dec. 4. The whole business went on for 10 years, financed jointly by federal, state and city money. Malo, who gave the $1 million cost estimate, doesn't expect to receive all the research reports for at least six more months.

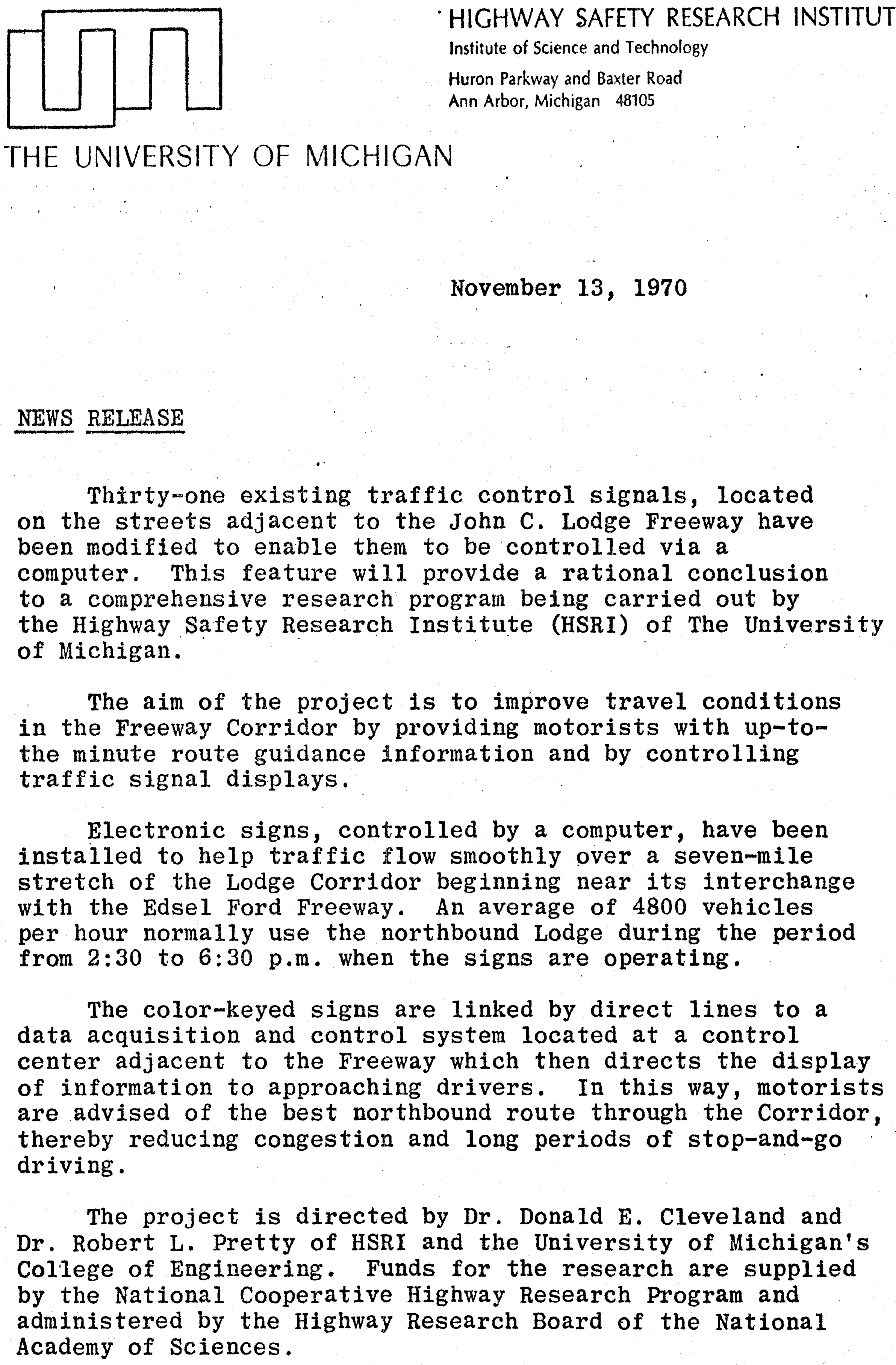
In the meantime, for those of you tunneling through the trench each day, here's a figure that should make clear what the big problem is:

Lodge traffic is now running as high as 160,000 vehicles in 24 hours. When fully completed in 1964, its designed daily capacity was 90,000.



