Title

Potential Benefits Of In-vehicle Information Systems (ivis): Demand And Incident Sensitivity Analysis

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Potential Benefits of In-Vehicle Information Systems (IVIS): Demand and Incident Sensitivity Analysis

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PATH 60A.L STATEMENT

The research reported herein is a part of the program on Advanced Technology for the Highway, PATH, within the Institute of Transportation Studies, at the University of California, Berkeley. PATH aims to increase the capacity of the most used highways, to decrease traffic congestion, and to improve the safety and air quality. It is a cooperative venture of automakers, electronic companies, local, state and federal governments and universities.

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EXECUTIVE SUMMARY

A preliminary evaluation of In-Vehicle Information Systems (IVIS) has been conducted by a research team at ITS and a final report entitled "Potential Benefits of In-Vehicle Information Systems in a Real Life Freeway Corridor under Recurring and Incident-Induced Congestion" [July 1988] [1] has been submitted to the PATH program. The principle end-products of the mentioned effort were the development of a simulation test-bed for the Santa Monica freeway (SMART) corridor and the estimation of the travel time savings to potential (IVIS) users under two traffic scenarios: recurring congestion non-incident and non-recurring congestion incident scenarios.

A key assumption in the last year study was that an incident on the freeway system does not affect travel times on the surface street system because the percentage of vehicles diverting to the surface street system is small.

As only two traffic scenarios were analyzed in the last year report, the research in this working paper continues along the same line but with more traffic scenarios. The research uses the same assumptions of the previous study, assumptions are listed at the beginning of chapter II. The objective of this research is to conduct traffic demand and incident sensitivity analysis of potential benefits of IVIS. This is accomplished by studying the variations in in traffic demand levels, variations in incident severity, and variations in incident location. An experiment is designed as shown in Figure 3, chapter II as a work plan for sensitivity analysis. Demand is divided into three levels: average, moderately heavy, and heavy traffic demand. Average traffic demand refers to the "typical day" traffic demand level analyzed in the last year base case of the non-incident typical day recurring congestion traffic scenario. Moderately heavy and heavy traffic demand levels are 5% and 10% higher than the level of a typical traffic day respectively. Incident severity is also divided into three levels : no incident, moderate incident, and heavy incidents. The moderate incident is defined as a 45 minute duration incident with approximately two lane blockage on the mainline of the freeway, while a heavy incident is the same as the moderate incident but with a 90 minutes duration.

Two incident locations were considered: one is upstream and one is downstream of the freeway. For the upstream incident all possible traffic scenarios (a total of nine scenarios) were considered and travel time savings were analyzed. For the downstream incident only moderate incident scenarios (a total of three incident scenarios one for each traffic demand level) were analyzed.

The conclusions from the investigations made are based on the assumptions previously identified. The sensitivity of potential benefits of In-Vehicle Information Systems (IVIS) to traffic demand, incident severity and location can be summarized as follows:

1. Potential benefits are very marginal and considered insignificant under the non-incident average traffic demand situation.

2. Potential benefits for long distance freeway to freeway travelers can be significant under non-incident conditions but only when freeway demands are five or ten percent higher than normal. Travel time savings are on the order of 3 minutes to a maximum of 13 minutes for an average trip length of 30 minute during the peak hour.

3. Potential benefits for long distance freeway travelers can be significant during the duration **of** incidents under average traffic conditions. Time savings on the order of 5 to 10 minutes for a 30 minutes average length trip were observed.

4. Under upstream incident conditions increasing demand by five or ten percent does not increase potential benefits significantly.

5. Under downstream incident conditions increasing demand by five percent increases potential benefits significantly. When increasing demand by ten percent, the maximum travel time savings were observed in this study (14 minutes savings for a 30 minute average trip length).

6. Under both incident conditions, when an incident duration is doubled, the time period during which there are potential benefits (or significant travel time savings) slightly more than doubles.

7. Under both incident conditions and five or ten percent heavier freeway demand, travel potential benefits were large. Travel time savings were significant (a range of 4 to 14 minutes) for a 30 minute average trip length. However, introducing incidents under such conditions did not increase the potential benefits significantly.

8. The effect of the location of the incident on potential benefits was studied only under moderate incident conditions. The major conclusion of the comparison between the two incident locations is that under heavy traffic demand level the downstream incident gave higher travel time savings than that of the upstream incident.

9. Potential benefits were generally different for each origin group in the study. It was noticed that the furthest the origin is from the freeway the larger time savings are for trips starting at that origin. Trips originating at origins downstream of the incident did not have any potential benefit under incident conditions.

10. The so far exhaustive sensitivity analysis predicted a range of travel time savings between 0 and 14 minutes for the 30 minutes average trip length. These estimates of potential benefits are optimistic and further refinement to such estimates is expected to give lower estimates.

Recommendations for future research are made in the last chapter and the main direction is an evaluation towards more realistic assessment of potential benefits of IVIS. This can be achieved by analyzing the key assumptions in the previous *one* and half year study such as increasing traffic demand level on the surface street links, consideration of drivers currently diverting under incident conditions, increasing the percentage of IVIS equipped vehicles, studying the constraints and limitations of surface street system for the diverted traffic.

CHAPTER 1

INTRODUCTION

A. Background

A preliminary evaluation of In-Vehicle Information Systems (IVIS) has been conducted by a research team at ITS and a final report entitled "Potential Benefits of In-Vehicle Information Systems in a Real Life Freeway Corridor under Recurring and Incident-Induced Congestion" [July 1988] [l] has been submitted to the PATH program. The principle end-products of the mentioned effort were the development of a simulation test-bed for the Santa Monica freeway (SMART) corridor and the estimation of the travel time savings to potential (IVIS) users under non-incident and incident situations. The real life Santa Monica freeway corridor in Los Angeles, California, was simulated using the FREQ8 and TRANSYT-7F simulation models. The Santa Monica freeway corridor represented a typical congested freeway corridor. The freeway study limits were: San Diego freeway in the west to Harbor freeway in the east; Venice boulevard in the north to Adams boulevard in the south. The limits are shown in Figure 1. The study period was from 6:00 a.m to 10:00 a.m. and covers the morning peak period in the inbound direction. The four hour time period was divided into sixteen time slices of fifteen minutes each. The traffic counts provided by CALTRANS and LADOT were gathered from several years of data (1984-1988) and based on meetings with CALTRANS and LADOT it was assumed that these traffic counts represented traffic counts of a "typical day" on which the analysis in the mentioned report was based.

The output of the FREQ8 and TRANSYT-7F simulation was travel times on the freeway links and the surface street links. Travel

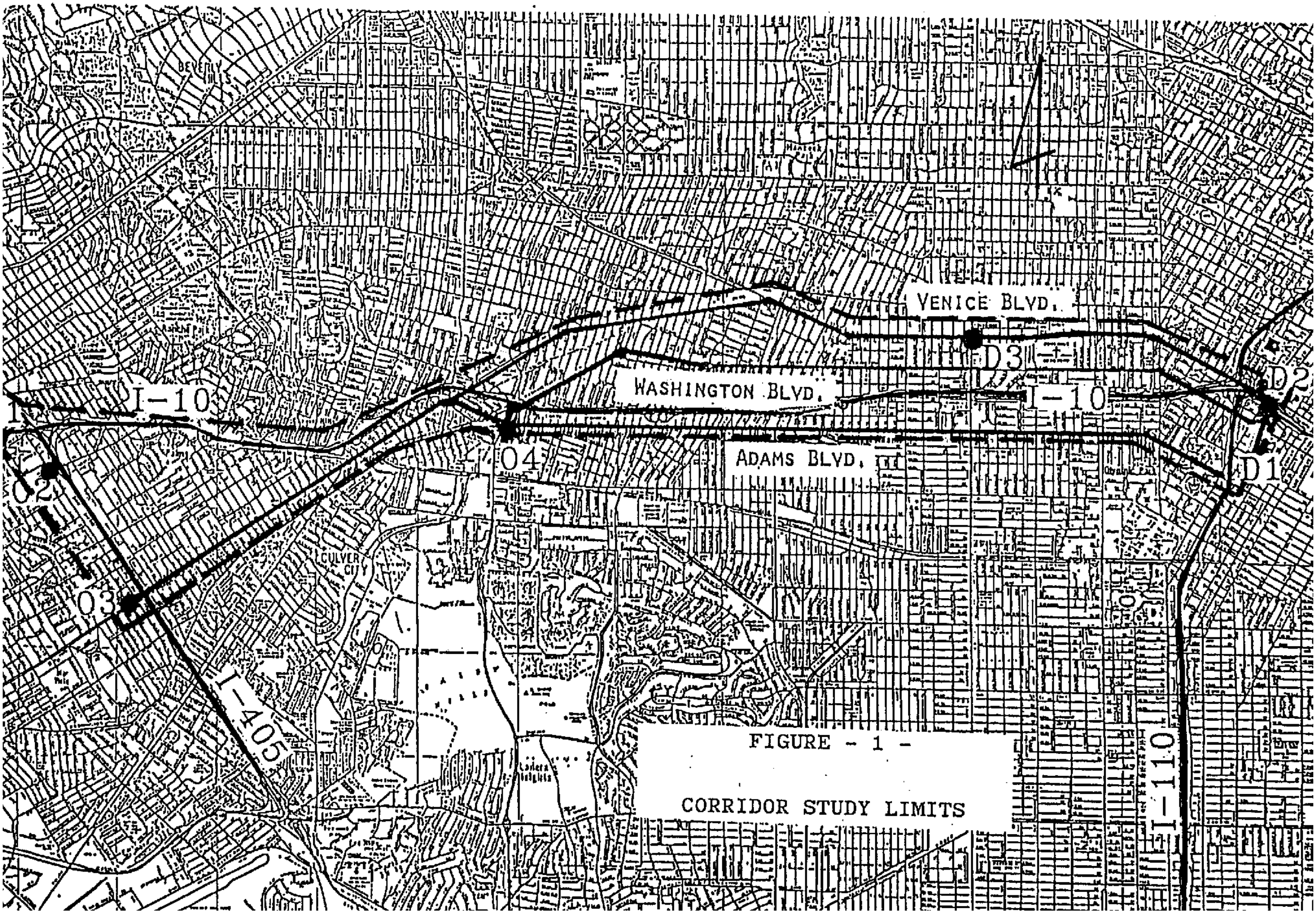


FIGURE - 1 -

CORRIDOR STUDY LIMITS

times for both the freeway links and surface street links from these models were transformed to a network model developed entitled PATHNET. PATHNET was utilized to determine the travel times for the "shortest path" between any origin and destination point in the corridor or for any other path in the corridor so desired (e.g user selected path). A survey was conducted to determine typical routes used by actual commuters in the Santa Monica freeway corridor in the home to work trip. The survey suggested that the preferred route for the majority of drivers interviewed was a freeway biased route. The survey sample size was small and was taken from a selected group of drivers.

The shortest path is assumed to be the perfect information path. Comparison between the "shortest path" travel time and the travel time of the freeway biased path was made for a set of four origin points and three destination points, see Figure 1. These comparisons of travel times were the basis of determining potential benefits of (IVIS).

Under the recurring, non-incident congestion scenario, the travel time savings when utilizing the "shortest path" were generally negligible (less than three minutes for a 20-25 minute trip) when compared to the travel time of the freeway-biased path. Under the non-recurring, incident congestion scenario (where the incident was created on the freeway), travel time savings were found to be significant (greater than three minutes for a particular trip), when comparing the "shortest path" travel time with the travel time of the freeway-biased path during certain times in the study period. The greatest travel time savings occur during the time slices following the introduction of the freeway incident, from 6:45 to 7:15 a.m, with a maximum savings of 10 minutes for a 30 minute trip.

The results of the study were specific to the corridor under investigation and other limitations and constraints, e.g time of the study and the 12 O-D pairs selected as in Figure 1.

A key assumption in the study was that an incident on the freeway system does not affect travel times on the surface street system because the percentage of vehicles diverting to the surface street system is small.

For further detail of the methodology used in the previous analysis the reader should consult last year's final report [l].

B. The Problem

In addition to some restrictive assumptions used in analyzing the two scenarios (one non-incident scenario and one incident scenario) in the last year report, the two scenarios discussed were inadequate to observe the sensitivity of the potential benefits of (IVIS) to different factors such as traffic demand level, incident severity, and incident location. The next step in continuing this research was to study the sensitivity of potential benefits to variations in the mentioned factors.

C. Objectives

The objectives of this sensitivity analysis study is to investigate how sensitive are the potential benefits of (IVIS) to the following:

1. Variations in traffic demand levels from that of a typical day.

2. Variations in incident severity level, and

3. Variations in incident location.

The three factors: traffic demand level, incident severity level, and incident location will be discussed in the following chapter. The results of last year's investigation are incorporated in this report.

CHAPTER 2

STUDY APPROACH

A. Assumptions

There are three constraints used in the previous year's report that will be investigated in the analysis in this working paper, these constraints are the following:

* Several traffic demand levels other than that of a typical day will be considered.

* Several incident severity levels will be considered instead of one level.

* More than one location for the incident will be considered.

Nonetheless, because of the complexity and the large amount of work needed to investigate all assumptions and constraints at once, several assumptions and constraints of the last year analysis report will continue to hold throughout this study, these are the following:

* An incident on the freeway system does not affect travel times on the surface street system because the percentage of vehicles diverting to the surface street system is small.

* Variations in traffic demand level will be only considered on the freeway not on the surface streets.

* Drivers who self divert in case of an incident are not considered and therefore network equilibrium issue is not handled.

* The SMART corridor is a typical corridor.

* The simulation results apply only to the inbound morning peak period.

* Same 12 O-D pairs will be used for analysis, see Figure 1.

* The user selected route is the freeway biased route.

* The number of lanes blocked by the incident is two lanes.

* The beginning time of the incident is 6:30 a.m in all incident scenarios analyzed.

* The only MOE measure used in the estimation of the potential benefits of (IVIS) is travel time.

* Travel time on congested links of the freeway has the same unit cost value as travel time on free flow links of the freeway.

* In the analysis of time savings for the two traffic scenarios, it was assumed that time savings of less than or equal to three minutes are insignificant. Not only the savings might be masked by random variations and driver behavior, but the threshold at which drivers might perceive benefits from optimum routing is unlikely to be less than three minutes.

It is expected that future work will be directed to investigate the effect of constraints listed above.

B. Design of the Experiment (The 3-D Matrix)

1. First Incident Location

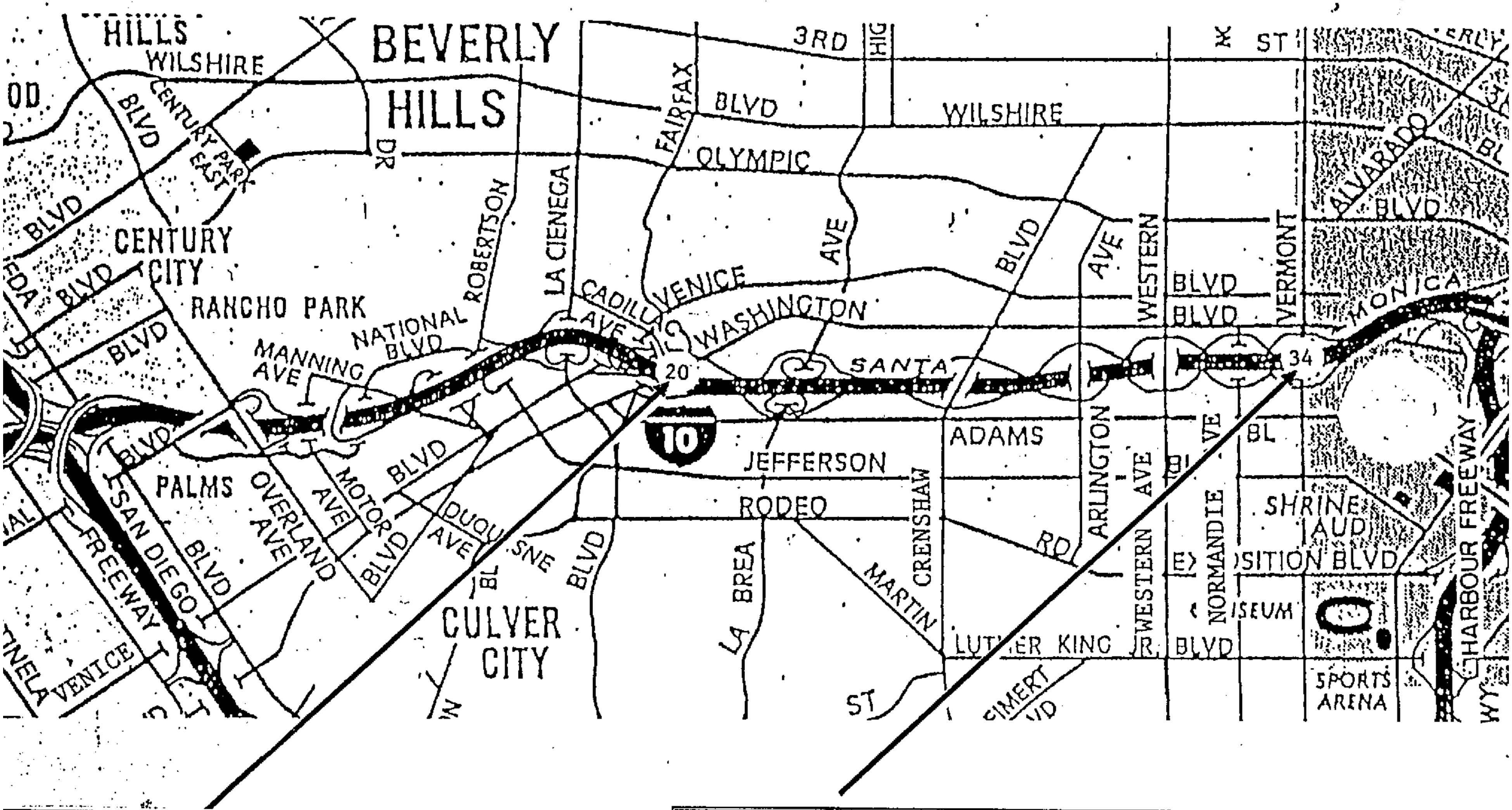
The first incident location is in the upstream subsection (Venice On-ramp to Washington On-ramp), see Figure 2 and Table 1. This subsection is coded in FREQ as eastbound SS#2O. It is roughly located in the first third of the freeway when travelling inbound. SS#2O is a five lane subsection with a normal capacity of 9300 vph. The incident is designed as a two-lane blockage incident. The capacity reduction was 4300 vph except for the last fifteen minutes of the incident where capacity of SS#20 recovered a 500 vph due to the initial process of incident clearance. The incident occurs at 6:30 a.m. in the morning and continues for 45 minutes or 90 minutes depending on the level of severity of the incident as will be explained later.

