A SYSTEMS ANALYSIS FOR A REAL-TIME FREEWAY TRAFFIC INFORMATION SYSTEM FOR THE INBOUND GULF FREEWAY CORRIDOR

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ABSTRACT

The traffic operations on the inbound Gulf Freeway were analyzed to determine if an acceptable level of service was being provided when an accident, stalled vehicle, or other similar incident occurred on the freeway. The magnitude and frequency of the congestion and delays experienced due to the occurrence of incidents were found to be significant. The conclusion was reached that the need exists for improving the traffic operations on the inbound Gulf Freeway when incidents occur on it.

The diversion of traffic around incidents on the freeway was determined to be a feasible method of reducing the congestion and increasing the level of service. To accomplish this objective, a real-time freeway traffic information system is required. As a first step in the development of a total corridor information system, a small-scale real-time freeway traffic information system is recommended for immediate implementation on the inbound Gulf Freeway. The operational results obtained from this small system can be used as inputs to the design of the recommended total corridor system.

SUMMARY

Freeway ramp control systems have proved their effectiveness in increasing the level of service on urban freeways which had previously been experiencing congestion caused by the traffic demand exceeding the normal capacity of the freeway. However, these ramp control systems basically try to service traffic demands regardless of where the demands may exist in time and space. Fortunately, when no incidents have occurred on the freeway, the freeway traffic demands are usually in proportion to available capacity. However, when accidents, stalled vehicles, or other lane blocking incidents occur on the freeway, the freeway traffic demands frequently far exceed the remaining capacity. As a consequence, present ramp control systems are overtaxed and congestion results.

One method of reducing the congestion caused by freeway incidents is by diverting traffic around the bottleneck onto the frontage road and arterial streets having available capacity. This diversion could be accomplished by providing freeway traffic information to motorists at strategic locations within the freeway corridor. These locations should provide convenient access points to suitable routes which would bypass the incident on the freeway.

In recognition of the congestion and traffic safety problem caused by the unpredictable occurrence of incidents, one of the objectives of Project 139, entitled "Freeway Control and Information Systems," was to develop and test prototype communication devices for use at: 1) freeway entrance ramps, 2) freeway thru lanes, and 3) on arterial streets approaching the freeway. This project is an outgrowth of previous research on the Gulf Freeway in Houston, Texas.

A systems analysis of the inbound Gulf Freeway has been conducted toward the design of a real-time freeway traffic information system. The study is based on data collected during 1968, 1969, and 1970.

It is the conclusion of this study that the need exists for reducing the congestion and improving the level of service on the inbound Gulf Freeway when incidents occur on it.

The results of the study also indicate that a real-time traffic information system which provides accurate, reliable, and meaningful freeway traffic information would be a feasible alternative toward reducing congestion and improving the level of service of the inbound Gulf Freeway motorists when incidents occur. The following additional findings were drawn from the results of the study:

1. Significant congestion and delay frequently occurs on the inbound Gulf Freeway due to the reduction in capacity caused by the frequent occurrence of incidents on the main-lanes of the freeway.
2. Most incidents on the inbound Gulf Freeway are non-injury accidents and stalled vehicles. These incidents usually block only one of the three lanes of the freeway. Forty-seven percent were vehicle stalls and 46 percent were non-injury accidents.
3. Approximately 80 percent of the incidents which occur on the inbound Gulf Freeway reduce its capacity by one-half or more.
4. The freeway traffic demand would exceed the capacity if an incident occurs on the freeway any time between 6 AM to 7 PM. Congestion would result during this time interval when an incident occurs;

the most severe congestion would occur during the morning and afternoon peak hours.

5. On the average, approximately 13 incidents occur on the inbound Gulf Freeway from the Reveille interchange to Scott from Monday through Friday during the time period from 6 AM to 7 PM.
6. During the morning peak hours of 6:30 - 8:30 AM, 3.3 incidents occur from Monday through Friday on the inbound Gulf Freeway. On the average, one of these incidents per week is a major incident, causing at least five minutes of delay per vehicle for travel between Woodridge and Cullen and at least 11 minutes of delay for travel between Broadway and Cullen.
7. Approximately one-fourth of all incidents which occur during the peak hours result in minimal delay in themselves but do create a safety hazard due to the resulting shock wave they produce. In addition, most incidents which occur during the off-peak hours usually would not create severe congestion but they do create queueing on the main-lanes of the freeway which is a serious traffic hazard to uninformed motorists approaching the incident.
8. It appears feasible to reduce congestion and delay caused by incidents by diverting traffic around the bottleneck location on the freeway through the use of a real-time freeway traffic information system which provides accurate, reliable, and meaningful traffic information to the motorists.
9. Traffic on the freeway, on the frontage road, and within the corridor should be considered for possible diversion since the

diversion of any of these could result in a significant reduction in delay.

10. The diversion of the traffic in the corridor along the following alternate routes appears feasible:
    a. Telephone
    b. Lawndale
    c. Bellfort
11. The diversion of inbound Gulf Freeway and ramp traffic along the inbound Gulf Freeway frontage road from the Wayside exit ramp to the Dumble entrance ramp appears feasible. Added computer control at the Wayside and Telephone interchanges and surveillance of the South H.B. and T. railroad crossing of the frontage road would be desirable.
12. Diversion of S.H. 225 and Broadway traffic on the inbound frontage road section from Broadway to the Mossrose entrance ramp appears feasible when an incident has occurred upstream of the Mossrose entrance ramp.

Recommendations for Implementation

Based on the findings of this study of the traffic characteristics and operations of the inbound Gulf Freeway Corridor and the present state-of-the-art of traffic information systems, the following recommendations are offered:

1. The State should consider the immediate implementation and evaluation of a real-time freeway traffic information subsystem on the inbound Gulf Freeway. This subsystem should provide an

integrated operation of freeway, frontage road, and arterial traffic control. The results of the operation of this subsystem would be used to develop operational strategies and specifications for use in the design of future information systems.

2. The recommended subsystem consists of:
    a. The installation of changeable message signs at the Griggs and Telephone entrance ramps.
    b. The installation of a changeable message sign on the inbound Gulf Freeway near the Wayside entrance ramp such that the freeway and Wayside ramp traffic could make effective use of the information provided. This sign could also be used for diversion of traffic off the freeway onto the frontage road to bypass congestion between the Telephone exit ramp to the Dumble entrance ramp.
    c. Surveillance of the railroad crossings of the frontage roads at Griggs and Lombardy (South H. B. & T.).
    d. Computer control of the frontage road intersections at Wayside and Telephone.
3. Plans should be prepared for the installation of a total corridor freeway traffic information system as the results of the performance of the subsystem become available. Installation of the system should be effected pending the satisfactory performance of the subsystem.
4. Additional research should be directed toward determining the functional requirements and design for guiding motorists on alternate and diversion routes.

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I. INTRODUCTION

The Problem

The primary cause of traffic congestion on urban freeways is that the traffic demand exceeds the capacity of a section(s) of freeway to service it. The capacity of the critical section or "bottleneck" causing the congestion may be limited by the physical geometrics of the freeway section. When the uncontrolled freeway traffic demand exceeds the physical geometric capacity of a section, freeway ramp control systems have proved their effectiveness in reducing the congestion and in improving the level of service afforded the freeway motorists (1, 2, 3, 4, 5, 6). The success of freeway ramp control arises primarily from its capability to control entrance ramp traffic flow so that the total freeway traffic demand on a section of freeway will not exceed the normal geometric capacity of the freeway section.

The occurrence of an accident or other lane blockage incident on the freeway reduces the capacity of the section of freeway significantly below what is normally provided. When a major incident occurs causing a significant bottleneck, the capabilities of present freeway ramp control systems are typically exceeded and freeway congestion and delay results even though unused capacity may exist on the frontage road or other parallel arterials within the freeway corridor.

A freeway corridor is assumed to consist of the freeway, frontage roads to the freeway, feeder streets to the freeway, and other arterials which may serve as alternative routes to the freeway. An urban freeway corridor is typically directionally oriented and usually lies between an outlying residential area of a city and the downtown section. From the viewpoint of

a freeway corridor system, the freeway may contribute perhaps a third to a half of the available corridor capacity. Thus, it would be desirable if a system could be developed to prevent, or at least minimize, the amount of congestion experienced due to the occurrence of major incidents on the freeway by better utilization of available capacity within the freeway corridor.

Solution Approach

From a control system viewpoint, what is needed when a major incident occurs on the freeway is to intercept freeway demand before it reaches the reduced capacity location caused by the incident and to redirect the demand into areas of the freeway corridor where excess capacity exists. A primary reason that this desired diversion of demand does not presently occur when an incident happens is because of insufficient reliable, meaningful and timely information available to the motorist to help him select the most efficient route to his destination.

To obtain this desired redistribution in traffic demand, a corridor surveillance, information and control system will be required. The surveillance function is required to detect and evaluate the nature of incidents and to determine the appropriate operational control strategy to follow. The real-time information system will provide information to motorists that will enable them to intelligently select and follow their best alternative course of action. The control function is desired so that the traffic controllers, located at the intersections along those alternate routes where increased usage is expected, can be adjusted to accommodate the short-term changes in traffic patterns and demands.

Based on the criterion that a system be designed for immediate and practical implementation, changeable message signs offer promise as one effective method of communicating with the urban freeway driver in real-time (7). The use of commercial radio also seems promising, however, a major change in procedural policies relating to the acquisition and reporting of traffic information would be required prior to the adaption of this type system for the application that is being considered (8, 9).

Driver Attitudes and Preferences

The results of a recent comprehensive questionnaire study, documented in earlier reports (10, 11), have shown that urban freeway drivers desire real-time freeway traffic information which is not currently provided by freeway signing. The survey also revealed that the diversion of freeway traffic demand to reduce congestion would appear to be possible under certain conditions. The results showed that a large majority of freeway motorists would desire to respond to real-time information about congested freeway conditions by rerouting to expedient alternate routes when they were known by drivers to be available. Motorists are slightly more inclined to divert to alternate routes before they enter the freeway (92 percent preference) than after they are on the freeway (75 percent preference). They also prefer to receive information about traffic conditions before they enter the freeway.

Changeable message signs and commercial radio were preferred over telephone and television services as modes for communicating with the driver in real-time. The two information descriptors preferred for describing freeway traffic congestion were as follows: 1) the location and length

of the congested area, and 2) the degree of congestion.

Study Objectives

The magnitude, duration, and frequency of incidents that occur on the inbound Gulf Freeway, together with the resulting congestion and delays, indicate the need for providing real-time freeway traffic information to motorists within the inbound Gulf Freeway Corridor. When these incident characteristics are analyzed in conjunction with information as to where the incidents occur and the locations of available corridor capacity and traffic flow patterns, the traffic demands which can more readily benefit from receiving real-time freeway traffic information can be identified. With this information, feasible locations for implementating corridor freeway traffic information displays can be determined and their priorities for implementation established. A corridor traffic information system can then be designed and operational policies formulated. This report is concerned with a systems analysis of the inbound Gulf Freeway corridor directed toward the design of a real-time driver information system.

II. INCIDENT CHARACTERISTICS OF THE INBOUND GULF FREEWAY

The operation and control strategy of a freeway corridor surveillance, information and control system will depend primarily on the traffic conditions on the freeway main-lanes since the freeway serves as the principal traffic facility for the entire corridor. When an incident occurs on the freeway, it must be quickly detected, located, and analyzed so that an appropriate response can be initiated in an expedient manner. The location of the incident serves to identify the beginning of the congestion area and defines where additional capacity is needed. The severity and duration of the incident indicates the amount of congestion that might be expected. Thus, the incident characteristics of the inbound Gulf Freeway will serve as a major input for the design of the corridor driver information system.

The Inbound Gulf Freeway

The Gulf Freeway in Houston is a six-lane divided facility. The portion of the Gulf Freeway presently under freeway ramp control extends from the Reveille Interchange inbound toward downtown for 3.5 miles to the Dumble entrance ramp. The freeway is an at-grade type and is carried over the major arterials and railroad crossings producing a roller coaster effect on the main-lanes of the freeway. Within the area of the freeway directly affected by control, there are eight locations where sight distances for the freeway motorist are limited due to geometrics as depicted in Figure 1. Three major overpass structures, numbers 4, 7, 8 in Figure 1, provide only very limited sight distances. The available sight distances are further reduced during the rush hours due to the high traffic volumes. A rather high

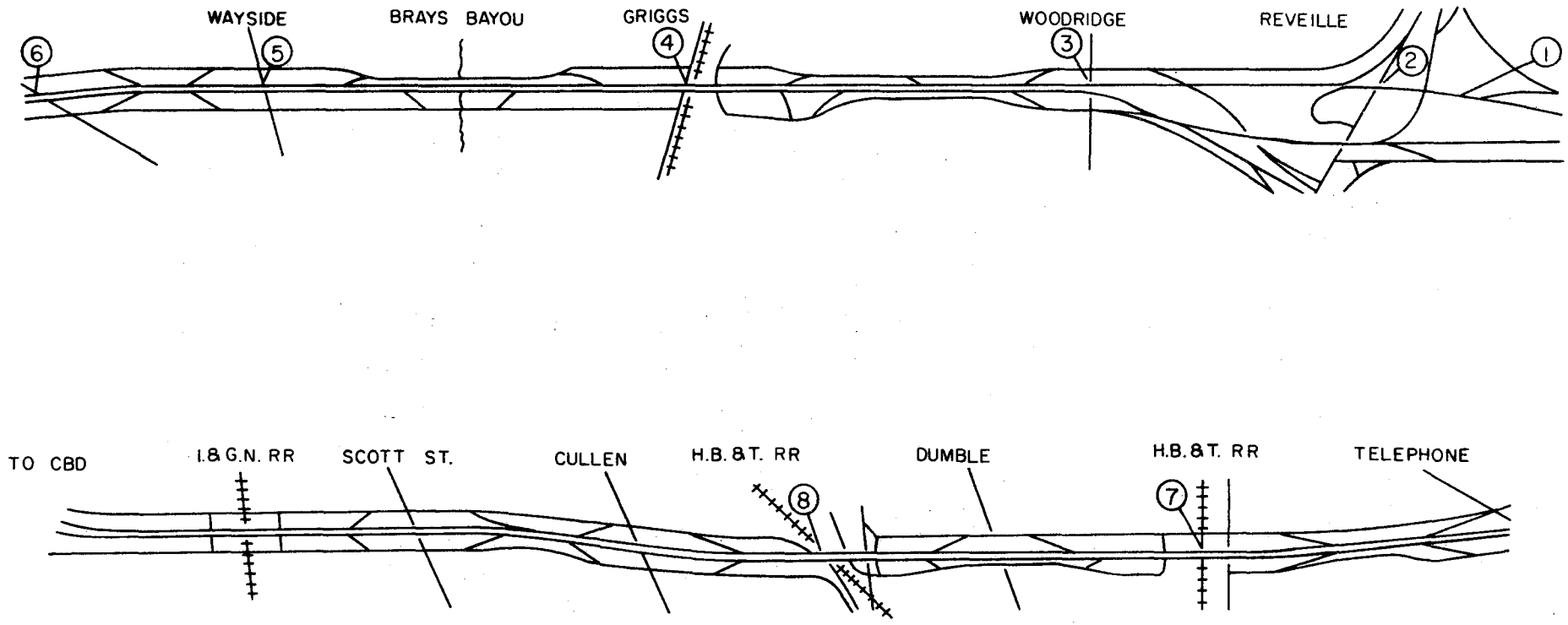

FIGURE 1 - LOCATIONS OF LIMITED SIGHT DISTANCE ON INBOUND GULF FREEWAY

frequency of rain and fog occurs in Houston which adds to the potential accident problem.

Freeway surveillance and capacity analyses have indicated that the inbound Gulf Freeway has a capacity of approximately 5600-5800 vehicles per hour over the overpass structures (12). Thus, as the volumes depicted in Figure 2 for the 7-8 AM morning rush hour indicate, the inbound freeway is normally flowing near capacity during this period of time. The high volume to capacity ratios which exist on the inbound Gulf Freeway make it very susceptible to congestion during the morning rush hour if an incident occurs.

Incident Characteristic Studies

Studies were conducted on the Gulf Freeway to determine vehicular incident characteristics and the influence of these incidents on freeway operations. During 1968 and 1969, a log of those incidents which occurred on the six mile section of the Gulf Freeway from Broadway to Cullen under television surveillance was maintained on weekdays from 6 AM to 6 PM. Entries were noted of the locations of the incidents, the times incidents occurred, police investigation and removal times, and when traffic conditions returned to normal. During this two year study period, a total of 2343 lane blocking incidents of varying duration were observed of which 53 percent were inbound and 47 percent were outbound. An incident log was maintained in 1970 on weekdays from 7-9 AM and for one month from 6 AM to 7 PM. Due to the comprehensive nature of the 1968 and 1969 study data, most of the incident results reported herein come from this source. The 1970 data indicate that no appreciable changes occurred in the incident characteristics during 1970.

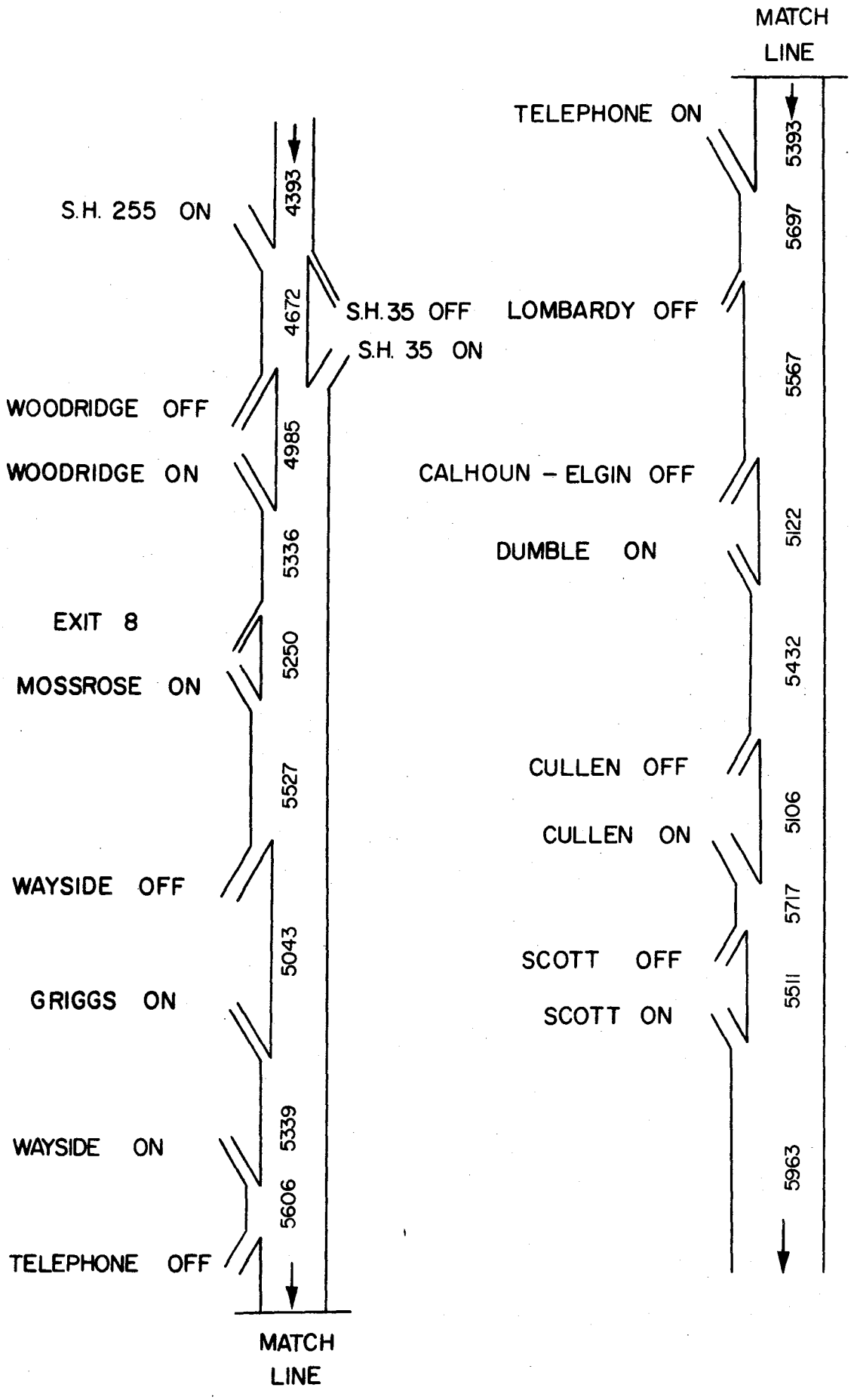

FIGURE 2 – VOLUME FLOW MAP – INBOUND GULF FREEWAY – 7:00 – 8:00 AM JULY 1969.