Motorists liked the arrows, hated the speed signs

FIGURE G-1



HIGHWAY SAFETY RESEARCH INSTITUTE
Institute of Science and Technology
Huron Parkway and Baxter Road
Ann Arbor, Michigan 48105

THE UNIVERSITY OF MICHIGAN

November 13, 1970

NEWS RELEASE

Thirty-one existing traffic control signals, located on the streets adjacent to the John C. Lodge Freeway have been modified to enable them to be controlled via a computer. This feature will provide a rational conclusion to a comprehensive research program being carried out by the Highway Safety Research Institute (HSRI) of The University of Michigan.

The aim of the project is to improve travel conditions in the Freeway Corridor by providing motorists with up-to-the minute route guidance information and by controlling traffic signal displays.

Electronic signs, controlled by a computer, have been installed to help traffic flow smoothly over a seven-mile stretch of the Lodge Corridor beginning near its interchange with the Edsel Ford Freeway. An average of 4800 vehicles per hour normally use the northbound Lodge during the period from 2:30 to 6:30 p.m. when the signs are operating.

The color-keyed signs are linked by direct lines to a data acquisition and control system located at a control center adjacent to the Freeway which then directs the display of information to approaching drivers. In this way, motorists are advised of the best northbound route through the Corridor, thereby reducing congestion and long periods of stop-and-go driving.

The project is directed by Dr. Donald E. Cleveland and Dr. Robert L. Pretty of HSRI and the University of Michigan's College of Engineering. Funds for the research are supplied by the National Cooperative Highway Research Program and administered by the Highway Research Board of the National Academy of Sciences.

FIGURE G-2

The system helps guide rush-hour motorists by using traffic flow data from the Freeway and possible alternate routes to determine appropriate directional displays on the signs. The data is gathered by overhead and pavement detectors located on the Freeway and on the surface streets. As conditions on the Freeway change, the information on the signs is constantly changed to provide motorists with the best possible directions.

Control of the thirty-one signals is the last of the innovative features developed by HSRI. The signals will be operated so that they will provide maximum available green time to the approach street of an intersection having the highest demand or volume of traffic. The computer will attempt to control the traffic light timings to provide a progression of movement not only in the through-direction but even after a turning movement has been made. Motorists avoiding the Northbound Lodge Freeway during the evening peak period will thus receive a higher level of service. The maximum green time will enable the motorist to arrive at the northbound Lodge entrance ramps in less time than normal.

Final results of the research will aid traffic engineers in other large cities in determining ways to improve freeway corridor travel. The experimental system on the Lodge may eventually become a permanent part of traffic control here. The computerized system is completely integrated, with each part of the surveillance complementing the other - to the benefit of the motorist. The system helps ease the stress of freeway driving by allowing motorists to drive at a constant speed. In addition, the total time associated with the trip should be reduced.

The system is expected to start on November 16, 1970 and run through to December 4, 1970.

FIGURE G-2 (con't)

THE UNIVERSITY OF MICHIGAN NEWS

News Service
6014 Administration Building
Ann Arbor, Michigan 48104

December 4, 1970 (9)
Contact: Bill Hampton
Phone: 764-7260

RELEASE ON RECEIPT

ANN ARBOR---An experimental traffic control system along Detroit's John C. Lodge Freeway Corridor ends two years of operation Friday (Dec. 4).

The complex control system, operated since January of 1969 by highway researchers at The University of Michigan, warned motorists of freeway or ramp congestion ahead and suggested alternate non-freeway routes.

The system has included 26 variable message route signs along the Lodge corridor in Detroit and Highland Park, television surveillance equipment, ramp monitors and signals and 31 computer controlled traffic signals.

Detroit and Wayne County workmen are expected to remove the traffic equipment before the end of the month.

The project has been headed by Prof. Donald E. Cleveland and associate research engineer Robert L. Pretty of the U-M Highway Safety Research Institute and department of civil engineering.