2. Second Incident Location

The second incident location is in the downstream subsection (Vermont Off-ramp to Vermont On-ramp), see Figure 2 and Table 1. This subsection is coded in FREQ as eastbound SS#34. It is roughly located in the last third of the freeway when travelling inbound. SS#34 is a five lane subsection with a normal capacity of 9400 vph. The incident is designed as a two-lane blockage incident. The capacity reduction was 4300 vph except for the last fifteen minutes of the incident where capacity of SS#34 recovered a 500 vph due to the initial process of incident clearance. The incident occurs at 6:30 a.m. in the morning and continues for 45 minutes (only one level of severity was considered at this location).

3. Final Design of the Experiment

Realizing that the sensitivity analysis requires a significant number of computer simulation runs and given the time and budget



ASTBOUND SUBSECTION 20 (SS#20)
VENICE ON-RAMP TO WASHINGTON ON-RAMP)
AINLINE NORMAL CAPACITY = 9300 VPH

EASTBOUND SUBSECTION 34 (SS#34)
(VERMONT OFF-RAMP TO VERMONT ON-RAMP)
MAINLINE NORMAL CAPACITY = 9400 VPH

FIGURE - 2 - TWO INCIDENT LOCATIONS (SS#20 AND SS#34)

Table (1)

TWO INCIDENT LOCATIONS (SS#20 AND SS#34)

<table>
<tr><th colspan="3">EASTBOUND SUBSECTION 20 (SS#20)
(VENICE ON-RAMP TO WASHINGTON ON-RAMP)
MAINLINE NORMAL CAPACITY = 9300 VPH</th><th>EASTBOUND SUBSECTION 34 (SS#34)
(VERMONT OFF-RAMP TO VERMONT ON-RAMP)
MAINLINE NORMAL CAPACITY = 9400 VPH</th></tr>
<tr><th colspan="3">MAINLINE NET CAPACITY DURING INCIDENT</th><th>MAINLINE NET CAPACITY DURING INCIDENT</th></tr>
<tr><th>INCIDENT SCENARIO
TIME (A.M.)</th><th>MODERATE INCIDENT</th><th>HEAVY INCIDENT</th><th>MODERATE INCIDENT</th></tr>
<tr><td>6:30 - 6:45</td><td>5000</td><td>5000</td><td>5100</td></tr>
<tr><td>6:45 - 7:00</td><td>5000</td><td>5000</td><td>5100</td></tr>
<tr><td>7:00 - 7:15</td><td>5500</td><td>5000</td><td>5600</td></tr>
<tr><td>7:15 - 7:30</td><td>N/A</td><td>5000</td><td>N/A</td></tr>
<tr><td>7:30 - 7:45</td><td>N/A</td><td>5000</td><td>N/A</td></tr>
<tr><td>7:45 - 8:00</td><td>N/A</td><td>5500</td><td>N/A</td></tr>
</table>

constraints, an experiment was carefully designed to get the optimal amount of information about sensitivity of potential benefits of (IVIS) with the least amount of computer runs. Figure 3 shows the design of the experiment as a three dimensional matrix with two faces: face (1) or the front face and face (2) or the back face. Horizontal and vertical dimensions are the same in both faces. Face (1) simulates scenarios (matrix cells) related to SS#2O or (Venice On-ramp to Washington On-ramp) incident, while face (2) simulates scenarios (matrix cells) related to SS#34 (Vermont Off-ramp to Vermont On-ramp) incident.

a. Design of face (1) or SS#2O Incident Scenarios (A 3 X 3 Matrix)

This is the front face of the 3-D matrix which simulates scenarios (matrix cells) related to SS#20 incident. Two types of variations are considered in this face, one is the variations in the level of traffic demand which is the horizontal dimension and the other is the variations in the level of incident severity which is the vertical dimension.

The level of traffic demand used for two traffic scenarios analyzed in the last year report was considered as that level of a "typical traffic day" which could be referred to as "average demand". Since time savings of the non-incident scenario were negligible at the average demand level, it will be more interesting to investigate time savings of scenarios with higher (rather than lower) traffic demand levels from that of an average traffic day. Two other demand levels are analyzed in this experiment: moderately heavy, and heavy traffic demand. The moderately heavy traffic demand level is a 5% increase in traffic demand over that of an average day traffic demand level while a heavy traffic demand level is a 10% increase in traffic demand over that of an average day traffic. Therefore there are a total of three traffic demand levels in the horizontal dimension:

FIGURE (3) SENSITIVITY ANALYSIS: A THREE DIMENSIONAL MATRIX

FACE (2) SS#34 INCIDENT

	DEMAND LEVEL >	AVERAGE	MODERATELY HEAVY	HEAVY
	INCIDENT SEVERITY	100%	105%	110%
	NO INCIDENT	NA2**	N-M2	NH2
3 TS	MODERATE INCIDENT	MA2	MM2	MH2

FACE (1) SS#20 INCIDENT

	DEMAND LEVEL	AVERAGE	MODERATELY HEAVY	HEAVY
	INCIDENT SEVERITY	100%	105%	110%
	NO INCIDENT	NA1**	NM1	NH1
3 TS	MODERATE INCIDENT	MA1**	MM1	MH1
6 TS	HEAVY INCIDENT	HA1	1 HM1	HH1

** COMPLETED WORK FROM LAST YEAR PROJECT.

average, moderately heavy, and heavy.

In the incident scenario analyzed in the last year report, an incident was introduced by blocking two lanes in SS#20. The incident lasted for 45 minutes starting at 6:30 a.m. and ending at 7:15 a.m. just as the congestion peak starts. Capacity was reduced by 4300 vph (out of 9300 vph which is the normal capacity of SS#20) for 30 minutes and then capacity was reduced by 3800 vph for the last 15 minutes when the incident was being cleared. The severity of an incident is defined, here, in terms of how long the incident lasted. The incident level in the incident scenario analyzed in last year's report is considered as a moderate type incident. Three levels of incidents are considered: no incident, moderate, and heavy incident. The heavy incident is defined relative to the moderate type incident to be as twice as long. However, both incidents are at the same location and start at 6:30 a.m. The heavy incident continues until 8:00 a.m., therefore overlaps in time with the heavier morning peak traffic and this adds more to its 90 minutes length severity.

With the three demand levels and the three incident levels, a 3X3 matrix having all possible combinations is formulated, see upper matrix in Figure 4. The matrix has cells with a three characters code: the first character is a letter that refers to the incident level, e.g "N" refers to "No Incident", while the second character is a letter that refers to the demand level, e.g "A" refers to "Average" demand level. The third character is a number that refers to what face (incident location) one is analyzing, e.g in upper matrix of Figure 4 "l" refers to face (1) which is SS#2O incident.

Obviously the two cells "NAl" and "MAl" are those cells which have been analyzed in the last year report. There are seven additional cells to be analyzed in face (1).

FIGURE 4 FACE (1) AND FACE (2) MATRICES

FACE (1)

INCIDENT IN SS#20 (VENICE ON-WASHINGTON ON)

	DEMAND LEVEL	AVERAGE	MODERATELY HEAVY	HEAVY
	INCIDENT SEVERITY	100%	105%	110%
	NO INCIDENT	NAl**	NM1	NH1
3 TS	MODERATE INCIDENT	MA1**	MM1	MHl
6 TS	HEAVY INCIDENT	HAl	HM1	HHl

** COMPLETED WORK FROM LAST YEAR PROJECT.

FACE (2)

INCIDENT IN SS#34 (VERMONT OFF-VERMONT ON)

	DEMAND LEVEL S-P >	AVERAGE	MODERATELY HEAVY	HEAVY
	INCIDENT SEVERITY	100%	105%	110%
	NO INCIDENT	NA2**	NM2**	NH2**
3 TS	MODERATE INCIDENT	MA2	MM2	MH2

** SAME CELLS OF FACE (1)

b. Design of Face (2) or SS#34 Incident Scenarios (A 2 X 3 Matrix)

Face (2) is parallel to face (1) and is the back face of the 3-D matrix. Face (2) investigates scenarios of incidents at another location which is SS#34 or (Vermont Off-ramp to Vermont ON-ramp) subsection. This subsection has the same number of lanes as ss#20.

Face (2) horizontal dimension is identical to face (1) horizontal dimension. There are the same three levels of traffic demand: average, moderately heavy, and heavy.

There are only two incident levels in the vertical dimension, one is the no incident level and the second is the moderate incident level. The definition of the moderate incident level is exactly the same as that of face (1).

As shown in the lower matrix of Figure 4, the no incident cells NA2**, NM2**, and NH2** are exactly the same as NA1**, NM1, and NH1 of face (1) respectively.

CHAPTER 3

STUDY RESULTS - FIRST INCIDENT LOCATION

A. Introduction

The main output of this working paper will be the results of the two faces of the 3-D matrix experiment summarized in (12) twelve tables of travel time savings of the shortest path (SP) vs. the freeway biased path (FB) for different O-D pairs. There will be also twelve queue diagrams accompanying these tables. The queue diagrams are obtained from the output of the FREQ simulation runs.

The differences between travel time for the (SP) and travel time for the (FB) rounded off to the nearest minute are summarized in these twelve tables.

In this chapter scenarios of the first incident location will be discussed as in Figure 4. There is a total of nine tables with their associate queue diagrams.

B. Comparisons Between Tables of Travel Time Savings

With four origins and three destinations selected in the study there are twelve possible O-D pairs. The twelve O-D pairs are grouped into four O-D groups as shown in Figure (5).

FIGURE (5) 4 O-D GROUPS

DEST. ORIGIN	Dl	D2	D3	O-D PAIR GROUP
01	Ol-Dl(	Jl-D2	Ol-D3	GROUP1
02	02-Dl(	32-D2	02-D3	GROUP2
03	03-Dl(	33-D2	03-D3	GROUP3
04	04-Dl(	34-D2 *	04-D3	GROUP4

Locations of origins one through four and destinations one through three are shown in Figure 1, Chapter I. Origin-l is on the Santa Monica freeway mainline (just west of the San Diego freeway) and represents the beginning point of the study on the freeway. Origin-2 is the intersection of National and Sawtelle boulevards which is west of the San Diego freeway and is fairly close to Origin-l. Origin-3 is the intersection of Venice and Sawtelle boulevards. Origins 1,2,3 represents entrance gateways to the corridor. Origin-4 is one that is in between the eastern and western study limits and is located at the intersection of Adams and Fairfax boulevards. It should be noticed that Origin-3 is the furthest origin from the freeway among all four origins.

Destination 1 represents the end of the study limits on the freeway (just east of the Harbor freeway). Destination 2 is the intersection of Figuroua and Venice which represents drivers leaving the freeway to enter Downtown Los Angeles. Destination 3 is located at the intersection of Western and Venice boulevards and it represents a destination between the beginning and the end of the study limits.

In the following analysis travel time savings larger than three minutes are considered to be significant.

C. Analysis

The study results related to the first incident location are presented and discussed in this chapter. The first three sections of the analysis part are devoted to assessing the effect of the three traffic demand levels on the three levels of incident severity. In relation to the previous Figure 3, this would represent a horizontal comparison of cells in the front face of the design of experiment. The final three sections of this chapter are devoted to assessing the effect of incident severity under three levels of traffic demand. In relation to the previous Figure 3, this would represent vertical comparisons of cells in the front face of the design of experiment.

In each of the following sections comparisons of travel time savings will be made for each of the four origin groups. These savings are intended to represent the differences between travel time used by current motorists without IVIS and travel time by the shortest routing anticipated to be used by motorists with IVIS. The travel time savings have been rounded off to the nearest minute. For each origin group there are three distinctly different destinations. The travel time savings for each origin and destination combination are presented for each of the sixteen 15 minute time slices between 6:00 a.m. and 10:00 a.m.

1. Effect of Traffic Demand Under No Incident Situation

Three traffic demand levels are considered: average, moderately heavy, and heavy. These three cells are denoted as cells NA1, NM1, and NH1 in the previous Figure 3 which depicted the design of experiment. These results will be discussed in the next three subsections in order of increasing traffic demand level.

a. Average Traffic Demand Level (NA1)

The freeway congestion pattern under the average traffic demand level without an incident is shown in Figure 6. The horizontal scale is distance along the freeway with traffic moving from left to right. The vertical scale is time with the beginning time of 6:00 a.m. at the bottom of the diagram and increasing upwards. The freeway location where trips from the four selected origins currently enter the freeway and trips to three selected destinations currently leave the freeway are shown at the bottom of this Figure.

Congestion begins at about 6:30 a.m. and continues until 9:15 a.m. There are three bottlenecks as indicated in subsection 21, 28, and 36. Except for traffic entering at origin 4 and/or leaving at destination 3, all other origin-destination trips must pass through all three bottlenecks if the motorists choose to use the freeway. The heaviest congestion is encountered from 7:30 to 8:00 a.m.

The travel time savings under the average traffic demand level without an incident is shown in Table 2. The four sub-tables denote trips with origin at location 01, 02, 03, and 04 respectively. Each sub-table includes the results for trips with destinations at location D1, D2, and D3 respectively. The horizontal scale of each sub-table is time and results are shown for each of the sixteen 15 minutes time slices. Travel time savings over three minutes are considered significant and the values are circled. Savings over five minutes are considered to be very significant and are enclosed in double frame squares.

Except for trips originating at origin 4 between 7:30 and 8:00 a.m. all other travel time savings are not considered to be significant. This implies that current users under the average traffic demand level without an incident appear to balance the corridor route usage and there is little difference between

FIGURE 6

CONTOUR DIAGRAM OF QUEUE LENGTH

NAT CELL: NO INCIDENT AVERAGE TRAFFIC DEMAND SCENARIO (INCIDENT SS#20)

```
TIME                                                                                                                           BEGIN
SLICE ...........................................................................................*..........................   TIME
                                                                                                                            .
   24 .                                                                                                                     . -  11:45
   23 .                                                                                                                     . -  11:30
   22 .                                                                                                                     * -  11:15
   21 .                                                                                                                     . -  Il:oo
   20 .                                                                                                                     . -  10:45
   19 .                                                                                                                     . -  10:30
   18 .                                                                                                                     . -  10:15
   17 .                                                                                                                     . -  lo:oo
   16 .                                                                                                                     . -   9:45
   15 .                                                                                                                     . -   9:30
   14 .                                                                                                                     . -   9:15
   13 .                                                                                       **                 *  ***     . -   9:oo
   12 .                                                                                    *****           *** ********     . -   a:45
   11 .                                                                                  *******          **** ********     . -   8:30
   10 .                                                                                   *********    ****************     . -   8:15
    9 .                                                                                   *********  ******************     . -   8:00
    8 .                                                                                 *******************************     . -   7:45
    7 .                                                                                  ******************************     . -   7:30
    6 .                                                                                  *******       ****************     . -   7:15
    5 .                                                                                    *****          *** *********     . --  7:oo
    4 .                                                                                        *          ***   *******     . -   6:45
    3 .                                                                                                             ***     . -   6:30
    2 .                                                                                                                     . -   6:15
    1 .                                                                                                                     . -   6:00
                                                                                                                            .
      .....................................................................................................................
       :    :       :       :                :       :       :       :   :   ::  :   :  : ::::::  :::: : : ::::::::::::::
       01   02      03      04      05      06      07      08      09      12              21            28         36   40
                                                                     |       |               |             |          |    |
       SUBSECTION NUMBER                                             |       |               |             |          |    |
                                                                     |       |               |             |          |    |
                                                                     01      02,            04             D3         D2   DI
                                                                            03
```

BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION. M DENOTES QUEUED VEHICLES DUE TO MERGING. B DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION AND MERGING. (WHEN BOTH QUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

01, 02, 03, AND 04 : DENOTE LOCATIONS WHERE TRIPS ORIGINATING AT 01, 02, AND 03 JOIN THE FREEWAY.

DI, D2, AND D3 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO D1, D2, AND D3 LEAVE THE FREEWAY.

TABLE 2

Travel Time Savings in Minutes (Rounded to Nearest Minute)
(NAl) Scenario (Shortest Path vs. Freeway-Biased Path)

LEGEND

☐ HIGH. SIG. TIME SAY.

○ SIG. TIME SAV.

From 01 to:

D1	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0
D2	0	0	0	0	0	1	2	2	1	1	1	1	0	0	0	0
D3	0	0	0	0	0	1	2	2	1	1	1	1	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 02 to:

D1	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0
D2	0	0	0	0	0	1	2	2	1	1	1	1	0	0	0	0
D3	0	0	0	0	0	1	2	2	1	1	1	1	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 03 to:

D1	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0
D2	0	0	0	0	0	1	2	2	1	1	1	1	0	0	0	0
03	0	0	0	0	0	1	2	2	1	1	1	1	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 04 to:

D1	0	0	0	0	3	3	④	⑤	0	0	0	0	0	0	0	0
D2	0	0	0	0	3	3	⑤	$\boxed{6}$	1	1	0	0	0	0	0	0
D3	0	0	0	0	3	3	④	⑤	1	0	0	0	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

freeway travel time and non-freeway travel times. This is not a surprising result for a peak period home-to-work trip pattern where the motorists know "normal" traffic conditions and experiment with route choice until almost all choices result in essentially the same travel times.

