CDOH-DTD-R-90-14

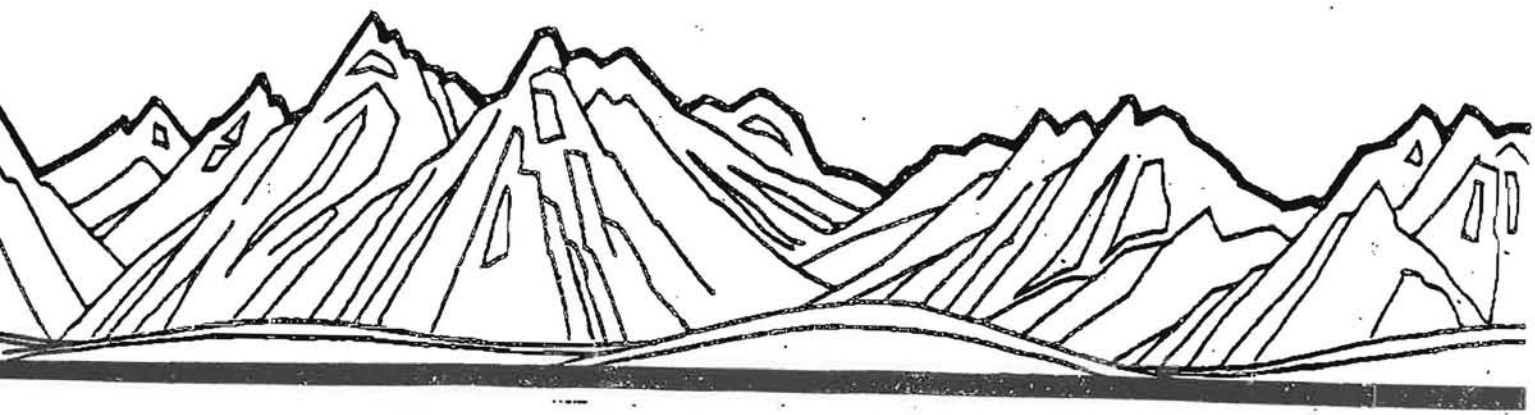
STUDY OF URBAN INTERCHANGE PERFORMANCE

I-25/GARDEN OF THE GODS ROAD, COLORADO SPRINGS

EVANS AVENUE/SANTA FE DRIVE, DENVER

STATE OF COLORADO

RESEARCH STUDY NUMBER HPR-PR0001(23)



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16. Abstract

Two single point urban interchanges (S.P.U.I.) were studied in order to evaluate performance and safety characteristics under varying conditions of operation. Comparative data is presented for travel time delay studies, intersection delay studies, volumes, accidents, and maintenance. One of the S.P.U.I.s is located at Sante Fe and Evans in Denver; it is a retrofit design of an urban diamond. The second S.P.U.I. is located at I-25 and Garden of the Gods Road in Colorado Springs; it is a replacement for a tight urban diamond interchange (T.U.D.I.)

Implementation

The study concludes that the S.P.U.I. design is appropriate in restricted right-of-way situations, needs improved guide signing, needs well-maintained pavement markings, and that the justification of in-pavement guide lighting is questionable.

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EVANS AVENUE/SANTA FE DRIVE, DENVER
STATE OF COLORADO

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0.0 ABSTRACT

Two single point urban interchanges (S.P.U.I.) were studied in order to evaluate performance and safety characteristics under varying conditions of operation. Comparative data is presented for travel time delay studies, intersection delay studies, volumes, accidents, and maintenance. One of the S.P.U.I.s is located at Sante Fe and Evans in Denver; it is a retrofit design of an urban diamond. The second S.P.U.I. is located at I-25 and Garden of the Gods Road in Colorado Springs; it is a replacement for a tight urban diamond interchange (T.U.D.I.) The study concludes that the S.P.U.I. design is appropriate in restricted right-of-way situations, needs improved guide signing, needs well-maintained pavement markings, and that the justification of in-pavement guide lighting is questionable.

1.0 INTRODUCTION

1.1 PROBLEM STATEMENT

In developed urban areas, expansion of an interchange to accommodate excess demand is limited by the availability of right-of-way. A single point urban interchange (S.P.U.I.) may offer increased capacity and improved operational patterns in the same right-of-way or less than would a diamond interchange. Colorado Department of Highways (CDOH) has three operating S.P.U.I.'s: Santa Fe/Evans in Denver, C-470/ Morrison in Jefferson County and I-25/Garden of the Gods in Colorado Springs.

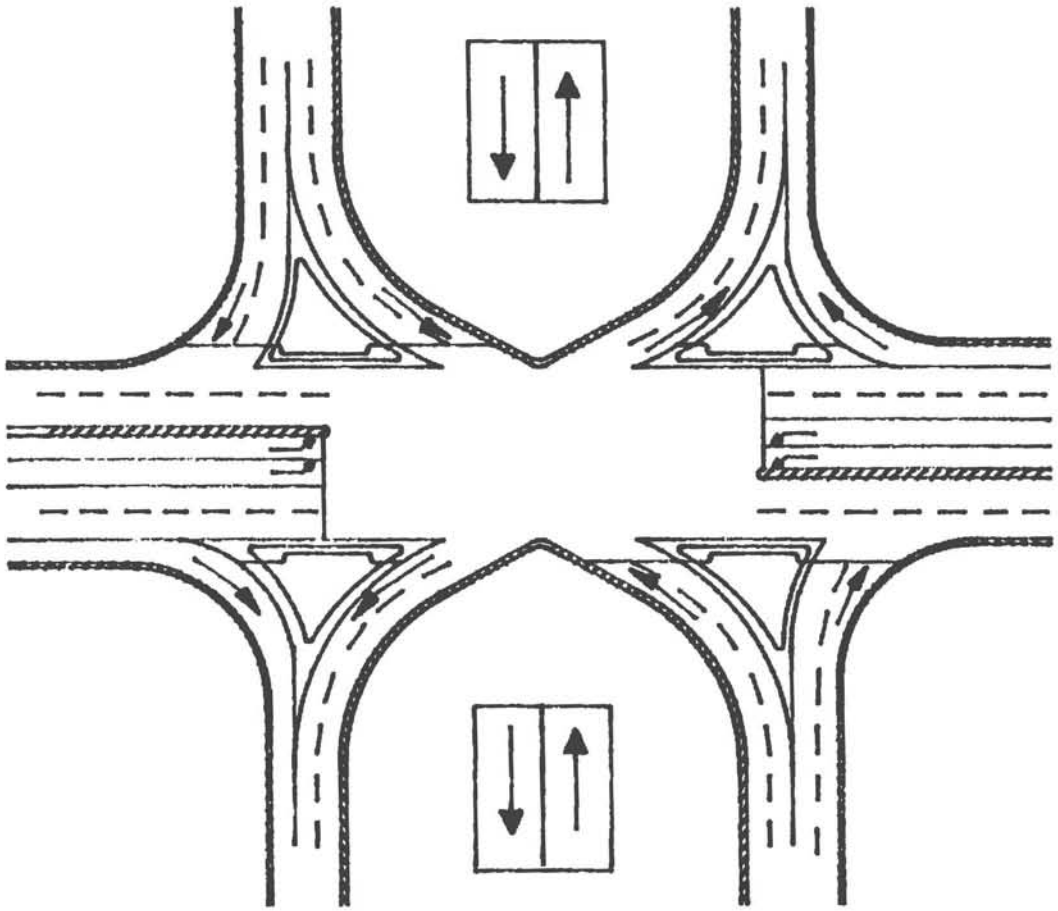
Little research exists into the comparability of a S.P.U.I. versus a tight urban diamond interchange (T.U.D.I.) under the same operating conditions. This study was undertaken to evaluate and compare the performance of these two types of interchanges in service in Colorado. Results of this study will be used to further perfect the design and operation of S.P.U.I.'s in Colorado.

1.2 BACKGROUND

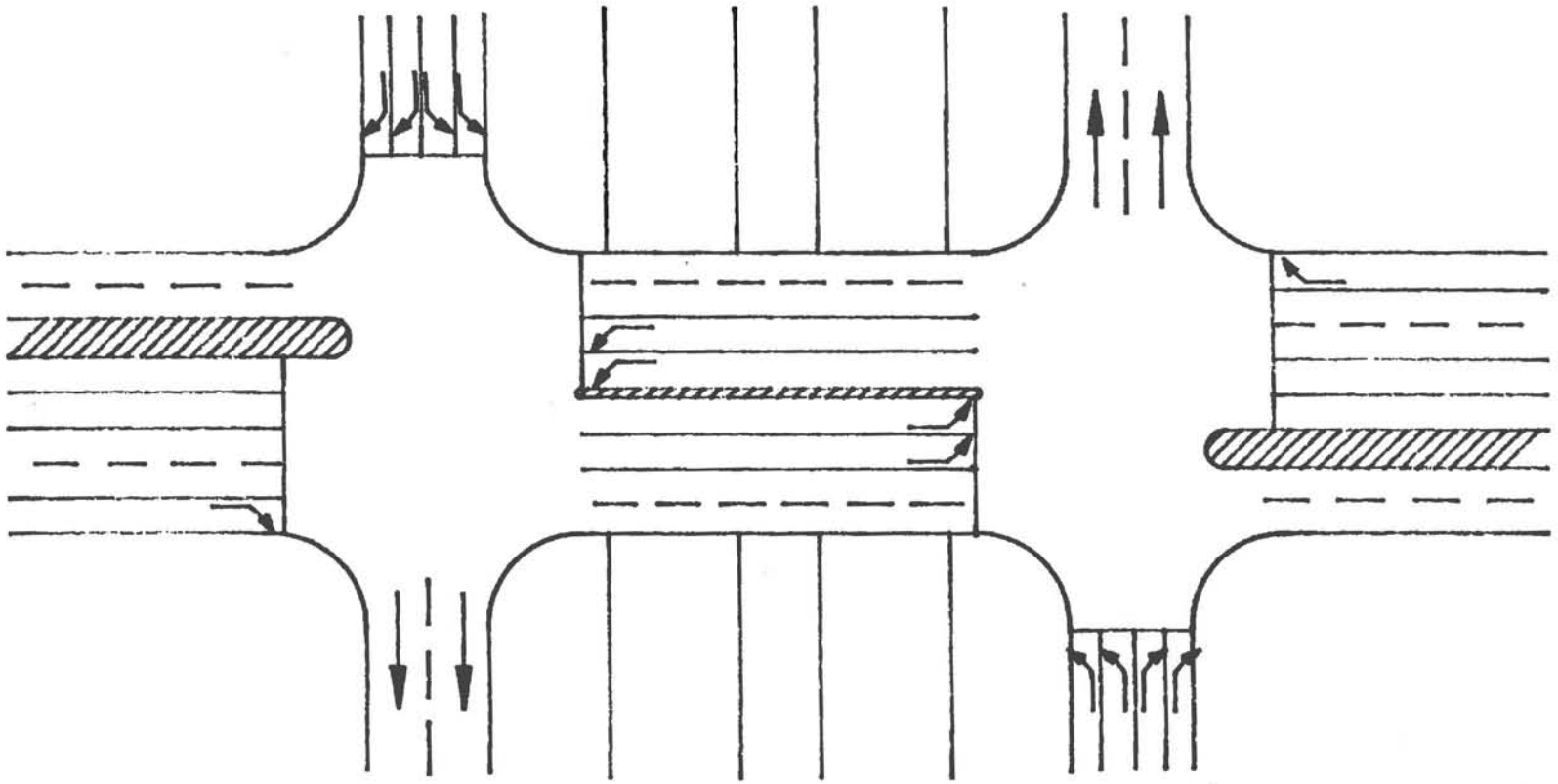
Within the last twenty-five years, the need to increase the capacity of urban interchanges within the limits of existing right-of-way prompted the development of the S.P.U.I (see Figure 1.1). The S.P.U.I. is a variation of the diamond interchange (see Figure 1.2).

To save space, access ramps in a diamond interchange come onto the minor road at an angle. Two signalized intersections control movements between access ramps and minor roads. In the T.U.D.I, the distance between the signalized intersections is reduced to further save space. Reducing the distance between the signalized intersections can cause congestion and queing caused by poor timing or excess demand often blocks one or both of the intersections.

The National Cooperative Highway Research Program (NCHRP) also commissioned a study of S.P.U.Is. NCHRP's study is to develop guidelines for the design of S.P.U.I.s and provide operational information. Results of the study titled, "Single Point Urban Interchange (S.P.U.I.) Design and Operational Analysis" are due at the end of 1990. Results of this CDOH study will be made available to NCHRP.



SINGLE POINT URBAN INTERCHANGE (S.P.U.I)
FIGURE 1.1



TIGHT URBAN DIAMOND INTERCHANGE (T.U.D.I)

FIGURE 1.2

1.3 RESEARCH OBJECTIVE

The primary objective of this study was to provide recommendations for improvements to the design and operation of S.P.U.I.s in Colorado. The three year study evaluated the performance of S.P.U.I.s under varying conditions and compares the T.U.D.I. at I-25/Garden of the Gods Road to the new S.P.U.I. there.

2.0 INTERCHANGE ANALYSIS

2.1 DESCRIPTION OF FACILITY

2.1.1 Santa Fe/Evans Single Point Urban Interchange (S.P.U.I.) - After

The S.P.U.I. at Santa Fe/Evans is located in the south-central portion of Denver. The interchange was built in 1986. It was retro-fitted above Santa Fe using the existing structures.