Types of Incidents

The results of the 1968 and 1969 incident study indicate that most incidents on the Gulf Freeway were either accidents or stalled vehicles. A summary of the types of incidents observed and their corresponding frequencies of occurrence are presented in Table 1. Accidents and stalled vehicles occurred at almost the same rate. Of the total incidents observed, 49.3 percent were accidents and 47.6 percent were stalled vehicles. The non-injury accident was the predominate type of accident.

Incident Locations on Inbound Gulf Freeway

The location where an incident occurs on the inbound Gulf Freeway defines the point of reduced capacity within the corridor and the beginning of the congested section. It is around this point that all communication and control strategies would focus. If most of the incidents and congestion on the inbound Gulf Freeway occurred in one or two locations, then these areas could be given the greatest emphasis in design.

Incidents due to vehicle stalls, debris spills, and certain types of accidents would normally be expected to occur in a random manner under uniform conditions. The geometrics of the inbound Gulf Freeway are not uniform and therefore some variation in the frequency of incidents would be expected. As was noted previously, there are eight areas having some sight distance restrictions with the three railroad overpasses providing only limited sight distances. Early studies on the Gulf Freeway by Keese and Mullins concluded that the restricted sight distances created by the overpasses on the Gulf Freeway contribute to a high frequency of accidents on and just beyond the far side of the overpasses (13). Additional studies

TABLE 1

INBOUND AND OUTBOUND INCIDENT CHARACTERISTICS
WHICH OCCURRED FROM 6 AM to 6 PM ON WEEKDAYS
DURING 1968 AND 1969 ON THE GULF FREEWAY

Type of Incident	Number of Incidents	Percent of Incidents
Stalls	1117	47.6
Accidents		
Non-Injury	1091	46.6
Injury	63	2.7
Lost Load	37	1.6
Other	35	1.5
Total	2343	100.0

reported by Drew and Dudek under the Level of Service research program disclosed high values of acceleration noise in these areas (14). The high acceleration noise on the far side of the overpasses can be ascribed to rapid decelerations and is indicative of accident potential locations.

Data collected on the location of incidents for the inbound Gulf Freeway during 1969 and for one month in 1970 indicate that a higher frequency of incidents exists in the vicinity of the major overpass structures but that the entire inbound section is susceptible to incidents. Figure 3 depicts the nature of the morning (6:30 - 9 AM) and afternoon (3:30 - 6 PM) occurrence of accidents by location. The location of stalls is presented in Figure 4. These two types of incidents are summarized in Figure 5 into a composite of stalls and accidents approximating the frequency of total incidents by location along the freeway. Again, these results show that incidents and the resulting congestion occur over the entire inbound Gulf Freeway to the extent that all sections within the surveillance and control area merit consideration.

Effects of Incidents on Freeway Capacity

When an incident occurs on the freeway and if no diversion is attempted, the congestion that results depends on the reduction in the freeway capacity caused by the incident, the normal freeway traffic demand, and the time the incident exists. These factors were evaluated to determine the effects of incidents on the traffic operations on the inbound Gulf Freeway.

The reduction in capacity of the inbound Gulf Freeway due to incidents has recently been reported (15, 16). It would be expected that the reduction

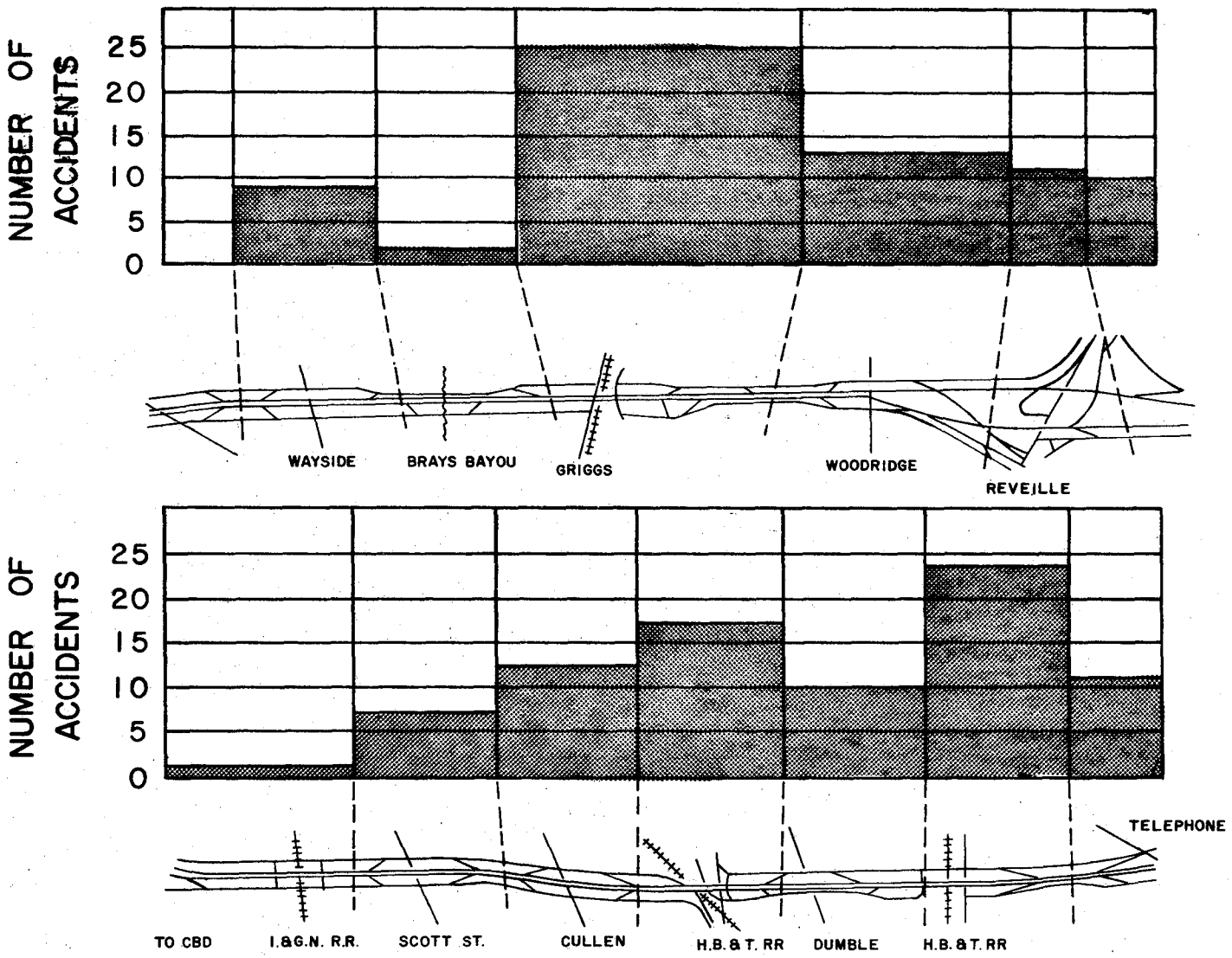

FIGURE 3 - DISTRIBUTION OF ACCIDENTS ON INBOUND GULF FREEWAY - 6:30-9:00 AM AND 4:30-6:00 PM

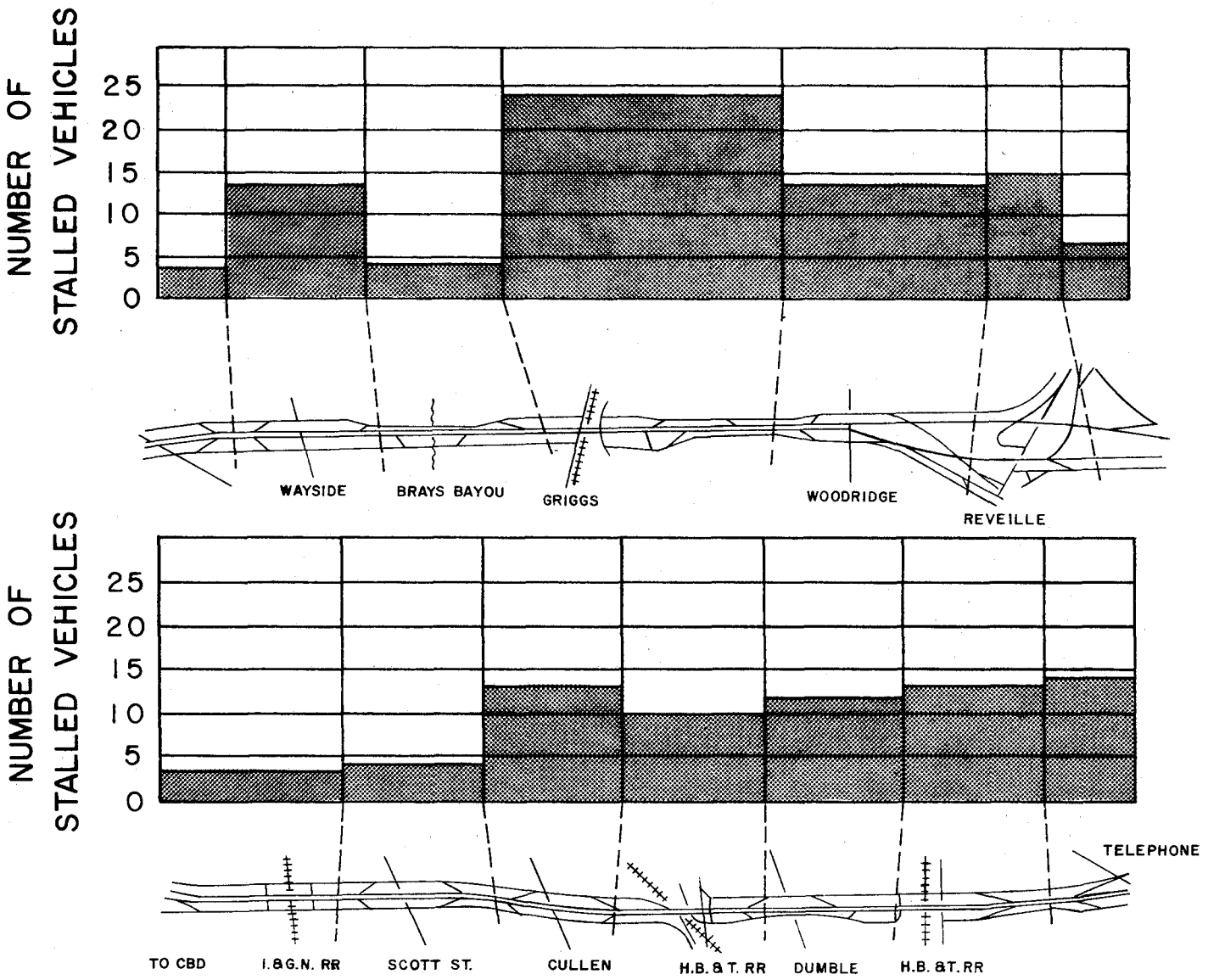

FIGURE 4 – DISTRIBUTION OF STALLED VEHICLES ON INBOUND GULF FREEWAY – 6:30–9:00 AM AND 4:30–6:00 PM

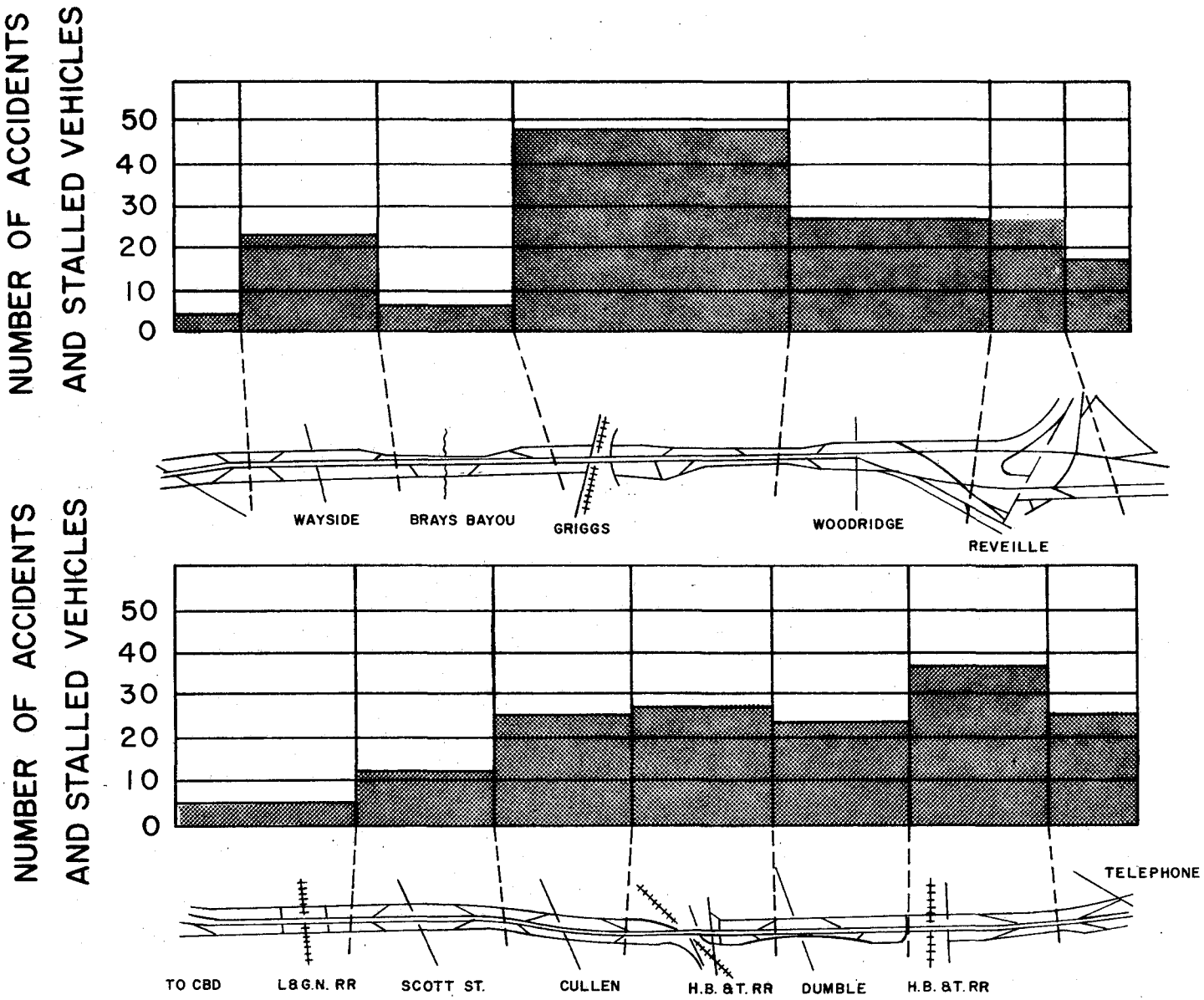

FIGURE 5 - DISTRIBUTION OF ACCIDENTS AND STALLED VEHICLES ON INBOUND GULF FREEWAY 6:30 - 9:00 AM AND 4:30 - 6:00 PM

in capacity would depend on the number of lanes blocked and the type of incident. Most of the incidents were found to block only one lane. Table 2 presents the number of lanes blocked by stalls and accidents as determined from the study. A greater proportion of stalls occurred in the outside lane whereas accidents were more uniformly distributed across the three lanes and ramps. In the usual case, only one lane was blocked by an incident. Only 11.5 percent of the accidents and 0.7 percent of the stalls blocked two or more lanes.

Four types of incidents were evaluated to determine their effects on reducing the capacity of the inbound Gulf Freeway. Table 3 summarizes the statistical results reported for each type of incident studied. It can be determined from Table 3 that a one lane blockage by a non-injury accident or stall reduces the capacity of the inbound Gulf Freeway by approximately 50 percent, even though the physical reduction in usable traffic lanes is only 33 percent. The presence of an accident on the freeway shoulder reduces the capacity by 33 percent of normal flow due to the effect of the "gapers block" phenomenon. An accident which blocks two lanes reduces the capacity by 79 percent compared to a 67 percent reduction in the number of available lanes.

A statistical analysis revealed that there was no significant difference between the capacities of single lane blocking accidents and those due to stalled vehicles. Thus, since stalls and single lane blocking accidents make up almost 95 percent of all incidents (Table 1), almost all incidents will reduce the capacity of the inbound Gulf Freeway to between 2750 and 2880 vehicles per hour for a period of time.

TABLE 2

CHARACTERISTICS OF LANE BLOCKAGE
BY STALLED VEHICLES AND ACCIDENTS
ON GULF FREEWAY

Lane Blocked	Stalls		Accidents	
	Number	Percent	Number	Percent
One Lane		86.2		63.5
Outside	432		244	
Center	231		204	
Median	299		284	
Two Lanes	8	0.7	111	9.6
Three Lanes	0	0.0	22	1.9
Ramps	134	12.0	238	20.6
Other	13	1.1	51	4.4
Total	1117	100.0	1154	100.0

Source: Reference 15.

TABLE 3

AVAILABLE CAPACITY ON INBOUND GULF FREEWAY DURING DIFFERENT INCIDENT CONDITIONS

Condition	Number of Incidents	Sample Size (No. Min.)	Average Flow Rate (Veh/Hr)
Normal Flow		312	5560
Stall (one lane blocked)	4	43	2880
Non-Injury Accident (one lane blocked)	17	167	2750
Accident (two lanes blocked)	6	53	1150
Accident on Shoulder	23	254	4030

Source: Reference 16.

Time Incidents Occur

Since the average rate of occurrence of incidents has a statistical nature and depends to a certain extent on the number of vehicle miles of travel, the occurrence of incidents would be expected to vary throughout the day as the volumes of the freeway change. The average percentage distribution of incidents per hour by time of day presented in Table 4 indicates this to be the case for the Gulf Freeway. Also shown in Table 4 is the average number of incidents that occur from Monday through Friday by time of day. An average of 3.3 incidents occur in the inbound direction within the surveillance area from Monday through Friday from 7-9 AM and 3.7 incidents per week occur from 4-6 PM. In addition, an average of 12.2 incidents occur per week from 6 AM to 6 PM in the inbound direction. These rates of occurrence are significant and are indicative of the need that exists on the inbound Gulf Freeway for providing freeway traffic information to improve traffic operations by increasing capacity and safety during incidents.