Trips originating at origin 4 and destined to destination Dl, D2, and D3 between 7:30 a.m. and 8:00 a.m. have predicted significant travel time savings of 4 to 6 minutes. Only the downstream more congested freeway section is used by these motorists. Current users under the average traffic demand level without an incident could have significant travel time savings by using the shortest route which is the alternate surface street route rather than the freeway biased route. However, the travel time savings for trips between origin 04 and destination D3 may be overestimated because current motorists may not be freeway biased motorists and some may "know" the shortest route.

b. Moderately Heavy Demand Level (NM1)

The freeway congestion pattern under the moderately heavy demand level without an incident is shown in Figure 7. Congestion began at 6:30 a.m. and continued until lo:15 a.m. The two major bottlenecks are indicated as occurring in subsection 21 and 36. The heaviest congestion occurred between 7:15 and 8:00 a.m. A comparison between Figure 7 and the previous Figure 6 indicates that increasing the traffic demand level from average to moderately heavy (a five percent increase), significantly increased the length and duration of congestion. This is particularly true upstream of the bottleneck in subsection 21. Because of the "metering" effect of this bottleneck, the increase in severity of congestion in the downstream section is not as great.

The travel time savings under the moderately heavy traffic demand level without an incident is shown in Table 3. The most

FIGURE 7

CONTOUR DIAGRAM OF QUEUE LENGTH

NM1 CELL: NO INCIDENT AND MODERATELY HEAVY TRAFFIC DEMAND SCENARIO (INCIDENT SS#20)

```
TIME                                                                                                        BEGIN
SLICE .-............................................................................|.......................  TIME
      .                                                                                                    .
   24 .                                                                                                    . - 11:45
   23 .                                                                                                    . - 11:30
   22 .                                                                                                    . - 11:15
   21 .                                                                                                    . - II:oo
   20 .                                                                                                    . - 10:45
   19 .                                                                                                    . - 10:30
   18 .                                                                                                    . - 10:15
   17 .                                                                        *                           . - 1o:oo
   16 .                                                      *******************                           . -  9:45
   15 .                                                     ********************                           . -  9:30
   14 .                                                 ************************                 *  ***    . -  9:15
   13 .                                             ****************************          **** ***  ***    . -  9:OO
   12 .                                             ****************************        ****** ********    . -  8:45
   11 .                                             ****************************       ****************    . -  8:30
   10 .                                                 ************************     ******************    . -  8:15
    9 .                                                  ***********************   ********************    . -  8:00
    8 .                                                   *********************************************    . -  7:45
    7 .                                                       *****************************************    . -  7:30
    6 .                                                            ************************************    . -  7:15
    5 .                                                                 ********      *****************    . -  7:oo
    4 .                                                                       **          *************    . -  6:45
    3 .                                                                                         *******    . -  6:30
    2 .                                                                                                    . -  6:15
    1 .                                                                                                    .. - 6:00
      .
      ......................................................................................................
       :   :      :      :      :      :      :     :      :  :  :: :  :  : :::::: :::: : : ::: :::: ::::::
       01     02    03     04    05     06    07     08    09     12           21           29      35   40
                                                           |      |            |            |       |    |
       SUBSECTION NUMBER                                   |      |            |            |       |    |
                                                           |      |            |            |       |    |
                                                           01     02,          04           D3      D2   DI
                                                                  03
```

BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION. M DENOTES QUEUED VEHICLES DUE TO MERGING. B DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION AND MERGING. (WHEN BOTH QUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

01, 02, 03, AND O4 : DENOTE LOCATIONS WHERE TRIPS ORIGINATING AT 01, 02, AND 03 JOIN THE FREEWAY.

DI, D2, AND D3 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO DI, D2, AND D3 LEAVE THE FREEWAY.

TABLE 3

Travel Time Savings in Minutes (Rounded to Nearest Minute)
(NMl) Scenario (Shortest Path vs. Freeway-Biased Path)

LEGEND

☐ HIGH. SIG. TIME SAV.

O SIG. TIME SAY.

From	Dl	0	0	0	0	1	2	$\boxed{6}$	3	1	1	1	1	1	1	1	1
01	D2	0	0	0	0	1	2	$\boxed{7}$	④	1	1	1	1	1	1	1	1
to:	D3	0	0	0	0	1	2	$\boxed{7}$	④	1	1	1	1	1	1	1	1

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	D1	0	0	0	0	1	2	$\boxed{8}$	④	2	1	2	1	2	2	1	2
.02	D2	0	0	0	0	1	2	$\boxed{8}$	⑤	2	1	2	1	2	2	1	2
to:	D3	0	0	0	0	1	2	$\boxed{8}$	⑤	2	2	2	2	2	2	1	2

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	D1	0	0	0	0	1	3	$\boxed{10}$	$\boxed{7}$	⑤	④	⑤	⑤	⑤	⑤	⑤	⑤
03	D2	0	0	0	0	1	④	$\boxed{11}$	$\boxed{8}$	⑤	④	⑤	④	⑤	⑤	⑤	⑤
to:	D3	0	0	0	0	1	3	$\boxed{10}$	$\boxed{7}$	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	D1	0	0	0	0	3	⑤	$\boxed{6}$	⑤	0	0	0	0	0	0	0	0
04	D2	0	0	0	0	④	$\boxed{6}$	$\boxed{7}$	$\boxed{6}$	1	1	0	0	0	0	0	0
to:	D3	0	0	0	0	3	⑤	$\boxed{6}$	⑤	1	0	0	0	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

significant savings occur between 7:15 and 8:00 a.m. for all origin-destination combinations and vary from 4 to 11 minutes. Savings before 7:15 a.m. appear to be insignificant. Savings after 8:00 a.m. also appear to be insignificant except for trips originating at origin 03. Trips from origin 03 continue to have significant savings after 8:00 a.m. because the origin is further away from the freeway, there is a good direct surface street connecting the origin to destination freeway on-ramps, and the freeway is heavily congested during this period of time.

A comparison between Table 3 and the previous Table 2 indicates that increasing the traffic demand level from average to moderately heavy (a five percent increase) significantly increased the travel time savings particularly between 7:15 and 8:00 a.m. Travel time savings increased from a range of 1 to 6 minutes to a range of 2 to 11 minutes. The savings were the largest for the upstream origins 01, 02, and 03 because of the extremely heavy congestion on the upstream portion of freeway. Another difference is that significant time savings to trips originating at 03 continue until 10:00 a.m. These results imply that relatively small unexpected increases in the traffic demand level more than doubles the travel time savings during the peak hour and for certain O-D trips this trend continues for two additional hours. (The furthest origin from the freeway has the largest savings).

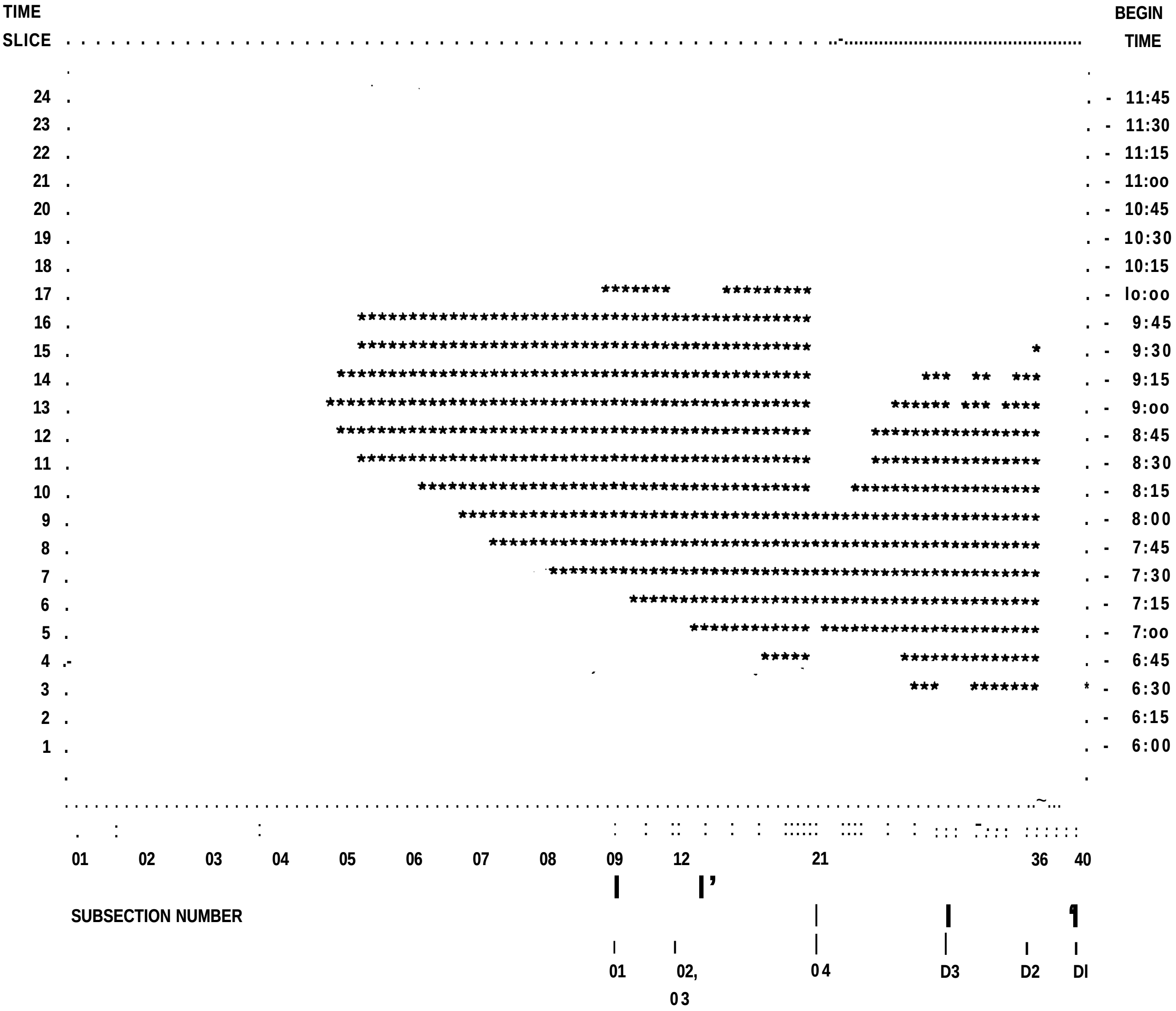
c. Heavy Demand Level (NHl)

The freeway congestion pattern under the heavy demand level without an incident is shown in Figure 8. Congestion began at 6:30 a.m. and continued until 10:00 a.m. The two major bottlenecks are indicated as occurring in subsection 21 and 36. The heaviest congestion occurred between 7:15 and 8:00 a.m. but the longest queue occurred between 8:45 and 9:00 a.m. A comparison between Figure 8 and the previous Figure 7 indicates that increasing the traffic demand level from moderately heavy to

FIGURE 8

CONTOUR DIAGRAM OF QUEUE LENGTH

NH1 CELL: NO INCIDENT HEAVY TRAFFIC DEMAND SCENARIO (INCIDENT SS#20)



BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES OUEUED VEHICLES DUE TO MAINLINE CONGESTION. H DENOTES QUEUED VEHICLES DUE TO MERGING. B DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION AND MERGING. (WHEN BOTH QUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

01, 02, 03, AND 04 : DENOTE LOCATIONS WHERE TRIPS ORIGINATING AT 01, 02, AND 03 JOIN THE FREEWAY.

DI, D2, AND D3 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO DI, D2, AND D3 LEAVE THE FREEWAY.

TABLE 4

Travel Time Savings in Minutes (Rounded to Nearest Minute)
(NHl) Scenario (Shortest Path vs. Freeway-Biased Path)

LEGEND

☐ HIGH. SIG. TIME SAV.

○ SIG. TIME SAV.

From	D1	0	0	0	0	1	⑤	$\boxed{9}$	④	1	1	1	1	1	1	1	1
01	D2	0	0	0	0	2	$\boxed{6}$	$\boxed{10}$	⑤	2	1	1	1	1	1	1	1
to:	D3	0	0	0	0	2	⑤	$\boxed{9}$	⑤	2	1	1	1	1	1	1	1

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	D1	0	0	0	0	1	$\boxed{6}$	$\boxed{10}$	$\boxed{6}$	2	1	2	1	2	2	1	2
02	D2	0	0	0	0	2	$\boxed{7}$	$\boxed{11}$	$\boxed{7}$	3	1	2	1	2	2	1	2
to:	D3	0	0	0	0	2	$\boxed{7}$	$\boxed{10}$	$\boxed{6}$	3	2	2	2	2	2	1	2

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	D1	0	0	0	0	2	$\boxed{9}$	$\boxed{12}$	$\boxed{8}$	⑤	④	⑤	④	⑤	⑤	⑤	⑤
03	D2	0	0	0	0	2	$\boxed{9}$	$\boxed{13}$	$\boxed{9}$	$\boxed{6}$	⑤	⑤	④	⑤	⑤	⑤	⑤
to:	D3	0	0	0	0	2	$\boxed{9}$	$\boxed{12}$	$\boxed{8}$	$\boxed{6}$	⑤	⑤	⑤	⑤	⑤	⑤	⑤

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	D1	0	0	0	0	④	$\boxed{6}$	$\boxed{7}$	⑤	1	0	0	0	0	0	0	0
04	D2	0	0	0	0	⑤	$\boxed{7}$	$\boxed{7}$	$\boxed{6}$	2	1	1	0	0	0	0	0
to:	D3	0	0	0	0	④	$\boxed{6}$	$\boxed{6}$	⑤	1	0	0	0	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

heavy (a five percent increase), significantly increased the length but not the duration of congestion which occurred between 6:30 and 10:00 a.m. The same metering effect was observed as in the previous non-incident moderately heavy traffic demand scenario (NM1) caused less congestion in the downstream bottleneck. Travel time savings under the heavy traffic demand level without an incident are shown in Table 4. The maximum significant savings were only 2 minutes larger than those of the moderately heavy traffic demand level without an incident. Significant time savings occur between 7:15 and 8:00 a.m. for all origin-destination combinations. Time savings vary from 4 to 13 minutes. Except for 04, savings before 7:15 appear to be insignificant. Savings after 8:00 a.m. also appear to be insignificant except for 03 where the savings pattern is similar to that of the moderately heavy traffic and no-incident scenario.

A comparison between Table 4 and the prevoius Table 3 indicates that increasing the traffic demand level from moderately heavy to heavy (a five percent increase) did not increase travel time savings significantly between 7:30 and 8:00 a.m., however, a significant increase is noticed between 7:15 and 7:30 a.m. The range of 2 to 6 minutes has increased to become 5 to 9 minutes. The savings were largest for the upstream origins 01, 02, and 03 because of the extremely heavy congestion on the upstream portion of the freeway. It is also noticed, as in the previous Table 3, that time savings to trips originating at 03 continue to be significant until 10:00 a.m.

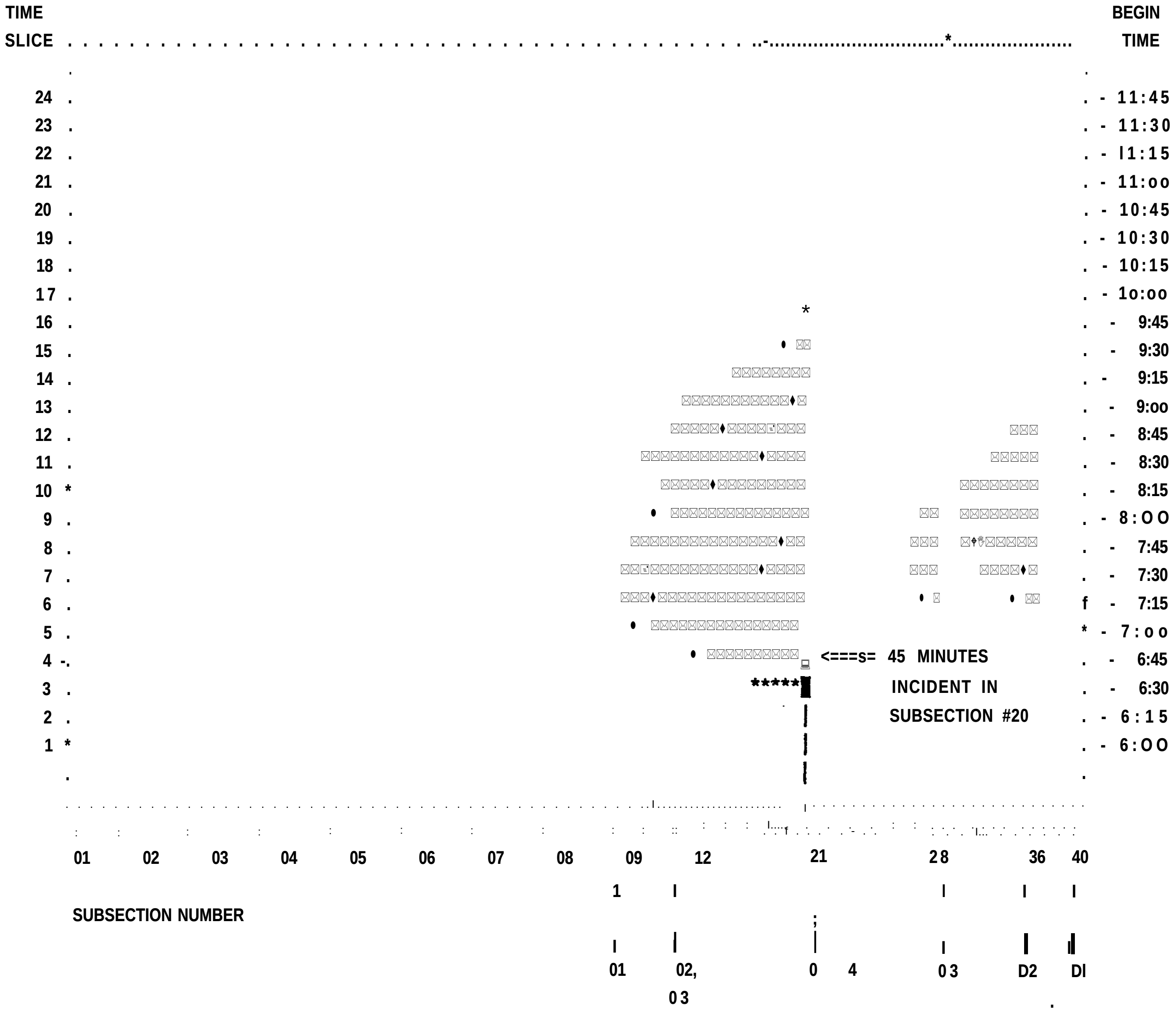
2. Effect of Traffic Demand Under Moderate Incident Situation

Three traffic demand levels are considered: average, moderately heavy, and heavy. These three cells are denoted as cells MAl, MMl, and MHl in the previous Figure 3 which depicted the design of experiment. These results will be discussed in the next three subsections in order of increasing traffic demand level.