Santa Fe Drive is a six lane north-south major arterial dividing Denver. Evans Avenue is a four lane east-west arterial. The S.P.U.I. consists of the intersection of Evans Avenue and Santa Fe Drive access ramps. The interchange is of the point-above type. The major road, Santa Fe Drive, passes under the intersection. The facility consists of four through lanes east-west, single left turn lanes from east-west Evans Avenue to Santa Fe Drive north-south, dual left turn lanes from Santa Fe Drive to Evans Avenue and single right turn lanes for each approach. See Figure 2.1 for the general layout of this interchange.

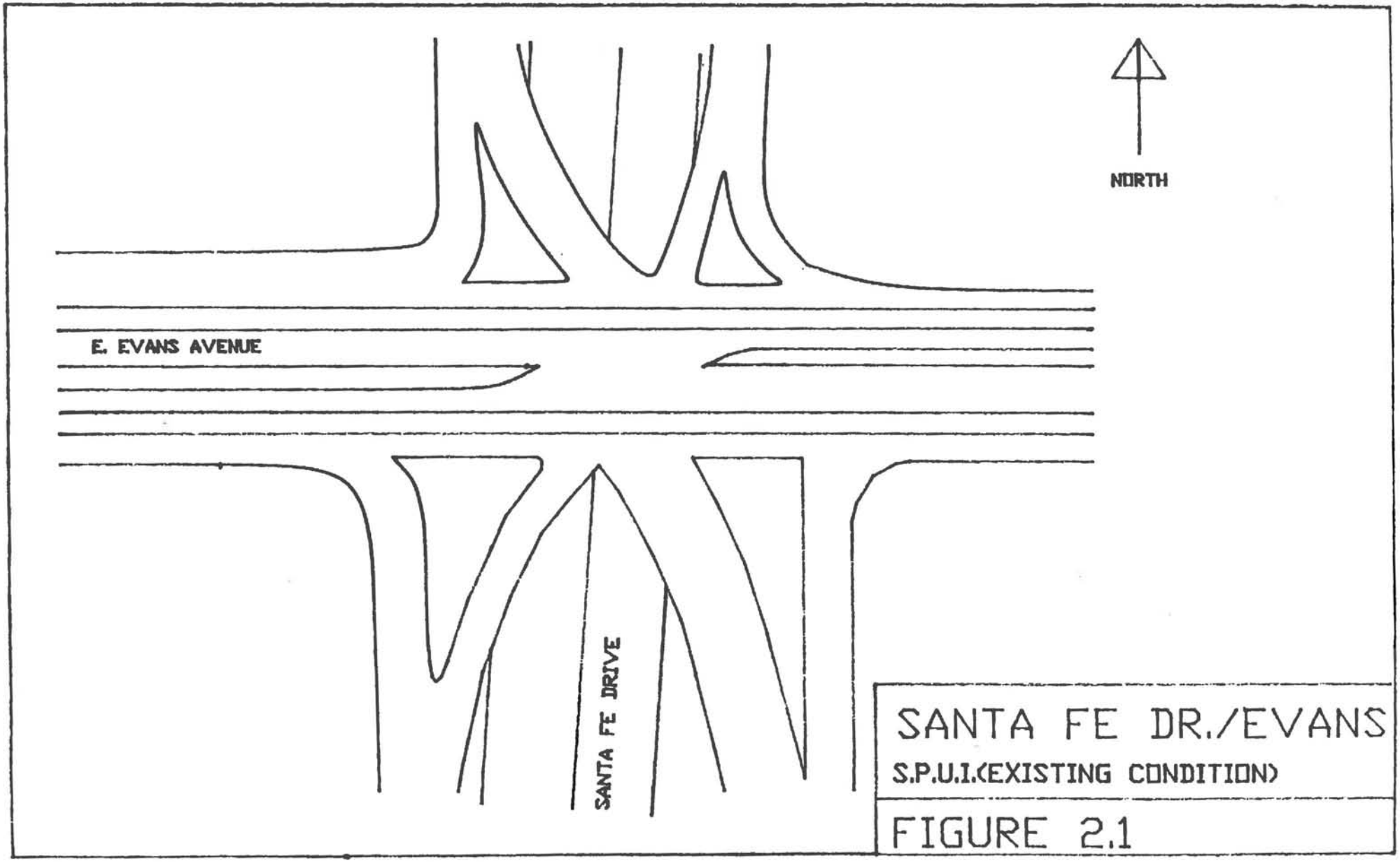
2.1.2 I-25/Garden of the Gods road Tight Urban Diamond Interchange (T.U.D.I.) - Before

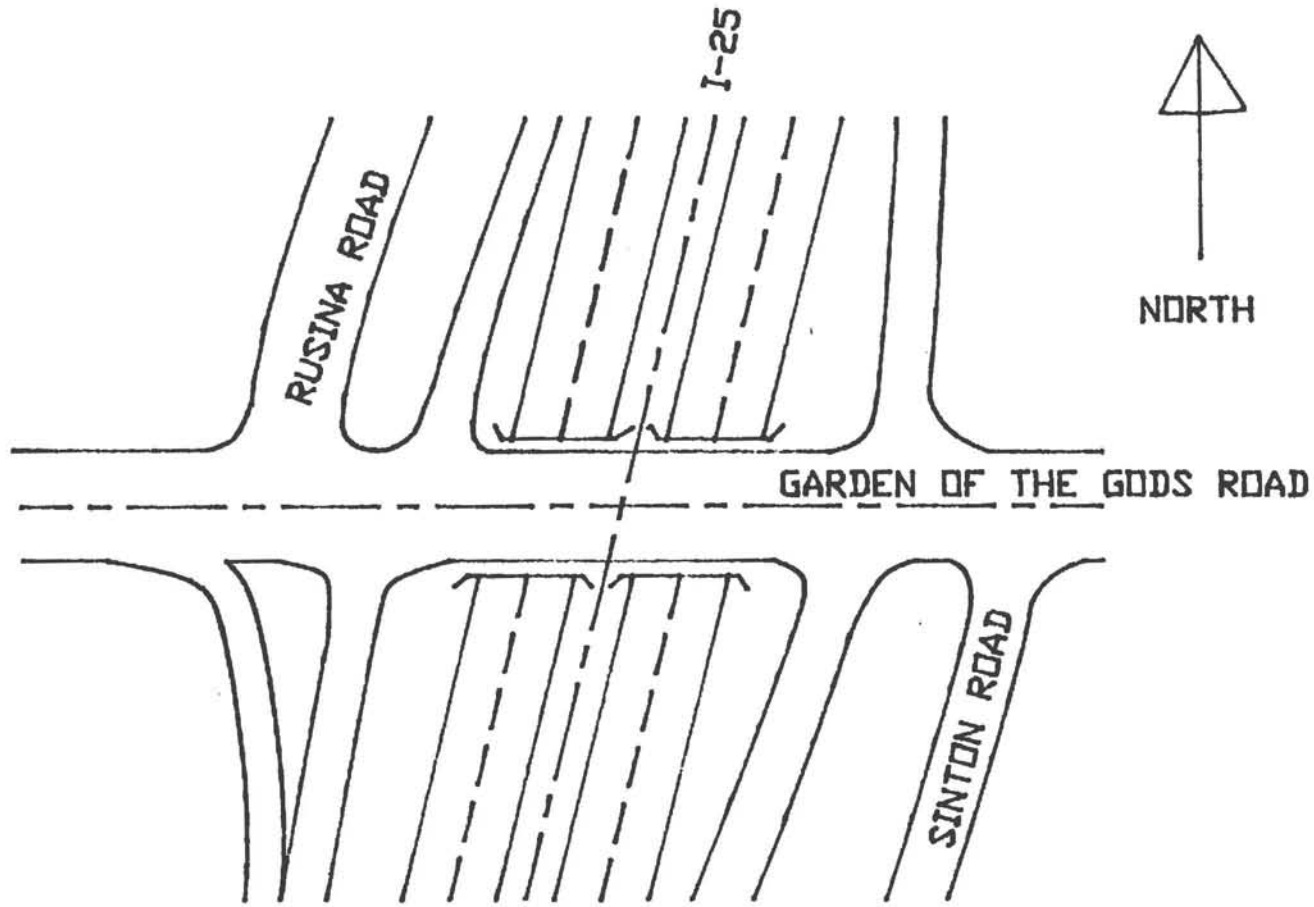
The T.U.D.I. at I-25/Garden of the Gods road was located in the northwestern portion of Colorado Springs. I-25, at the time of the original interchange, was a four lane, limited access freeway facility passing over Garden of the Gods Road. Prior to construction of the new S.P.U.I., Garden of the Gods Road was a four-lane divided facility with left turn lanes to the northbound and southbound on-ramps to I-25. The on and off ramps for I-25 to Garden of the Gods Road were two lane with one right turn lane for each off-ramp. Rusina Road formed a tee intersection with Garden of the Gods Road just west of the southbound I-25 off-ramp and was permitted both left and right turns onto Garden of the Gods Road. Sinton Road formed a tee intersection just east of the northbound I-25 off-ramp and was permitted both left and right turns onto Garden of the Gods Road. See figure 2.2 for a general layout of the I-25/Garden of the Gods' Road T.U.D.I.

2.1.3 I-25/Garden of the Gods Single Point Urban Interchange (S.P.U.I.) - After

The I-25/Garden of the Gods Road interchange was replaced with a S.P.U.I. in 1988.

I-25 is a four lane north-south interstate through Colorado Springs. Garden of the Gods Road is a six lane east-west urban arterial. The S.P.U.I. consists of the intersection of Garden of the Gods Road and the access ramps of I-25. The


NORTH
E. EVANS AVENUE
SANTA FE DRIVE
SANTA FE DR./EVANS
S.P.U.I.(EXISTING CONDITION)
FIGURE 2.1



I-25/GARDEN OF THE GODS ROAD

(T.U.D.I.)

FIGURE 2.2

interchange is of a point-under type. The major road, I-25, passes over Garden of the Gods Road. Garden of the Gods road consists of six through lanes east-west, dual left turn lanes for each approach and single right turn lanes for each approach. The new structure for I-25 over Garden of the Gods Road is currently four lanes with future expansion to six lanes. The northbound and southbound off ramps for I-25 have dual left turn lanes. Rusina Road forms a tee intersection with Garden of the Gods Road, but is now only permitted right turns onto Garden of the Gods Road. Sinton Road forms a tee intersection with Garden of the Gods Road, but is now only permitted right turns onto Garden of the Gods Road. See Figure 2.3 for the general layout of the I-25/Garden of the Gods Road S.P.U.I.

2.2 DATA COLLECTION AND REDUCTION

Under the scope of this study, general data was to be collected for the following conditions:

(1) A.M. and P.M. peak periods
(2) Off-peak periods
(3) Subpavement lighting on
(4) Subpavement lighting off

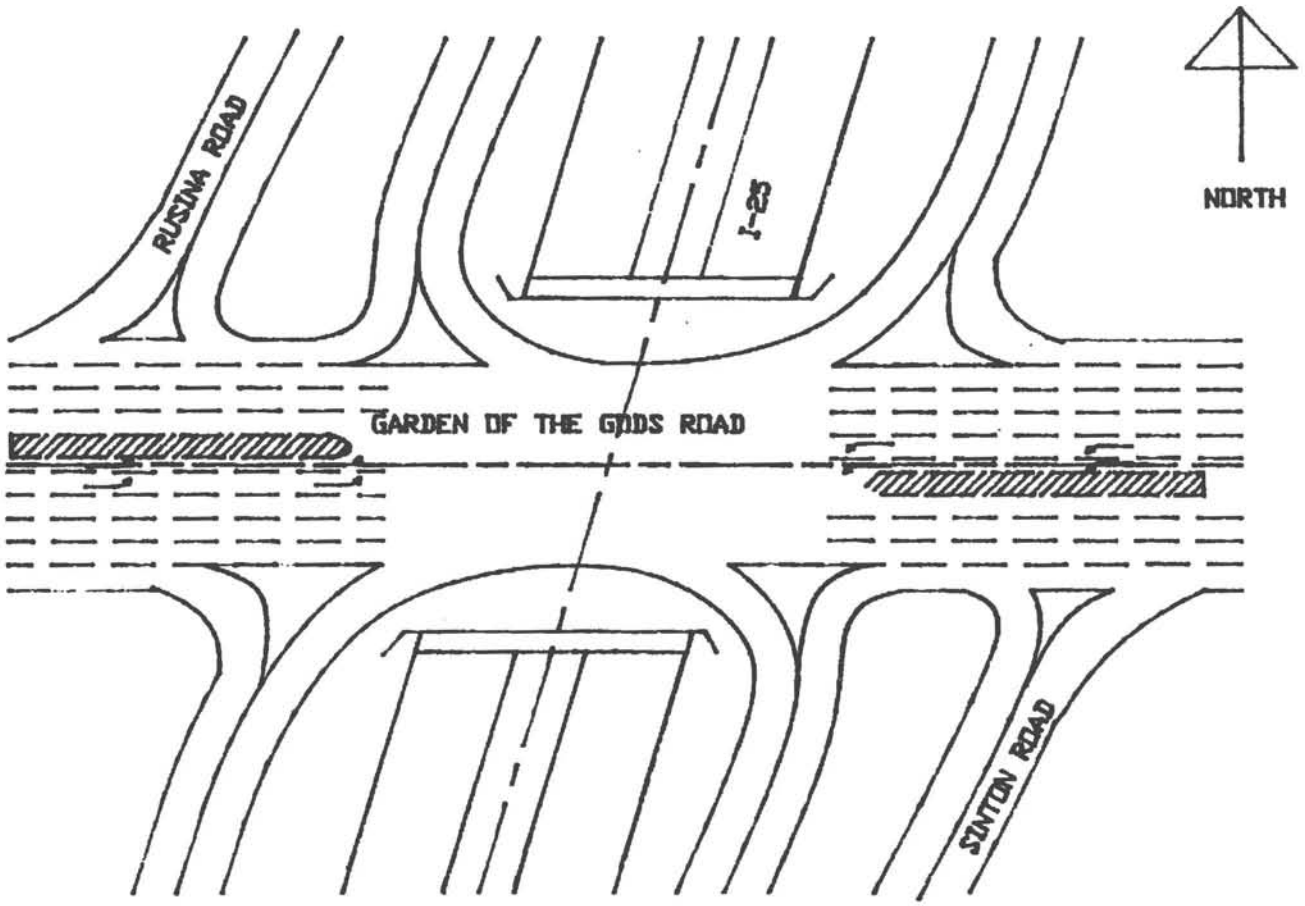
An IBM PC and Lotus program were used in the reduction of the data collected.