They said their evaluation report of the system will be completed early next year. They noted that the report will contain particularly valuable comments from motorists on the Lodge Freeway who filled out questionnaires about the traffic control system.

The U-M researchers added that the results of their project will apply to other freeways in and out of the Detroit area. They said their report will help the Michigan Department of State Highways decide whether a similar traffic control system should be installed permanently. The state highway department controls freeway operations in the Detroit area.

(more)

FIGURE G-3

Cleveland and Pretty suggest that regular motorists on the Lodge Freeway continue to follow routes suggested in the past by the special sign system, especially during rush hours.

They particularly urge drivers to avoid the West Grand Boulevard-Lodge Freeway interchange during peak traffic hours.

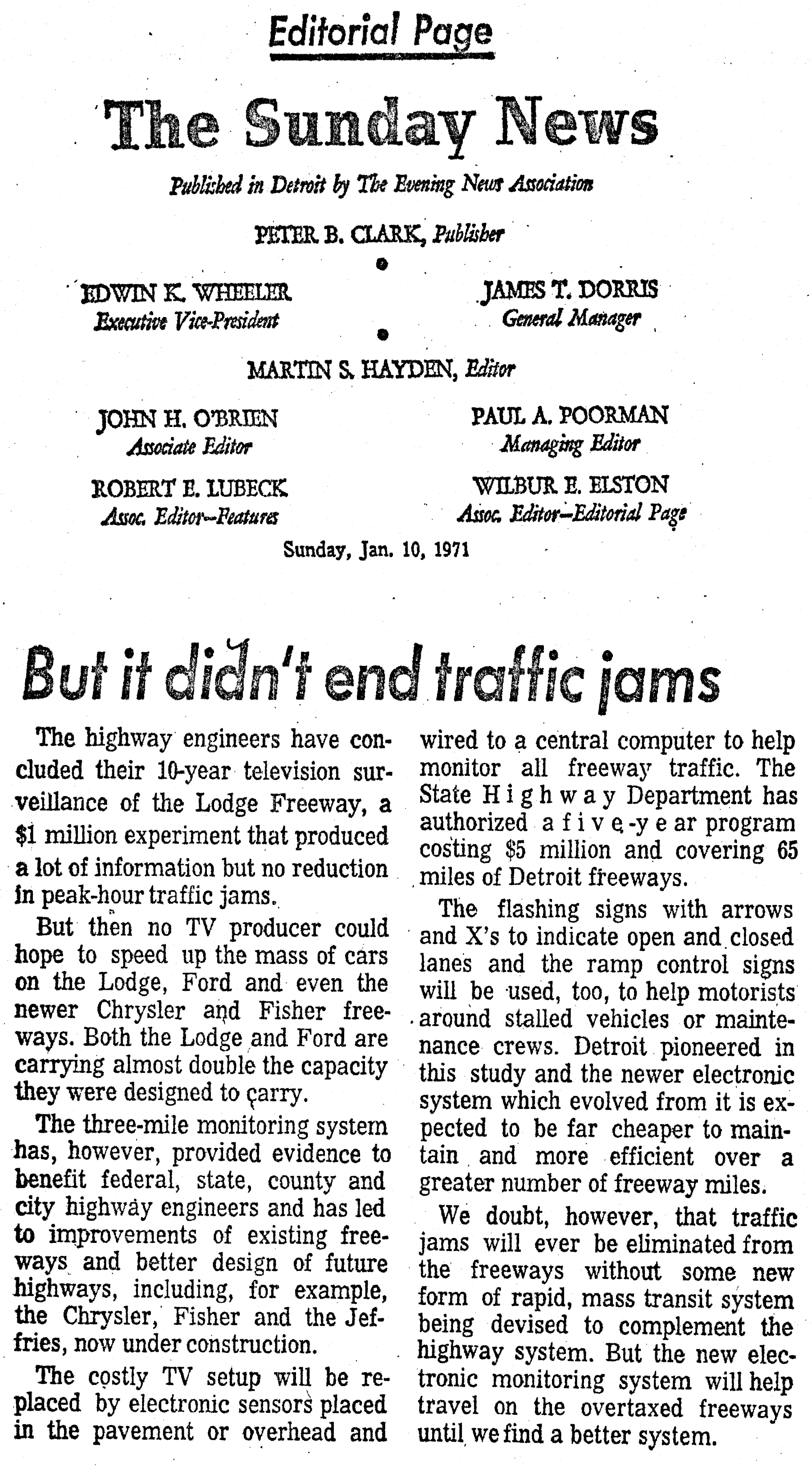
Cleveland and Pretty noted that the Lodge Freeway has been used for traffic research almost continuously since 1960. From 1960 to 1966, it was the site of work by the Michigan State Highway Department and the National Proving Ground for Freeway Surveillance, Control and Electronic Traffic Aids. In 1967-68, research by the Texas Transportation Institute was carried out there.