FIGURE 9

CONTOUR DIAGRAM OF QUEUE LENGTH

HA1 CELL: MODERATE INCIDENT AND AVERAGE TRAFFIC DEMAND SCENARIO (INCIDENT SS#20)



BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION. M DENOTES QUEUED VEHICLES DUE TO MERGING. B DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION AND MERGING. (WHEN BOTH QUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

01, 02, 03, AND 04 : DENOTE LOCATIONS WHERE TRIPS ORIGINATING AT 01, 02, AND 03 JOIN THE FREEWAY.

DI, D2, AND D3 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO DI, D2, AND D3 LEAVE THE FREEWAY.

a. Average Traffic Demand Level (MA1)

The freeway congestion pattern under the average traffic demand level with a moderate incident is shown in Figure 9. The 45 minutes two lane blockage incident introduced in SS#20 is shown as a dotted black bar that extends from 6:30 to 7:15 a.m. on the queue diagram in Figure 9. Congestion began by introducing the incident at 6:30 a.m. and ended at 10:00 a.m. The downstream bottleneck SS#36 shows less congestion than in the non-incident scenarios discussed earlier. This indicates that the incident bottleneck in SS#2O has a large metering effect (larger than that of the bottleneck in SS#2l for non-incident scenarios). A third but rather small bottleneck appears in SS#28.

The travel time savings under average traffic demand level with a moderate incident are shown in Table 5. All travel time savings between 6:45 a.m. and 7:15 a.m. are considered to be significant except for trips originating at origin 4. This is due to the fact that the incident started at 6:30 and continued until 7:15 a.m. therefore causing a considerable difference between the travel time of the FB path and the SP during the last 30 minutes of the incident occurrence. Origin 4 is located downstream of the incident and hence the FB path is exactly the same as the SP after the incident occurrence and consequently there is no savings for this group. Significant time savings are in the range of 4 to 10 minutes. Trips originating at 03 and destined to Dl, D2, and D3 have predicted significant savings also from 7:15 to 8:00 a.m. and later from 9:00 to 9:15 a.m. This strange behavior can be interpreted if one recalls that TRANSYT-7F simulation is based on one hour periods and therefore surface streets link travel time changes on an hourly basis while freeway link travel time attained from FREQ changes on a fifteen minutes basis.

b. Moderately Heavy Traffic Demand Level (MM1)

The freeway congestion pattern under the moderately heavy traffic

TABLE 5

Travel Time Savings in Minutes (Rounded to Nearest Minute)
(MA1) Scenario (Shortest Path vs. Freeway-Biased Path)

LEGEND

☐ HIGH. SIG. TIME SAV.

○ SIG. TIME SAV.

From	**D1**	0	0	1	④	$\boxed{6}$	1	1	"	1	1	1	1	1'	1'	1'	1 '0 '
01	**D2**	0	0	1	④	$\boxed{6}$	1	1	1	1	1	1	1	1	1	1	0
to:	1 D3	10	10	11	13	$\boxed{16}$	11	11	11,	1	1	1	1	1	1	1	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	Dl	0	0	1	④	$\boxed{8}$	2	3	2	2	1	2	1	1	1	1	0
02	D2	0	0	1	④	$\boxed{8}$	2	3	2	2	1	2	1	1	1	1	0
to:	D3	0	0	1	④	$\boxed{8}$	2	3	2	2	1	2	1	1	1	1	0

Time: 060-0 0630 0700 0730 0800 0830 0900 0930 1000

From	**D1**	0	0	1	$\boxed{7}$	$\boxed{10}$	④	⑤	④	2	1	2	1	⑤	3	1	0
03	**D2**	0	0	1	$\boxed{7}$	$\boxed{10}$	④	⑤	④	2	1	2	1	⑤	3	1	0
to:	**D3**	0	0	1	$\boxed{7}$	$\boxed{10}$	④	⑤	④	2	1	2	1	⑤	3	1	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

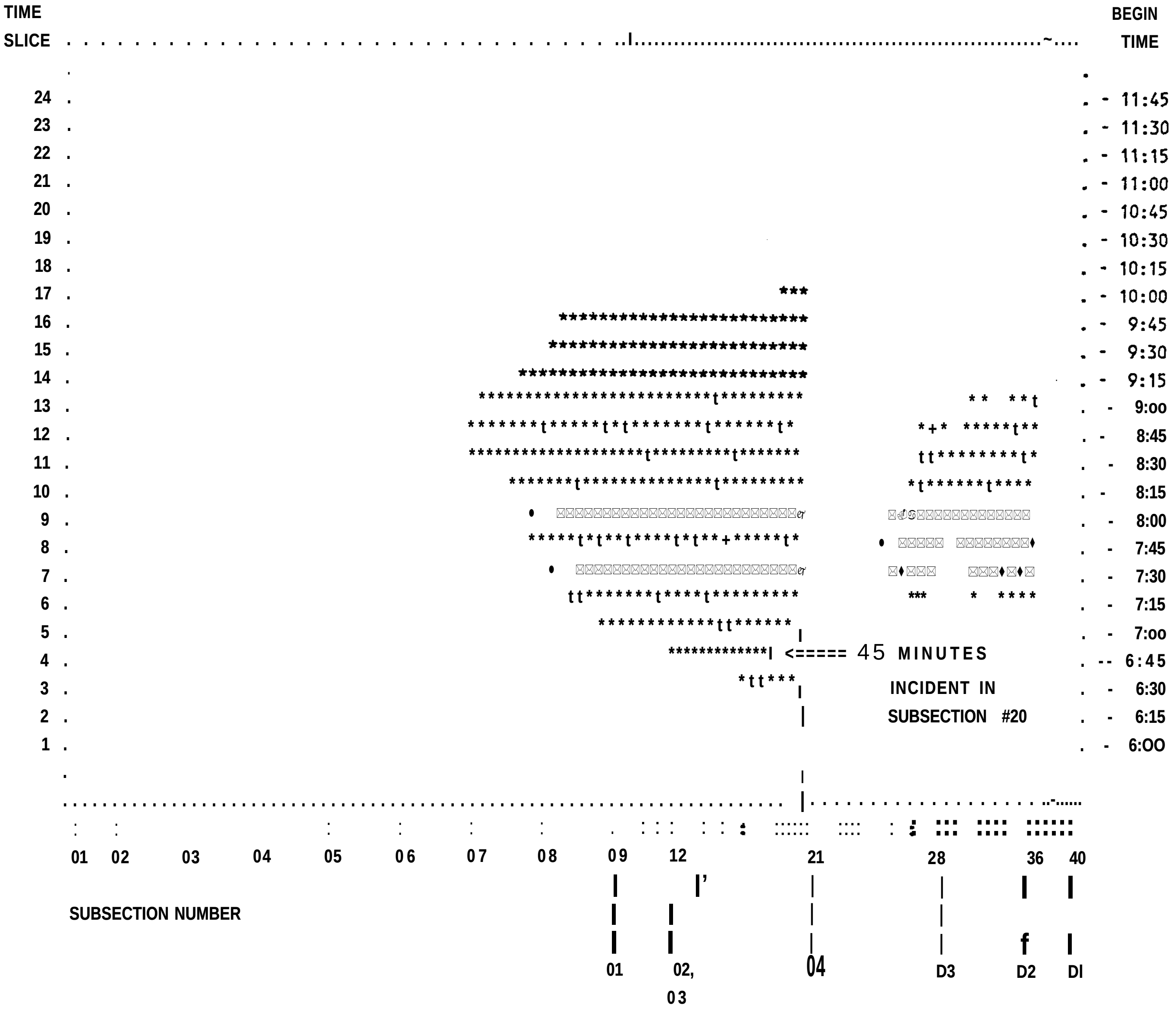
From	D l	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04	D2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
to:	D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

FIGURE 10

CONTOUR DIAGRAM OF QUEUE LENGTH

MM1 CELL: MODERATE INCIDENT AND MODERATELY HEAVY TRAFFIC DEMAND SCENARIO (INCIDENT SS#20)



BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES QUEUED VEHICLES DUE 70 MAINLINE CONGESTION. M DENOTES QUEUED VEHICLES DUE TO MERGING. B DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION AND MERGING. (WHEN BOTH QUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

01, 02, 03, AND 04 : DENOTE LOCATIONS WHERE TRIPS ORIGINATING AT 01, 02, AND 03 JOIN THE FREEWAY.

DI, D2, AND D3 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO DI, D2, AND D3 LEAVE THE FREEWAY.

TABLE -6:

Travel Time Savings in Minutes (Rounded to Nearest Minute)
(MMl) Scenario (Shortest Path vs. Freeway-Biased Path)

LEGEND

▭ HIGH. SIG. TIME SAV.

○ SIG. TIME SAV.

From	D1	0	0	1	④	8	1	1	1	1	1	1	1	1	1	1	1
01	D2	0	0	1	④	8	1	1	1	1	1	1	1	1	1	1	1
to:	D3	0	0	1	④	8	1	1	1	1	1	1	1	1	1	1	1

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	D1	0	0	1	⑤	9	2	3	2	2	1	2	1	2	1	1	2
02	D2	0	0	1	⑤	9	2	3	2	2	1	2	1	2	1	1	2
to:	D3	0	0	1	⑤	9	2	3	3	2	1	2	1	2	1	1	2

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	Dl	0	0	2	8	11	④	⑤	④	⑤	④	⑤	④	⑤	⑤	⑤	⑤
03	D2	0	0	2	8	11	④	⑤	④	⑤	④	⑤	④	⑤	⑤	⑤	⑤
to:	D3	0	0	2	8	11	④	⑤	⑤	⑤	④	⑤	④	⑤	⑤	⑤	⑤

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	Dl	0	0	0	0	0	0	~	0	0	0	0	0	0	0	0	0 0
04	D2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
to:	D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Time:-, 0600 0630 0700 0730 0800 0830 0900 0930 1000 demand level with a moderate incident is shown in Figure 10. Congestion began at 6:30 and ended at 10:00 a.m. A comparison between Figure 10 and the previous Figure 9 shows that both upstream and downstream congestion has increased in the moderately heavy traffic demand and moderate incident scenario. The longest queue upstream of the incident section occurred between 8:15 and 8:30 a.m. Same "metering" effect of reducing congestion of the downstream bottleneck is observed.

The travel time savings under moderately heavy traffic demand level with a moderate incident are shown in Table 6. Except for trips originating at origin 4, all travel time savings between 6:45 and 7:15 a.m. are considered to be significant. Trips originating at 03 exhibits significant time savings also from 8:00 to 10:00 a.m. Also trips originating at 03, as usual, have the maximum time savings among all trips originating at other origins. Origin 4 has zero time savings for the same reason as in section C.2.a above.

The range of time savings for both average and moderately heavy traffic demand levels under the moderate incident scenario are very close (4 to 10 minutes compared to 4 to 11 minutes).

c. Heavy Traffic Demand Level (MHl)

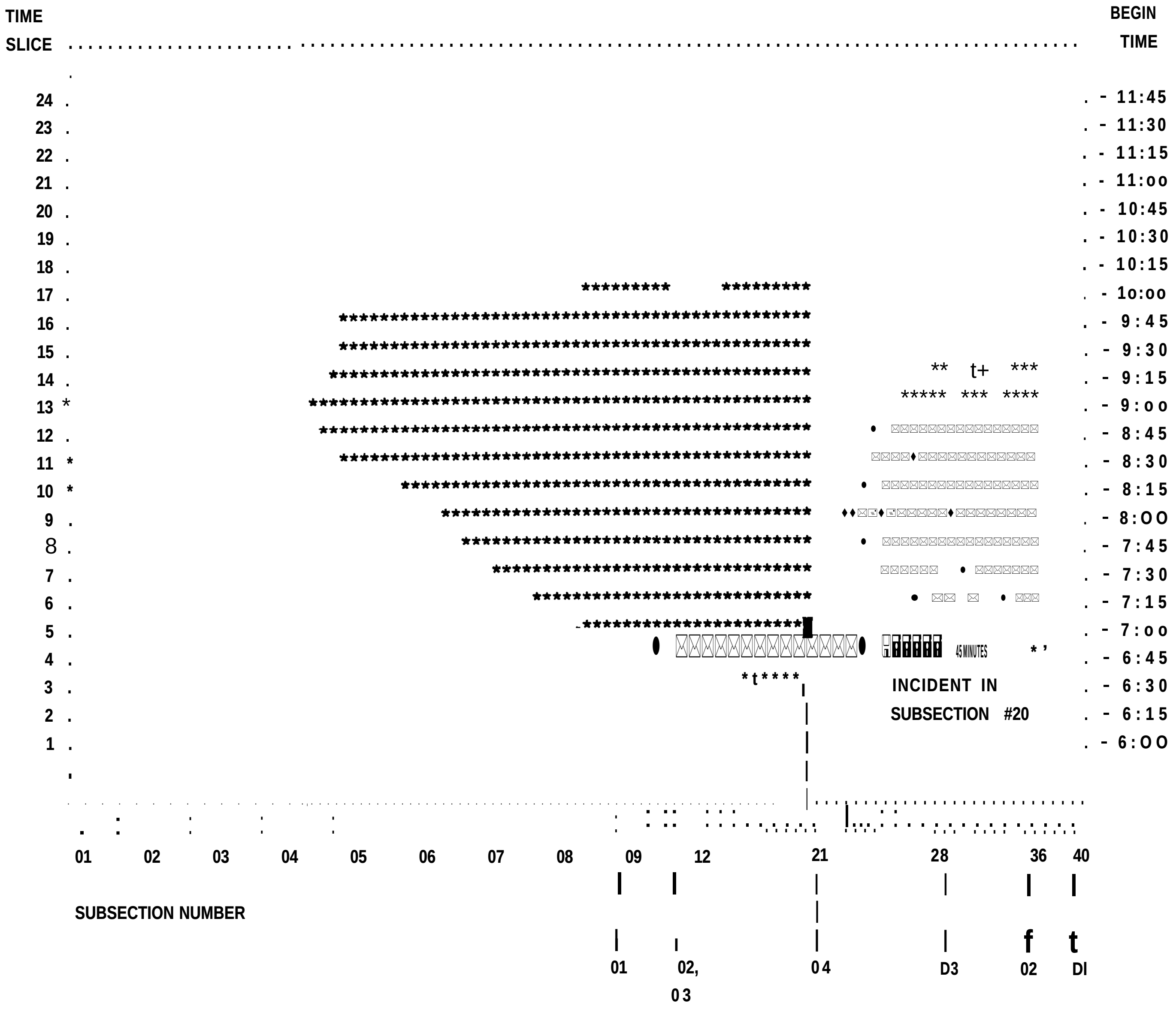
The freeway congestion pattern under the heavy traffic demand level with a moderate incident is shown in Figure 11. Congestion began at 6:30 and ended at 10:00 a.m. A comparison between Figure 11 and the previous Figure 10 shows that congestion of both upstream bottleneck (or incident subsection) and downstream bottleneck has increased over the previous moderate incident and moderately heavy traffic scenario. The largest queue length occurred between 8:45 and 9:00 a.m. Same "metering" effect of reducing congestion of the downstream bottleneck is observed.

The travel time savings under MHl or moderate incident and heavy

FIGURE 11

CONTOUR DIAGRAM OF QUEUE LENGTH

MHI CELL: MODERATE INCIDENT AND HEAVY TRAFFIC DEMAND SCENARIO (INCIDENT SS#20)



BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION. M DENOTES QUEUED VEHICLES DUE TO MERGING. B DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION AND MERGING. (WHEN BOTH QUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

01, 02, 03, AND 04 : DENOTE LOCATIONS WHERE TRIPS ORIGINATING AT 01, 02, AND 03 JOIN THE FREEWAY.

DI, DZ,.AND D3 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO DI, D2, AND 03 LEAVE THE FREEWAY.

TABLE 7

Travel Time Savings in Minutes (Rounded to Nearest Minute)
(MHl) Scenario (Shortest Path vs. Freeway-Biased Path)

LEGEND

☐ HIGH. SIG. TIME SAV.

○ SIG. TIME SAV.

From 01 to:	D1	0	0	2	⑤	8	1	1	1	1	1	1	1	1	1	1	1
	D2	0	0	2	⑤	8	1	1	1	1	1	1	1	1	1	1	1
	D3	0	0	2	⑤	8	1	2	1	1	1	1	1	1	1	1	1

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 02 to:	D1	0	0	2	6	9	2	3	2	2	1	2	1	2	2	1	2
	D2	0	0	2	6	9	2	3	2	2	1	2	1	2	2	2	1
	D3	0	0	2	6	9	2	3	3	2	2	2	2	2	2	2	1

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 03 to:	D1	0	0	2	10	11	⑤	⑤	⑤	⑤	④	⑤	④	⑤	⑤	⑤	⑤
	D2	0	0	2	10	11	⑤	⑤	⑤	⑤	⑤	⑤	④	⑤	⑤	⑤	⑤
	D3	0	0	2	10	11	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 04 to:	D1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

traffic demand level scenario are shown in Table 7. Except for trips originating at origin 4, all travel time savings between 6:45 and 7:15 a.m. are considered to be significant. Time savings follow a similar pattern as in C.1.b above (or the moderate incident and the moderately heavy traffic demand scenario). Origin 3 has the maximum time savings between 6:45 and 7:15 a.m. Savings are largest in this period for all origin groups except for origin 4 group which has no savings at all. Origin 4 as usual has zero time savings for the same reason as in section C.2.a above.