2.2.1 Travel Time Delay Studies

Travel time delay studies are conducted to evaluate the quality of traffic movement along a route and to determine the locations, types, and extent of traffic delays. The efficiency of flow is measured by travel and running speed.

Travel time delay can be determined by making test runs with a test car at various times of the day when traffic is considered to be high, moderate and low. Traffic volume during peak hours (7:00 A.M. to 9:00 A.M. and 4:00 P.M. to 6:00 P.M.) are mostly directional. Inbound traffic in the morning is generally high, while outbound traffic is relatively low. Conversely, outbound traffic volumes in the afternoon is generally high, while traffic inbound is relatively low. A single round trip could provide data in regard to high and low traffic volumes. Test runs during the morning and afternoon peak periods provide data over a wide range of speeds and densities compatible with Levels of Service (L.O.S.) A through F.

Eighteen test runs generating more than 130 vehicle miles of travel were done to collect the data needed for travel time and delay for the before study. Sixteen runs were done on the after study. Traffic flow during the test runs was stopped at



I-25/GARDEN OF THE GODS ROAD

S.P.U.I. EXISTING CONDITION

FIGURE 2.3

some signalized intersections and also slowed due to traffic frictions encountered by the test car.

There were 12 trips on each run and each trip was divided into segments between control points. Control points are assigned locations along a trip where the technician recorded time as the test car passed each point. The trip was segmented to determine the performance of each trip as a whole in terms of speed and level of service and to be able to locate problem segments within each trip during the evaluation (see Appendix).

The methodology for travel time delay was taken from the "Manual for Traffic Engineering Studies (Chapter 7)." Figure 2.4 shows a generic example of the trip routes.

No before trips were taken for Santa Fe/Evans.

Using Lotus 123, data collected was sorted by time of day (A.M.-peak, P.M.-peak and off-peak) per trip and per trip segment. The average travel speed for each trip and segment was computed using the methods in the "Manual of Traffic Engineering Studies."

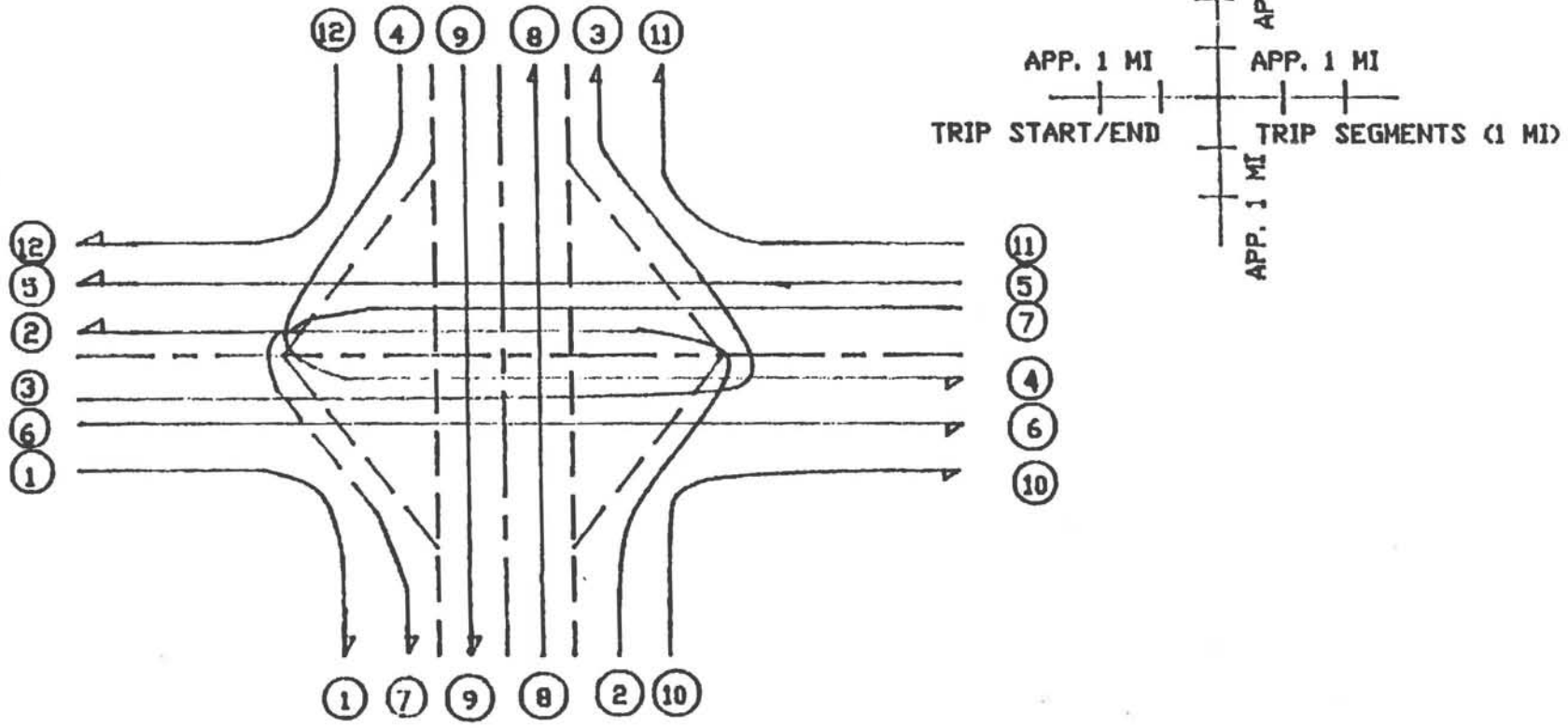
From the travel time delay studies, the arterial L.O.S. were obtained. The L.O.S. were classified according to corresponding arterial type and average travel speed in accordance with the Highway Capacity Manual. The following classifications of arterial type were assumed:

Garden of the Gods Road	Class 2
I-25	Class 1
Evans Avenue	Class 2
Santa Fe Drive	Class 1

See Table 2.1 for a breakdown of average travel speeds and corresponding L.O.S.

TABLE 2.1
ARTERIAL CLASS AND L.O.S

Arterial Class	1	2
Range of Free Flow Speeds (MPH)	45-35	35-20
Typical Free Flow Speed (MPH)	40 MPH	33 MPH
Level of Service	**Average Travel Speed (MPH)**	
A	≥35	≥30
B	≥28	≥24
C	≥22	≥18
D	≥17	≥14
E	≥13	≥10
F	≥13	≥10



TYPICAL TRIP ROUTES AND SEGMENTS

FIGURE 2.4

2.2.2 Intersection Delay

Intersection Delay Studies are conducted to evaluate the performance of intersections in allowing traffic to enter and pass through or to enter and turn onto another route. The control at the intersection is a primary factor evaluated in this study. This procedure provides a detailed evaluation of the stopped-time delay at the intersection. Stopped-time delay is defined as the time during which the traffic is actually stopped.

The methodology used in obtaining data for this study was taken from the "Manual of Traffic Engineering Studies (Chapter 8)." A technician was located at the intersection of the study area with an intersection delay formatted form and stopwatch. His responsibility was to count and record numbers of vehicles stopped on the approach for each observation time indicated. The stopwatch was started at the beginning of the study to advise the observer of the proper intervals for counting the stopped vehicles. A vehicle was counted more than once in the delay determination if it was stopped during more than one sampling time. A separate tabulation of the approach volume was made for each time period by classifying the vehicles either stopped or not stopped.

Using Lotus 123, data collected was sorted by time of day (A.M.-peak and off-peak) movement. The total delay per approach vehicle and percent of vehicles stopped were calculated following the methods in the "Manual of Traffic Engineering Studies".

With the time delay per stopped vehicle information, the level of service was obtained from Table 2.2. This table is from the Highway Capacity Manual, Chapter 11, Signalized Intersections.

TABLE 2.2
LEVEL-OF-SERVICE CRITERIA FOR SIGNALIZED INTERSECTIONS
"HIGHWAY CAPACITY MANUAL"

LEVEL OF SERVICE	STOPPED DELAY PER VEHICLE (SECONDS)
A	< = 5
B	5.1 TO 15
C	15.1 TO 25
D	25.1 TO 40
E	40.1 TO 60
F	> = 60

The S.P.U.I. provides relief by placing all left turns at a single point. This reduces the number of signalized intersections from two to one. Left turns onto or off the ramps are offset enough that conflicting left turns occur simultaneously. Three signal phases at a S.P.U.I. can provide the same access as four phases at a T.U.D.I. The S.P.U.I.'s ability to efficiently handle left turns make it ideal for interchanges where the number of left turns is large. The S.P.U.I.'s three phase advantage can be lost at interchanges with continuous one-way frontage roads, due to the fourth phase necessary for through movements.

Some controversy exists concerning the operational performance of a S.P.U.I. compared to a T.U.D.I. (Refer to "A Comparison of Two Diamond Interchange Forms in Urban Areas", Leisch and "The Urban Interchange", Greiner Engineering). In theory, large left turn radii and simplified geometry increase the capacity. In practice, the large left turn radii can cause driver confusion and provides a large open space. Drivers need additional signs and lane delineation to assist them through a S.P.U.I. CDOH installed subpavement lights at C-470/Morrison and I-25/Garden of the Gods Road as additional lane delineation for left turns.

CDOH undertook this study in 1986. At that time, the S.P.U.I. at Santa Fe/Evans was under construction. CDOH requested information from all states and many large cities concerning design of S.P.U.I.s and the use of subpavement lights. A survey conducted at the beginning of this study identified twelve S.P.U.I.s then operating and thirty being considered for specific locations. Five of the twelve S.P.U.I.s operating had subpavement lights. Two of the five had the lights turned off due to maintenance problems.

During the course of this study, CDOH built the S.P.U.I. at C-470/Morrison and proposed a S.P.U.I. at I-25/Garden of the Gods Road. CDOH expanded this study in 1987 to include a before and after comparison at I-25/Garden of the Gods Road.

2.2.3 Volume counts

Vehicle counts are taken to determine the number of vehicles entering the intersection. Counts for this study were taken in 15 minute intervals during the A.M.-peak, P.M-peak, and off-peak periods for each movement. Two methods were used. The first method located a field observer in the intersection and the second method used was video taping with subsequent viewing and counting. The methodology used in obtaining data for this study was taken from the "Manual of Traffic Engineering Studies."

The data collected was sorted by movement and by time of day (A.M.-peak, P.M.-peak and off-peak) and converted to vehicles per hour by multiplying the 15-minute counts by 4.

2.2.4 Accident Data

CDOH provided accident data for each interchange before and after the S.P.U.I. construction. Data for three years before and three years after was available at Santa Fe/Evans. At I-25/Garden of the Gods Road, three years before and one year after was available (the S.P.U.I was completed in 1989).

The data was broken down by type of accident, location, light condition, weather condition, and pavement condition(snow or ice). The accident rate per year was selected to compare data before and after construction.

2.2.5 Maintenance

The city of Colorado Springs provided information concerning maintenance of the subpavement lights at I-25/Garden of the Gods Road. No written records are kept for maintenance of the subpavement lights. A discussion with the members of the maintenance group provided the necessary data.

2.3 FIELD OBSERVATIONS

2.3.1 Santa Fe/Evans

Observations made in the field show several areas of concern. They are as follows:

1. Sight Distance
   Since the right turn movements are under stop sign control and left turns are under reduced speed operation, all movements can be said to meet the preferred design values for stopping sight distances,with the exception of the southbound left turn movement.

   For example, the cross-road sight distance for the southbound right turn movement is compounded by the approach of the westbound through traffic hidden by the crest of the vertical curve east of the intersection center and the northbound left turn traffic hidden by the slope of the northbound ramp. Southbound drivers attempting a right turn must also anticipate oncoming westbound vehicles approaching from behind their normal leftmost field of vision. In field observations, vehicles operating in these two movements were the most tentative and hazardous of all the movements at the intersection. See Figure 2.5 for marginal intersection sight distances.