Time Freeway Susceptible to Incident

The previous results have indicated that incidents occur throughout the day on the inbound Gulf Freeway and that most incidents reduce the total capacity of the freeway to approximately 2880 vehicles per hour or less. Since congestion develops when traffic demand exceeds capacity, the inbound Gulf Freeway will be susceptible to congestion due to incidents during those periods of time when the normal freeway flow is greater than 2880 vehicles per hour. Volume counts taken over the entire day at the Griggs overpass in the inbound direction are presented in Figure 6. These

TABLE 4

INBOUND AND OUTBOUND INCIDENTS BY TIME OF DAY, DIRECTION OF TRAVEL AND AVERAGE NUMBER FOR WEEKDAYS, MONDAY-FRIDAY (1968-1969)

Hour Ending	Stalls %	Accidents %	Incidents %	Number of Incidents Monday-Friday Inbound	Outbound
7AM	4.4	3.8	4.2	.6	.4
8AM	13.8	11.6	12.4	1.9	1.0
9AM	8.5	10.1	9.3	1.4	.7
10AM	3.3	3.9	3.6	.5	.4
11AM	3.2	6.0	4.6	.6	.5
12 NOON	4.7	5.2	4.9	.6	.6
1PM	4.8	5.0	4.9	.6	.6
2PM	4.4	6.6	5.4	.6	.6
3PM	4.7	7.0	5.9	.7	.7
4PM	8.2	10.6	9.4	1.0	1.1
5PM	16.9	16.9	16.9	1.8	2.0
6PM	23.1	13.3	18.5	1.9	2.2
Total	100.0	100.0	100.0	12.2	10.8

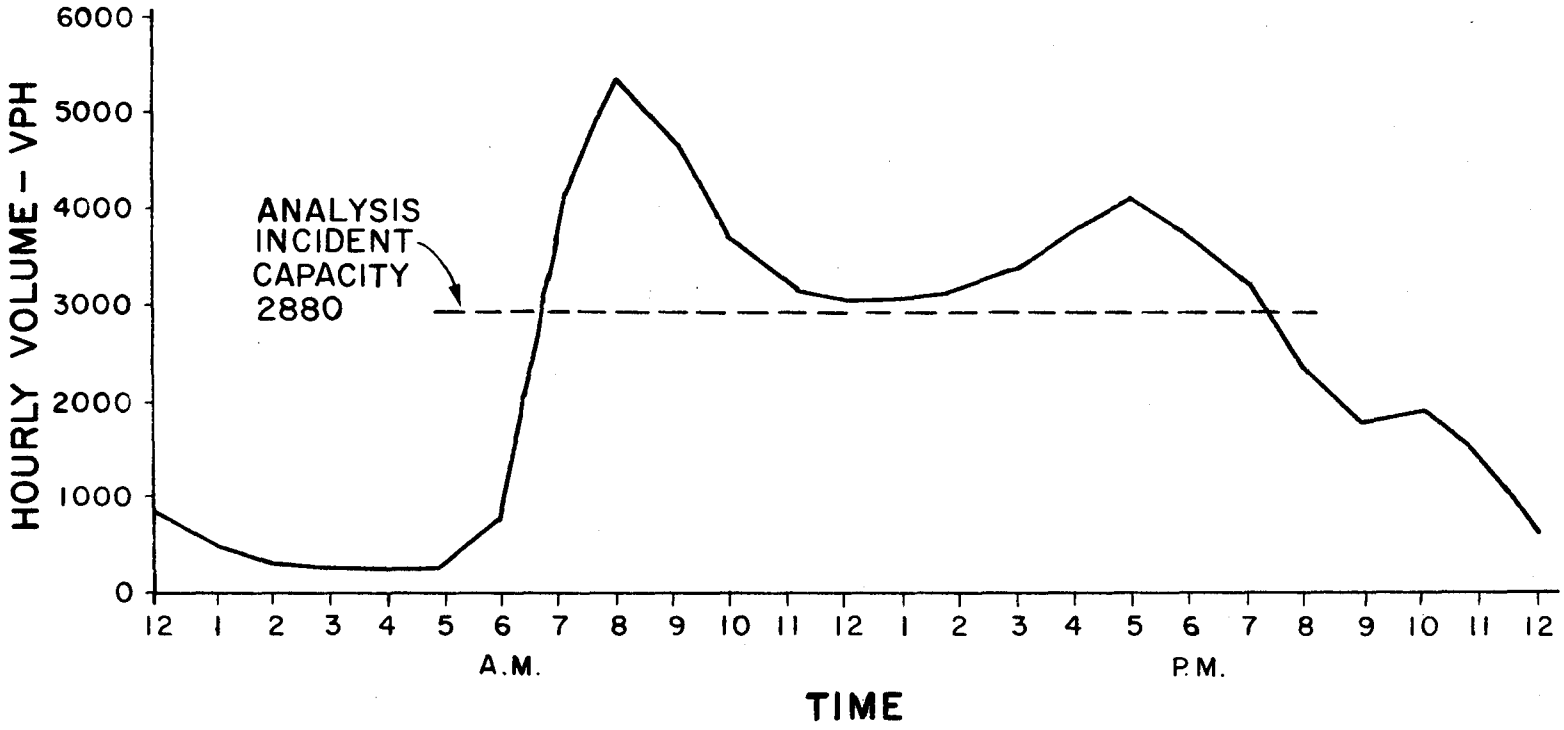

FIGURE 6 - INBOUND GULF FREEWAY INCIDENT CAPACITY AND 24-HOUR VOLUMES AT GRIGGS OVERPASS

results show that volumes exceed the incident capacity of 2880 vehicles per hour from 6 AM to 7 PM for a total of 13 consecutive hours. Thus, if an incident occurs during this period and exists for an extended interval of time, congestion can be expected to develop.

Duration of Incidents

A primary factor that influences the amount of congestion and delay that develops due to an incident is the time the reduction in capacity caused by the incident lasts. The longer the duration of the incident, the more severe will be the resulting congestion and delays.

Previous studies on the Gulf Freeway have indicated that accident and stalled vehicle incidents which require police assistance may exist for a considerable period of time (15), as is indicated in Table 5. For an average accident requiring police assistance, 19 minutes elapse from the moment the accident occurs until an increase in freeway capacity is obtained by removing the accident from the freeway lanes. An additional 25.6 minutes is required to complete the accident investigation which strongly suggests that the investigation not be conducted on the shoulder during heavy traffic conditions.

The results given in Table 5 also show that the average duration of stalled vehicles requiring police assistance is also considerable. These stalled vehicles would reduce the capacity of the freeway for an average duration of 18.3 minutes. Recalling from Table 3 that a stalled vehicle blocking a lane reduces the capacity almost as much as a single lane accident, it is apparent that significant delays can result due to stalled vehicles as well as accidents.

TABLE 5

AVERAGE TIMES REQUIRED FOR SERVICING
ACCIDENTS AND STALLED VEHICLES REQUIRING
POLICE ASSISTANCE ON GULF FREEWAY FOR 1968 AND 1969

Type of Incident	Event Serviced	Average Time of Event (min.)	Elapsed Time of Incident (min.)
Accident			
	Police Arrived	12.0	12.0
	Accident Removed	7.0	19.0
	Investigation Completed	25.6	44.6
Stall			
	Police Arrived	9.4	9.4
	Stall Removed	8.9	18.3

The variability in the time that incidents physically exist on the inbound Gulf Freeway is presented in Figure 7. These results were based on a sample of all incidents observed during 1968, 1969 and 1970, and not only those incidents requiring police assistance. The duration of an incident consists only of the elapsed time the incident vehicle was present and is not the time the congestion existed on the freeway. Thirty percent of all incidents were observed to last four minutes or less. Approximately 30 percent of all incidents were observed to last 13 minutes or more and 10 percent of all incidents were observed to last 30 minutes or more.

Consequences of Incidents

The consequences of incidents are usually directly related to the reduction in capacity that occurs and to the duration of time the incident reduces the capacity of the main-lanes of the freeway. The consequences are in the form of congestion, delay, shock waves in the traffic stream which lead to induced accidents, etc. The following model of a hypothetical incident on the inbound Gulf Freeway will be presented to illustrate some of the relationships involved.

It is assumed in Figure 8 that an average stalled vehicle incident requiring police assistance occurs at 7 AM on a lane of the inbound Gulf Freeway. This time is near the beginning of the peak rush hour. The total delay that results can be computed as the area enclosed between the normal inbound Gulf Freeway traffic demand curve and the output or capacity curve at the incident location. When the stall occurs, the slope of the capacity curve is reduced reflecting a reduction in freeway capacity from approximately 5700 vehicles per hour to 2880 per hour for a one lane

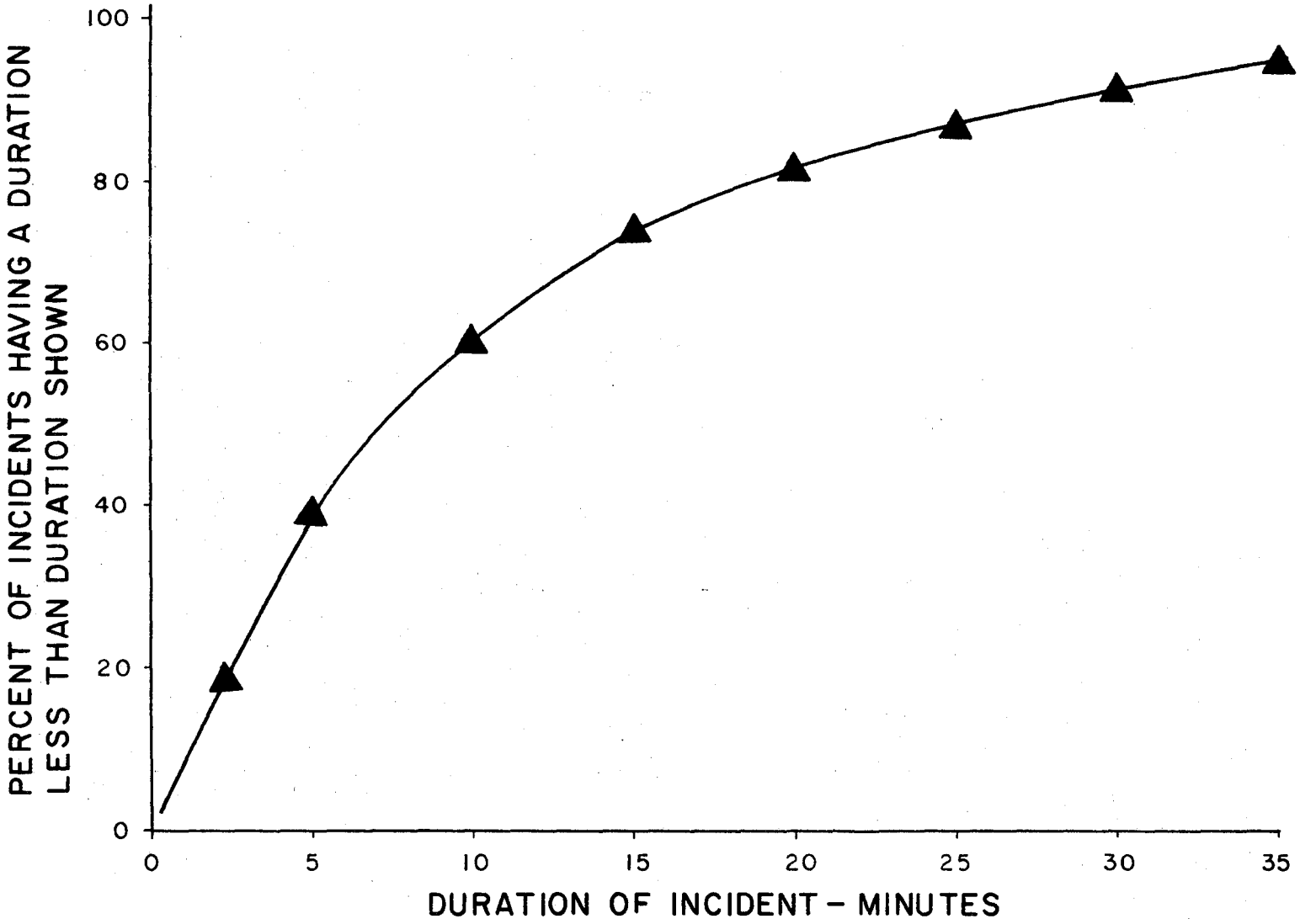

FIGURE 7 — CUMULATIVE DISTRIBUTION OF THE DURATION OF INCIDENTS ON GULF FREEWAY

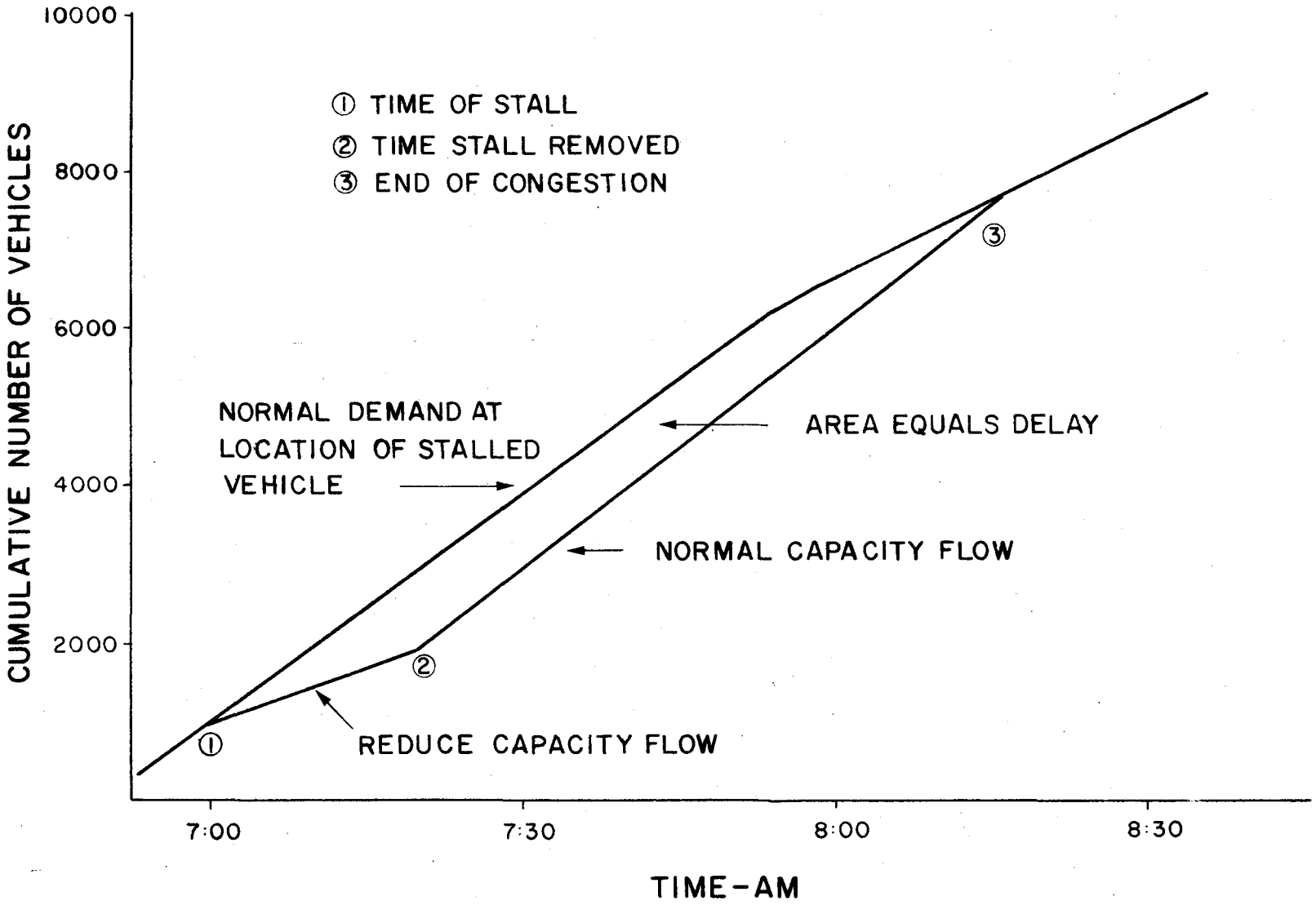

FIGURE 8– EXAMPLE OF DELAY CAUSED BY A STALLED VEHICLE BLOCKING ONE LANE AT 7A.M. ON INBOUND GULF FREEWAY

blockage due to a stall as was noted in Table 3. The slope of the capacity curve returns to normal when the stall is removed 18.3 minutes later (Table 5).

This hypothetical incident on the inbound Gulf Freeway would result in 800 vehicle hours of delay and an average delay per vehicle of approximately eight minutes. Similar computations for a one lane blockage accident yield 1010 vehicle hours of delay and an average delay of about 11 minutes per vehicle.

It can be seen from the previous example that on the average, delays would increase as the duration of the incident increases. Average travel times determined from travel time studies made on the inbound Gulf Freeway during incidents tend to substantiate this result. Figure 9 presents the average results of 63 travel times of vehicles traveling on the inbound Gulf Freeway from Broadway to Cullen during incidents of varying durations which occurred from 6:30 - 8:30 AM. A travel time was taken when the congestion due to the incident appeared to be near its maximum level. The results show that the average travel time and the delay per vehicle increases as the average duration increases.

These results suggest that the frequency and the variation in the duration of incidents occurring on the inbound Gulf Freeway are primary factors in determining the operating conditions of the freeway. The more frequently incidents occur, the more frequently congestion can result. The results of Figure 8 and 9 indicate that the longer the duration of the incident, the more likely severe delay is to occur.

The average number of incidents that occur from Monday through Friday

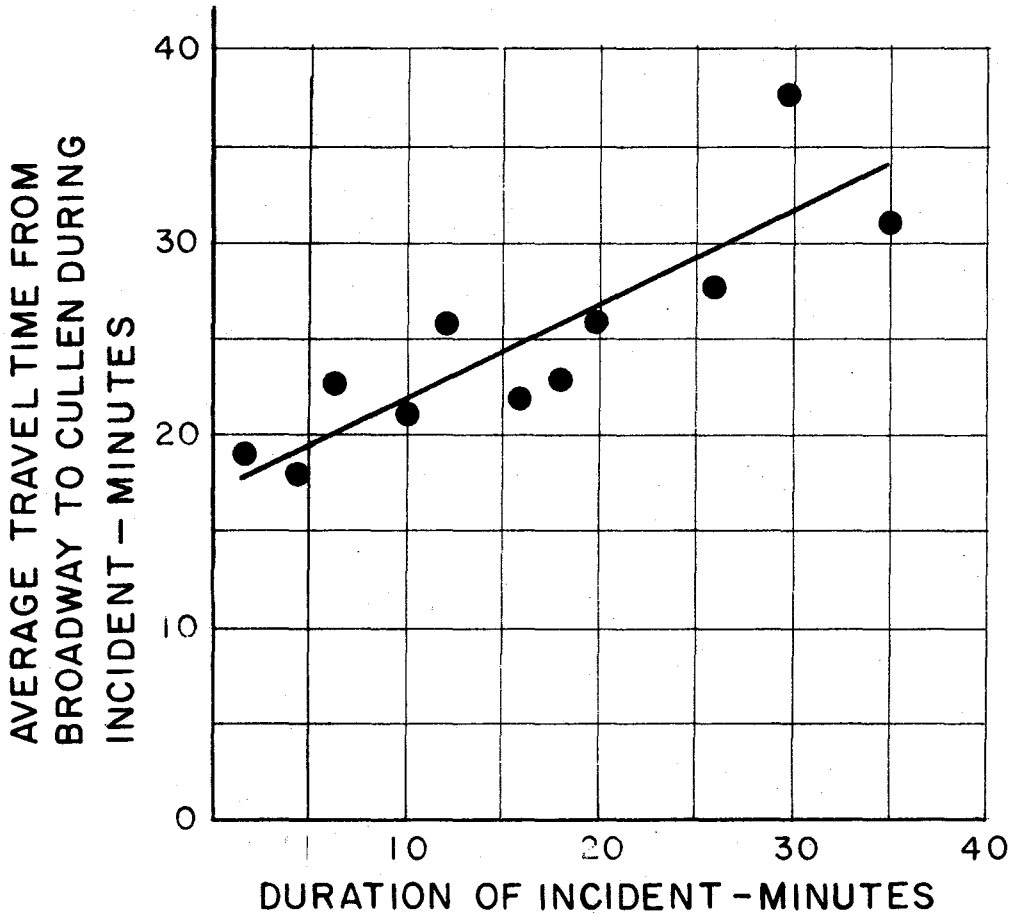

FIGURE 9 - AVERAGE TRAVEL TIME FROM BROADWAY TO CULLEN DURING INCIDENTS OF VARYING DURATION FROM 6:30 - 8:30 A.M.

during the hours of 6 AM to 6 PM was presented in Table 4. From 7 - 9 AM when the inbound traffic demand is the largest, a total of 3.3 incidents occur per week. While all of these incidents create a potential hazardous traffic environment which could induce traffic accidents, fortunately not all incidents result in excessive delays. This fact is due in part to the variability in the duration of incidents on the inbound Gulf Freeway as noted in Figure 7.