Increasing traffic demand level under moderate incident conditions by 5% or even by 10% did not have as expected effect on increasing travel time savings. This is related to the "metering" effect of the incident bottleneck upstream of the freeway which caused longer queues that back further upstream when traffic demand level was increased. The queue extends upstream of origin 1 (which is the beginning of the study limit) in both MM1 and MHl scenarios. Therefore, it should not matter for a driver who starts at origin1 and wants to travel to destination Dl (for example) how long the queue behind him is!

3. Effect of Traffic Demand Under Heavy Incident Situation

Three traffic demand levels are considered: average, moderately heavy, and heavy. These three cells are denoted as cells HAl, ml, and HHl in the previous Figure 3 which depicted the design of experiment. These results will be discussed in the next three subsections in order of increasing traffic demand level.

a. Average Traffic Level (HA1)

The freeway congestion pattern under the average traffic demand level with a heavy incident is shown in Figure 12. Congestion began at 6:30 and ended at 10:00 a.m. A black dotted bar of length proportional to the duration of a 90 minutes incident

FIGURE 12

CONTOUR DIAGRAM OF QUEUE LENGTH

HA1 CELL: HEAVY INCIDENT AND AVERAGE TRAFFIC DEMAND SCENARIO (INCIDENT SS#20)

```
TIME                                                                                        BEGIN
SLICE . . . . . . . . . . . . . . . . ..I.............. . . . . . . . . . . . . . . . . . . . . .  TIME
      .                                                                                 .
  24  .                                                                                 . -  11:45
  23  .                                                                                 . -  11:30
  22  .                                                                                 . -  11:15
  21  .                                                                                 . -  11:oo
  20  .                                                                                 . -  10:45
  19  .                                                                                 . -  10:30
  18  .                                                                                 . -  10:15
  17  .                                                                                 . -  1o:oo
  16  .                                                  *********                      . -   9:45
  15  I                                               ************                      . -   9:30
  14  .                                           ****************                      . -   9:15
  13  .                                     **********************                      . -   9:oo
  12  .                                 **************************                      . -   8:45
  11  .                              *****************************                      . -   8:30
  10  *                                ***************************                      . -   8:15
   9  .                             ******************************                      . -   8:00
   8  .                      ************************************█                      . -   7:45
   7  .                           *******************************█                      * -   7:30
   6  .                                ***t******~**t**tt******    <=====  90 MINUTES   . -   7:15
   5  .                                        *******+*t******t:          INCIDENT IN  . -   7:oo
 - 4  .                                              • ⊠⊠⊠⊠⊠⊠⊠⊠⊠⊠          SUBSECTION #20  * -   6:45
   3  .                                                    et***:                       . -   6:30
   2  .                                                         |                       . -   6:15
   1  .                                                         |                       . -   6:00
      .                                                         |
      . . . . . . . . . . . . . . . . . . . . . . . . .*. . . . . .|. . . . . . . . . ..I...............
      :    .    :    :    :    :    :    :    :  :  ::  :  :  :  :::::   :::: : : .~. .:. . .:| : : : : : :
     01   02   03   04   05   06   07   08   09   12         21         29      35   40
                                              |    |"        |          |       |    |
 SUBSECTION NUMBER                            |    |                            |    |
                                              |    |         |          |       |    |
                                             01   02,       04         D3      D2   DI
                                                  03
```

BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION. M DENOTES QUEUED VEHICLES DUE TO MERGING. B DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION AND MERGING. (WHEN BOTH OUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

01, 02, 03, AND 04 : DENOTE LOCATIONS WHERE TRIPS ORIGINATING AT 01, 02, AND 03 JOIN THE FREEWAY.

DI, D2, AND D3 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO DI, D2, AND D3 LEAVE THE FREEWAY.

TABLE 8

Travel Time Savings in Minutes (Rounded to Nearest Minute)
(HAl) Scenario (Shortest Path vs. Freeway-Biased Path)

LEGEND

□ HIGH. SIG. TIME SAV.

○ SIG. TIME SAV.

From	**D1**	0	0	1	3	6	7	7	6	1	1	1	1	1	1	1	1
01	**D2**	0	0	1	3	6	7	7	6	1	1	1	1	1	1	1	1
to:	**D3**	0	0	1	3	6	7	7	6	1	1	1	1	1	1	1	1

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	D1	0	0	1	3	8	8	8	7	1	1	2	1	2	1	1	1
02	D2	0	0	1	3	8	8	8	7	1	1	2	1	2	1	1	1
to:	D3	0	0	1	3	8	8	8	7	1	1	2	1	2	1	1	1

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From.	D1	0	0	1	7	10	10	10	9	④	④	⑤	④	⑤	⑤	④	3
03	D2	0	0	1	7	10	10	10	9	④	④	⑤	④	⑤	⑤	④	3
to:	D3	0	0	1	7	10	10	10	9	④	④	⑤	④	⑤	⑤	④	3

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	Dl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
04	02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
to:	D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

extends vertically (between 6:30 a.m. and 8:00 a.m.). This is the definition used for a heavy incident. The downstream congestion is completely eliminated by the "metering" effect. The longest queue observed is between 7:30 and 7:45 a.m. Table 8 shows travel time savings under the heavy incident and average traffic demand scenario (HAl). For all origin groups and except for origin 4 group travel time savings are significant between 7:00 and 8:00 a.m. Travel time savings for origin 3 group are also significant between 8:00 a.m. and 10:00 a.m. and between 6:45 and 7:00 a.m.

b. Moderately Heavy Traffic Demand Level (HMl)

The freeway congestion pattern under the moderately heavy traffic demand level with a heavy incident is shown in Figure 13. Congestion began at 6:30 and ended at lo:15 a.m. A comparison between Figure 13 and the previous Figure 12 shows that congestion under the heavy incident and moderately heavy traffic demand level (HMl) has increased upstream of the freeway and maximum queue length extended upstream of origin 1 and became larger than that of the previous (HAl) maximum queue length. The maximum queue length occurred between 8:15 and 9:00 a.m.

Table 9 shows travel time savings under the heavy incident and moderately heavy traffic demand level. Travel time savings are significant for a period of one hour and fifteen minutes (6:45 to 8:00 a.m.) for all origin groups (except origin 4 group). Similar pattern of time savings for origin 3 group hold as in the previous (HAl) incident scenario. The increase in travel time savings over the (HAl) scenario (the traffic demand of which is 5% less) is almost negligible (or less than two minutes) for most cells in the table.

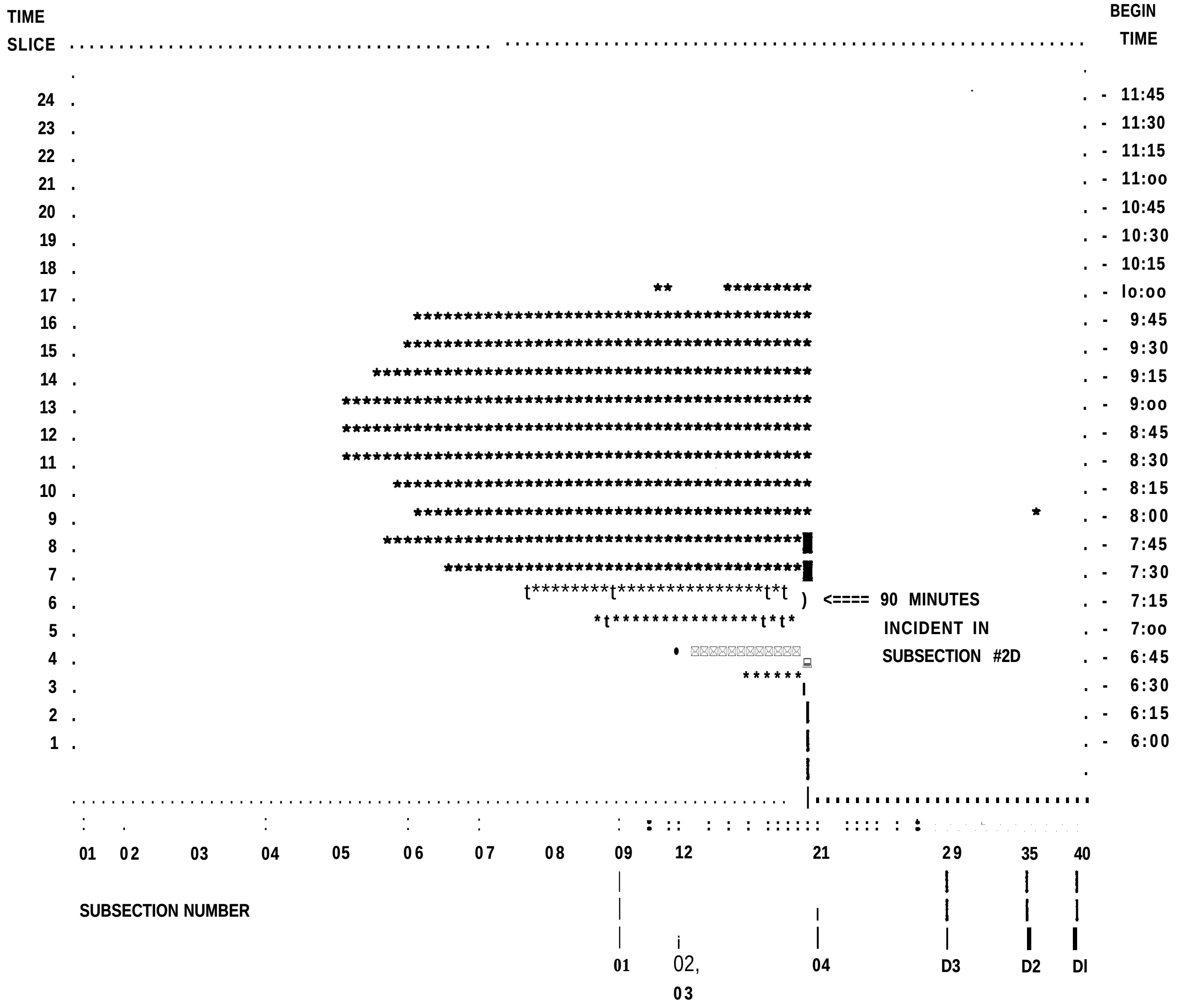
c. Heavy Traffic Demand Level (HHl)

The freeway congestion pattern under the heavy traffic demand level with a heavy incident is shown in Figure 14 and travel time

FIGURE 13

CONTOUR DIAGRAM OF QUEUE LENGTH

HMI CELL: HEAVY INCIDENT AND MODERATELY HEAVY TRAFFIC DEMAND SCENARIO (INCIDENT SS#20)



BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION. M DENOTES QUEUED VEHICLES DUE TO MERGING. B DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION AN0 MERGING. (WHEN BOTH QUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

01, 02, 03, AND O4 : DENOTE LOCATIONS UHERE TRIPS ORIGINATING AT 01, 02, AND 03 JOIN THE FREEWAY.

DI, D2, AND D3 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO DI, D2, AND D3 LEAVE THE FREEWAY.

TABLE 9

Travel Time Savings in Minutes (Rounded to Nearest Minute) - (HMl) Scenario (Shortest Path vs. Freeway-Biased Path)

LEGEND

□ HIGH. SIG. TIME SAV.

○ SIG. TIME SAV.

From 01 to:

D1	0	0	1	⑤	8	7	7	6	1	1	1	1	1	1	1	1
D2	0	0	1	⑤	8	7	7	6	1	1	1	1	1	1	1	1
D3	0	0	1	⑤	8	7	7	6	1	1	1	1	1	1	1	1

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 02 to:

D1	0	0	1	⑤	9	8	8	7	1	1	2	1	2	2	1	2
D2	0	0	1	⑤	9	8	8	7	1	1	2	1	2	2	1	2
D3	0	0	1	⑤	9	8	8	7	1	1	2	1	2	2	1	2

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 03 to:

D1	0	0	2	9	11	10	10	[illegible]	④	④	⑤	④	⑤	⑤	⑤	⑤
D2	0	0	2	9	11	10	10	9	④	④	⑤	④	⑤	⑤	⑤	⑤
D3	0	0	2	9	11	10	10	9	④	④	⑤	④	⑤	⑤	⑤	⑤

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 04 to:

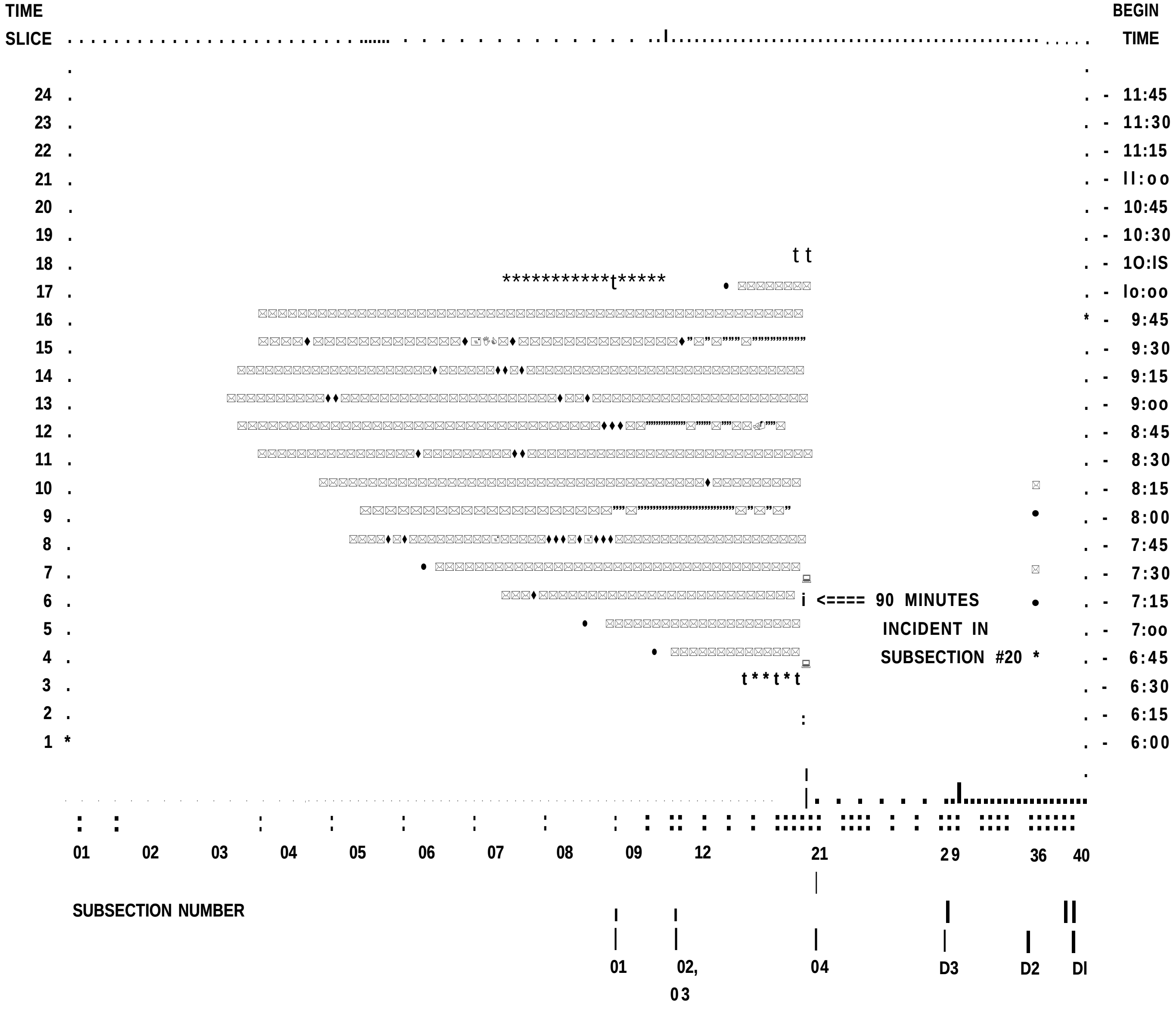
Dl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

FIGURE 14

CONTOUR DIAGRAM OF QUEUE LENGTH

HHI CELL: HEAVY INCIDENT AND HEAVY TRAFFIC DEMAND SCENARIO (INCIDENT SS#20)



BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION. M DENOTES QUEUED VEHICLES DUE TO MERGING. B DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION AND MERGING. (WHEN BOTH QUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

O1, O2, O3, AND O4 : DENOTE LOCATIONS WHERE TRIPS ORIGINATING AT O1, O2, AND O3 JOIN THE FREEWAY.

D1, D2, AND D3 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO D1, D2, AND D3 LEAVE THE FREEWAY.

TABLE 10

Travel Time Savings in Minutes (Rounded to Nearest Minute)
(HHl) Scenario (Shortest Path vs. Freeway-Biased Path)

LEGEND

a HIGH. SIG. TIME SAV.

O SIG. TIME SAY.

From 01 to:

D1	0	0	2	⑤	8	7	7	6	1	1	1	1	1	1	1	1
D2	0	0	2	⑤	8	7	7	6	1	1	1	1	1	1	1	1
D3	0	0	2	⑤	8	7	7	6	1	1	1	1	1	1	1	1

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 02 to:

D1	0	0	2	6	9	8	8	7	1	1	2	1	2	2	1	2
D2	0	0	2	6	9	8	8	7	1	1	2	1	2	2	1	2
D3	0	0	2	6	9	8	8	7	1	1	2	1	2	2	1	2

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 03 to:

D1	0	0	2	10	11	10	10	9	④	④	⑤	④	⑤	⑤	⑤	⑤
D2	0	0	2	10	11	10	10	9	④	④	⑤	④	⑤	⑤	⑤	⑤

I D3 I 01 01 +I+I4 9I@I@Iwm[01~1d

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 04 to:

Dl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

savings are shown in Table 10. The only noticeable difference between congestion in Figure 14 and that in Figure 13 (HMl)is that queue length has extended further upstream of origin 1 in Figure 14. One would expect that this is not going to affect travel time savings for drivers travelling from any of the four origins to any of the three destinations. This conclusion is reflected in Tables 10 and 9 which look more or less identical.

The general conclusion that one can make about the heavy incident scenarios in SS#20 is that increasing traffic demand level from average to moderately heavy to heavy did not make a significant difference in terms of travel time savings.