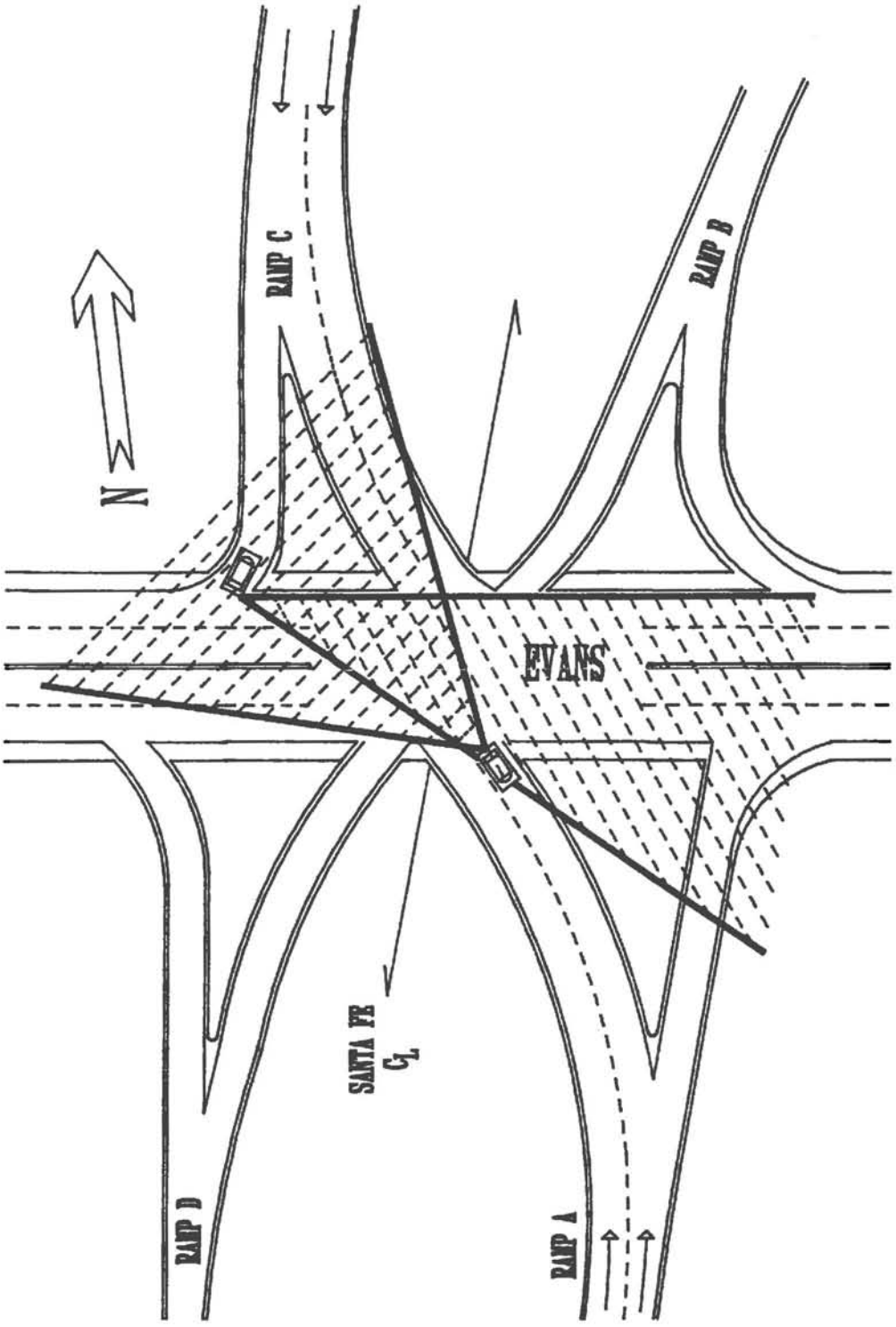


FIGURE 2.5: Santa Fe/Evans S.P.U.I. Design Sight Distance Exceptions

2. Signing, Marking

a. Signing: The weaving on the on-ramp movements near the intersection could be eliminated with proper advance directional signs on the ramps indicating which lanes at the intersection approaches serve left and right turning movements.

b. Marking: For this type of intersection (S.P.U.I.), the marking of the pavement is very important to channelize the traffic to the right direction so as to avoid confusion for users. Most of the markings were worn away by the effects of the winter snow removal efforts.

3. Turning Radii

During field observations at the site, it was noted that large trucks sometimes appeared to have difficulty performing some of the turning maneuvers. This difficulty was particularly prevalent with the north and southbound right turning movements.

2.3.2 I-25/Garden of the Gods

Observations made in the field and viewing of video cassettes of the I-25/Garden of the Gods S.P.U.I. indicate several areas of concern for vehicle conflicts. They are as follows:

1. Left turn traffic from east-west Garden of the Gods Road are occasionally making U-turns against the opposing through traffic as seen in Figure 2.6 as ①.

2. A conflict seems to occur for the off-ramps left turn traffic, whereby a few vehicles get out of their lane to the right and face left turn traffic as shown in Figure 2.6 as ②.

3. Some of the off-ramp right turn traffic seems to be unaware of the conflicting off-ramp left turn traffic and crosses into their path. See Figure 2.6 for examples of this conflict (③).

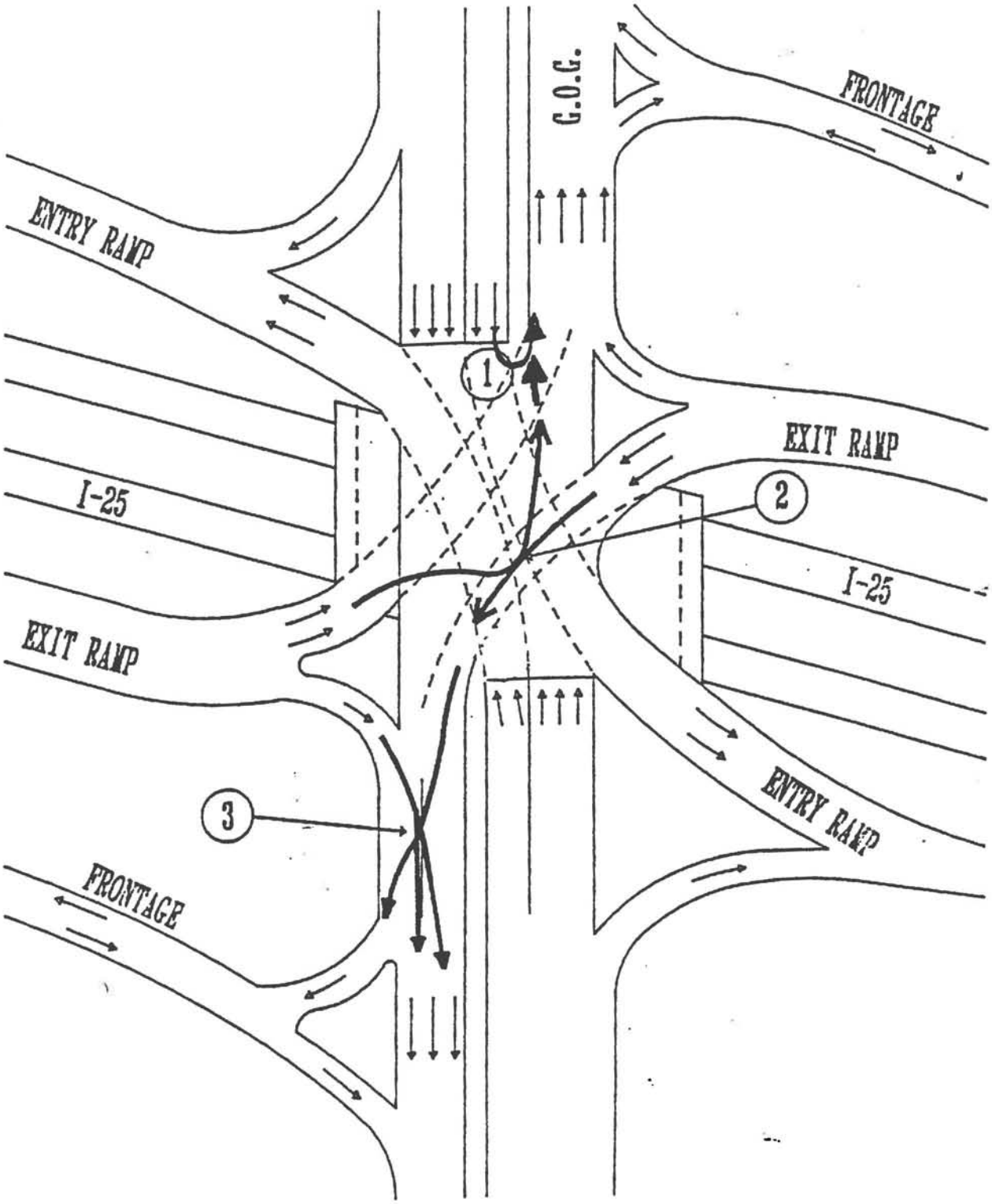


FIGURE 2.6: I-25/Garden of the Gods Vehicle Conflicts

3.0 SANTA FE/EVANS SINGLE POINT URBAN INTERCHANGE EVALUATION

3.1 GENERAL STATEMENTS

Santa Fe Drive and Evans Avenue are two busy major arterials in the Denver Metro area. Before construction of the S.P.U.I., high volumes of left turning traffic on all approaches created a serious capacity and safety problem. The situation was further complicated by the close proximity of an at-grade railroad crossing.

This high volume of left turning traffic on all approaches, constricted right-of-way and the close proximity of the railroad made the location a prime candidate for a single point urban interchange. The construction of the new retro-fitted S.P.U.I. at Santa Fe/Evans was completed in 1986.

Under the scope of this study, only the operational characteristics of the after facility (S.P.U.I.) were observed; the decision to do a study was made after it was too late to obtain existing before data.

3.2 ARTERIAL LEVEL OF SERVICE

As can be seen from Table 3.1 and Figure 3.1, the current operating Levels of Service for the twelve different trips available at Santa Fe/Evans are mostly A's and B's. This is to be expected with the facility, since it was designed for 20 years after the date of construction completion to operate at a Level of Service C.

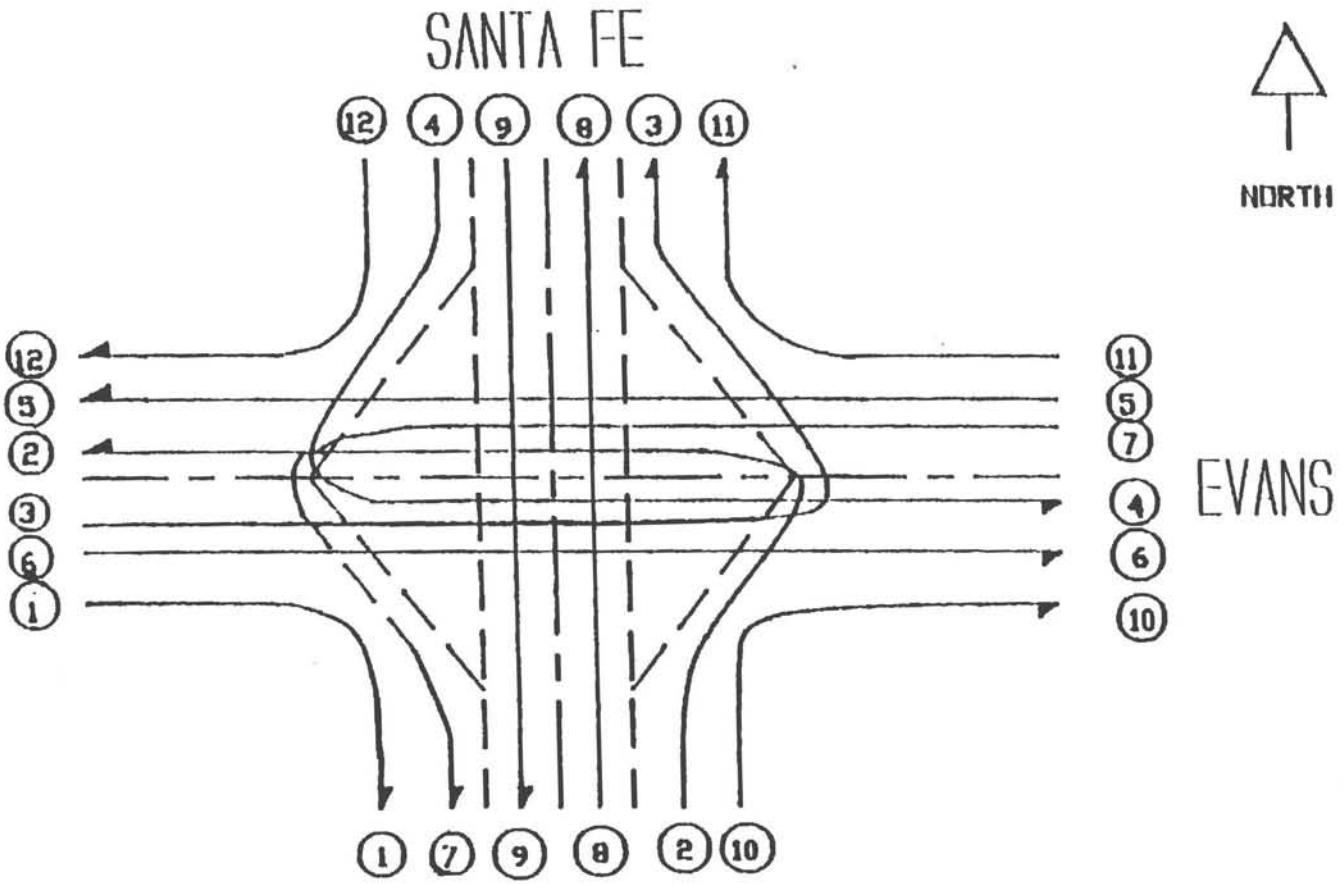
A factor of significant influence on the operation of a facility is the signalization timing and sequencing. This factor could have some bearing on the two trips which are operating at a Level of Service C. These two trips both consist of left turning movements as can be seen from Figure 3.1. Trip 3 consists of eastbound Evans to northbound Santa Fe and Trip 4 consists of southbound Santa Fe to eastbound Evans.