The effects of the variability of the duration of incidents is reflected in the distribution in travel times which result due to incidents on the inbound Gulf Freeway as depicted in Figure 10. Travel times of vehicles from Broadway to Cullen were recorded during the apparent maximum congestion for incidents which occurred from 6:30 - 8:30 AM. One travel time was recorded for each of 63 incidents which were studied in this manner during 1969 and 1970. The average normal travel time from Broadway to Cullen was 12 minutes. Thirty percent of the travel times were 23 minutes (11 minutes of delay) or longer. Five percent of the incidents resulted in delays of over 23 minutes.

Selection of Analysis Incident

It is apparent in Figure 10 that some incidents result in little delay while other incidents result in extensive delays. In the following chapter, an analysis will be presented which compares the travel times of alternate routes to those of the inbound Gulf Freeway during an incident. It was necessary to select some incident severity level (cumulative percentile in Figure 10) for the analysis. Minor incidents would occur frequently but the consequences would not justify their use, whereas catastrophic

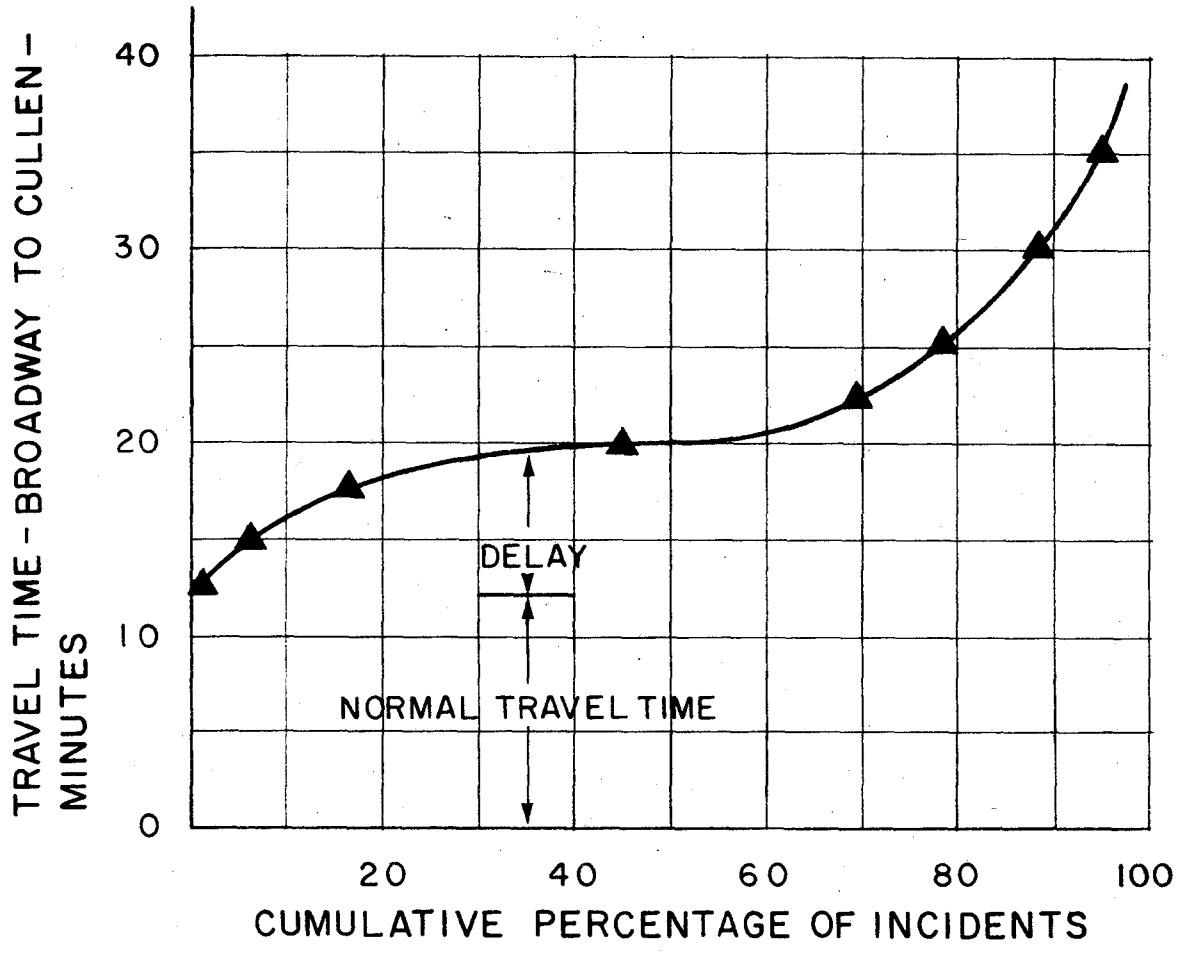

FIGURE 10 – TRAVEL TIME AND DELAY FROM BROADWAY TO CULLEN AS RELATED TO INCREASING SEVERITY OF INCIDENTS FROM 6:30 – 8:30 A.M.

incidents would result in major delays but it would not occur frequently enough to consider using in the analysis.

The analysis incident level selected was that incident severity which would be equalled or exceeded once per week by incidents on the inbound Gulf Freeway from 6:30 - 8:30 AM. In order to determine the resulting cumulative percentile level in Figure 10, note from Table 4 that an average of 3.3 incidents occur from 7 - 9 AM. It is assumed that the incident rate from 6:30 - 8:30 AM, the desired time interval, is the same as from 7 - 9 AM. As was indicated in Figure 10, only a portion of the 3.3 incidents assumed to occur from 6:30 - 8:30 AM result in significant delays. The most severe 30 percent of the total 3.3 incidents would occur at the selected frequency of once per week. (e.g. 30% x 3.3 = 0.99 incidents per week) The most severe 30 percent is equivalent to the 70th percentile incident of Figure 10. This analysis incident would result in a sizeable 11 minutes of delay for motorists traveling from Broadway to Cullen (Figure 10), yet it occurs frequently enough to justify its use.

Summary

Incidents have been shown to frequently occur over the entire length of the inbound Gulf Freeway from Broadway to Cullen. These incidents significantly reduce the capacity of the freeway and congestion could result from 6 AM to 7 PM due to them. Approximately 13 lane blocking incidents would be expected to occur per week during the 6 AM - 7 PM time period when the freeway is susceptible to incidents. At least one major incident occurs on the average from 6:30 - 8:30 AM per week. Many minor incidents occur

throughout the day resulting in shock waves in the traffic stream. Thus, a real-time freeway traffic information system is needed in the inbound Gulf Freeway corridor to reduce congestion, and to improve traffic operations, safety, and the level of service afforded the inbound Gulf Freeway motorists.

III. ALTERNATE ROUTES IN THE INBOUND GULF FREEWAY CORRIDOR

A large percentage of the morning rush hour trips which use urban freeways are home-to-work trips. These repetitive commuter trips usually begin on residential streets, proceed to progressively larger arterials and reach the freeway at the motorists' normal points of entry. The net result of many motorists' desiring to use the freeway at the same time for a portion of their trips creates heavy traffic demand on the freeway. Since one method of improving freeway operations during a major incident on the freeway is to reduce the traffic demand on the freeway, it is fortunate that many motorists desiring to use the freeway have alternate routes available. Some alternate routes may not include the freeway, whereas other alternates may lead to the freeway at different locations than would be normally used. Motorists appear to be rather familiar with the characteristics of their alternate routes and have subjectively evaluated them based on their own personal driving experiences.

The concept of alternate routes used here does not include diversion along frontage roads to bypass a congested section of freeway. Diversion along frontage roads is very important to the overall effort of reducing congestion during incidents. However, frontage road diversion requires a unique coordination of frontage road and freeway traffic information and control and, therefore, merits a separate analysis which will be presented in the next chapter.

The selection of a particular route by a motorist may be the result of an impulse action, or the result of a rational decision based upon some

real-time cue received prior to the selection. However, few accurate and timely real-time cues are presently available to the urban motorist. The clock may provide the motorist with a cue to historical traffic conditions, or perhaps the driver may make his decision to select an alternate route based on the fact that he has been experiencing unusual traffic congestion along his normal route. Some urban drivers are using commercial radio broadcasts of traffic information as a real-time cue (8). However, based on the observed repeatability of freeway entrance ramp traffic volumes, most drivers apparently take their usual routes to the freeway even when major incidents have occurred on it. This is due to the fact that meaningful freeway traffic information is not presently available to them before they reach their decision points with respect to their alternate routes.

Thus, if timely, accurate, and meaningful freeway traffic information were provided motorists while alternate routes are still available, an increase in the usage of the alternate routes could be expected when the freeway is heavily congested. A reduction in freeway congestion and delay could be expected as a consequence of this reduction in freeway traffic demand, thereby reducing total system travel time which includes the travel times of the diverted motorists.

The diversion of freeway demand to alternate routes requires that these alternatives have the capability of carrying the additional diverted traffic. In addition, they must be more desirable to the prospective drivers to be diverted than the congested freeway. The exact factors that motorists consider in determining the desirability of an alternate route has not been well established. It is reasoned that the travel time savings obtained,

when an alternate route is taken instead of a congested freeway, would probably be an indicator of the desirability of the alternate. Other more qualitative indicators may be the driver effort required in rerouting, the amount of circuitous travel, familiarity with the route, adjacent land uses, etc.

An investigation was made of four major arterials in the inbound Gulf Freeway corridor to determine if these arterials could meet the alternate route requirements of capacity and desirability. Capacity studies and turning movement counts at critical intersections were made to determine unused capacity which would be available for diverted traffic. Travel time and traffic operations studies were conducted on the arterials and the inbound Gulf Freeway to evaluate whether motorists might consider the arterials to be acceptable alternate routes.

Description of the Corridor

The inbound Gulf Freeway corridor consists of several skewed arterial and collector grid patterns with the inbound Gulf Freeway running north through the corridor (Figure 11). Trip origins for motorists using the inbound freeway occur mainly in the Pasadena area, along the southern part of the freeway, and in southern Houston. This traffic has four basic destination points: 1) the CBD, 2) northern Houston, 3) the Southwest Freeway area, and 4) major generators adjacent to the Gulf Freeway, e.g., University of Houston.

Freeway Travel Time and Delay

The travel time on the inbound Gulf Freeway during an incident can be assumed to consist of the normal travel time plus the delay time caused by

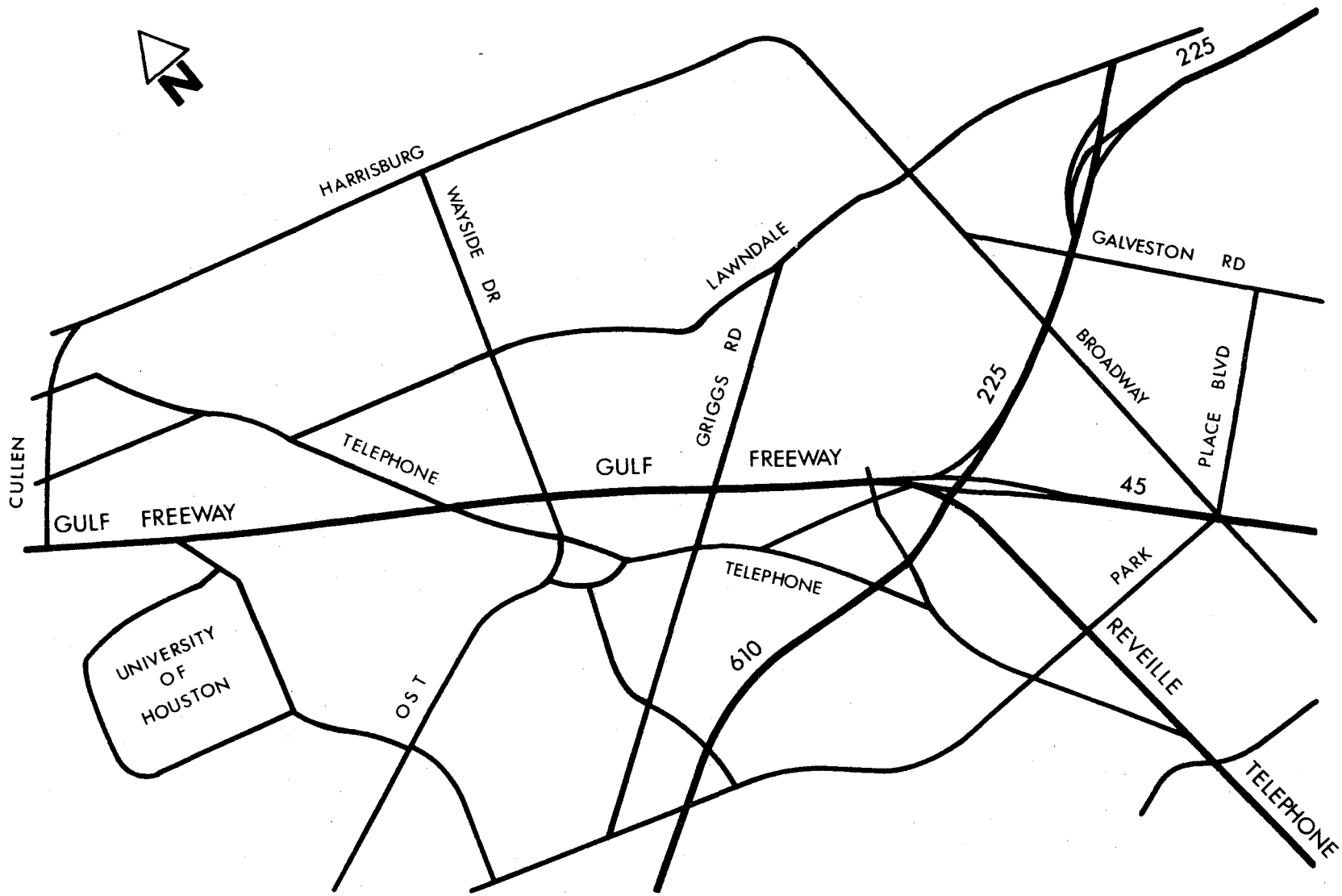

FIGURE II - INBOUND GULF FREEWAY CORRIDOR

the incident. In this analysis the "analysis incident" selected was the 70th percentile incident which has the characteristics of resulting in more delay than 70 percent of all incidents observed from 6:30-8:30 AM (Figure 10) and occurs approximately once per week during this time period. The incident would be classified as a major incident even though 30 percent of the incidents observed on the inbound Gulf Freeway resulted in more delay.

Travel time data were analyzed for incident and non-incident days during 1969 and 1970 for the inbound Gulf Freeway to determine the expected delays that would result when the selected analysis incident occurs between 6:30-8:30 AM. The average travel time and delay results are presented in Table 6. Increasing incident severities in cumulative percentiles are shown to indicate the sensitivity of delay to incident severity. The 70th percentile incident corresponds to the analysis incident, whereas the zero percentile incident represents average normal traffic conditions from 6:30-8:30 when no incidents have occurred.

Travel times were recorded for vehicles from Broadway to Cullen (See Figure 10), which is the maximum coverage possible with the television surveillance system, and from Woodridge to Cullen. As is given in Table 6, the analysis incident results in an 11 minute delay per vehicle to traffic using the inbound Gulf Freeway from Broadway to Cullen. Five minutes of delay would be experienced by motorists from Woodridge to Cullen. It is indicated that six minutes of delay would occur from Broadway to Woodridge in the Reveille Interchange area. Operational experience indicates that the delay from Bellfort to Broadway is approximately the same as from

TABLE 6

TRAVEL TIMES AND DELAYS ON INBOUND GULF FREEWAY
FROM 6:30-8:30 AM AS A FUNCTION OF INCIDENT SEVERITY

Location and Results	Cumulative Percentile Incident 0% (No Incident)	67% (Analysis Incident)	95%
Broadway to Cullen			
Travel Time	12	23	35
Delay	0	11	23
Woodridge to Cullen			
Travel Time	9	14	22
Delay	0	5	13
Broadway to Woodridge			
Travel Time	3	9	13
Delay	0	6	10
Bellfort to Cullen			
Estimated Delay	0	17	33

Broadway to Woodridge during a major incident (six minutes). Thus, the estimated delay from Bellfort to Cullen would be 17 minutes during the analysis incident.

Surveillance of the S.H. 225 and S.H. 35 controlled entrance ramps has shown that traffic may experience considerable delays at these ramps also. At 7:30 AM a vehicle normally takes ten minutes to travel through the S.H. 225 ramp queue and about eight minutes at the S.H. 35 ramp. Based on previous observations, it is estimated that the travel time through these queues would double during the analysis incident.

Travel Times on Alternate Routes

Field investigations have established four possible alternate routes which might be used instead of the inbound Gulf Freeway by Pasadena and southern Houston motorists to destinations in downtown and northern Houston. These four alternate routes, the corresponding freeway route, and their associated distances are given in Table 7. The characteristics and acceptability of the alternate routes will be presented. It should be noted that other routes to the downtown area that remain to the west of the freeway have been eliminated as candidates since the traffic would either be required to pass by the University of Houston campus, or take extended and discontinuous routes.

Harrisburg Route: Figure 12 is a map showing the location of the location of the Harrisburg route and the normal freeway route. Harrisburg is a possible alternate route to downtown for traffic originating in the Pasadena area. As noted in Figure 12, the Harrisburg route begins near Pasadena on Lawndale at Allen-Genoa. It follows Lawndale to Broadway,

TABLE 7

CANDIDATE ALTERNATE ROUTES FOR
INBOUND GULF FREEWAY TRAFFIC

Alternate	Distance to Cullen (miles)	Freeway	Distance to Cullen (miles)
Harrisburg	7.2	225-Gulf Fwy.	6.8
Lawndale	6.8	225-Gulf Fwy.	6.8
Bellfort	7.2	Gulf Fwy.	5.9
Telephone	5.9	35-Gulf Fwy.	5.8

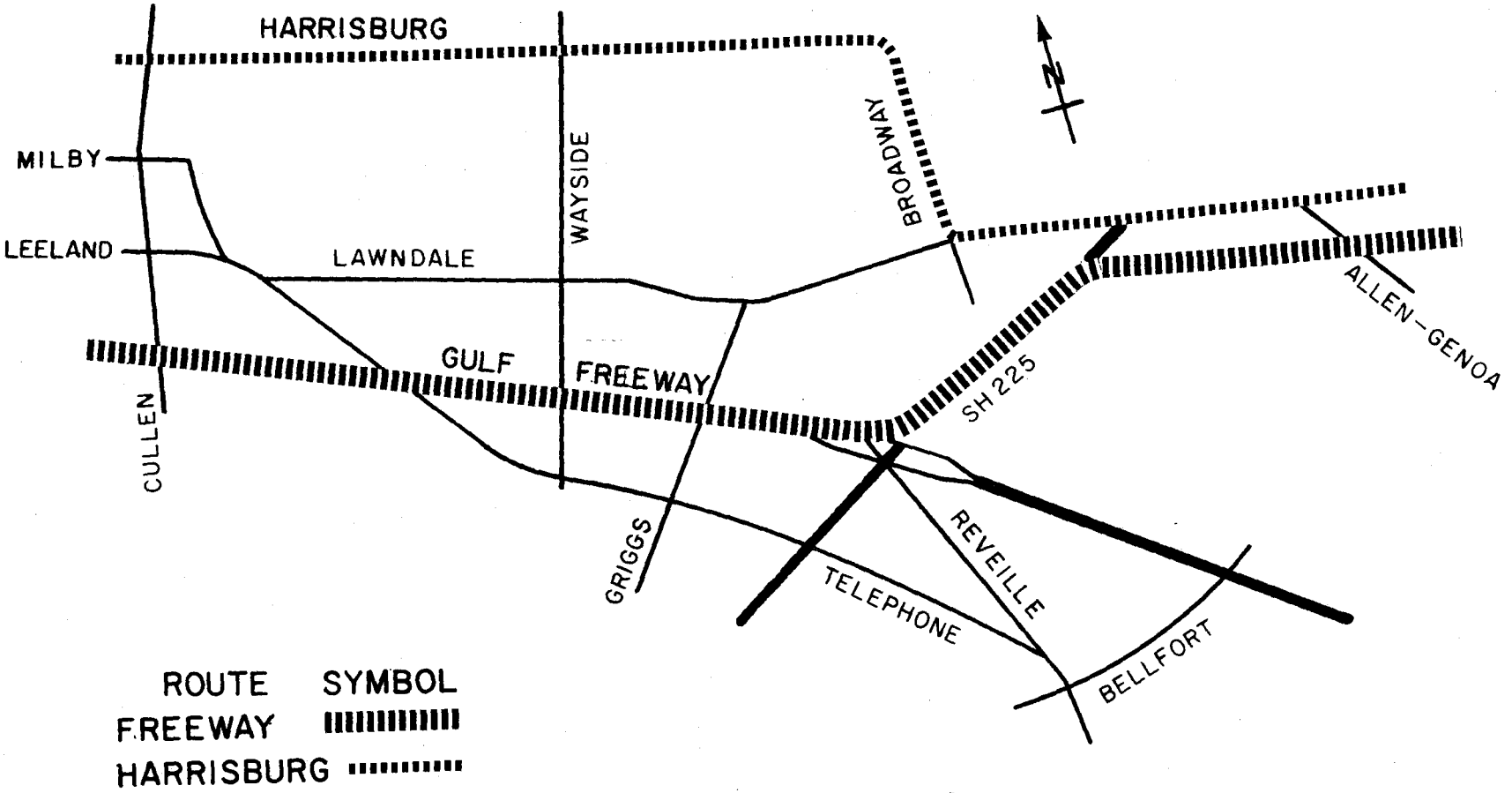

FIGURE 12 - HARRISBURG ALTERNATE ROUTE

along Broadway to Harrisburg, and continues along Harrisburg to Milby. The normal freeway route from Pasadena to the downtown area begins on S.H. 225 at Allen-Genoa, entering the Gulf Freeway at the S.H. 225 entrance ramp at the Reveille Interchange. It then follows the inbound Gulf Freeway to Cullen.