4. Effect of Incident Severity Under Average Traffic Demand Level:

Comparison between travel time savings for three incident severity levels are considered: no incident, moderate incident, and heavy incident. These three cells are denoted as cells NAl, MAl, and HA1 in the previous Figure 3 which depicted the design of experiment. These results will be discussed in the next three subsections in order of increasing incident level.

a. No Incident Situation (NAl)

This scenario has been discussed in detail in section C.1.a of this chapter.

b. Moderate Incident Situation (MA1)

The reader is referred to section C.2.a of this chapter where MA1 scenario has been discussed in detail. However, a comparison of a situation with no incident and another with a moderate incident, both under average traffic conditions, [i.e a comparison between (Table 2, Figure 6) and (Table 5, Figure 9) respectively] reveals that significant changes in both congestion pattern and the magnitudes of travel time savings has occurred. The congestion of the downstream bottleneck in NAl scenario has been reduced by the metering effect of the upstream incident (bottleneck). While congestion in both NAl and MA1 scenarios started at 6:30, congestion ended at 9:00 a.m. in NAl scenario but ended at 9:45 a.m. in MA1 scenario. In case of NAl scenario travel time savings were insignificant (except for origin 4 group). In case of MA1 scenario travel time savings were significant and were in the range of 4 to 10 minutes for all origin groups (except origin 4 group 1.

c. Heavy Incident Situation (HAl)

A comparison between the three queue diagrams (Figure 12, Figure 9, and Figure 6) shows that under average traffic demand level congestion of the downstream bottleneck decreases gradually as one moves from NAl to HA1 scenarios, i.e the heavier the incident is, the larger the metering effect is. At the same time congestion of the upstream incident bottleneck increases gradually and the queue length becomes larger.

In terms of travel time savings HA1 obviously has the largest savings and HA1 has peak significant travel time savings for one hour (for origin 1 and 2 groups) and for one hour and fifteen minutes for origin 3 group. Since the freeway downstream of SS#20 became uncongested, both the shortest path and the freeway biased path for trips originating at origin 4 and destined to Dl, D2, and D3 became identical and travel time savings are consequently equal to zero.

The difference in magnitude of travel time savings between HA1 and MA1 is large in the period from 7:15 to 8:00 a.m. This is due to the fact that incident of HA1 scenario is 45 minutes larger than incident of MA1 scenario.

5. Effect of Incident Severity Under Moderately Heavy Traffic Demand Level

Comparison between travel time savings for three Incident severity levels are considered: no incident, moderate incident, and heavy incident. These three cells are denoted as cells NMl, MM1 and HMl in the previous Figure 3 which depicted the design of experiment. These results will be discussed in the next three subsections in order of increasing incident level.

a. <u>No Incident Situation (NM1)</u>

This scenario has been discussed in detail in section C.1.b of this chapter.

b. <u>Moderate Incident Situation (MMl)</u>

The reader is referred to sections C.1.b and C.2.b for a detailed discussion of NM1 and MM1 scenarios respectively.

A comparison between MM1 and NM1 or (Figure 7, Table 3) and (Figure 10, Table 6) respectively shows that the congestion of downstream bottleneck has decreased in MM1 from that of NM1 while the opposite is true for the congestion of the upstream bottleneck.

A comparison between travel time savings in NM1 and MM1 scenarios shows that both scenarios have peak significant savings for a period of half an hour for origin groups 01, 02, and 03. However, the one half hour period with significant time savings in case of NM1 (no incident) is from 7:30 to 8:00 a.m. while it is from 6:45 a.m. to 7:15 a.m. in the case of MM1 scenario. This is explained by the fact that the incident started at 6:30 and ended at 7:15 a.m. The range of 4 to 11 minutes time savings hold for both traffic scenarios: NM1 and MMl.

c. Heavy Incident Situation (HMl)

The reader is referred to sections C.3.b for a detailed discussion of HMl scenario.

A comparison between HMl and MM1 or (Figure 13, Table 9) and (Figure 10, Table 6) respectively shows that the same trend in congestion holds as in part C.5.b above. Travel time savings for HMl are significant for a period of one hour and fifteen minutes (from 6:45 to 8:00 a.m.) while it is only significant for a period of half an hour for MM1 (between 6:45 and 7:15 a.m.). This is because the duration of the incident in HMl (90 minutes) is twice as much as it is in MM1 (45 minutes). The range of travel time savings is 4 to 10 minutes and is almost identical for both scenarios.

6. Effect of Incident Severity Under Heavy Traffic Demand Level

Comparison between travel time savings for three Incident severity levels are considered: no incident, moderate incident, and heavy incident. These three cells are denoted as cells NHl, MH1 and HHl in the previous Figure 3 which depicted the design of experiment. These results will be discussed in the next three subsections in order of increasing incident level.

a. No Incident Situation (NHl)

This scenario has been discussed in detail in section C.3.b of this chapter.

b. Moderate Incident Situation (MHl)

The reader is referred to sections c.2.c for a detailed discussion of MHl scenario.

A comparison between MHl and NH1 or (Figure 11, Table 7) and (Figure 8, Table 4) respectively shows that the usual trend of congestion pattern (downstream congestion decreases while upstream congestion increases under incident situation when compared to a non-incident situation for the same traffic demand level). This also tells that the metering effect of incident SS#20 is larger that of the natural bottleneck of SS#21 even under the heaviest traffic demand level used (which is 10% over normal traffic demand level). This explains the strange behavior in travel time savings for MHl and NH1 (Tables 7 and 4 respectively). For NH1 (the non-incident scenario) significant time savings expand over 45 to 60 minutes period depending on what origin group one is looking at, while travel time savings expand only over a 30 minutes period under the moderate incident situation and same traffic demand level. Even in magnitude travel time savings for the NH1 scenario is still higher (the maximum is equal to 13 minutes) compared to a maximum of 11 minutes in the MHl scenario.

c. Heavy Incident Situation (HHl)

The reader is referred to sections c.3.c for a detailed discussion of HHl scenario.

A comparison between HH1 and MHl scenarios or (Figure 14, Table 10) and (Figure 11, Table 7) respectively shows that the congestion of the downstream bottleneck has been eliminated because of the metering effect where the upstream incident bottleneck became the worst possible among all incident scenarios for SS#20 (recall that HHl stands for Heaviest Incident and Heaviest Traffic Demand Level at SS#20 in face 1 of the experiment in Figure 3, chapter 2).

A comparison between travel time savings for both HHl and MHl (Tables 10 and 7 respectively) shows that travel time savings are significant for a period of one hour and fifteen minutes for all origin groups except for origin 4 group in the HHl scenario while travel time savings are very significant for only a period of 30 minutes for the first three origin groups in the MHl scenario.

The range of values of significant time savings is similar for both scenarios (5 to 11 minutes).

The general conclusion for the heavy traffic demand level scenarios is that doubling the incident duration from 45 minutes to 90 minutes (therefore doubling incident severity) more than doubles the period during which travel time savings are significant (30 minutes to 75 minutes).

It is noticed that for all traffic incident scenarios in SS#20 maximum travel time savings for all origins occur from 7:00 to 7:15 a.m. without exception, while maximum travel time savings for all non-incident scenarios for all origins without exception occur between 7:30 and 7:45 a.m. (the morning peak traffic period).

CHAPTER 4

STUDY RESULTS - SECOND INCIDENT LOCATION

A. Introduction

The study results related to the second incident location are presented and discussed in this chapter. The initial section is devoted to assessing the effect of the three traffic demand levels of the moderate incident situation. In relation to the previous Figure 3 this would represent a horizontal comparison of cells in the second row of the back face of the design experiment. The final three sections of this chapter are devoted to assessing the effect of an incident under three traffic demand levels.

B. Effect of Traffic Demand Under Moderate Incident Situation

Three traffic demand levels are considered: average, moderately heavy, and heavy. These three cells are denoted as cells MA2, MM2, and MB2 in the previous Figure 3 which depicted the design of experiment. These results will be discussed in the next three subsections in order of increasing traffic demand level.

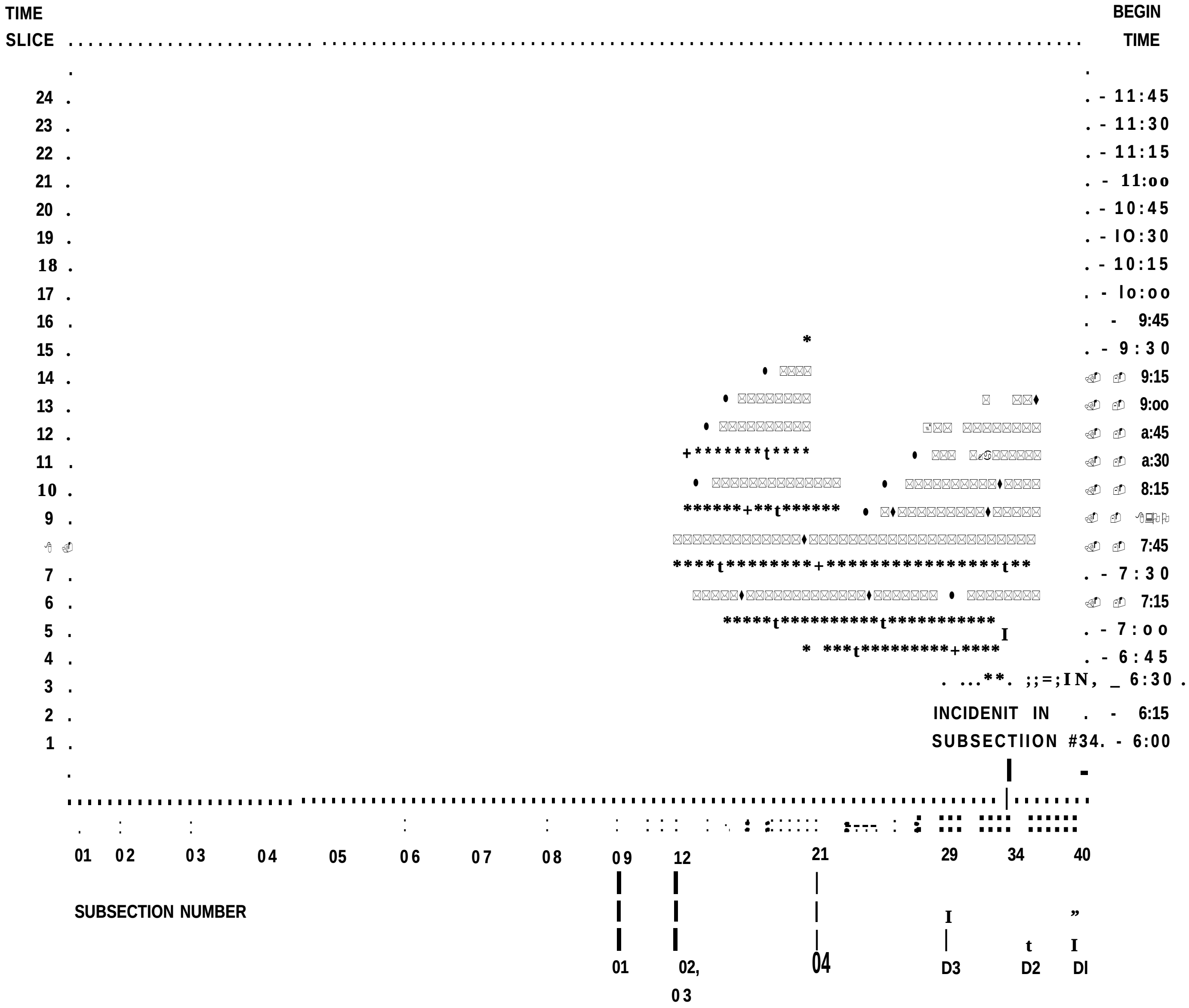
1. Average Traffic Level (MA2)

The freeway congestion pattern under the average traffic demand level with a moderate incident is shown in Figure 15. The 45 minute two-lane blockage incident introduced in SS#34 shown as a dotted black bar that extends from 6:30 to 7:15 a.m. on the queue diagram in Figure 15. Congestion began when the incident occurred at 6:30 a.m. and ended at 9:30 a.m. There are two other bottlenecks: one downstream of the incident subsection which is

FIGURE 15

CONTOUR DIAGRAM OF QUEUE LENGTH

MA2 CELL: MODERATE INCIDENT AND AVERAGE TRAFFIC DEMAND SCENARIO (SW34 INCIDENT)



BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES PUEUED VEHICLES DUE TO MAINLINE CONGESTION. I4 DENOTES QUEUED VEHICLES DUE TO MERGING. B DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION AND MERGING. (WHEN BOTH QUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

01, 02, 03, AND 04 : DENOTE LOCATIONS WHERE TRIPS ORIGINATING AT 01, 02, AND 03 JOIN THE FREEWAY.

DI, D2, AND 03 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO DI, D2, AND D3 LEAVE THE FREEWAY.

TABLE II

Travel Time Savings in Minutes (Rounded to Nearest Minute)
(MA2) Scenario (Shortest Path vs. Freeway-Biased Path)

LEGEND

□ HIGH. SIG. TIME SAV.

○ SIG. TIME SAV.

From	Dl	0	0	0	1	④	1	2	2	~ 1	1	1	1	1	1 0		0
01	D2	0	0	0	2	~	1	2	2	1	1	1	1	1	1	0	0
to:	D3	0	0	0	1	@	2	2	2	1	1	1	1	1	1	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	Dl	0	0	0	1	④	1	2	3	1	1	1	1	1	1	0	0
02	D2	0	0	0	2	~	1	3	~	1	1	1	1	1	1	0	0
to:	D3	O	O	O	l	Q^n ,	2	3	④	2	1	1	1	1	1 0		0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From	D1	0	0	0	1	④	3	⑤	⑤	④	④	④	④	3	2	0	0
03	D2	0	0	0	2	⑤	3	⑤	$\boxed{6}$	④	④	④	④	3	2	0	0
to:	D3	0	0	0	1	⑤	3	⑤	$\boxed{6}$	⑤	④	④	④	3	2	0	0

Time: 0600 0630 0700 0730 0800 0’830 0900 0930 1000

From	D1	0	0	0	1	$\boxed{7}$	④	⑤	⑤	0	0	0	0	0	0	0	0
04	D2	0	0	0	2	$\boxed{8}$	④	$\boxed{6}$	$\boxed{6}$	1	1	0	0	0	0	0	0
to:	D3	0	0	0	1	$\boxed{7}$	④	⑤	⑤	1	0	0	0	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

SS#36 and the other one is upstream of the incident subsection which is SS#2l. Travel time savings are shown in Table 11. Travel time savings are significant for all origin groups between 7:00 and 7:15 a.m. (or the last fifteen minutes of the incident duration). Travel time savings are significant for origin 3 group also from 7:30 to 9:00 a.m. and for origin 4 group from 7:00 to 8:00 a.m. In this scenario travel time savings are significant for origin 4 group because SS#34 (or the incident subsection) is located downstream of origin 4 and therefore a driver travelling from 04 to any destination downstream using the freeway will have to go through SS#34 bottleneck. This has created a significant difference between the freeway biased travel time and the shortest path travel time (which does not use the freeway). The difference was in the range of 4 to 8 minutes for 04 group.

2. Moderately Heavy Traffic Demand Level (MM2)

The freeway congestion pattern under the moderately heavy traffic demand level with a moderate incident is shown in Figure 16. Congestion began at 6:30 and ended at lo:15 a.m. A comparison between Figure 16 and the previous Figure 15 shows that the only difference is in the size of the upstream congestion (time and space wise) where the maximum queue length in Figure 16 extended upstream of SS#9 (i.e origin 1 location) while the maximum queue length was still downstream of origin 1 in Figure 15 (MA2 scenario).

A comparison between Table 12 (for MM2 scenario) and Table 11 (for MA2 scenario) shows that travel time savings became significant over a longer time period for all origins. Also the magnitudes of travel time savings for MM2 are larger than those of MA2 (a range of 4 to 10 minutes compared to a range of 4 to 7 minutes respectively).

FIGURE 16

CONTOUR DIAGRAM OF OUEUE LENGTH

MM2 CELL: MODERATE INCIDENT AND MODERATELY HEAVY TRAFFIC DEMAND SCENARIO (SS#34 INCIDENT)

```
TIME                                                                                                           BEGIN
SLICE ......................................................................................................     TIME
      .                                                                                                     .
   24 .                                                                                                     . - 11:45
   23 .                                                                                                     . - 11:30
   22 .                                                                                                     . - 11:15
   21 .                                                                                                     . - 11:oo
   20 .                                                                                                     . - 10:45
   19 .                                                                                                     . - 10:30
   18 .                                                                                                     . - 10:15
   17 .                                                                        **                           . - lo:oo
   16 .                                                     *********************                           . -  9:45
   15 .                                                    **********************                           . -  9:30
   14 .                                                **************************                 *  ***    . -  9:15
   13 .                                             *****************************          **** ***  ***    . -  9:oo
   12 .                                            ******************************        ****** ********    . -  8:45
   11 .                                            ******************************       ****************    . -  8:30
   10 .                                                **************************     ******************    . -  8:15
    9 .                                                  ************************   ********************    . -  8:00
    a .                                                  ***********************************************    . -  7:45
    7 .                                                      *******************************************    . -  7:30
    6 .                                                      ************************************* *****    . -  7:15
    5 .                                                            *********************************█       . -  7:oo
    4 .                                                                      ***********************█ <===  . -  6~45
   3- ;                                                                                    *********I 45 MIN. - 6:30
    2 .                                                                                      INCIDEN'T  IN  . -  6:15
    1 .                                                                                      SUBSECT'ION #34. -  6:00

      ............................................................................................1........
       :   .      :      :              :             :      :  :  ::  :  :  :  ::::::  ::::  :  :  :::  ::::  ::::::
       01     02     03     04     05     06     07     08     09     12            21            29   34   36   40
                                                                                              |
       SUBSECTION NUMBER                                         I     |  "         |                    I    f
                                                                 I     I            |           |        I    I
                                                                 01     02,         04          D3       D2   DI
                                                                       03
```

BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES PUEUED VEHICLES DUE TO MAINLINE CONGESTION. M DENOTES OUEUED VEHICLES DUE TO MERGING. B DENOTES PUEUED VEHICLES DUE TO MAINLINE CONGESTION AND MERGING. (WHEN BOTH OUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

01, 02, 03, AND 04 : DENOTE LOCATIONS WHERE TRIPS ORIGINATING AT 01, 02, AND 03 JOIN THE FREEWAY.