TABLE 3.1

SANTA FE/EVANS S.P.U.I.

ARTERIAL LEVEL OF SERVICE

	A.M. PEAK		P.M. PEAK		OFF-PEAK	
TRIP	TRAVEL SPEED	LOS	TRAVEL SPEED	LOS	TRAVEL SPEED	LOS
1	29	B	29	B	37	A
2	25	B	26	B	28	B
3	16	D	23	C	21	C
4	18	C	20	C	22	C
5	28	B	23	C	27	B
6	23	C	21	C	25	B
7	31	A	20	C	27	B
8	39	A	46	A	46	A
9	44	A	29	B	43	A
10	36	A	31	A	31	A
11	28	B	26	B	29	B
12	27	B	29	B	29	B



TRIP ROUTES SANTA FE / EVANS

FIGURE 3.1

3.3 INTERSECTION LEVEL OF SERVICE

As may be seen from Table 3.2, the signalized intersection of the S.P.U.I. is currently operating approximately at Level of Service C. This low L.O.S. is probably due to the long red times for left turning movements. This is an operational characteristic which is probably more controlled by the current signalization plan than the actual geometrics of the interchange itself.

3.4 VOLUMES

The results of the volume counts for before and after construction of the S.P.U.I. indicate a 14 percent increase in eastbound A.M. peak traffic and a 22 percent increase in eastbound P.M. peak traffic. The westbound movements indicate a decrease of 10 percent for the A.M peak and an increase of 56 percent for the P.M. peak. The substantial increase for the westbound P.M. peak movement may be due to counting error, assuming a mechanical counter was used for the before data collection. See Figure 3.2.

3.5 ACCIDENTS - SANTA FE/EVANS

The accident rate at Santa Fe/Evans decreased to 1/3 the rate before the S.P.U.I. For the thirty-three months preceeding construction of the S.P.U.I., one hundred and twenty-seven accidents occurred (46 accidents/year). Of those, seventy-two were property damage only and twenty eight involved injuries. No fatalities were recorded. The majority of the accidents (38) were rear-end collisions, followed by broadside (18) and approach turn (15), see Table 3.3.

Following construction of the S.P.U.I., forty-three accidents occurred (14 accidents/year). Twenty-three involved property damage only, nineteen were injury accidents and one was a fatality. Rear-end collisions remained the majority (40), followed by side-swipe (same direction) (16) and broadside (14), see Table 3.3.

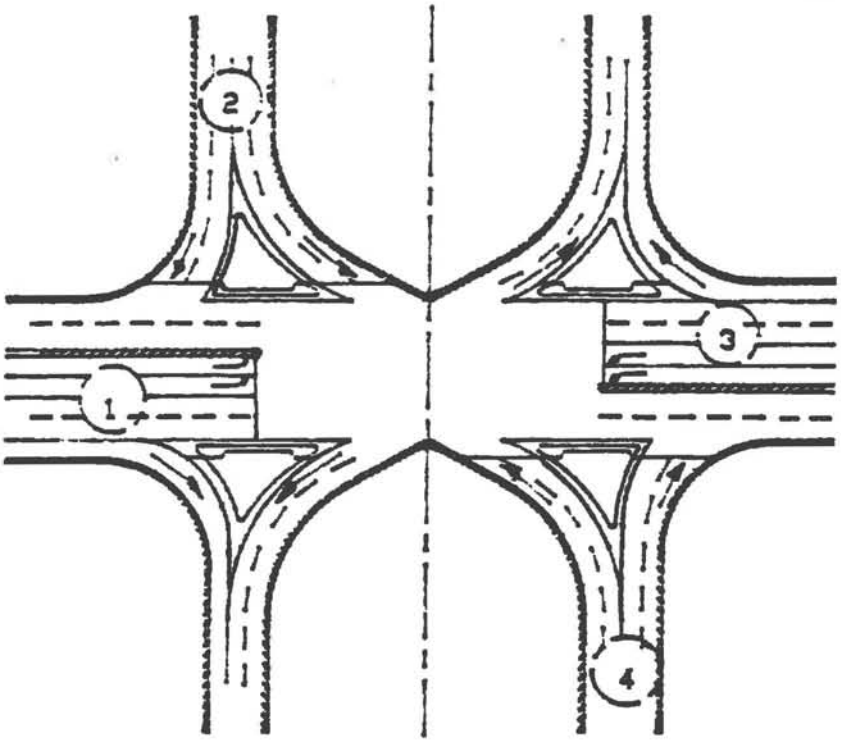
Volume counts at the interchange show an increase in vehicles through the interchange after construction.

TABLE 3.2

INTERSECTION LEVEL OF SERVICES PER MOVEMENT

AT SANTA FE/EVANS S.P.U.I.

MOVEMENT	PEAK	AVERAGE SECONDS DELAY PER APPROACH VEHICLE	LOS	PERCENT STOPPING
NORTH	A.M.	18.8	C	93
	P.M.	22.9	C	96
	OFF	18.9	C	85
SOUTH	A.M.	31.5	D	94
	P.M.	27.7	D	91
	OFF	30.3	D	94
EAST	A.M.	17.3	C	53
	P.M.	14.9	B	45
	OFF	16.5	C	57
WEST	A.M.	13.2	B	49
	P.M.	13.4	B	46
	OFF	10.0	B	46



SANTA FE/EVANS VOLUME COUNTS
FIGURE 3.2

VOLUME COMPARISON - SANTA FE / EVANS

MOVEMENT	A.M. PEAK BEFORE	A.M. PEAK AFTER	P.M. PEAK BEFORE	P.M. PEAK AFTER	OFF-PEAK BEFORE	OFF-PEAK AFTER
@ POINT 1						
L	#	264	#	280	#	176
T	#	1096	#	884	#	616
R	#	84	#	96	#	92
TOTAL	1270	1444	1034	1260	#	884
@ POINT 2						
L	#	140	#	208	#	96
R	#	80	#	68	#	128
@ POINT 3						
L	#	180	#	148	#	104
T	#	816	#	1072	#	1620
R	#	136	#	176	#	192
TOTAL	1253	1132	787	1396	#	1916
@ POINT 4						
L	#	52	#	104	#	76
R	#	103	#	136	#	100

NOTE : ALL COUNTS ARE VEHICLES PER HOUR
# DENOTES MISSING DATA

TABLE 3.3

ANNUAL ACCIDENT DATA

		SANTA FE & EVANS		I-25/GARDEN OF THE GODS	
		11/1/83 - 10/1/85 6/1/87 - 6/1/89		1/1/85 - 8/1/88 6/1/89 - 5/1/90	
		BEFORE	AFTER	BEFORE	AFTER
I.	NO. OF ACCIDENTS	46	14	37	36
	ONE-CAR ACCIDENT	6	2	4	3
	TWO-CAR ACCIDENT	35	10	29	33
	THREE OR MORE	5	2	4	0
II.	SAFETY:				
	FATAL ACCIDENT	0	0(0.33)	0	0
	INJURY ACCIDENT	13	6	11	15
	PROPERTY DAMAGE	33	8	25	21
III.	LOCATION:				
	ON ROADWAY	41	11	33	32
	OFF-ROADWAY	5	3	4	4
IV.	LIGHT CONDITIONS:				
	DAYLIGHT	35	10	30	33
	DARK, NOT LIGHTED	1	0	3	0
	DARK, LIGHTED	10	4	4	3
V.	ADVERSE CONDITIONS:				
	WEATHER: RAINING	2	1	2	2
	SNOWING	1	1	3	1
	ROAD: WET	5	1	2	4
	SNOWY	1	1	1	1
	ICY	1	1	2	1

4.0 EVALUATION AND COMPARISON OF I-25/GARDEN OF THE GODS

4.1 GENERAL STATEMENT

In order to understand the comparison of the performance of before and after facilities, the following should be recognized:

1. The new S.P.U.I. at I-25/Garden of the Gods is designed for a design year of 2008 and the current study has been completed in 1990. This leads to the conclusion that the facility has, or should have, a surplus of capacity.

2. The before facility (T.U.D.I.) had only two through lanes for east-west bound traffic and single left turn lanes for the approaches, versus the after facility (S.P.U.I.), which has three through lanes for east-west bound traffic and dual left turn lanes for each approach.

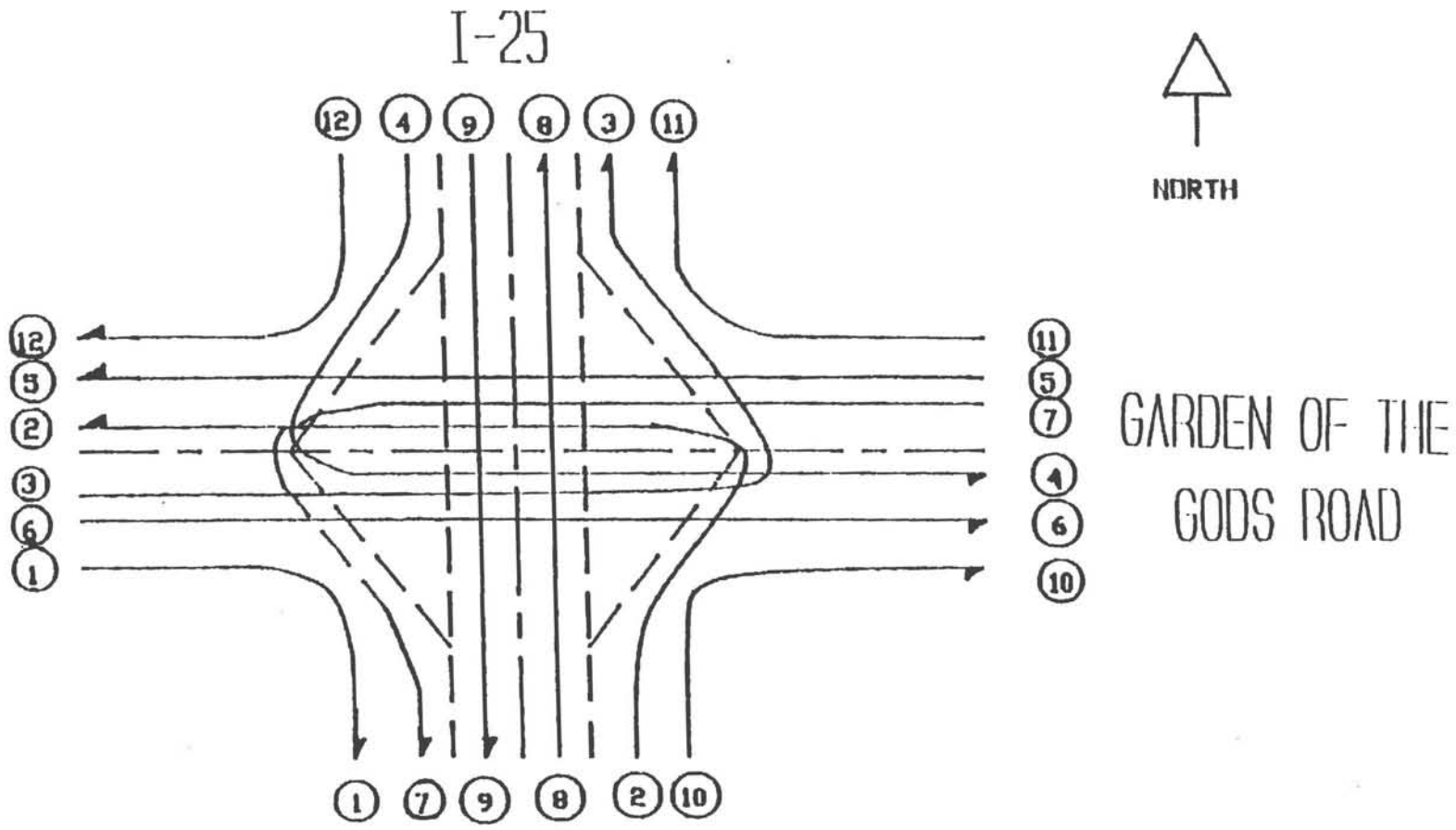
3. The before situation (T.U.D.I.) consisted of two signalized intersections and the after facility (S.P.U.I.) consists of one signalized intersection.

4.2 ARTERIAL L.O.S.

From the comparison charts (Figures 4.1,4.2,4.3,4.4 and Table 4.1) it may be seen that on the average the arterial levels of service did improve for the S.P.U.I.

Several areas of concern should be mentioned. First, additional lanes were added, both for through and turning lanes, on the S.P.U.I. in comparison to the before facility (T.U.D.I.). These additional lanes with their attendant added capacity, would in themselves increase the arterial level of service.

Second, the after facility (S.P.U.I.) was designed for the year 2008. The facility is designed to operate at a level of service C in the proposed design year, so clearly it should currently operate at a level of service well above C, which it does with a level of service of A for essentially all trips and all periods.