Travel time studies for both the normal freeway route and the Harrisburg route were made during the morning rush hours under normal traffic operations and the results are shown as the bottom two curves in Figure 13. Usually the freeway route was faster, however, some queueing delay was experienced during the peak period while the S.H. 225 entrance ramp was under control. The freeway travel time during the analysis incident (the top curve in Figure 13) was determined by adding the delays expected to the freeway route's normal travel time. From zero to ten minutes of delay occur at the S.H. 225 entrance ramp depending on the time in the morning and five minutes of delay would be experienced from Woodridge to Cullen, as shown in Table 6. Thus, a total delay of from five to fifteen minutes would result due to the incident.

Lawndale Route: As is depicted in Figure 14, this route is similar to the Harrisburg route in that it can serve the Pasadena motorists and the decision point for taking it is also on Lawndale at Allen-Genoa. However, it is slightly shorter and closer to the Gulf Freeway than the Harrisburg route. The close proximity of the Lawndale route to the Gulf Freeway would allow drivers to return to the freeway, perhaps along Griggs (Figure 15) or Wayside (Figure 16), enter the CBD in the same general area as the freeway, or conveniently reach the University of Houston campus.

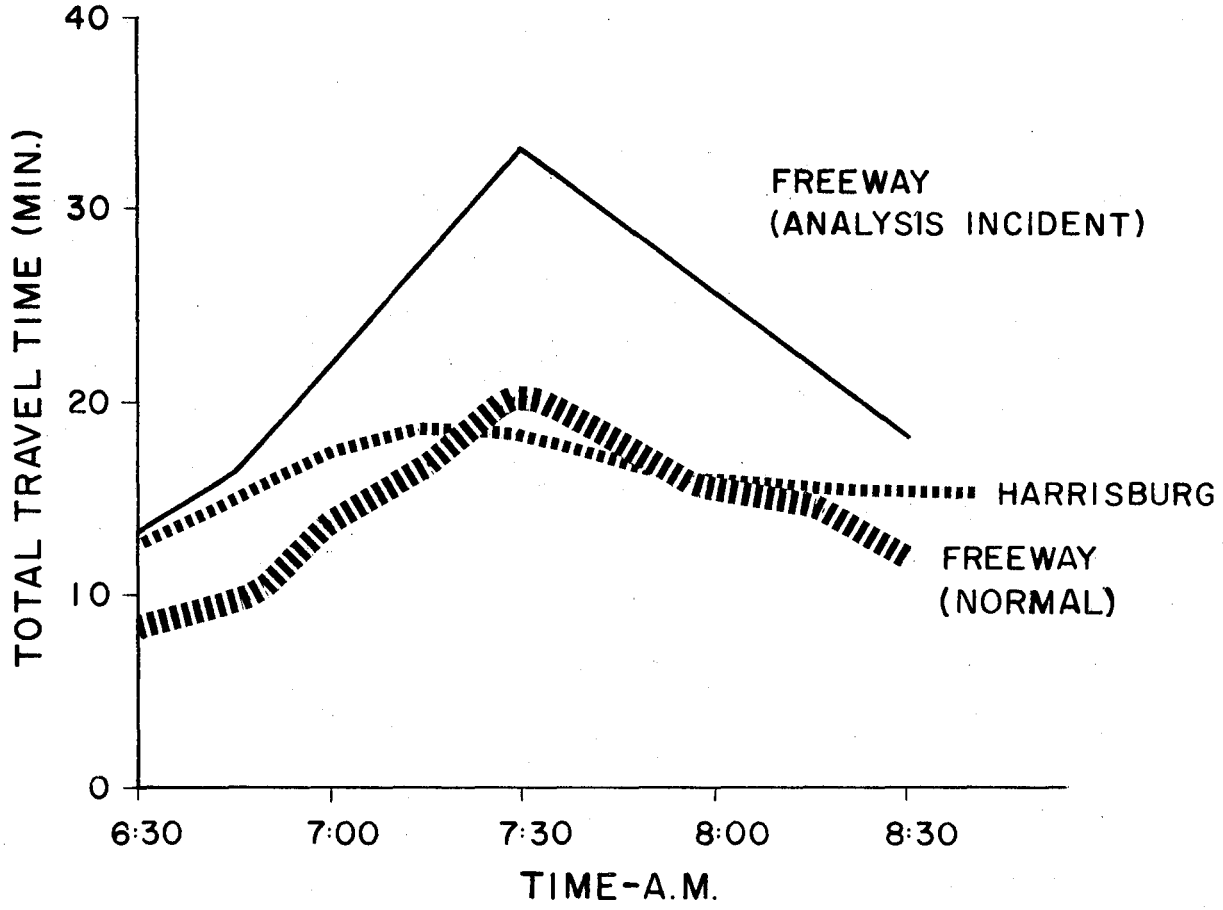

FIGURE 13 – TRAVEL TIME ON HARRISBURG ALTERNATE ROUTE AND ON FREEWAY – 6:30 – 8:30 A.M.

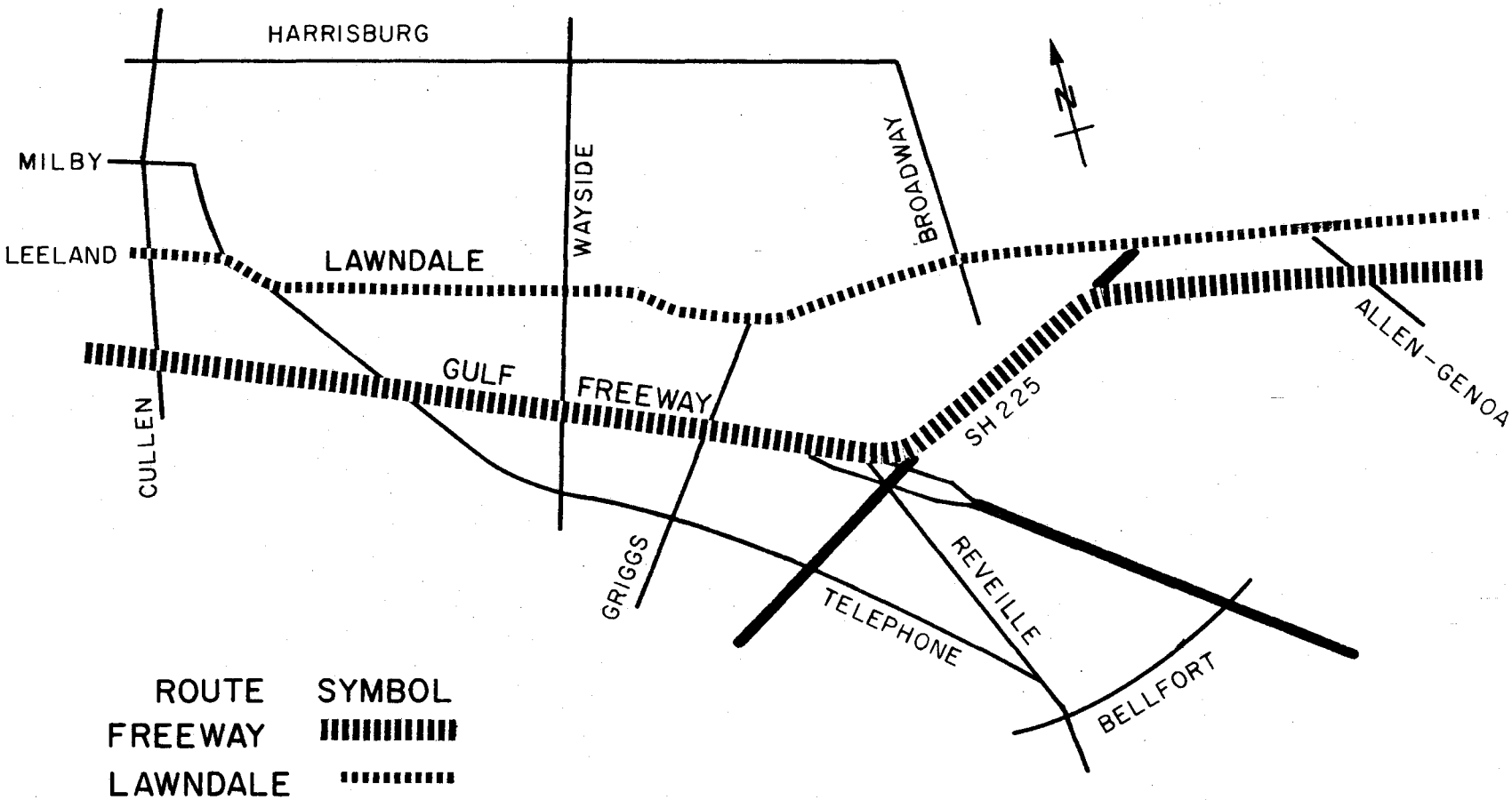

FIGURE 14 – LAWNDALE ALTERNATE ROUTE

FIGURE 15 - LAWNDALE AT GRIGGS

FIGURE 16 - LAWNDALE AT WAYSIDE

The comparison of travel times for the two routes is shown in Figure 17. The lower two curves were determined from travel time runs taken during non-incident days. As similarly presented for the Harrisburg route, the freeway travel times during the analysis incident are shown in the uper curve and are the same as is the previous case. The Lawndale alternate route travel times are less than the freeway when an analysis incident occurs on the freeway.

Bellfort Route: The Bellfort alternate route depicted in Figure 18 begins near the Gulf Freeway, proceeds along Bellfort to Telephone, and follows Telephone to Cullen. It provides an alternate route to the inbound Gulf Freeway for traffic originating in the southeastern part of the corridor. This traffic, which may normally use S.H. 3 (Winkler), Broadway, or Bellfort to get to the freeway, could take the Bellfort route to avoid a congested section of the inbound Gulf Freeway. The route is 1.3 miles longer than the normal freeway route.

Travel times under normal conditions, as shown by the lower two curves in Figure 19, indicate that the freeway is considerably faster than the alternate by about 8 minutes. A major incident on the Gulf Freeway will cause considerable delay, frequently creating freeway queues to Bellfort. The delay of 17 minutes from Bellfort to Cullen due to an analysis incident given in Table 6 was added to the normal freeway curve to yield the upper design incident curve for the freeway route. Again, the Bellfort route is faster than the freeway when the analysis incident has occurred on the freeway.

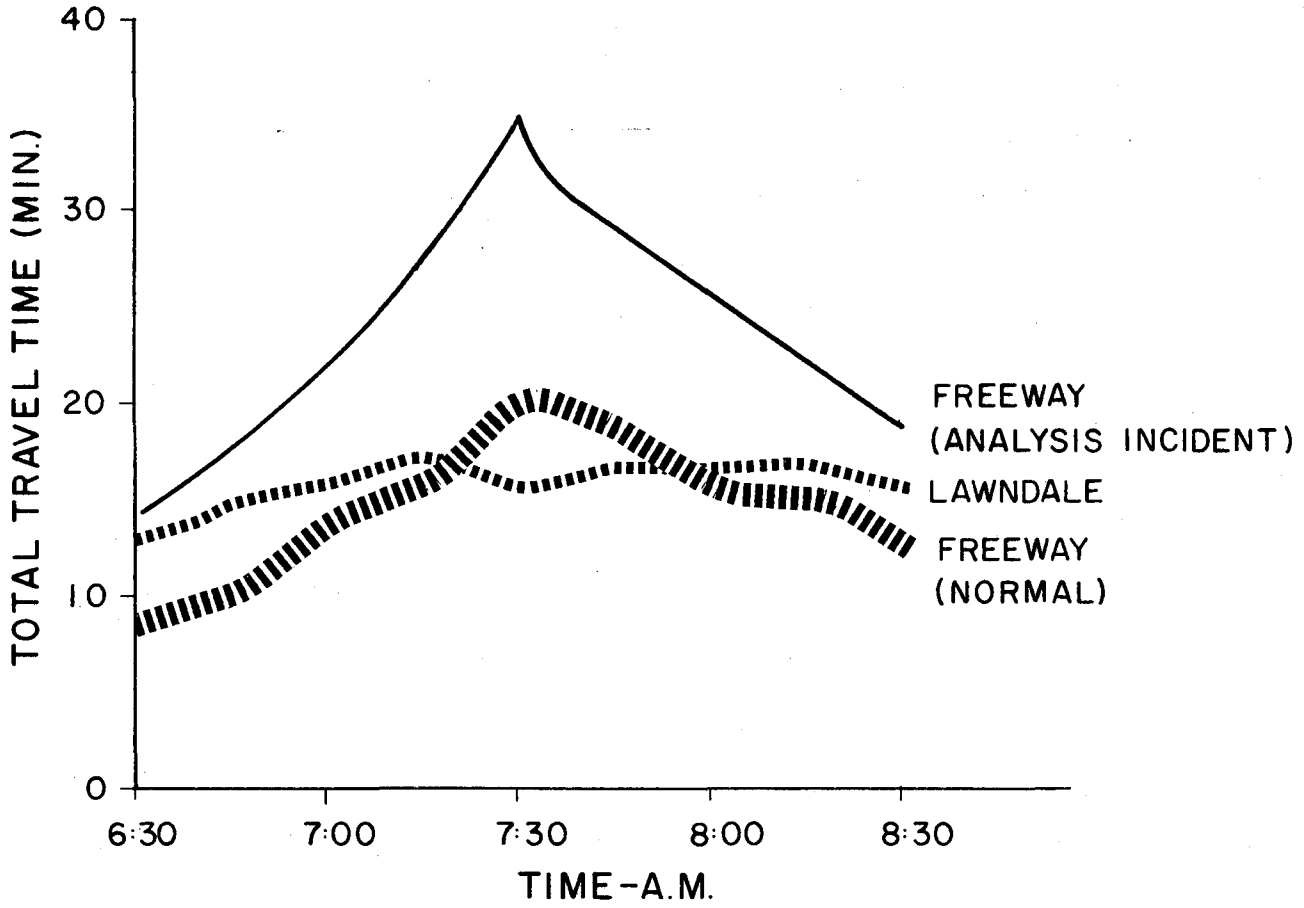

FIGURE 17 – TRAVEL TIME ON LAWNDALE ALTERNATE ROUTE AND ON FREEWAY – 6:30 – 8:30 A.M.