DI, D2, AND D3 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO DI, D2, AND D3 LEAVE THE FREEWAY.

TABLE 12

Travel Time Savings in Minutes (Rounded to Nearest Minute)
(MM2) Scenario (Shortest Path vs. Freeway-Biased Path)

LEGEND

☐ HIGH. SIG. TIME SAV.

○ SIG. TIME SAV.

From 01 to:

D1	0	0	0	2	$\boxed{7}$	3	1	3	1	1	1	1	1	1	1	1
D2	0	0	0	3	$\boxed{8}$	3		l @	l	1	1	1	1	1	1	1
D3	0	0	0	2	$\boxed{7}$	~	1	~	1	1	1	1	1	1	1	1

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 02 to:

D1	0	0	0	2	$\boxed{7}$	④	2	④	2	1	2	1	2	2	1	2
D2	0	0	0	3	$\boxed{8}$	④	2	⑤	2	1	2	1	2	2	1	2
D3	0	0	0	2	$\boxed{7}$	⑤	2	⑤	2	2	2	2	2	2	1	2

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 03 to:

D1	0	0	0	2	$\boxed{9}$	$\boxed{7}$	④	$\boxed{7}$	⑤	④	⑤	④	⑤	⑤	5	⑤
D2	0	0	0	3	$\boxed{10}$	$\boxed{7}$	④	$\boxed{8}$	⑤	④	⑤	④	⑤	⑤	5	⑤
D3	0	0	0	2	$\boxed{9}$	$\boxed{7}$	④	$\boxed{7}$	⑤	⑤	⑤	⑤	⑤	⑤	⑤	⑤

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

From 04 to:

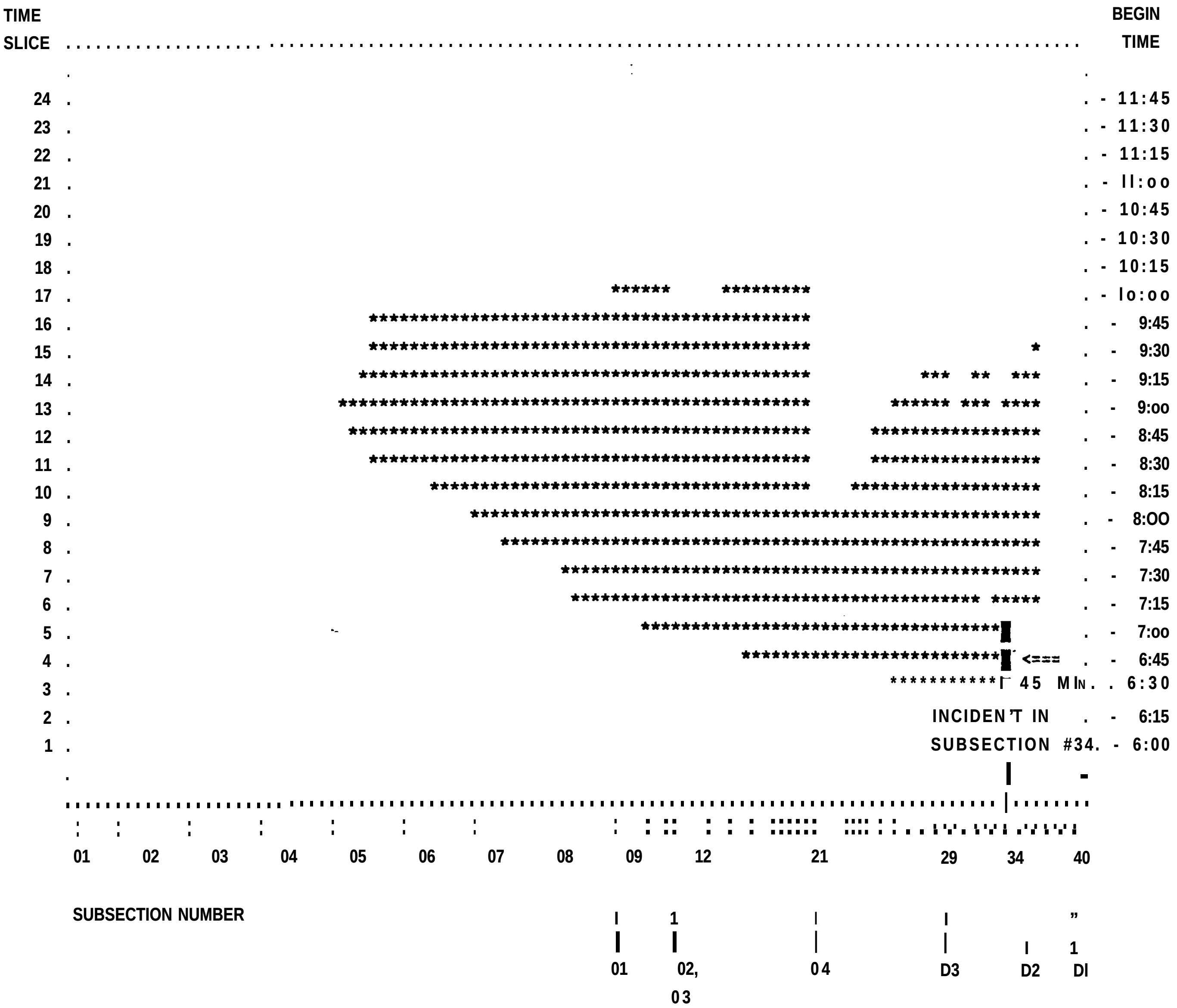
D1	0	0	0	3	$\boxed{8}$	④	④	⑤	0	0	0	0	0	0	0	0
D2	0	0	0	④	$\boxed{8}$	④	⑤	$\boxed{6}$	1	1	0	0	0	0	0	0
D3	0	0	0	3	$\boxed{7}$	⑤	⑤	⑤	1	0	0	0	0	0	0	0

Time: 0600 0630 0700 0730 0800 0830 0900 0930 1000

FIGURE 17

CONTOUR DIAGRAM OF PUEUE LENGTH

MH2 CELL: MODERATE INCIDENT AND HEAVY TRAFFIC DEMAND SCENARIO (INCIDENT SS#34)



BLANK DENOTES MOVING TRAFFIC. ASTERISK DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION. M DENOTES QUEUED VEHICLES DUE TO MERGING. B DENOTES QUEUED VEHICLES DUE TO MAINLINE CONGESTION AND MERGING. (WHEN BOTH QUEUES EXIST, LENGTH OF DISPLAY REPRESENTS MAINLINE CONGESTION.)

01, 02, 03, AND 04 : DENOTE LOCATIONS WHERE TRIPS ORIGINATING AT 01, 02, AND 03 JOIN THE FREEWAY.

DI, D2, AND D3 : DENOTE LOCATIONS WHERE TRIPS DESTINING TO DI, D2, AND D3 LEAVE THE FREEWAY.

3. Heavy Traffic Demand Level (MH2)

The freeway congestion pattern under the heavy traffic demand level with a moderate incident is shown in Figure 17. Congestion began at 6:30 and ended at lo:15 a.m. A comparison between Figure 17 and the previous Figure 16 shows that congestion in MH2 has increased upstream of SS#21 and queue length extended for a few miles upstream of origin 1. While downstream congestion has increased very little. This is due to the metering effect of SS#21 bottleneck. A comparison between travel time savings (Table 13 for MH2 with Table 12 for MM2) shows that significant travel time savings have extended over a larger time period in case of MH2 scenario (compare a one hour period to a 30-45 minutes period). Maximum travel time savings are observed for the MH2 scenario among all twelve scenarios discussed so far which are: 14 minutes for origin 3 group, 12 minutes for origin 2 group, 11 minutes for origin 1 group, and 9 minutes for origin 4 group.

A general conclusion is that maximum travel time savings are attained when a 45 minutes incident is introduced in SS#34 with a traffic demand level that is 10% higher than that of a normal traffic day level.

C. <u>Effect of Incident Severitv Under Various Traffic Demand Levels</u>

Comparison between travel time savings for two Incident severity levels are considered: no incident and moderate incident levels. There are two cells under each traffic demand level that will be compared in terms of travel time savings. Under the average traffic demand level these cells two cells are denoted as NA2 and MA2 in the previous Figure 3 which depicted the design of experiment. Under moderately heavy traffic demand level these cells are denoted as NM2 and MM2. Under heavy traffic demand level these cells are denoted as NH2 and MH2. These results

TABLE 13

Travel Time Savings in Minutes (Rounded to Nearest Minute)
(MH2) Scenario (Shortest Path vs. Freeway-Biased Path)

From	D1	0	0	0	④	$\boxed{10}$	④	1	④	1	1	1	1	1	1	1	1
01	D2	0	0	0	⑤	$\boxed{11}$	④	1	⑤	2	1	1	1	1	1	1	1
to:	D3	0	0	0	④	$\boxed{10}$	⑤	1	⑤	2	1	1	1	1	1	1	1
Time:		0600		0630		0700		0730		0800		0830		0900		0930	1000

From	D1	0	0	0	④	$\boxed{12}$	⑤	1	$\boxed{6}$	2	1	2	1	2	2	1	2
02	D2	0	0	0	⑤	$\boxed{12}$	⑤	2	$\boxed{7}$	3	1	2	1	2	2	1	2
to:	D3	0	0	0	④	$\boxed{12}$	$\boxed{6}$	2	$\boxed{6}$	3	2	2	2	2	2	1	2
Time:		0600-		0630-		0700		0730		0800		0830		0900		0930	1000

From	Dl	0	0	0	⑤	$\boxed{14}$	$\boxed{7}$	3	$\boxed{8}$	⑤	④	⑤	④	⑤	⑤	⑤	⑤
03	D2	0	0	0	⑤	$\boxed{14}$	$\boxed{7}$	④	$\boxed{9}$	$\boxed{6}$	⑤	⑤	④	⑤	⑤	⑤	⑤
to:	D3	0	0	0	⑤	$\boxed{14}$	$\boxed{8}$	④	$\boxed{8}$	$\boxed{6}$	⑤	⑤	⑤	⑤	⑤	⑤	⑤
Time:		0600		0630		0700		0730		0800		, O ” 830		0900		0930	1000

From	D1	0	0	0	⑤	$\boxed{8}$	@I	@l	@l	1	0	0	0	0	0	0	0
04	D2	0	0	0	⑤	$\boxed{9}$	⑤	$\boxed{6}$	$\boxed{6}$	2	1	1	0	0	0	0	0
to:	D3	0	0	0	④	$\boxed{8}$	⑤	⑤	⑤	1	0	0	0	0	0	0	0
Time:		0600		0630		0700		0730		0800		0830		0900		0930	1000

LEGEND

$\boxed{}$ HIGH. SIG. TIME SAV.

○ SIG. TIME SAV.

comparing between each pair of cells mentioned will be discussed in the next three subsections.

1. Effect of Incident Severity Under Average Traffic Demand Level

This is a comparison between NA2 scenario (Figure 6, Table 2 which is identical to NAl scenario) and MA2 scenario (Figure 15, Table 11) respectively. A comparison between the two queue diagrams shows that congestion in MA2 is larger than NA2 (time and space wise). Both congestions of NA2 and MA2 start at 6:30 a.m. While NA2 congestion ends at 9:00 a.m. and its maximum queue length extends upstream to SS#14, MA2 congestion ends at 9:30 a.m. and its maximum queue length extends upstream to SS#12 only. Travel time savings for MA2 are significant and obviously larger than those of NA2 which are insignificant and negligible for the first three origin groups 01, 02, and 03.

2. Effect of Incident Severity Under Moderately Heavy Traffic Demand Level

This is a comparison between NM2 (or NM1 scenario) (Figure 7, Table 3) and MM2 scenario (Figure 16, Table 12). There is not so much difference between both congestion situations in terms of which is worse (for all origins). The two queue diagrams look similar in terms of the size of downstream and upstream congestion.

A comparison between travel time savings shows similar magnitudes and the range is 4 to 10 minutes in both scenarios. However, for MM2 scenario travel time savings start to be significant 30 minutes earlier than the non-incident scenario (or NM2).

3. Effect of Incident Severity Under Heavy Traffic Demand Level

This is a comparison between NH2 (or NH1 scenario) (Figure 8, Table 4) and MH2 scenario (Figure 17, Table 13). Queue diagrams are quite similar in both scenarios and so are travel time savings. In general these two scenarios, gave the highest travel time savings for all origins among all scenarios. The maximum travel time savings were between 7:00 and 7:15 a.m. for MH2 scenario (which is the last fifteen minutes of the duration of the incident) while maximum travel time savings were between 7:30 and 8:45 a.m. for NH2 scenario which is during the morning peak period.

CHAPTER 5

STUDY RESULTS - INCIDENT LOCATION EFFECT

A. Introduction

The study results are to assess the effect of incident location on the freeway congestion pattern and travel time savings are presented and discussed in this chapter. The three sections are devoted to assessing the effect of the incident location under three traffic demand levels. In relation to the previous Figure 3 this would represent a comparison of cells between the front face and the back face of the design of the experiment.

B. Effect of Incident Location Under Average Traffic Demand Level

This is a comparison between MA1 scenario (Figure 9, Table 5) and MA2 scenario (Figure 15, Table 11) respectively. The two queue diagrams are significantly different. The downstream congestion in MA2 scenario is much larger than that of the MA1 scenario because of the new incident location at SS#34. Congestion upstream of the freeway looks slightly larger in the MA1 scenario than in the MA2 scenario. Travel time savings for the MA2 scenario are less than those of the MA1 scenario for all origin groups after 7:00 a.m. while the opposite is true from 6:45 to 7:00 a.m. These unexpected results are due to the complicated configuration of the shortest route which uses different sections of the freeway and changes over time. An example of such complications are shown in three time periods fifteen minutes each (from 6:30 to 7:15 a.m.) for the MA1 scenario in Appendix B. To explain why savings of MA2 scenario are less than those of MA1 for some time periods, one has to look at shortest paths of both scenarios in each fifteen minutes time period and then compare.

It is beyond the scope of this research to look at the shortest paths for all traffic scenarios at all travel time periods, however. This is an interesting study for future research.

C. Effect of Incident Location Under Moderatelv Heavy Traffic Demand Level

This is a comparison between MM1 scenario (Figure 10, Table 6) and MM2 scenario (Figure 16, Table 12) respectively. Similar pattern is observed as one compares between these two scenarios as in section B above for the queue diagrams. The congestion of the upstream bottleneck is larger in case of MM1 than it is in case of MM2. Therefore the metering effect has decreased in the MM2 scenario. A comparison between travel time savings for MM1 (Table 6) and MM2 (Table 12) shows that, except for origin 4 group, travel time savings are larger for MM1 than those for MM2 between 6:45 and 7:15 a.m. and the opposite is true after 7:15 a.m. During the period 6:45 to 7:15 a.m. the shortest path for scenario MM1 (or SS#20 incident) avoids going through the large queue upstream of SS#20 as shown in Figure 10. The shortest path joins the freeway downstream of SS#20 where it is near free flow conditions and continue until the end of the freeway study limits. This creates a large difference between the freeway biased route (which has to use the freeway all the way through and consequently go through SS#2O bottleneck) and the shortest path which uses the surface street system (from say 01) and then joins the freeway downstream of the incident subsection therefore avoiding the incident congestion. This explains why savings are large in case of MM1 scenario. To explain why savings of MM2 scenario are less than those of MM1 for some time periods (example 6:45 to 7:00 a.m.), one has to look at shortest paths of both scenario in each fifteen minutes time period and then compare.

D. Effect of Incident Location Under Heavy Traffic Demand Level

This is a comparison between MHl scenario (Figure 11, Table 7) and MH2 scenario (Figure 17, Table 13). A comparison between the two queue diagrams is similar to that of section C above. However, travel time savings are much higher in the MH2 scenario than they are in the MHl scenario. Maximum travel time savings for both scenarios are from 6:45 a.m. to 7:15 a.m.

The major conclusion of the comparison between the two incident locations is that only under heavy traffic demand levels that SS#34 incident gives higher travel time savings than that of SS#20 incident. Otherwise travel time savings are higher for SS#20 incident than those for SS#34 incident. Such unexpected results are due to the complexity of the shortest paths configuration which highly depends on traffic demand level and time when it is calculated. Also it is noticed that maximum time savings usually occurred in the last 15 or 30 minutes of the 45 minutes incident.

CHAPTER 6

MAJOR CONCLUSIONS

As the last three chapters analyzed all traffic scenarios in detail, this chapter tries to summarize the major findings of the (IVIS) traffic demand and sensitivity analysis.

The conclusions from these investigations are based on the assumptions previously identified. Major conclusions are:

1. Potential benefits are very marginal and considered insignificant under the no-incident average traffic demand situation.

2. Potential benefits for long distance freeway to freeway travelers can be significant under no-incident conditions but only when freeway demands are five or ten percent higher than normal. Travel time savings are on the order of 3 minutes to a maximum of 13 minutes for an average 30 minutes trip length during the peak hour.

3. Potential benefits for long distance freeway travelers can be significant during the duration of incidents under average traffic conditions. Time savings on the order of 5 to 10 minutes for a 30 minutes average length trip were observed.

4. Under upstream incident conditions increasing demand by five or ten percent does not increase potential benefits significantly.

5. Under downstream incident conditions increasing demand by five percent increases potential benefits significantly. When

increasing demand by ten percent, the maximum travel time savings were observed in this study (14 minutes savings for a 30 minute average trip length).

6. Under both incident conditions, when an incident duration is doubled, the time period during which there are potential benefits (or significant travel time savings) slightly more than doubles.

7. Under both incident conditions and five or ten percent heavier freeway demand, travel potential benefits were largest. Travel time savings were significant (a range of 4 to 14 minutes) for a 30 minute average trip length. However, introducing incidents under such conditions did not increase the potential benefits significantly.