TRIP ROUTES I-25 / GARDEN OF THE GODS ROAD

FIGURE 4.1

FIGURE 4.2

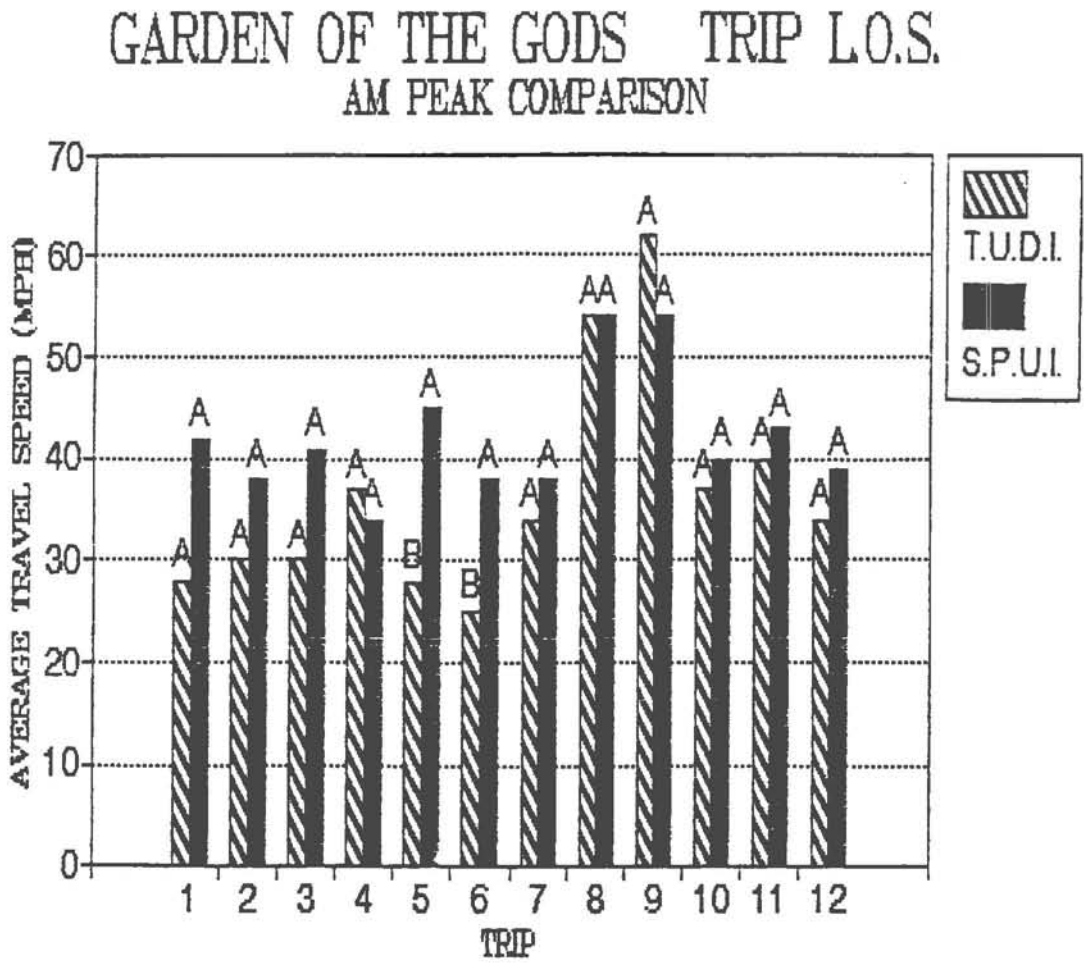

GARDEN OF THE GODS TRIP L.O.S.
AM PEAK COMPARISON
AVERAGE TRAVEL SPEED (MPH)
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12
TRIP
T.U.D.I.
S.P.U.I.

FIGURE 4.3

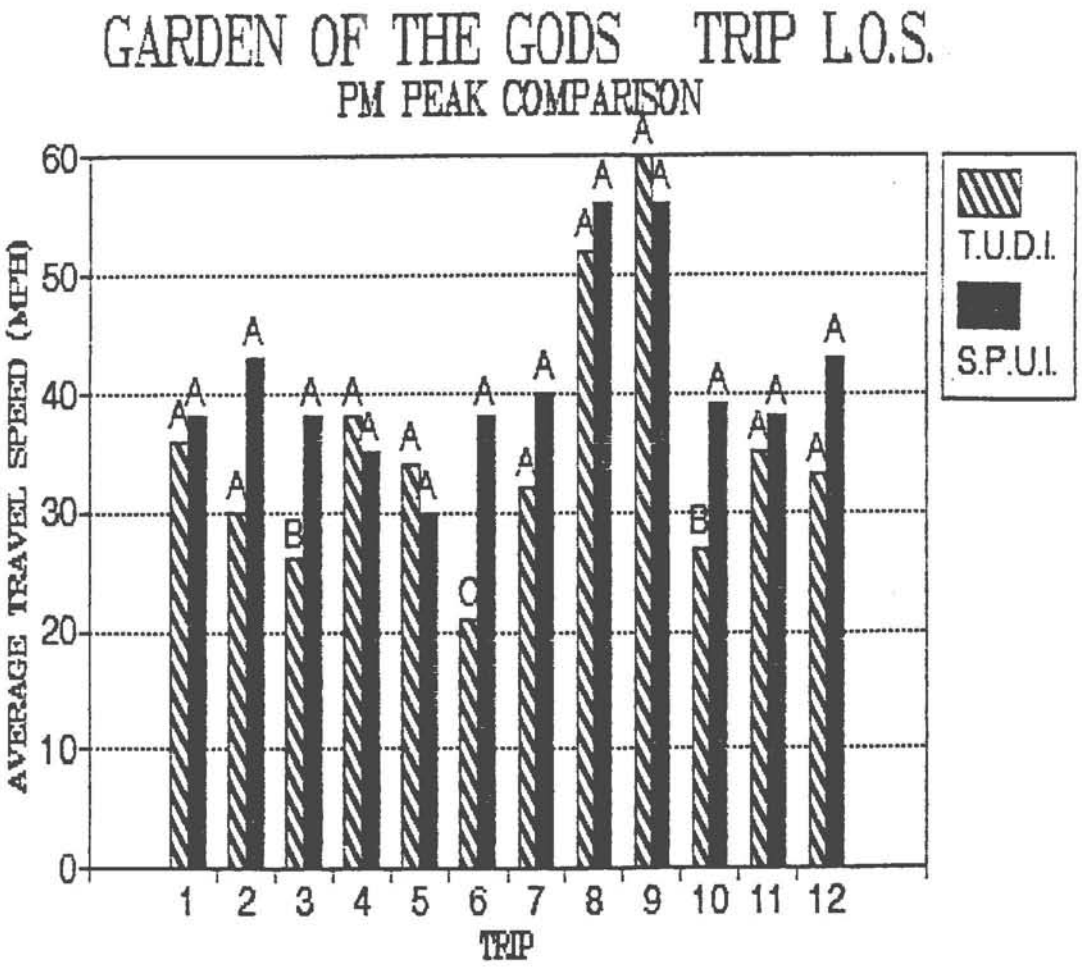

GARDEN OF THE GODS TRIP L.O.S.
PM PEAK COMPARISON
AVERAGE TRAVEL SPEED (MPH)
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12
TRIP
T.U.D.I.
S.P.U.I.

FIGURE 4.4

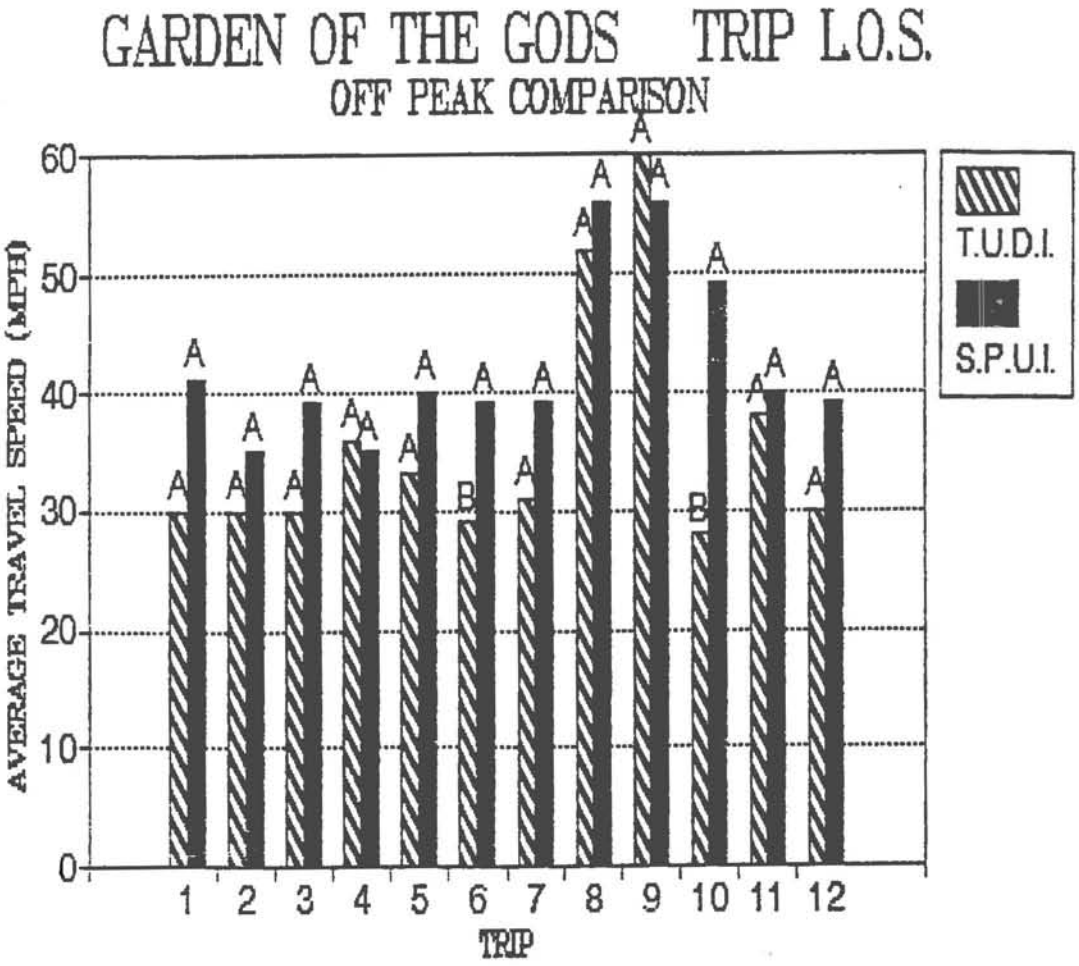

GARDEN OF THE GODS TRIP L.O.S.
OFF PEAK COMPARISON
AVERAGE TRAVEL SPEED (MPH)
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12
TRIP
T.U.D.I.
S.P.U.I.

TABLE 4.1

I-25/GARDEN OF THE GODS

GARDEN OF THE GODS
ARTERIAL LEVEL OF SERVICE COMPARISON

TRIP NO	T.U.D.I. MPH	BEFORE L.O.S.	S.P.U.I. MPH	AFTER L.O.S.
		AM PEAK		
1	28	A	42	A
2	30	A	38	A
3	30	A	41	A
4	37	A	34	A
5	28	B	45	A
6	25	B	38	A
7	34	A	38	A
8	54	A	54	A
9	62	A	54	A
10	37	A	40	A
11	40	A	43	A
12	34	A	39	A
		PM PEAK		
1	36	A	38	A
2	30	A	43	A
3	26	B	38	A
4	38	A	35	A
5	34	A	30	A
6	21	C	38	A
7	32	A	40	A
8	52	A	56	A
9	60	A	56	A
10	27	B	39	A
11	35	A	38	A
12	33	A	43	A
		OFF PEAK		
1	30	A	41	A
2	30	A	35	A
3	30	A	39	A
4	36	A	35	A
5	33	A	40	A
6	29	B	39	A
7	31	A	39	A
8	52	A	56	A
9	60	A	56	A
10	28	B	49	A
11	38	A	40	A
12	30	A	39	A

4.3 INTERSECTION LEVEL OF SERVICE

To compare the intersection Levels of Service it was necessary to get the field data into like format. Since the before situation was a Tight Urban Diamond Interchange (T.U.D.I.) with two signalized intersections and the after situation a Single Point Urban Interchange (S.P.U.I.) with one signalized intersection, this is necessary.

The process used to compare the two interchanges was to consider all traffic entering the intersection as one of four categories: northbound, southbound, eastbound and westbound. This simplification made it possible to more effectively compare the two interchanges. Another procedure used was to weigh the average vehicle delay seconds in regards to all approach vehicles per the four directions, along with individual approach directions.

As may be seen from Table 4.2, the L.O.S. of the interchange has improved for all three time periods. On the average, the intersection delay time was decreased by approximately 12 seconds for each vehicle. This amount of time becomes fairly significant if accumulated for total travel time saved per all vehicles per year.