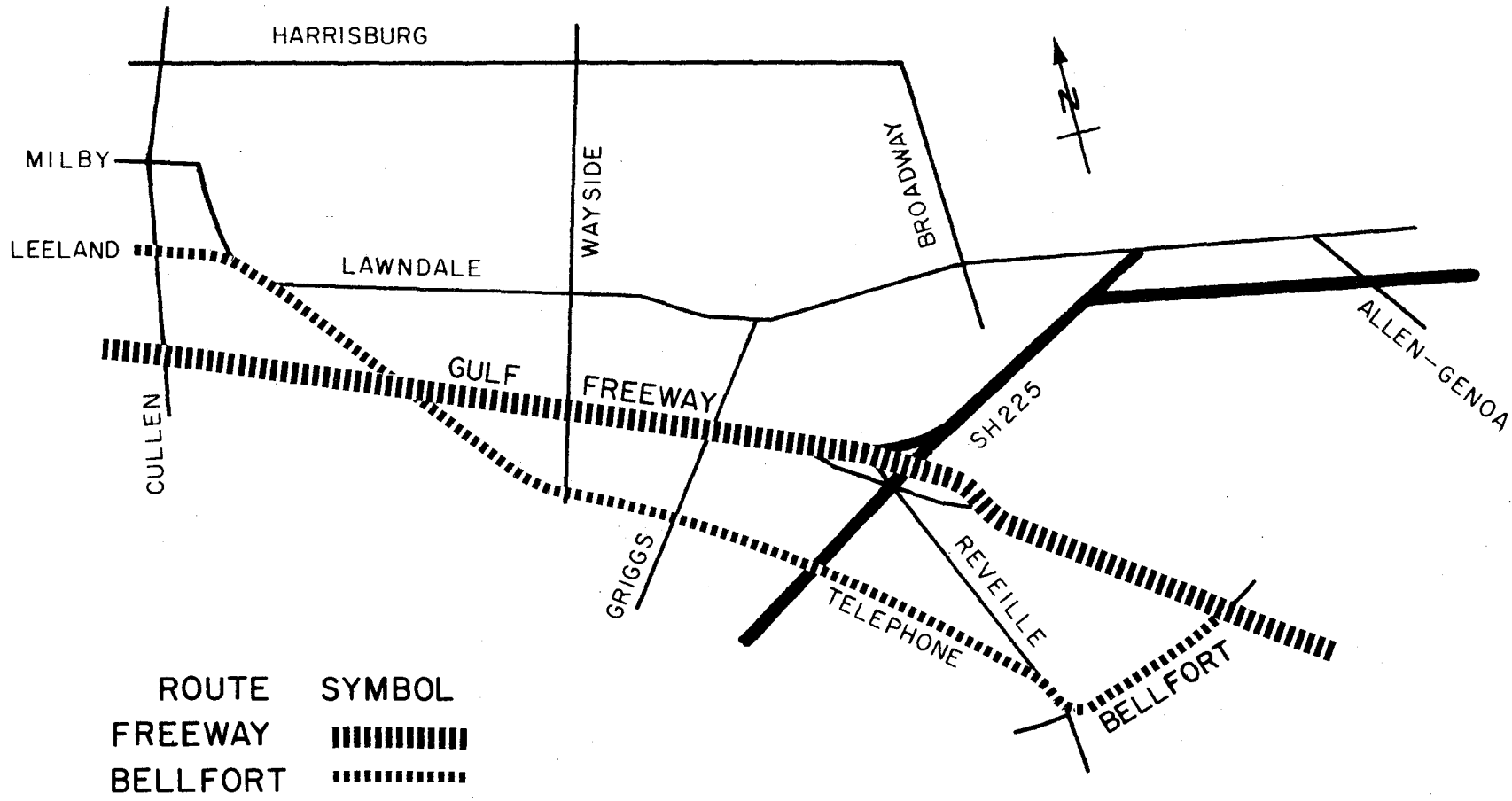

FIGURE 18 - BELLFORT ALTERNATE ROUTE

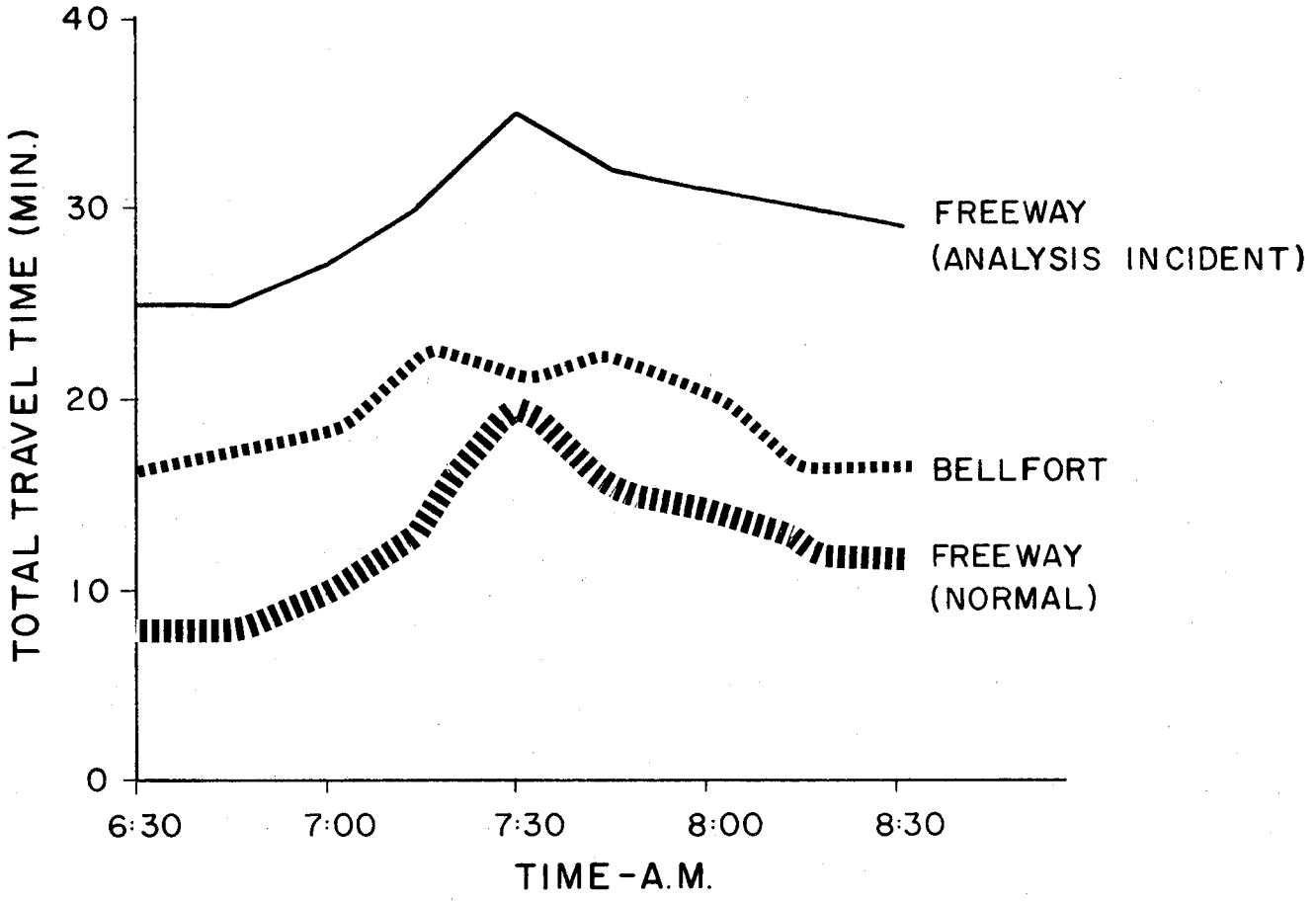

FIGURE 19- TRAVEL TIME ON BELLFORT ALTERNATE ROUTE AND ON FREEWAY - 6:30-8:30 A.M.

Telephone Route: The Telephone route begins on the west side of the freeway and follows Telephone Road underneath the freeway to the east side near downtown, as shown in Figure 20. This route begins on Telephone at Bellfort (Figure 21) and ends at Cullen. The usual inbound Gulf Freeway route for the motorists in southern Houston near Hobby Airport begins on Telephone. It then leaves Telephone (Figure 22) and extends along S.H. 35 (Reveille) to the S.H. 35 entrance ramp onto the Gulf Freeway and then follows the inbound Gulf Freeway to Cullen. Queueing delay occurs at the S.H. 35 entrance ramp during control similar to the S.H. 225 entrance ramp. Figure 23 shows the comparison of travel times for the freeway route and the Telephone alternate route during non-incident days and the freeway route when the analysis incident occurs on the freeway. Incident delay time includes five minutes from Woodridge to Cullen plus 0-8 minutes at the S.H. 35 entrance ramp, depending on the time of day.

The travel time characteristics of the freeway and four alternates have been presented. In general, the freeway route is faster under normal conditions. However, when an analysis incident occurs on the inbound Gulf Freeway, the alternate routes were faster.

Diversion Capabilities of Alternate Routes

Diverting traffic from a congested freeway to an alternate route must be done only when traffic operations warrant. For example, in order to avoid shifting much of the delay from the freeway to the alternate route, the amount of traffic diverted should not exceed the available capacity of the alternate route. This section is an evaluation of the four candidate alternate routes' capabilities for carrying additional traffic.

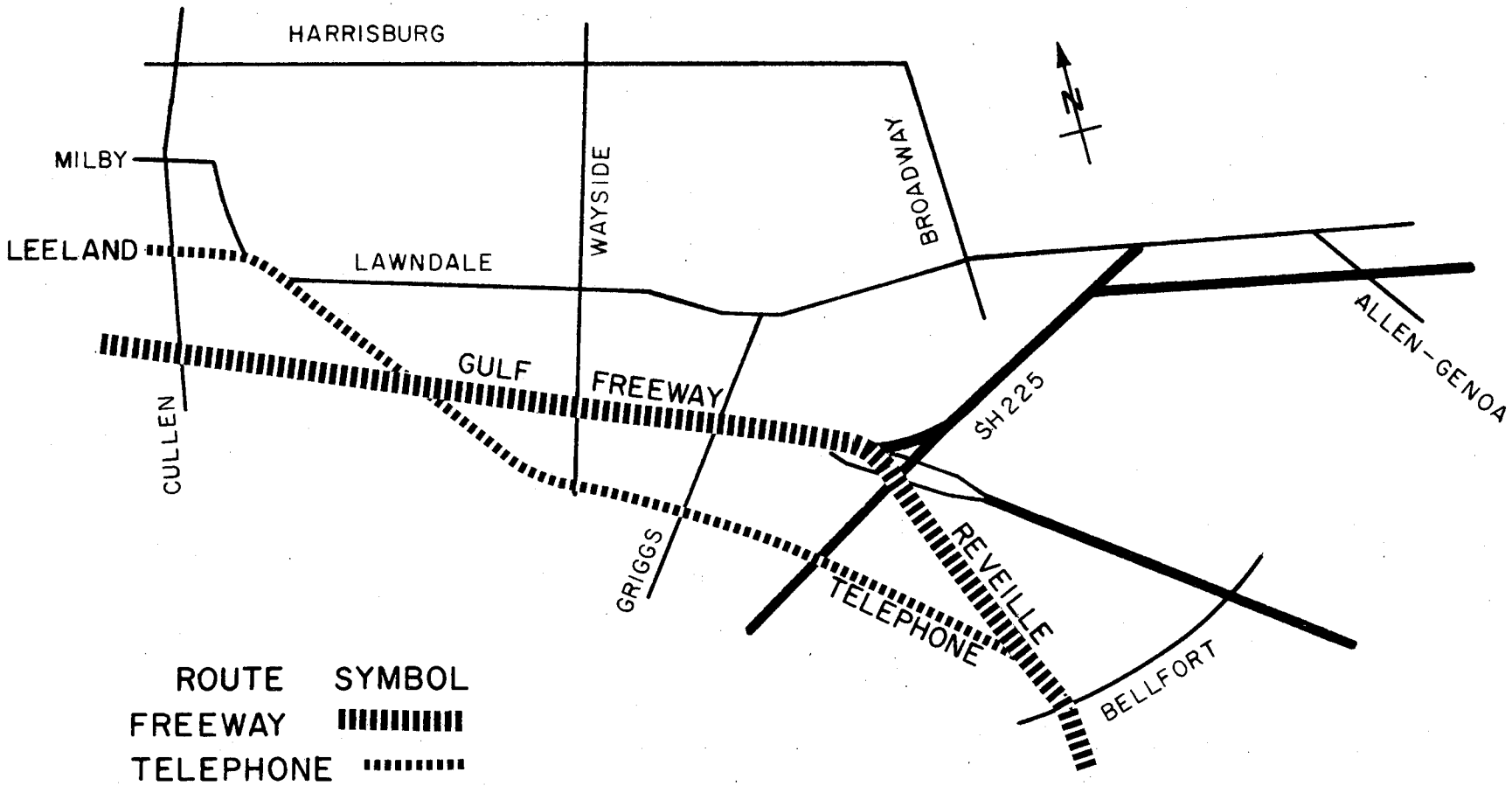

FIGURE 20- TELEPHONE ALTERNATE ROUTE

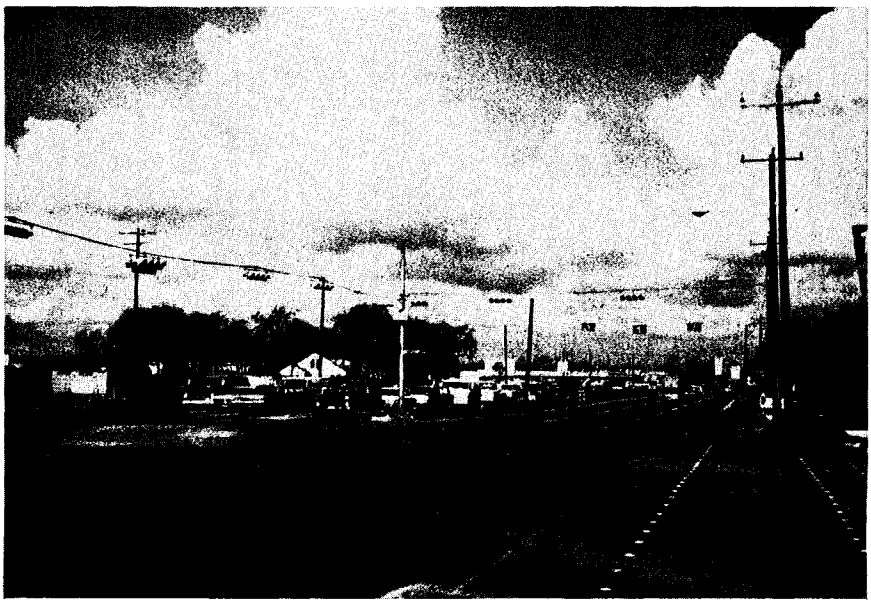

FIGURE 21-TELEPHONE AT BELLFORT

FIGURE 22-TELEPHONE AT S.H. 35

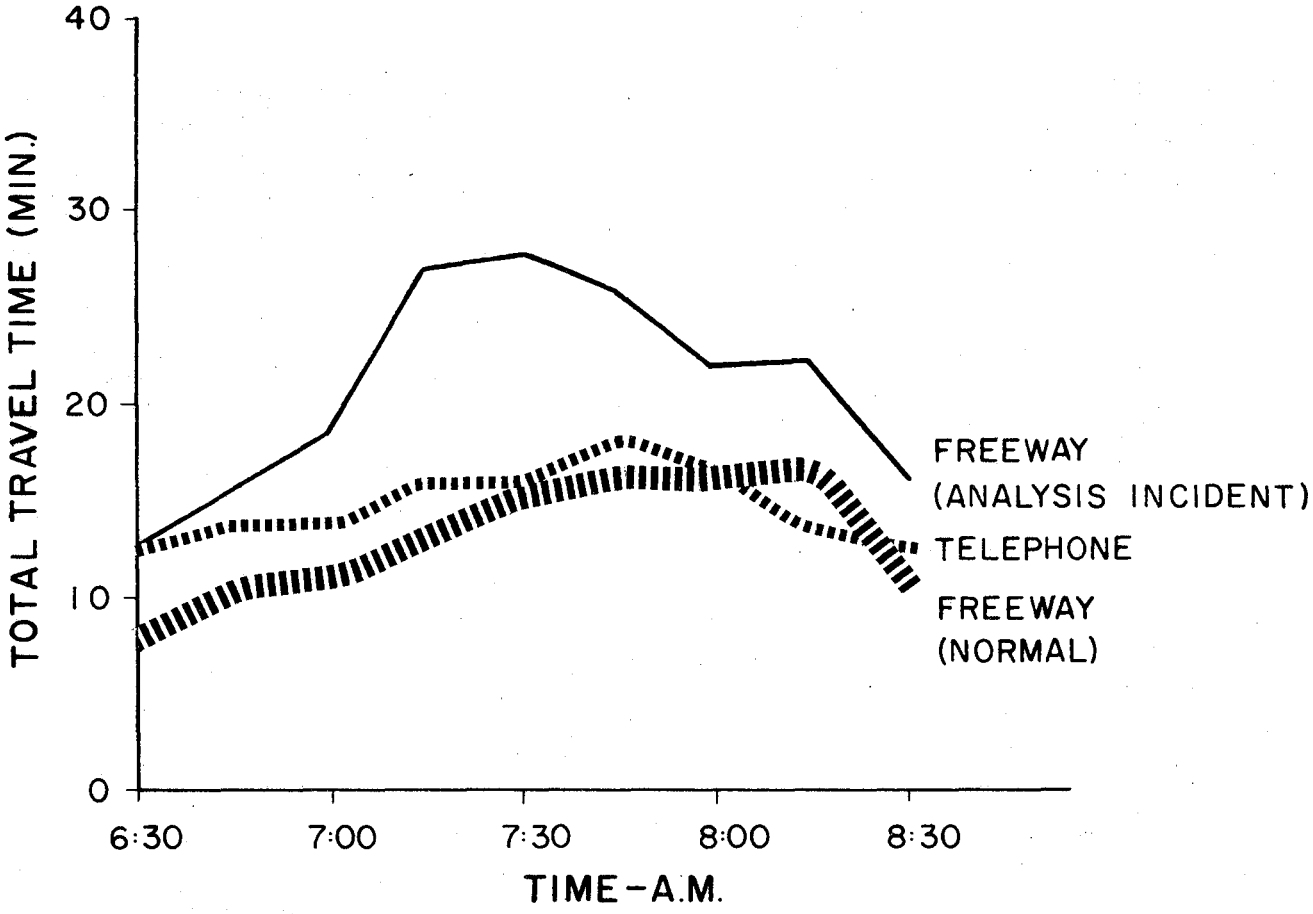

FIGURE 23— TRAVEL TIME ON TELEPHONE ALTERNATE ROUTE AND ON FREEWAY — 6:30-8:30 A.M.

The critical locations along these alternate routes within the corridor are at intersections with major cross streets. Table 8 is a list of the signalized intersections on the alternate routes. Those intersections which field observations revealed were possibly critical and merited further capacity analyses are also noted. Information collected at these potential bottleneck intersections included movement counts by five minute intervals, the signal phase timings, and the number of loaded cycles. Intersection and directional capacity calculations were made at 12 of these critical intersections. Calculations were made according to the Highway Capacity Manual (17). Table 9 is a summary of the capacity calculations, present demand, and diversion capacity for the inbound AM traffic movement.

Harrisburg Route: The Harrisburg route has adequate capacity for carrying approximately 250 vehicles per hour of diverted traffic. This capacity appears to be sufficient for the amount of diversion that might be possible since its location is probably unattractive to most drivers.

Lawndale Route: Two intersections on the Lawndale route are critical and will cause some delay. The Griggs-Lawndale intersection consists of five major legs with a railroad track crossing the center of the intersection. The fully actuated signals enable some additional capabilities for diversion (about 200 vph). The Lawndale-Wayside intersection is a potential bottleneck, but its modern traffic control equipment should keep delays to an acceptable level. This route is capable of carrying an additional 200 vph without significantly increasing the travel time or the need to modify existing signal control.

TABLE 8

SIGNALIZED INTERSECTIONS ON ALTERNATE ROUTES

Harrisburg Route (Lawndale-Broadway-Harrisburg)

Allen-Genoa	78th	Hughes Road
Central (S. Loop East)	*75th	Adams
*Lawndale	Forest Hill	Maplewood
Manchester	*69th	Eastwood
Cypress	*Wayside	Milby
*Navigation	66th	

Lawndale Route (Lawndale-Telephone-Leeland)

Allen-Genoa	Dismuke
Central (S. Loop East)	*Telephone
*Broadway	Wesley
*Griggs-Evergreen	Dumble
75th	Leeland
*Wayside	Cullen

Bellfort Route (Bellfort-Telephone-Leeland)

Gulf Freeway	Fairway	*Gulf Freeway
Broadway	Loop 610	*Lawndale
Glen Lock	Winkler	Wesley
*Telephone	Griggs	Dumble
*Reveille	Wheeler	Leeland
Dixie	Wayside	Cullen
Long		

Telephone Route (Telephone-Leeland)

*Bellfort	Wheeler
*Reveille	Wayside
Dixie	*Gulf Freeway
Long	*Lawndale
Fairway	Wesley
Loop 610	Dumble
Winkler	Leeland
Griggs	Cullen

*Intersection Count and Capacity Study

TABLE 9

EXISTING DIVERSION CAPACITIES
AT CRITICAL INTERSECTIONS

Intersection	Existing G/C Inbound	Computed Capacity (vphg)	Approach Capacity (vph)	Present Demand (vph)	Diversion Capacity (vph)
Lawndale-Broadway	0.30	2830	850	600	250
Harrisburg-Navigation	0.57	3290	1875	850	1025
Harrisburg-75th	0.47	3060	1425	800	625
Harrisburg-69th	0.39	2920	1150	925	225
Harrisburg-Wayside	0.50	2970	1475	750	725
Lawndale-Griggs +					200*
Lawndale-Wayside ++					200*
Lawndale-Telephone	0.45	2550	1150	625	525
Bellfort-Telephone	0.27	2990	800	625	175
Telephone-Bellfort	0.32	3800	1200	1200	0
Telephone-Reveille	0.45	3490	1550	1100	450
Telephone-South Frontage	0.28	3920	1100	1000	100
Telephone-North Frontage	0.62	3100	1925	875	1050
Telephone-Lawndale	0.38	3230	1225	825	400

\+ Fully actuated
++ Fully actuated, modified density
* Estimated

Bellfort and Telephone Routes: The Bellfort and Telephone routes have two major bottlenecks along their common route on Telephone Road. The Telephone-Bellfort intersection has some inbound movements loaded for part of the cycles between 7 and 8 AM. Added green time for right turns from Bellfort onto Telephone appears desirable for the Bellfort route. The Telephone interchange at the Gulf Freeway is complicated due to the adjacent frontage roads and cross streets. Since this particular intersection should be under computer control in 1971, it is assumed that additional green time could be assigned to inbound Telephone traffic when needed.

With the Telephone-Gulf Freeway interchange under computer control and with about ten additional seconds of green for right turns inbound at Bellfort (and Telephone), it is estimated that 200 vph can be diverted onto either the Bellfort or Telephone routes. It should be noted that maximum diversion cannot occur simultaneously on both routes since they are the same except for the Bellfort section. A summary of the diversion capabilities of these candidate alternate routes is presented in Table 10.