The U-M project was funded by the National Cooperative Highway Research Program. Grants were administered by the Highway Research Board of the National Academy of Sciences.

# # # # # # # # #

(Cleveland, Pretty, HSRI)(R1,2; RT1;Auto;Engl,3,5) bjw

FIGURE G-3 (con't)



Editorial Page

The Sunday News

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WILBUR E. ELSTON
Assoc. Editor—Editorial Page

Sunday, Jan. 10, 1971

But it didn't end traffic jams

The highway engineers have concluded their 10-year television surveillance of the Lodge Freeway, a $1 million experiment that produced a lot of information but no reduction in peak-hour traffic jams.

But then no TV producer could hope to speed up the mass of cars on the Lodge, Ford and even the newer Chrysler and Fisher freeways. Both the Lodge and Ford are carrying almost double the capacity they were designed to carry.

The three-mile monitoring system has, however, provided evidence to benefit federal, state, county and city highway engineers and has led to improvements of existing freeways and better design of future highways, including, for example, the Chrysler, Fisher and the Jeffries, now under construction.

The costly TV setup will be replaced by electronic sensors placed in the pavement or overhead and wired to a central computer to help monitor all freeway traffic. The State Highway Department has authorized a five-year program costing $5 million and covering 65 miles of Detroit freeways.

The flashing signs with arrows and X's to indicate open and closed lanes and the ramp control signs will be used, too, to help motorists around stalled vehicles or maintenance crews. Detroit pioneered in this study and the newer electronic system which evolved from it is expected to be far cheaper to maintain and more efficient over a greater number of freeway miles.

We doubt, however, that traffic jams will ever be eliminated from the freeways without some new form of rapid, mass transit system being devised to complement the highway system. But the new electronic monitoring system will help travel on the overtaxed freeways until we find a better system.

FIGURE G-4

APPENDIX H
PROJECT STATEMENT

"Excerpts From"

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Highway Research Board
National Academy of Sciences-National Research Council

FY '67

Project Statement

Research Project Title:

Optimizing Freeway Corridor Operations Through Traffic Surveillance, Communication, and Control.

General Problem Area:

Special Projects

Research Problem Statement:

To meet present and future traffic demands, the combined freeway and surface street system must operate more efficiently. Freeways through heavily developed areas have limited right-of-way which prevents, on an economic basis, their reconstruction for increased capacity. Practical measures for increasing operational efficiency of these facilities through heavily traveled corridors should be developed by judicious application of traffic surveillance, communication, and control.

Urban freeways comprise a major portion of the traffic-carrying capacity of the total vehicular route system in American cities. It is believed that surveillance, communication, and control of traffic on freeways as well as on the supplemental street systems can be improved, resulting in better service to the motoring public as a whole.

It is desired to apply the best traffic surveillance, communication, and control techniques in a typical urban freeway corridor and to study the results. Innovations that may be expected to enhance the operational efficiency should be explored.

The National Proving Ground for Freeway Surveillance Control and Electronic Traffic Aids located on the John C. Lodge Freeway in Detroit has been extensively equipped for freeway surveillance, and this freeway and the adjacent corridor is designated as the study site to develop and evaluate improved surveillance, communication and control techniques.

Objectives:

1. Determine method(s) for increasing the effectiveness of the system which involves the freeway and the adjacent surface street network within the corridor. Evaluate the methods on the study site with or without the use of additional hardware.

2. Recommend equipment configurations (that is, type and location) for the improved system which will represent the optimum balance in cost-effectiveness.

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