4.4 VOLUME COMPARISON

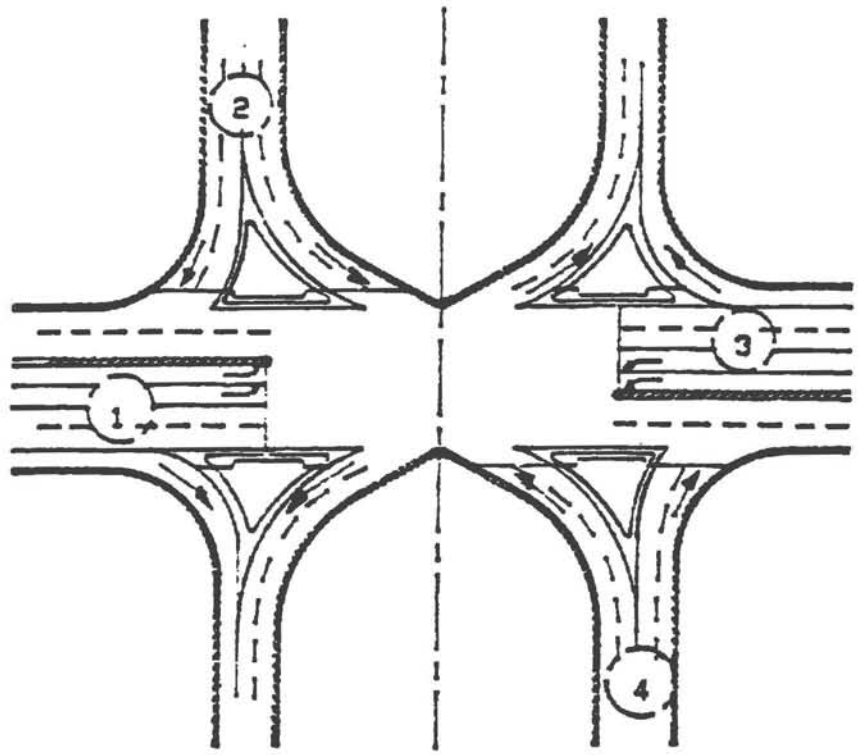
The results of the volume counts for before and after construction of the S.P.U.I. indicate an 8 percent increase in eastbound A.M. peak traffic. The westbound movements indicate a 19 percent decrease for A.M. peak traffic and a 19 percent decrease in P.M. peak traffic. See Figure 4.5.

GARDEN OF THE GODS INTERSECTION DELAY SUMMARY

		Eastbound			Westbound			Northbound		Southbound		Weighted Avg delay/veh	Weighted
		Left	Thru	Right	Left	Thru	Right	Left	Right	Left	Right	(Seconds)	L O S
Before	AM Peak												
	% of Total Vol	8%	17%	9%	7%	23%	2%	11%	8%	3%	12%		
	delay/veh (s)	37	25	0	41	35	0	39	39	49	49	33	D
After	AM Peak												
	% of Total Vol	9%	17%	8%	7%	16%	3%	9%	12%	3%	15%		
	delay/veh (s)	26	12	0	13	11	0	150	0	33	0	22	C
Before	PM Peak												
	% of Total Vol	8%	19%	10%	8%	20%	6%	9%	9%	4%	7%		
	delay/veh (s)	46	31	0	47	30	0	54	54	46	46	34	D
After	PM Peak												
	% of Total Vol	15%	25%	12%	6%	13%	2%	7%	9%	3%	9%		
	delay/veh (s)	29	9	0	32	8	0	26	0	28	0	12	B
Before	OFF Peak												
	% of Total Vol	8%	22%	10%	8%	15%	11%	8%	8%	3%	7%		
	delay/veh (s)	35	19	0	27	19	0	41	41	44	44	23	C
After	OFF Peak												
	% of Total Vol	8%	18%	9%	8%	19%	5%	8%	10%	3%	12%		
	delay/veh (s)	26	9	0	28	9	0	25	0	27	0	10	B

I-25/GARDEN OF THE GODS INTERSECTION L.O.S. COMPARISON

TABLE 4.2



I-25/GARDEN OF THE GODS ROAD

VOLUME COUNTS

FIGURE 4.5

VOLUME COMPARISON - I-25/GARDEN OF THE GODS

	A.M. PEAK		P.M. PEAK		OFF-PEAK	
MOVEMENT	BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER
@ POINT 1						
L	280	316	324	676	232	196
T	592	576	760	1144	616	444
R	304	264	400	532	276	224
@ POINT 2						
L	96	108	152	124	76	64
R	416	497	304	352	200	275
@ POINT 3						
L	256	232	348	272	228	208
T	838	552	816	612	432	476
R	64	104	252	112	304	124
@ POINT 4						
L	376	316	380	312	220	188
R	296	388	360	420	228	256

NOTE : ALL COUNTS ARE VEHICLES PER HOUR

4.5 ACCIDENTS - I-25/GARDEN OF THE GODS

The accident rate at I-25/Garden of the Gods Road shows no significant change between before and after the S.P.U.I.; 37 accidents before and 36 after. We suspect that the high after rate is due to the short length of time to develop a pattern (eleven months) and driver unfamiliarity. At least one more year of data is needed to see a trend.

For the thirty-six months before construction, one hundred and thirty-two accidents occurred (37/year). Ninety-five accidents involved property damage only and thirty-seven involved injuries. Sixty accidents were rear-end collisions, nineteen were broadside.

After the S.P.U.I. (eleven months ago), thirty-three accidents occurred (36/year). Nineteen involved property damage only and the remaining fourteen were injury accidents. One fatality at the interchange in June of 1990 was due to the driver's heart attack. Again, the majority of the accidents were rear-end collisions (11) followed by approach turn (10), while sideswipe and broadside had four each. See Table 3.3, page 24.

4.6 MAINTENANCE HISTORY

According to Wayne Lupton at the city of Colorado Springs, the subpavement lights at I-25/Garden of the Gods Road are not maintained on a set schedule. Sand causes a problem by filling up the lights in both summer and winter. Because Garden of the Gods Road is depressed, the water runs to the point below interchange area, depositing sand. The city of Colorado Springs uses a street cleaning machine to sweep the area when they notice a problem or citizens call in a complaint. Hand cleaning of lights is a preferred method to ensure removal of sand; however, the interchange cannot be closed to allow hand cleaning. Other than sand accumulation, there have been no other problems with the subpavement lights at I-25/Garden of the Gods Road.

5.0 CONCLUSIONS

5.1 GENERAL CONCLUSIONS

This study was limited in scope and applied to only two S.P.U.I.s. The following general conclusions were drawn:

5.1.1 The S.P.U.I. is an interchange design adaptation that offers opportunities to improve interchange geometrics and performance in highly restricted right-of-way situations. It is no panacea and should be carefully compared to other alternative solutions to determine its applicability to each individual site.

5.1.2 S.P.U.I. operational characteristics, overall capacity, and accident exposure could probably all be improved with better advance guide signing. Improved signage at the "island" area of the point seems needed. Free right off-ramp vehicles need signing to inform them of possible merging traffic from 10-11 o'clock directionally.

5.1.3 The pavement lights in S.P.U.I. may not be warranted, but further study and observation is needed. With improved signing and well-maintained pavement markings, in-pavement lighting may not be justifiable.

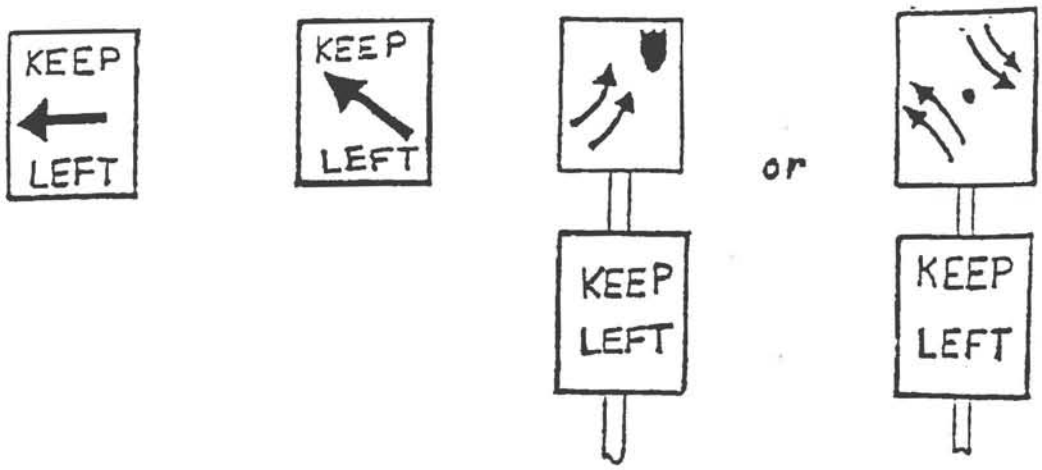
5.1.4 The S.P.U.I. is a relatively new type of interchange and is unfamiliar to many motorists. This lack of familiarity requires that pavement markings be repainted more frequently than under current maintenance practices in order that the guidance they provide not be lost.

5.1.5 The S.P.U.I. at Sante Fe has a sight distance problem. Limited sight distances can probably be traced to the retrofit nature of this interchange. It is recommended that improved signing be added to indicate to the motorist that limited and restricted sight distance problems exist at the intersection. As advance guidance and channelization is critical, it is recommended that adequate sight distance be considered a primary issue in all S.P.U.I. designs.

5.1.6 Conflicts at the Garden of the Gods/I-25 S.P.U.I.:

Conflict 1. It is necessary to make the U-turn prohibited sign more visible at the Garden of the Gods S.P.U.I.

Conflict 2. A "KEEP LEFT" sign instructing left-turn drivers off the I-25 exit ramp is needed in the center median under the bridge. A sign similar to one of the following is recommended:



Conflict 3. A sign to watch for oncoming left-turn traffic is needed to alert the drivers making the free right from the I-25 exit ramps. Drivers expect the left turn traffic to come from a right angle, not from an angle to the front and side. A "KEEP RIGHT" sign or one similar to the sign shown below should be considered.

5.1.7 Weighted L.O.S. Procedure for Intersection L.O.S. delay as a measure of the intersection efficiency at the S.P.U.I. was not considered appropriate. In a T.U.D.I., four phases are needed to accommodate the movements. A S.P.U.I. requires only three phases to accommodate the same movements. A more appropriate measure is the ability of the intersection to move vehicles during peak periods. This study defined weighted L.O.S. as the measure of how well vehicles got through the intersection. Vehicle counts by movement and delay per vehicle by movement were collected. Since the same movements happen in each interchange type, the delay by movement can be compared. The percent of vehicles making each movement was multiplied by the delay per vehicle. Summing these values for each movement gives a weighted L.O.S. for the intersection.

5.1.8 Problems with signalization at Sante Fe and Evans were observed. The specific signal timing at each intersection was not evaluated as part of this study. At S.P.U.I.s delay is not an appropriate measure of how well the intersection operates. In order to serve all movements, the delays can be on the order of 20-30 seconds, which is L.O.S. C for regular intersections. Since there are only three phases, each phase is activated more often but is longer than for a T.U.D.I. A more appropriate measure of effectiveness would be how many vehicles moved through the intersection during peak periods, compared to before.

5.1.9 It is recommended that a review of accidents at Garden of the Gods be performed after three years accumulation of data is available.