Summary of Travel Time Savings: A summary of the approximate times saved by individual vehicles using the candidate alternate routes instead of the inbound Gulf Freeway when an analysis incident occurs on it is presented in Table 11. These travel time savings are based on the savings indicated in Figures 13, 17, 20, and 23 less an estimate of the delay due to diversion that would be experienced on the alternate routes as indicated from the capacity studies. These results show that a savings in travel time would result for traffic with destinations in the CBD area if one of the

TABLE 10

SUMMARY OF THE DIVERSION CAPABILITIES OF THE CANDIDATE ALTERNATE ROUTES

Route	Diversion (vph)	Added Delay	Remarks
Harrisburg	250	1 cycle	Undesirable for most drivers
Lawndale	200	2 cycles	----------
Bellfort	200	2-4 cycles	a) additional green for right turn at Telephone provided b) computer control of Telephone-Gulf Freeway Interchange
Telephone	200	2-4 cycles	computer control of Telephone-Gulf Freeway Interchange

TABLE 11

TRAVEL TIME SAVED PER DIVERTED VEHICLE ON ALTERNATE ROUTE
WHEN ANALYSIS INCIDENT OCCURS ON INBOUND
GULF FREEWAY FROM 6:30-8:30 AM

Incident Occurs at	Alternate Route			
	Harrisburg	Lawndale	Bellfort	Telephone
6:30	0	0	6	0
7:00	4	5	6	5
7:15	8	9	7	8
7:30	11	14	12	10
7:45	10	11	8	6
8:00	8	8	5	4
8:30	2	2	6	1
Average 7-8 AM	8	9	8	7

alternate routes is taken when the analysis incident occurs on the freeway.

Ranking of Alternate Routes

Several items merit consideration in establishing the ranking (relative priority) of the various alternate routes. There must be sufficient capacity available to carry diverted traffic, and the travel time savings must be large enough to justify a driver's taking the alternate route. However, subjective factors also should be considered that reflect the quality of the alternate, difficulties in taking it, circuity of travel, etc. All four alternates are high volume arterials with many signals and much commercial development along them. The Harrisburg and Bellfort routes are circuitous. The Harrisburg route does not provide a motorist with easy access back to the freeway. Directing traffic onto the Bellfort route would not appear easy to achieve since most of the traffic would have to be diverted away from the freeway. The Telephone and Lawndale routes have better potential for diversion onto them since they are more direct and the decision points for taking them instead of the freeway are desirable.

The ranking of the four alternate routes for consideration in the development of a corridor freeway traffic information system are presented in Table 12. Also included are the quantitative and qualitative factors of the routes considered. These factors reflect the desirability and capability of each route to serve as an alternate route to the inbound Gulf Freeway when a major incident has occurred on it. As is given in Table 12, the Telephone and Lawndale alternate routes rank the highest. All routes, with the possible exception of Harrisburg, appear to be feasible for use as alternate routes.

TABLE 12

RANKING OF ALTERNATE ROUTES
IN THE INBOUND GULF FREEWAY CORRIDOR

Route	Average Travel Time Savings 7-8 AM	Available Capacity	Diversion* Feasibility	Ranking
Telephone	7	200+	Good	1
Lawndale	9	200	Fair	2
Bellfort	8	200+	Fair	3
Harrisburg	8	225	Low	4

+With computer control on Telephone at Gulf Freeway
*Ratings: Excellent, Good, Fair, Low

IV. DIVERSION ROUTES FOR THE INBOUND GULF FREEWAY

In the previous chapter, alternate routes were considered to be those routes that might be taken by motorists, instead of the inbound Gulf Freeway, when they had been informed that the traffic conditions on the freeway were unfavorable for their trips. The choice drivers would make would be either to take the alternate routes or continue to the freeway based solely on the real-time information provided. The locations of the decision points where the motorists might select the alternate routes usually are located away from the freeway. In addition, the alternate routes would be used for a considerable distance, and the freeway might not be used before the destinations are reached.

A different situation arises for traffic that is already in the vicinity of the freeway, e.g., on the frontage roads, or for traffic that is already on the freeway itself. This traffic has previously selected the freeway over the available alternate routes. In addition, these motorists can see actual freeway traffic conditions which may or may not indicate the quality of traffic operation that the freeway will provide them. For example, the freeway may be heavily congested downstream, while the immediate area of the freeway is still clear. Thus, the actual view of the freeway traffic may be misleading to the motorists.

If the freeway has experienced a serious incident, then it may be desirable where conditions permit to divert some of the traffic adjacent to and on the freeway along the frontage roads, until the congested area on the freeway is bypassed, and then return the traffic to the freeway. In

some cases, there may be a significant amount of traffic on the freeway which would normally leave at a downstream exit ramp in the congested section. These motorists might also be diverted along the frontage roads to their destinations if they knew the severity and location of the congestion. In order to distinguish the different nature of this traffic diversion task from that presented previously, routes which traffic on or adjacent to the freeway would use to bypass a congested freeway section are denoted as diversion routes rather than alternate routes.

Frontage Road Diversion

The successful diversion along the frontage roads of traffic that desires to enter the inbound Gulf Freeway first requires that the magnitude and location of the diversion traffic be identified. Diversion routes then must be found which can carry the additional traffic and provide convenient access back to the freeway. Figure 24 presents a schematic of the inbound Gulf Freeway and the names of entrance ramps located along it. The two-hour AM traffic flows on the ramps and frontage roads are presented in Figure 25. Figure 26 shows the ramp and traffic volumes on the inbound frontage road on S.H. 225 which flows directly into the inbound Gulf Freeway frontage road given in Figure 25.

As depicted in Figure 25, the inbound frontage road was designed to be discontinuous at the railroad crossings at Griggs and downstream of Dumble. In addition, an at-grade railroad crossing of the frontage road upstream of Dumble and two high volume signalized intersections at Telephone and at Wayside also merit special consideration. However, proposed surveillance and control improvements, together with present usage, indicate

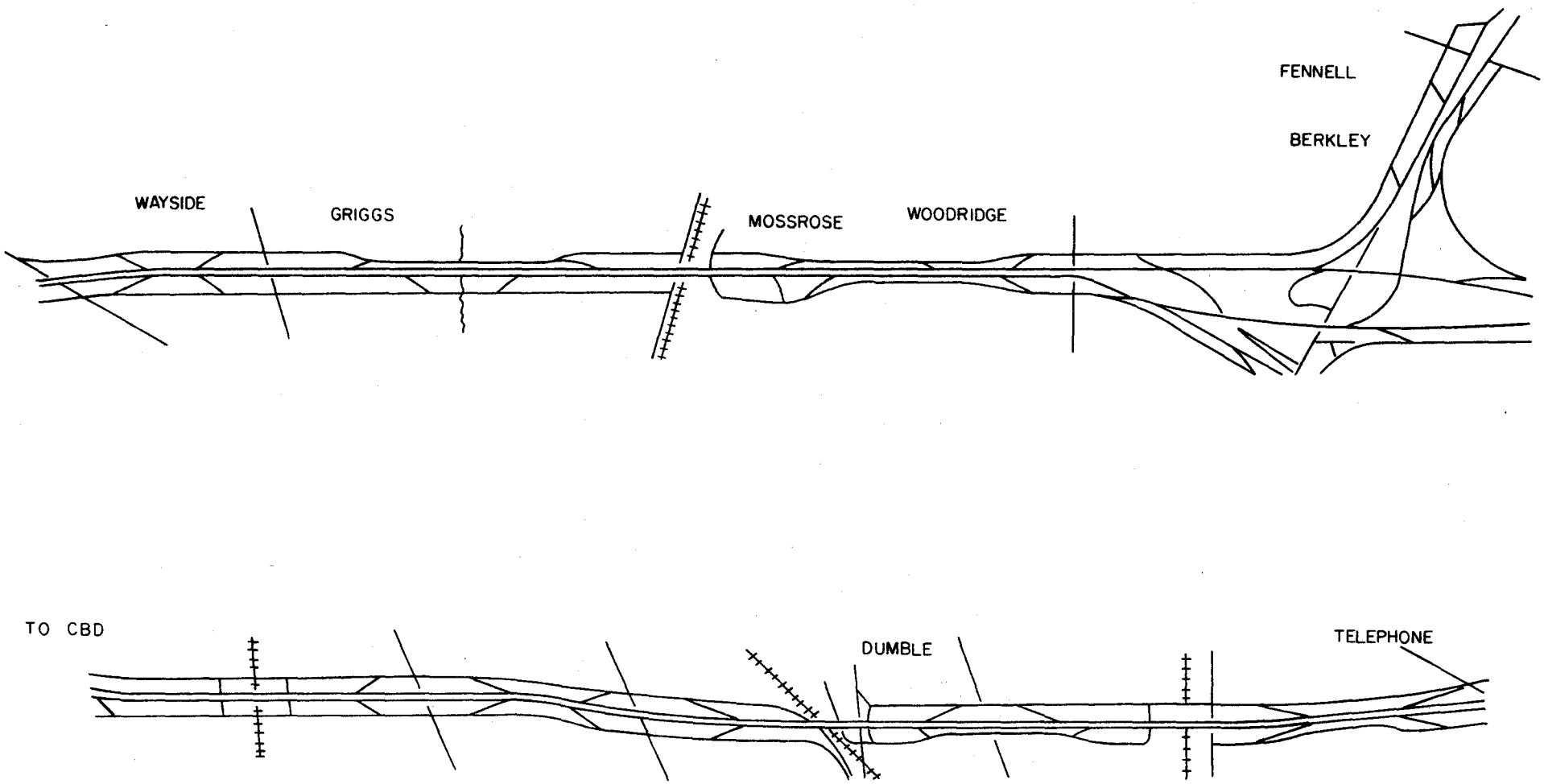

FIGURE 24 - ENTRANCE RAMPS FOR INBOUND GULF FREEWAY STUDY AREA

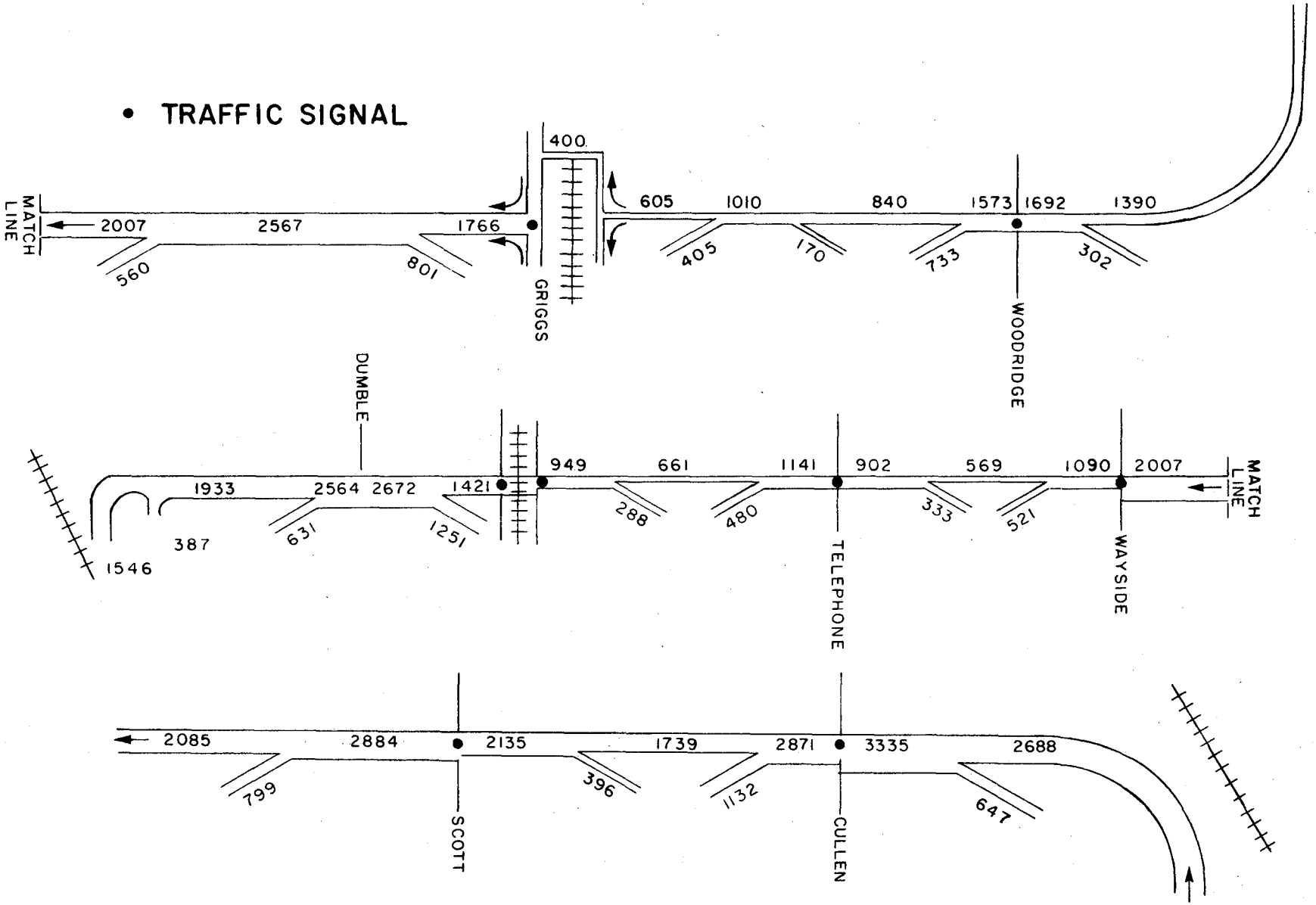

FIGURE 25 – FRONTAGE ROAD FLOW, INBOUND – 6:30-8:30 A.M.
NOVEMBER 1970

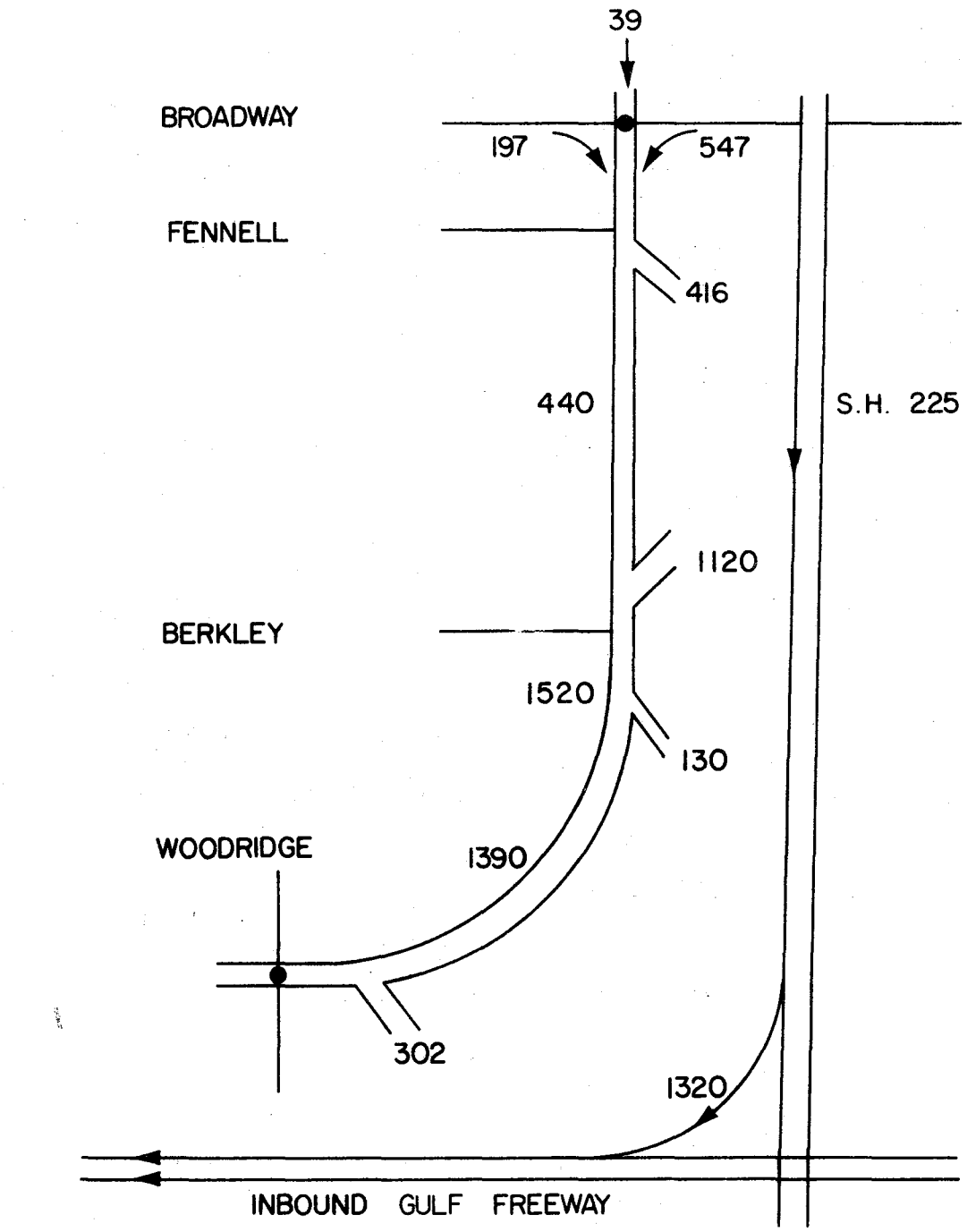

FIGURE 26 - TRAFFIC VOLUME ON INBOUND FRONTAGE ROAD ON S.H. 225 AND GULF FREEWAY 6:30 - 8:30 AM, NOVEMBER, 1970

that the entire length of the frontage roads from Broadway on S.H. 225 to Dumble can be considered for carrying some diverted traffic.

Computer control of the critical intersections at Telephone and Wayside, which is currently being designed, will provide additional control capabilities for servicing the short term increases in frontage road traffic demands during diversion. Frontage road studies at the South H.B. and T. railroad crossing upstream of Dumble indicate that over 1000 vehicles use this facility from 6:30 - 8:30 AM. Studies of the frequency of train crossings indicate that few trains cross between 7-8 AM while more frequent crossings occur between 8-9 AM. The frontage road is blocked only about five minutes from 7-8 AM. It is proposed that electronic surveillance of this railroad crossing be provided to insure that no diversion would be attempted over this section during a train crossing, avoiding undesirable traffic operation and delays. Similar surveillance should also be implemented for the railroad crossing at Griggs.

Evaluation of Ramp Locations

It has previously been noted that the entire length of the inbound Gulf Freeway is susceptible to incident causing congestion. This indicates that diversion of traffic around these incidents may be needed along the entire section. The potential volumes of traffic that might be diverted along the frontage road from the entrance ramps are indicated by their respective ramp demands. Thus, ramp demands are an important consideration in evaluating needed locations for freeway traffic information displays. Table 13 presents a listing of the entrance ramps, based on estimates of ramp demands as determined from 6:30 - 8:30 AM volume counts. The

TABLE 13

LISTING OF ENTRANCE RAMPS ON INBOUND GULF FREEWAY
BASED ON ESTIMATED DEMANDS USING 6:30-8:30 AM TRAFFIC FLOWS

Number	Entrance Ramp	Traffic Flow	Estimated Demand
1	Woodridge	733	733
2	Dumble	631	631
3	Griggs	560	600
4	Wayside	521	550
5	Telephone	480	500
6	Fennell	---	500*
7	Mossrose	405	405
8	Berkley	300	400+

*Estimated to Gulf Freeway on frontage road at Broadway

+Estimated to Gulf Freeway on frontage road at Berkley

estimated demands are not necessarily the same as the recorded traffic volumes since some traffic on the frontage road bypasses high volume, low capacity ramps to ramps with higher capacities.

The available sight distances of the inbound freeway traffic conditions downstream from the entrance ramps are also considered to be important in evaluating the locations where real-time freeway traffic information is needed. When short sight distances exist, as is the case at the Griggs ramp shown in Figure 27, motorists approaching the entrance ramp cannot accurately evaluate the downstream freeway traffic conditions. To illustrate, the freeway may be congested a short distance downstream but cannot be seen from the ramp, or the freeway may be heavily congested for several miles but only a small portion can be seen. In either case, the traffic conditions viewed are misleading and the entrance ramp motorists undesirably enters the congested freeway. This additional traffic compounds the existing congestion and could have been avoided in most cases if accurate freeway traffic information had been available at the ramp. Freeway traffic information displays located near the entrance ramps could provide the traffic information needed by motorists on the frontage roads to enable them to intelligently decide whether to enter the freeway.