8. The effect of the location of the incident on potential benefits was studied only under moderate incident conditions. The major conclusion of the comparison between the two incident locations is that under heavy traffic demand level the downstream incident gave higher travel time savings than that of the upstream incident.

9. Potential benefits were generally different for each origin group in the study. It was noticed that the further the origin is from the freeway, the larger time savings are for trips starting at that origin. Trips originating at origins downstream of the incident did not have any potential benefit under incident conditions.

10. The so far exhaustive sensitivity analysis predicted a range of travel time savings between 0 and 14 minutes for the 30 minutes average trip length. These estimates of potential benefits are considered to be optimistic because of the study assumptions. Further refinements to such estimates are expected to give lower estimates.

CHAPTER 7

FUTURE RESEARCH

A. Introduction

As the objective of this report was only to study how sensitive potential benefits of IVIS are to variations in demand, incident severity and location, a comprehensive evaluation statement of potential benefits can not yet be made.

As the calculated travel time savings may be interesting for express delivery, emergency and police vehicles, they may not be as such for a regular corridor driver. For commercial use of IVIS, this study can be sufficient to start a marketing research upon which a private sector enterprise decides whether to implement (adopt) such technology or not. However, for public use of IVIS, further study is needed to refine such estimates taking into consideration who will benefit and how much under more realistic assumptions.

This chapter gives suggestions of future research directions in the assessment of potential benefits of IVIS systems. The chapter briefly explores ideas that add in realism to the research methodology used in the last year report and this report.

B. Basic Assumptions

A number of assumptions would have to be studied thoroughly before one can make a comprehensive evaluation of potential benefits of IVIS. These assumptions are as follows:

1. Consideration of Diversion for Today's Drivers Under Incident Conditions

Studies have shown that a portion of today's corridor drivers who are unequipped with IVIS but familiar with the corridor do exercise diversion from the freeway to surface streets under incident conditions. To have an idea about such activity, the reader is advised to consult the study made in reference [2].

Traffic diversion by today's drivers who are unequipped with IVIS needs to be estimated when analyzing travel time savings. Diversion of such drivers when considered will reduce travel time on the freeway links but increase it on the surface street links. Therefore travel time savings are expected to be decrease and be lower than the estimates given in this analysis.

The next step in assessment of potential benefits would be to consider such diversion.

2. Increasing the Percentage of Drivers Equipped with IVIS

Increasing the percentage of drivers equipped with IVIS and diverting to surface streets (if considered along with the assumption 1 above) would lead to analysis of network equilibrium. This is a non-trivial task but estimates based on more realistic assumptions could be attained.

3. Limitations and Constraints of Surface Street Capacities

When one is considering a large percentage of drivers to divert to surface streets, one should not forget about the important limitation of excess surface street capacities. The constraint of maintaining a certain level of service on the route of diversion is binding and limits the amount of traffic that can be diverted. This implies that diversion to one path only (the shortest path) can be generally impractical because it will get saturated in no time. A multi-path diversion strategy should be used in which drivers are diverted to semi-optimal or near shortest paths instead of only one shortest path. What routes to divert people to? When, where, and how to divert drivers? are such three interesting questions for future research.

4. Increasing Demand on Surface Streets

Since the sensitivity analysis done in the previous chapters considered increasing freeway demand only, another more realistic sensitivity analysis could be done by increasing demand on surface streets as well. Since the time constraint in this study was crucial, this subject is an interesting topic for future research.

5. Use of Dynamic Shortest Paths Analysis

This research so far used a quasi-dynamic shortest path analysis, i.e it was assumed that shortest path does not change during a fifteen minutes period. This is not quite realistic. Also shortest paths were assumed not to change over the whole length of the trip when calculating travel time savings. A future research study would be needed to address the question of dynamic behavoiur of shortest paths in an urban network.

REFERENCES

1. Al-Deek, Haitham M., Martello, Mike M., May, Adolf D., and Sanders, Wiley, Potential Benefits of In-Vehicle Information Systems in A Real Life Freeway Corridor Under Recurring and Incident Induced Congestion, PATH Research Report UCB-ITS-PRR-88-2, 120 pages.

2. Shirazi, -Elham, Anderson, Stuart, and Stesney, John, Commuter Attitudes Towards Traffic Information Systems and Route Diversion, TRB, 67th Annual Meeting, January 11-14, 1988, Washington, D.C.

3. Sanders, W., PATHNET Refernce Manual, Available at ITS, 1988.

APPENDIX - A -

COMPUTER FILING SYSTEM

A. FREQ Files

All FREQ files are saved under similar names used as in the 3-D matrix (design experiment as in Figure 3, Chapter II), for example: NAl.FRQ stands for scenario NAl or "No Incident and Average Traffic Demand Scenario". The (12) FREQ files are saved in subdirectory D:\AL-DEEK\FIN-FREQ on the XT PATH personal computer in room 107A Mclaughlin Hall.

B. FREQ Transferred Files to the Macintosh Machine

All FREQ files are made ready to transfer to the Macintosh under filename XXX.CON, where XXX stands for the three code traffic scenario used in this report (i.e NAl) and "CON" stands for converted. All these files are saved in subdirectory D:\AL-DEEK\CONVERT on the XT PATH personal computer in room 107A Mclaughlin Hall.

C. Macintosh Files

The reader is referred to the PATHNET [3] documentation so as to learn how to use this package. All initial and final output file settings for each of the twelve traffic scenarios are saved in folders named as the traffic scenario enclosed in that folder, e.g NAl folder has got all NAl scenario results and output files in it. All such folders are saved in a bigger folder named "PATH STUFF" in which the application package "PATHNET" is also located. A backup copy on a 3 l/2 'I floppy diskette containing all of the Macintosh files is provided for extra security against loss or damage.

APPENDIX - B -

EXAMPLE OF CONFIGURATIONS OF SHORTEST PATHS DURING THREE TIME SLICES

Note

Example shows configurations of shortest path from origin 1 to destination 1 on the freeway for the (MA) scenario (the Moderate Incident and Average Traffic Demand scenario) from 6:30 a.m. (or start of incident in SS#20) to 7:15 a.m. (end of incident SS#20).

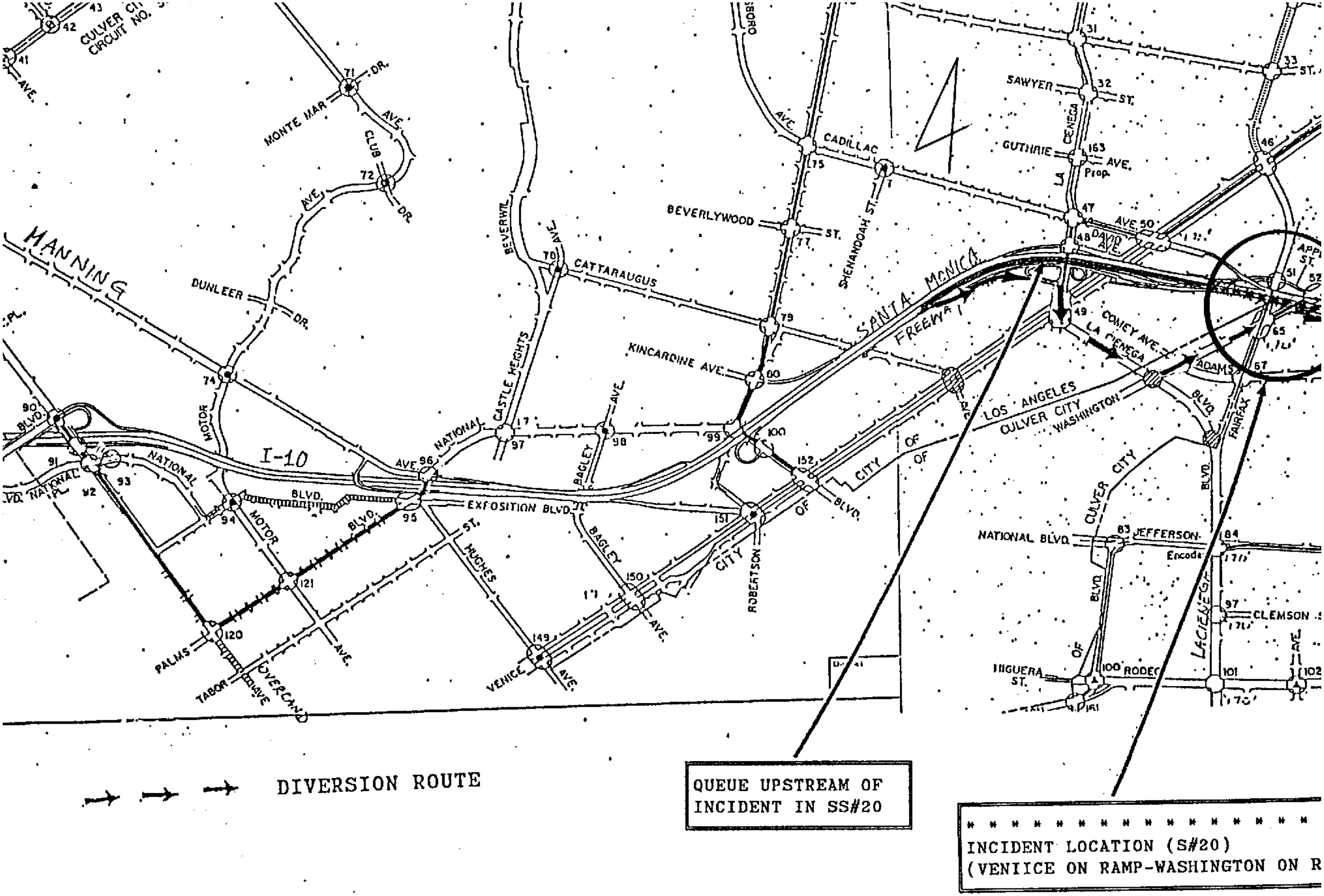


FIGURE B-1 DIVERSION ROUTE IN TIME SLICE ONE (6:30 a.m. - 6:45 a.m.)
(BEGINNING OF MODERATE INCIDENT)

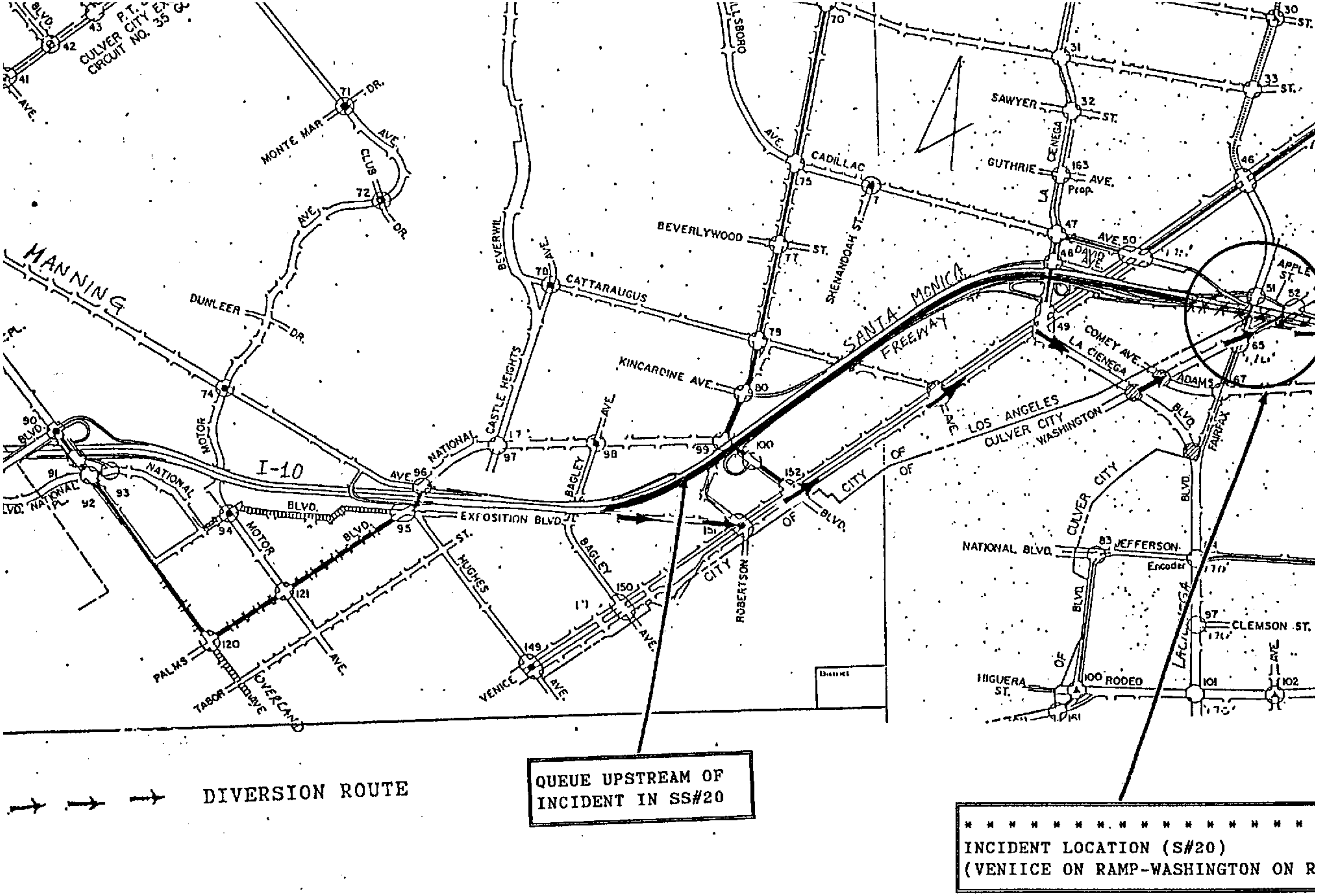
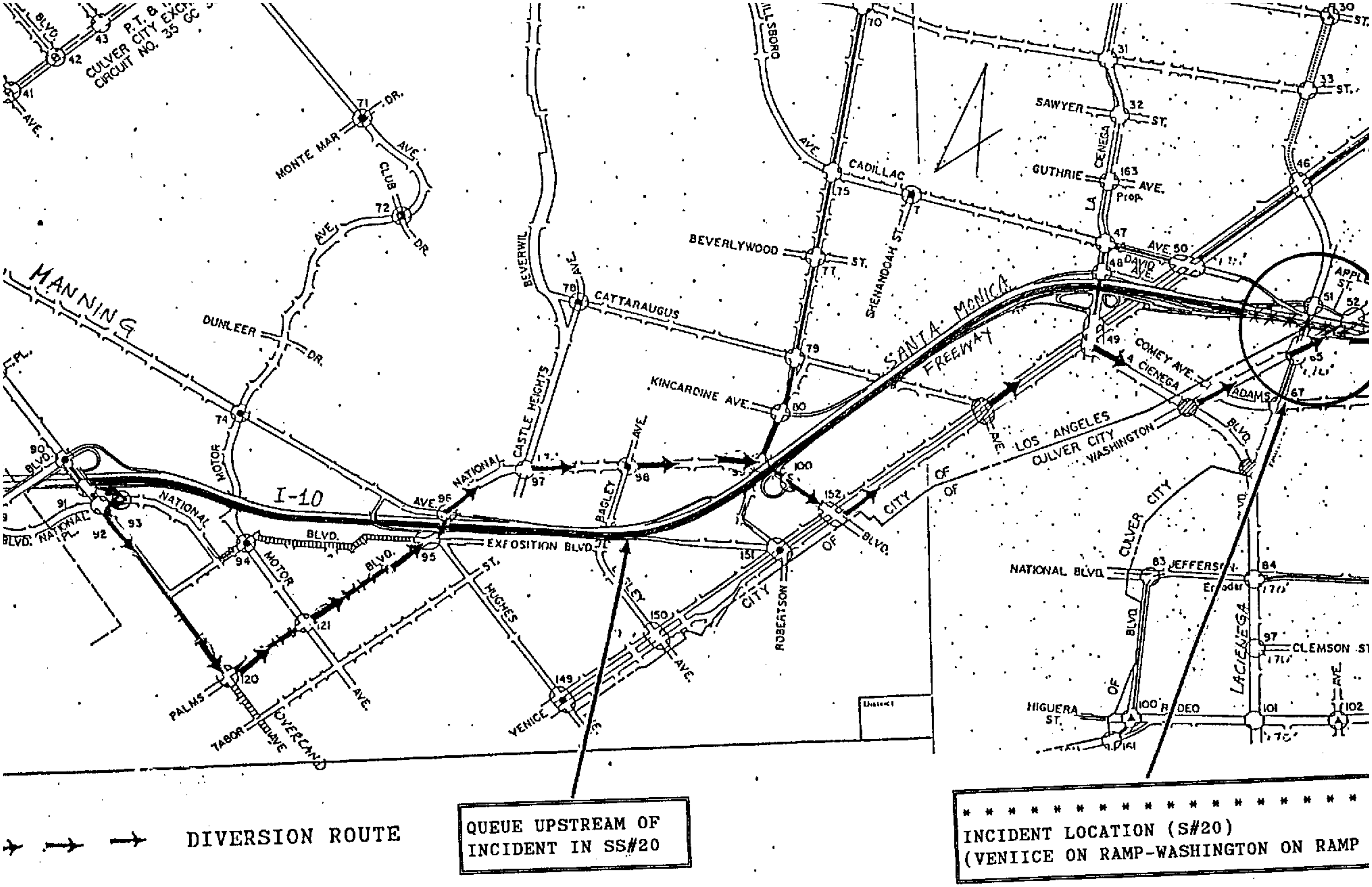


FIGURE B-2 DIVERSION ROUTE IN TIME SLICE TWO (6:45 a.m. - 7:00 a.m.)



→ → → DIVERSION ROUTE

QUEUE UPSTREAM OF INCIDENT IN SS#20

* * * * * * * * * * * * * * * * *
INCIDENT LOCATION (S#20)
(VENIICE ON RAMP-WASHINGTON ON RAMP

FIGURE B-3 DIVERSION ROUTE IN TIME SLICE THREE (7:00 a.m. - 7:15 a.m.)
(END OF INCIDENT)