The relative rankings of prospective sites for implementing frontage road diversion of traffic are presented in Table 14. These rankings were based on a composite index which reflects the ramp demands, the diversion capabilities of the frontage road with the proposed surveillance and control improvements, and the available sight distances. The diversion capabilities

FIGURE 27 - SHORT SIGHT DISTANCE OF DOWNSTREAM FREEWAY TRAFFIC EXIST AT SEVERAL ENTRANCE RAMPS AS SHOWN AT THE GRIGGS RAMP

TABLE 14

RANKINGS OF ENTRANCE RAMP LOCATIONS FOR FREEWAY TRAFFIC INFORMATION DISPLAYS FOR THE INBOUND GULF FREEWAY FRONTAGE ROAD

Ranking	Entrance Ramp Site Location	Demand	Diversion Capability*	Sight Distance+	Composite Index++
1	Griggs	600	.6	1.1	396
2	Wayside	550	.7	1.0	385
3	Telephone	500	.6	1.0	300
4	Fennell	500	.4	1.0	200
5	Woodridge	733	.2	1.0	146
6	Berkley	400	.3	1.0	120
7	Mossrose	405	.2	1.2	97
8	Dumble	631	.1	1.2	76

*Qualitative Factor, 1.0 is very good, 0.0 very poor.

+Qualitative Factor, 1.0 is very good, 1.2 very poor.

++Demand multiplied by qualitative factors.

of Woodridge, Berkley, Mossrose, and Dumble are low (0.1-0.3) due to the geometric discontinuity of the frontage road. Some diversion, however, is possible. As noted in Table 14, the Griggs, Wayside, and Telephone ramps are the more feasible site locations.

Freeway Traffic Diversion

As noted previously, the occurrence of a major incident on the inbound Gulf Freeway may reduce its effective capacity by 50 percent or more for an extended period of time, causing severe congestion during periods of high freeway traffic demand. Delays of five minutes or more are common during major incidents from Woodridge to Dumble. In an effort to reduce the severity of the congestion, the diversion of traffic from the freeway onto the frontage road should be considered as an integral part of the control strategy for responding to reduced capacity operations on the freeway.

The success of freeway diversion is improved if a sizeable number of freeway motorists will leave the freeway and use the frontage roads to bypass the congested area, or to leave the freeway and go directly to their destinations. The results of a recent survey of driver attitudes (10) indicate that 92 percent of freeway motorists would prefer to leave the freeway to bypass a severely congested area if they knew 1) the freeway was heavily congested, 2) the location of the congested area, and 3) whether the frontage road provided a reasonable bypass of the congestion.

Observations of current traffic operations on the inbound Gulf Freeway indicate that only a small amount of diversion from the freeway presently occurs when the freeway becomes heavily congested. Based on these

observations and the results of the aforementioned driver attitudes survey, it would appear that many freeway motorists are not diverting around major incidents, even though this is their desired preference.

Several reasons exists for this present discrepancy between motorists preference for diversion and diverting in practice. There is a shortage of information available to the inbound Gulf Freeway motorist about downstream traffic conditions. For all practical purposes, the only real-time traffic information now available is obtained by viewing the traffic ahead on the freeway. However, this information tends to be misleading and/or untimely due in part to the short sight distances on the freeway caused by the numerous overpass structures. Motorists that are already in the congested area usually cannot see far enough downstream to determine the actual location, cause, or expected duration of the incident, nor can they determine the delay that they will suffer due to it. Other freeway motorists, unaware of the congestion downstream, may unknowingly drive past the last remaining good diversion route around the congestion.

Thus, due to the lack of accurate real-time information, many motorists on the Gulf Freeway are not able to determine the actual location and degree of congestion when an incident occurs. They tend to misinterpret the actual incident situation which would cause them to underestimate the delays and other adverse consequences that they would suffer by remaining on the freeway. On the other hand, their evaluation of the frontage road as a bypass probably tends to be negative since they see no present indication that they would receive any special preferential treatment, such as frontage road signal coordination or additional green time at the

interchanges, if they divert to the frontage road.

A real-time freeway traffic information system located on the freeway and used in conjunction with surveillance and control of the freeway and frontage roads should solve these information and control needs. Accurate, meaningful and timely real-time information would be provided at strategic points along the freeway where freeway diversion is needed and feasible. Along with a public information campaign to explain to the motorists how the system works, the information devices and usage will inform the motorists that diverted traffic will receive high priority and will not be diverted into a more congested situation.

The selection of feasible locations for diversion of freeway traffic is dependent on the destinations and/or desired exit points of the freeway motorists which may be diverted and on the quality of the diversion routes available. The inbound Gulf Freeway primarily serves to link the outlying residential areas with the downtown section of Houston. Approximately 70 percent of the traffic entering the inbound Gulf Freeway control system in the Reveille Interchange area normally travel through the system without leaving the freeway. During the morning rush hours, this traffic amounts to about 3500 vehicles per hour. Approximately 2000 of these vehicles have destinations in the downtown area.

When an incident occurs on the freeway, the thru non-CBD traffic could use the frontage road to bypass the congestion from at least the Wayside exit ramp (See Figure 2) to the Dumble entrance ramp. The CBD traffic could also use this diversion route. In addition, the CBD traffic could exit at the Wayside or Telephone ramps and then use Telephone Road as a

diversion route to downtown.

The acceptability of the inbound Gulf Freeway frontage road for use in diverting freeway traffic around a congested section of freeway is indicated by the travel time freeway motorists would save by using the frontage road. Travel time and traffic operations studies were conducted to evaluate the section of frontage road from the Telephone exit ramp to the Dumble entrance ramp under different freeway and frontage road conditions. As is shown in Figure 24, this frontage road section includes the Telephone interchange and the crossing of the south H.B. & T. railroad tracks.

The results are summarized in Table 15 for three different traffic conditions which might occur during the hours of 7-8 AM. The travel time saved was determined as the difference between the freeway route travel time and the travel time required if a freeway motorist left the freeway at the Telephone exit ramp, travelled a distance of 1.2 miles along the frontage road to the Dumble entrance ramp, and then re-entered the freeway. The travel time savings of 2.8 minutes during an analysis incident on the freeway indicates that the diversion of freeway motorists onto the frontage road would appear to be feasible when the freeway becomes this congested (approximately once per week). The results also show that diversion would not be desirable when a train is crossing the frontage road. Even though trains block the frontage road only about 10 percent of the time from 7-8 AM, surveillance of the train crossing is considered very desirable.

An analysis of the exit ramp volumes, in conjunction with results of intersection turning movement counts and a knowledge of the major traffic

TABLE 15

COMPARISON OF FREEWAY AND FRONTAGE ROAD TRAVEL TIMES FROM TELEPHONE EXIT RAMP TO ON-FREEWAY AT DUMBLE FOR THREE TRAFFIC SITUATIONS, 7-8 AM

Traffic Situation	Traffic Conditions	Travel Time in Minutes	Time Saved in Minutes Using Frontage Road
1.	Freeway- Normal	2.3	
	Frontage Road- Normal	3.5	None (-1.2)
2.	Freeway- Analysis Incident on Freeway	7.3*	
	Frontage Road- Freeway Diversion Occurring to Frontage Road	4.5+	2.8
3.	Freeway- Analysis Incident on Freeway	7.3	
	Frontage Road- Freeway Diversion and Train Crossing Frontage Road	9.5++	None (-2.2)

*Assumes five minutes of delay as in Table 6 for Woodridge to Cullen.

+Approximately one minute of delay would be expected due to diversion.

++Assumes a train blockage of five minutes plus one minute from diversion.

generators located within the freeway corridor, provides information as to the destinations of traffic which exit the freeway within the control area. Exit ramp traffic flows for the 6:30 - 8:30 AM morning rush hours are presented in Table 16. These results reveal that approximately 1400 vehicles exit during the two-hour morning rush at the Calhoun-Elgin and Cullen ramps near Dumble (See Figure 2) with destinations on the University of Houston campus.

Thus, if a major incident occurred in the downstream section of the freeway, a portion of both thru and campus traffic could likely be diverted off the freeway onto the frontage roads at the Wayside, Telephone, or Lombardy exit ramps onto the frontage road to bypass the congestion. Campus bound traffic could also use the O.S.T. (U.S. 90 Alt.) to the University of Houston campus by exiting at Wayside.

Ranking of Freeway Locations

The possible locations for the implementation of inbound Gulf real-time traffic information displays on the main-lanes of the freeway are presented in Table 17. The rankings were developed based on the considerations of 1) rather uniform occurrence of incidents along the inbound Gulf Freeway, 2) computer surveillance and control of the two high volume intersections affecting frontage road operations at Wayside and Telephone, 3) surveillance of all railroad crossings on the frontage road, 4) the available diversion routes to known destinations of freeway traffic, and 5) the possibilities of diverting traffic around a major incident.

TABLE 16

LISTING OF EXIT RAMPS ON INBOUND GULF FREEWAY BY 6:30 - 8:30 AM TRAFFIC FLOW

Number	Exit Ramp	Traffic Flow
1	Calhoun-Elgin	1251*
2	Wayside	801
3	Cullen	647+
4	Telephone	333
5	Woodridge	302
6	Lombardy	288
7	Exit 8	170

*Primarily University of Houston Traffic

+Approximately 300 University of Houston Traffic

TABLE 17

LOCATION RANKINGS FOR IMPLEMENTING
REAL-TIME TRAFFIC INFORMATION DISPLAYS
ON THE INBOUND GULF FREEWAY

Ranking	Location* of Display	Diversion+ Rating
1	Telephone	Good
2	Wayside	Good
3	Lombardy	Fair
4	Exit 8	Poor
5	Woodridge	Poor

*Reference Figure 2.

+Ratings: Excellent, Good, Fair, Poor

Driver Information Requirements Along Diversion Routes

Previous research reported in an earlier project report (10) has identified some design requirements for a freeway traffic information system, particularly with respect to type of information, mode of communication, location, and visual display. The emphasis had been toward the portion of the total information system that would inform the freeway motorists about traffic conditions such that they could intelligently choose alternate routes when conditions warrant.

Once freeway traffic is directed to a diversion route, the motorists must be strategically guided toward their destinations. Route guidance becomes complex because of the variability in the effects of the incident and the varied destinations of the directed motorists. Thus, the guidance strategy may or may not redirect traffic to the freeway downstream of the incident. Although some modest attempts have been made to direct freeway traffic along diversion routes using both passive (18) and relative (19) signing, the requirements have not been fully established. Research is needed to better define the functional requirements and design for guiding the motorists along diversion routes.

V. CONCLUSIONS, FINDINGS AND RECOMMENDATIONS

A systems analysis of the inbound Gulf Freeway has been conducted toward the design of a real-time freeway traffic information system. The study is based on data collected during 1968, 1969, and 1970.

Conclusion

It is the conclusion of this study that the need exists for reducing the congestion and improving the level of service on the inbound Gulf Freeway when incidents occur on it.

Findings

The results of the study also indicate that a real-time traffic information system which provides accurate, reliable, and meaningful freeway traffic information would be a feasible alternative toward reducing congestion and improving the level of service of the inbound Gulf Freeway motorists during incidents. The following additional findings were drawn from the results of the study:

1. Significant congestion and delay frequently occurs on the inbound Gulf Freeway due to the reduction in capacity caused by the frequent occurrence of incidents on the main-lanes of the freeway.
2. Most incidents on the inbound Gulf Freeway are non-injury accidents and stalled vehicles. These incidents usually block only one of the three lanes of the freeway. Forty-seven percent were vehicle stalls and 46 percent were non-injury accidents.

3. Approximately 80 percent of the incidents which occur on the inbound Gulf Freeway reduce its capacity by one-half or more.
4. The freeway traffic demand would exceed the capacity if an incident occurs on the freeway any time between 6 AM to 7 PM. Congestion would result during this time interval with the most severe congestion occurring during the morning and afternoon peak hours.
5. On the average, approximately 13 incidents occur on the inbound Gulf Freeway from the Reveille interchange to Scott from Monday through Friday during the time period from 6 AM to 7 PM.
6. One major incident occurs on the average during the period of Monday through Friday from 6:30 - 8:30 AM which results in a delay of five minutes or more per vehicle for travel between Woodridge and Cullen and 11 minutes or more delay between Broadway and Cullen. Thirty percent of all incidents which occur during this time would result in the delays noted.
7. Approximately one-fourth of all incidents which occur during the peak hours result in minimal delay in themselves but do create a safety hazard due to the resulting shock wave they produce. In addition, most incidents which occur during the off-peak hours usually would not create severe congestion but they do create queueing on the main-lanes of the freeway which is a serious traffic hazard to uninformed motorists approaching the incident.
8. It appears feasible to reduce congestion and delay caused by incidents by diverting traffic around the bottleneck location on

the freeway through the use of a real-time freeway traffic information system which provides accurate, reliable, and meaningful traffic information to the motorists.

9. Traffic on the freeway, on the frontage road, and within the corridor should be considered for possible diversion since the diversion of any of these could result in a significant reduction in delay.
10. The diversion of the traffic in the corridor along the following alternate routes appears feasible:
    a. Telephone
    b. Lawndale
    c. Bellfort
11. The diversion of inbound Gulf Freeway and ramp traffic along the inbound Gulf Freeway frontage road from the Wayside exit ramp to the Dumble entrance ramp appears feasible. Added computer control at the Wayside and Telephone interchanges and surveillance of the South H.B. and T. railroad crossing of the frontage road would be desirable.
12. Diversion of S.H. 225 and Broadway traffic on the inbound frontage road section from Broadway to the Mossrose entrance ramp appears feasible when an incident has occurred upstream of the Mossrose entrance ramp.

Recommendations

Based on the findings of this study of the traffic characteristics and operations of the inbound Gulf Freeway corridor and the present state-of-

the-art of traffic information systems, the following recommendations are offered:

1. The State should consider the immediate implementation and evaluation of a real-time freeway traffic information subsystem on the inbound Gulf Freeway. This subsystem should provide an integrated operation of freeway, frontage road, and arterial traffic control. The results of the operation of this subsystem would be used to develop operational strategies and specifications for use in the design of future information systems.
2. The recommended subsystem consists of:
    a. The installation of changeable message signs at the Griggs and Telephone entrance ramps.
    b. The installation of a changeable message sign on the inbound Gulf Freeway near the Wayside entrance ramp such that the freeway and Wayside ramp traffic could make effective use of the information provided. This sign could also be used for diversion of traffic off the freeway onto the frontage road to bypass congestion between the Telephone exit ramp to the Dumble entrance ramp.
    c. Surveillance of the railroad crossings of the frontage roads at Griggs and Lombardy (South H.B. & T.).
    d. Plans should be prepared for the installation of computer control of the frontage road intersections at Wayside and Telephone.

3. Installation of a total corridor freeway traffic information system in accordance to the priorities shown in Figure 28. The recommendation is for signs to be located on the three feasible alternate routes, along the frontage roads, and at several decision points where traffic might be directed onto one or more of the alternates. Table 18 presents a summary of the recommended locations by priority. The sites selected and priorities given are based on the results of this study, previous cited research, and on the expected results from the performance of the recommended subsystem. Thus, the recommendations and relative priorities shown could possibly change depending on the success of the subsystem in rerouting, diversion, and guidance of motorists around incidents.
4. Additional research should continue directed toward determining the functional requirements and design for guiding motorists on alternate and diversion routes.

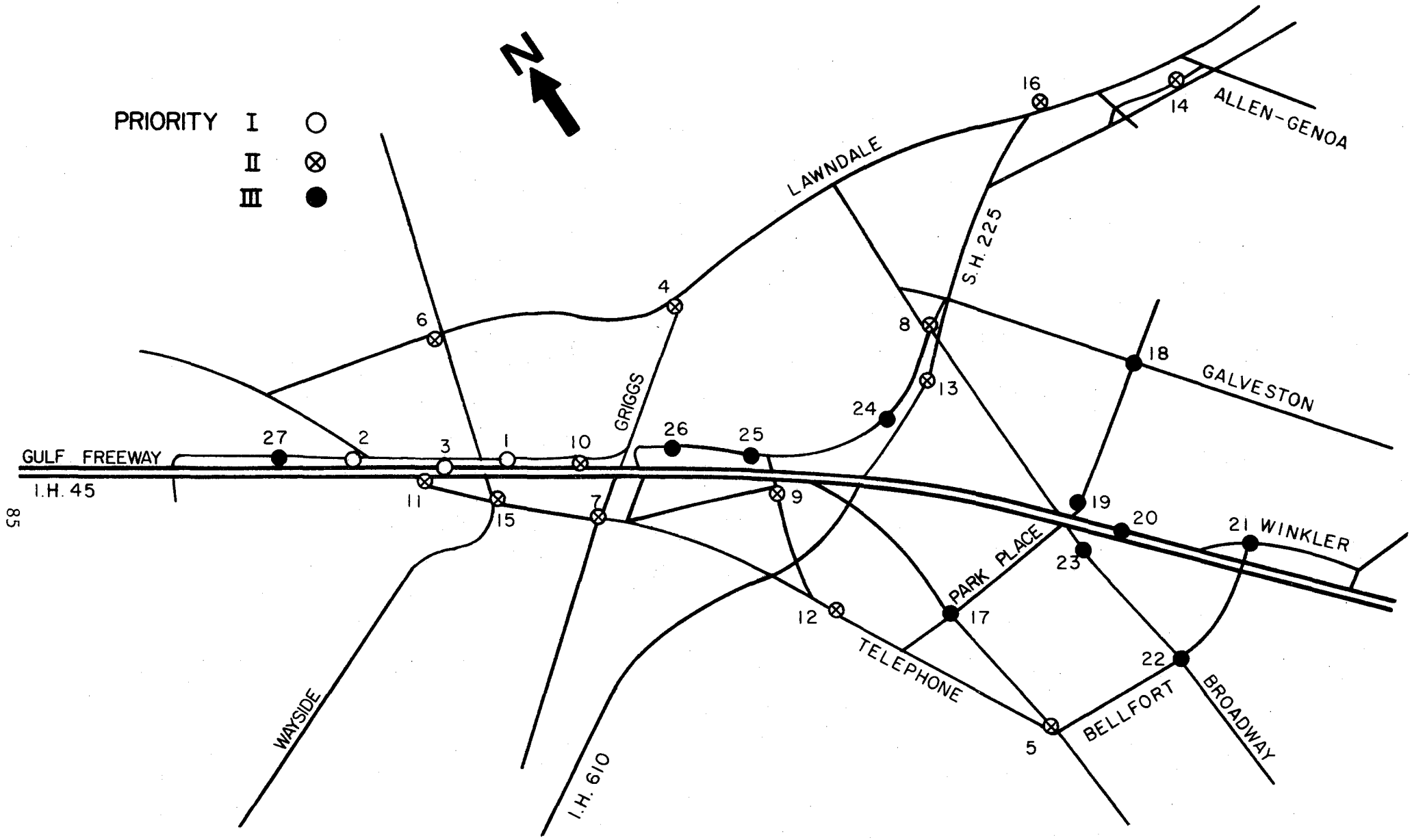

FIGURE 28 - RECOMMENDED LOCATIONS FOR REAL-TIME FREEWAY TRAFFIC INFORMATION DISPLAYS FOR INBOUND GULF FREEWAY CORRIDOR

TABLE 18

RECOMMENDED LOCATIONS FOR REAL-TIME FREEWAY TRAFFIC INFORMATION DISPLAYS IN ORDER OF PRIORITY FOR INBOUND GULF FREEWAY CORRIDOR

Priority I

1. Griggs entrance ramp
2. Gulf Freeway at Telephone exit
3. Telephone entrance ramp

Priority II

4. Lawndale @ Griggs
5. Telephone @ S.H. 35
6. Lawndale @ Wayside
7. Telephone @ Griggs
8. Broadway @ S.H. 225
9. Woodridge @ Winkler
10. Gulf @ Griggs Overpass
11. Telephone @ Gulf
12. Telephone @ Woodridge
13. S.H. 225 @ Fennell
14. Allen Genoa-S.H. 225
15. Telephone-Wayside

Priority III

16. Lawndale @ Central
17. S.H. 35 @ Park Place
18. Galveston @ Park Place
19. Park Place @ Gulf
20. Gulf Fwy. @ S.H. 3
21. Bellfort @ Winkler
22. Broadway @ Bellfort
23. Broadway @ Moline
24. Berkley ramp
25. Woodridge ramp
26. Mossrose ramp
27. Dumble ramp

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