6.0 APPENDIX

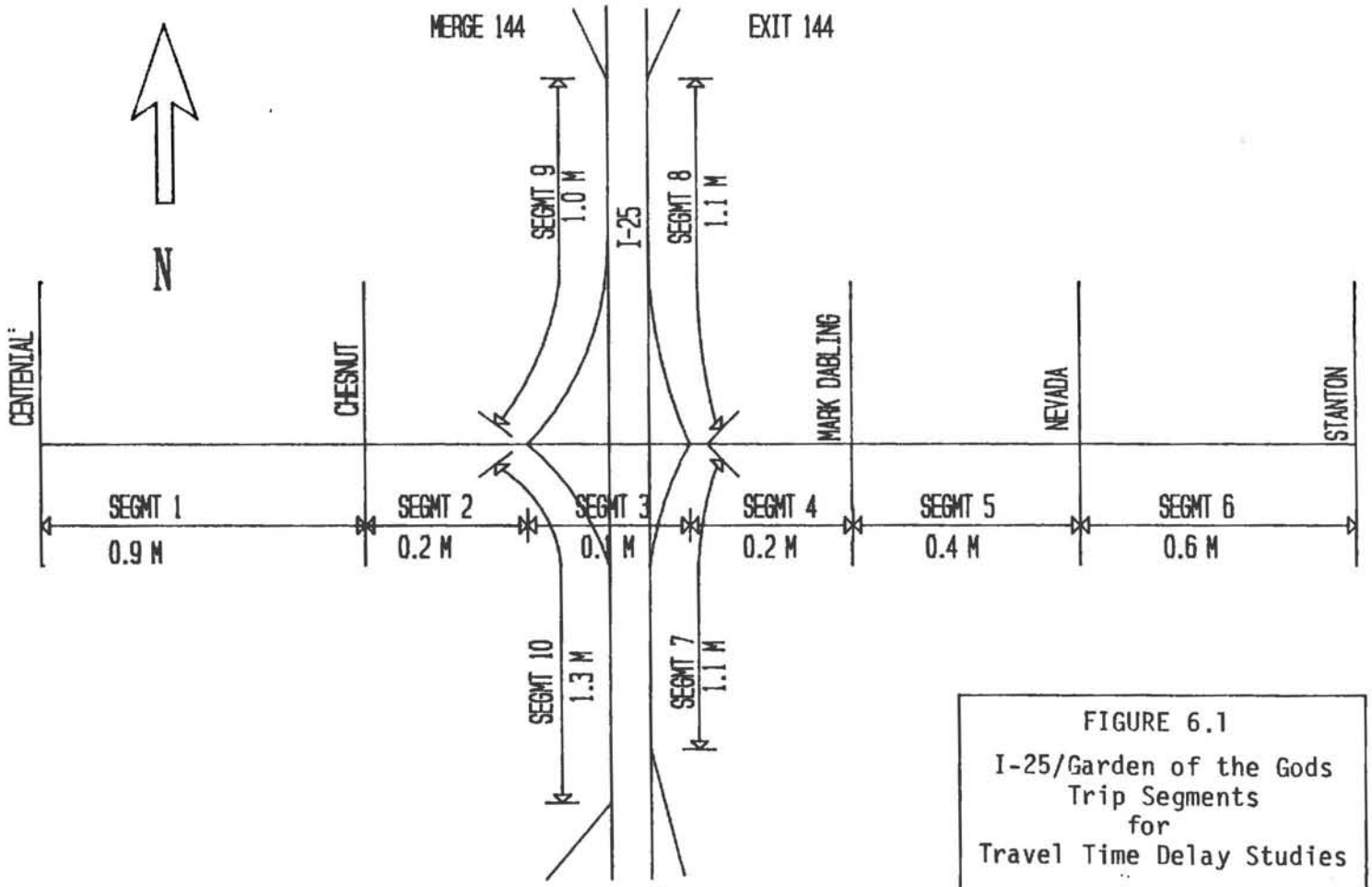


FIGURE 6.1

I-25/Garden of the Gods
Trip Segments
for
Travel Time Delay Studies

TABLE 6.1

TRIP 1-ARTERIAL LOS
GARDEN OF THE GODS

BEFORE			AFTER		
SEGMENT	OFF PEAK SPEED(MPH)	LOS	SEGMENT	OFF PEAK SPEED(MPH)	LOS
1	38	A	1	38.447997	A
2	15	E	2	41.55468	A
10	53	A	10	49.097506	A
	AM PEAK			AM PEAK	
1	31	A	1	35.5	A
2	12	F	2	39.827473	A
10	49	A	10	47.255177	A
	PM PEAK			PM PEAK	
1	43	A	1	33.592895	A
2	16	E	2	34.652052	A
10	51	A	10	47.968586	A

FIGURE 6.2
Arterial LOS
Garden of the Gods

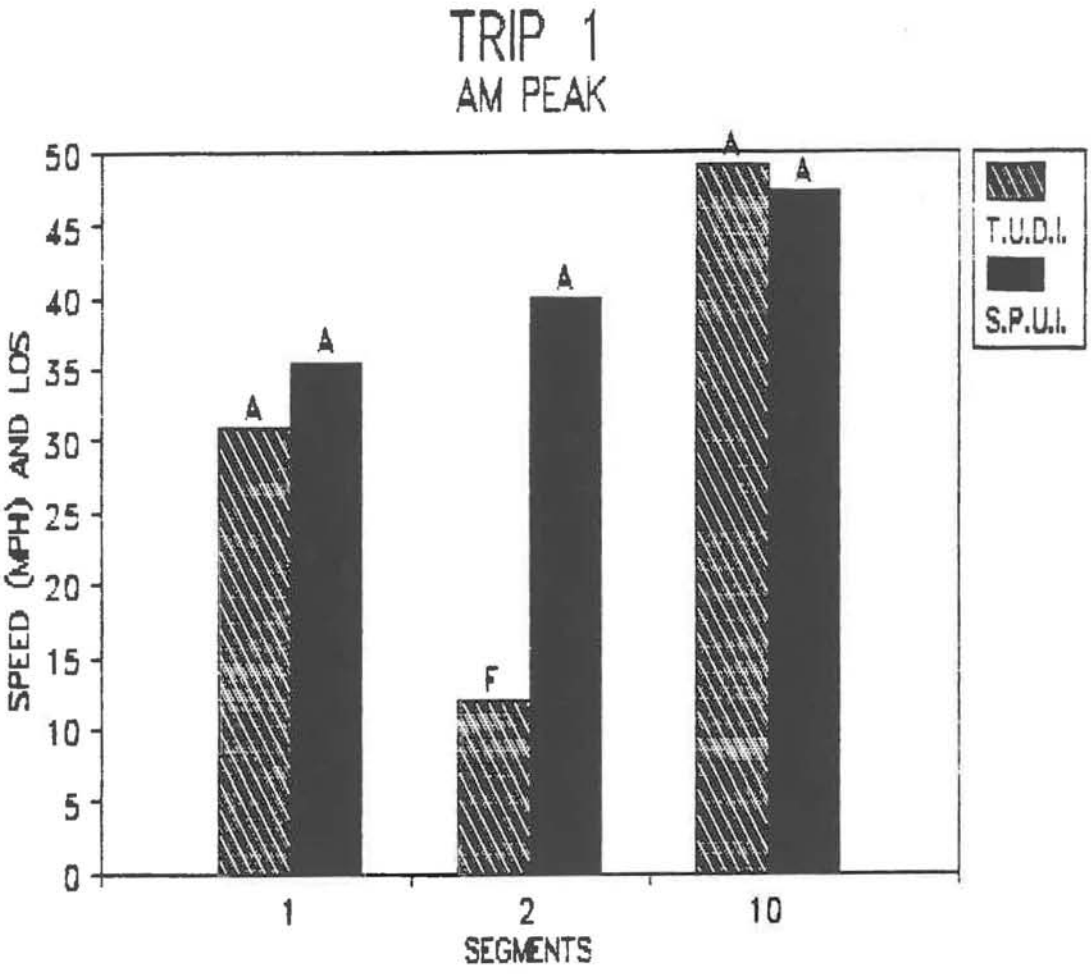


FIGURE 6.3
Arterial LOS
Garden of the Gods

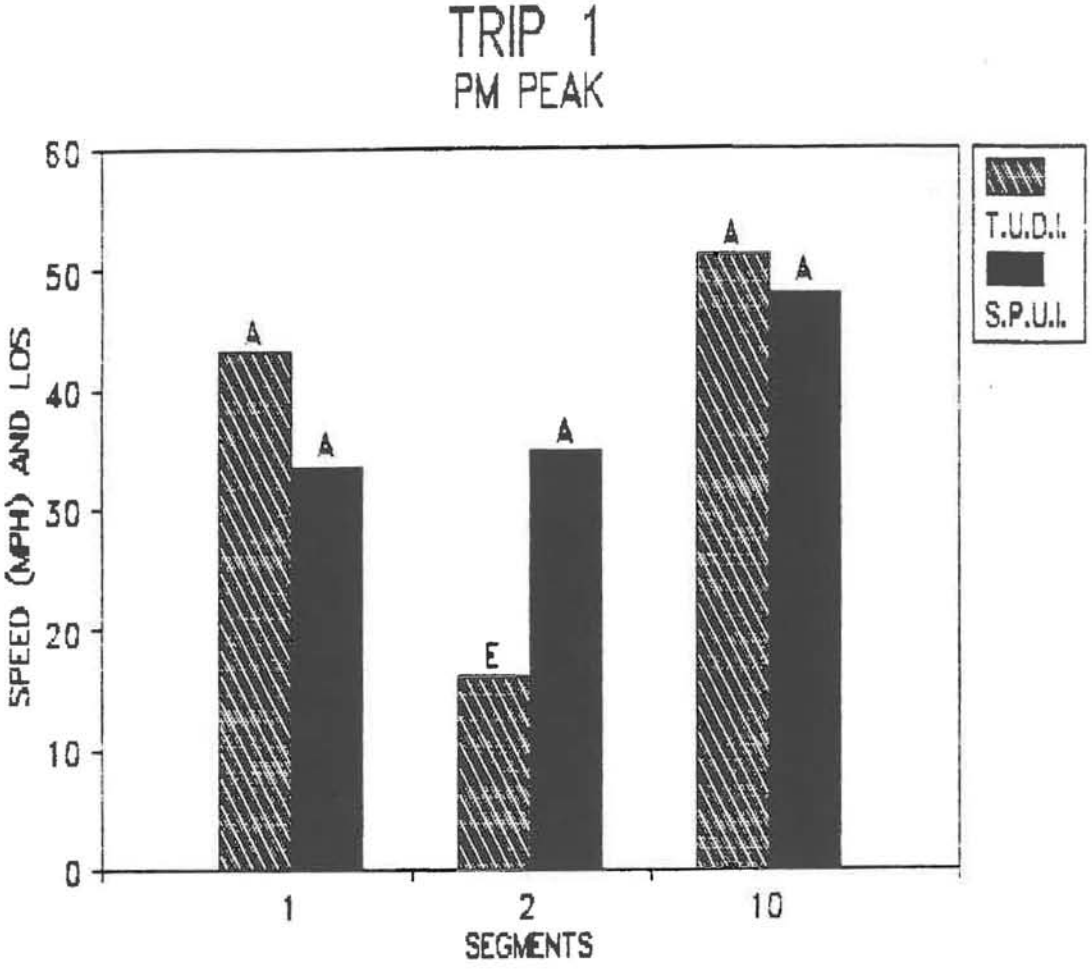


FIGURE 6.4

Arterial LOS

Garden of the Gods

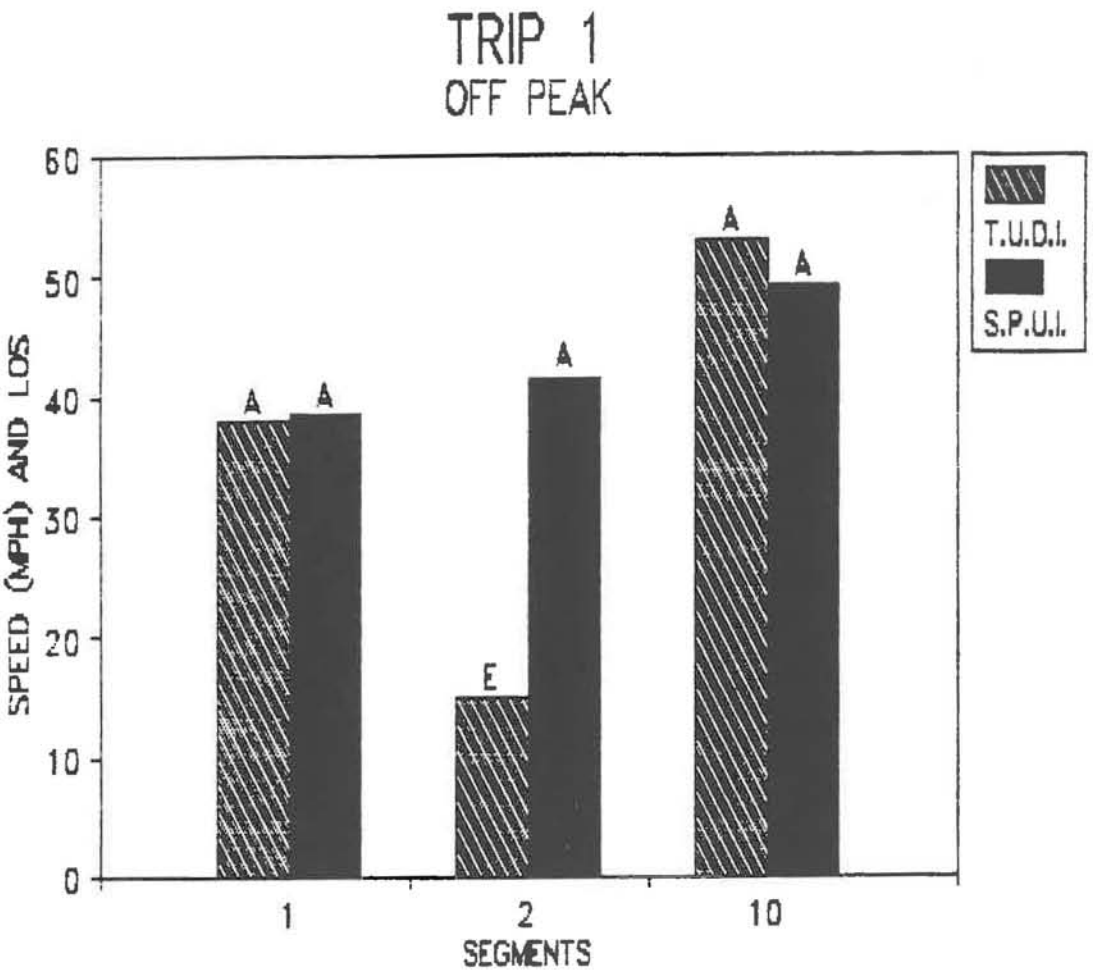


TABLE 6.2

TRIP 2-ARTERIAL LOS COMPARISON
GARDEN OF THE GODS

BEFORE			AFTER		
SEGMENT	OFF PEAK SPEED(MPH)	LOS	SEGMENT	OFF PEAK SPEED(MPH)	LOS
7	31	B	7	49	A
3	20	C	3	23.5	B
2	26	B	2	26.6	B
1	44	A	1	32	A
	AM PEAK			AM PEAK	
7	33	B	7	46.8	A
3	26	B	3	37.7	A
2	25	B	2	14.4	C
1	38	A	1	36.5	A
	PM PEAK			PM PEAK	
7	30	B	7	46.9	A
3	18	C	3	25.5	B
2	23	C	2	20.1	C
1	49	A	1	43.8	A

FIGURE 6.5

Arterial LOS

Garden of the Gods

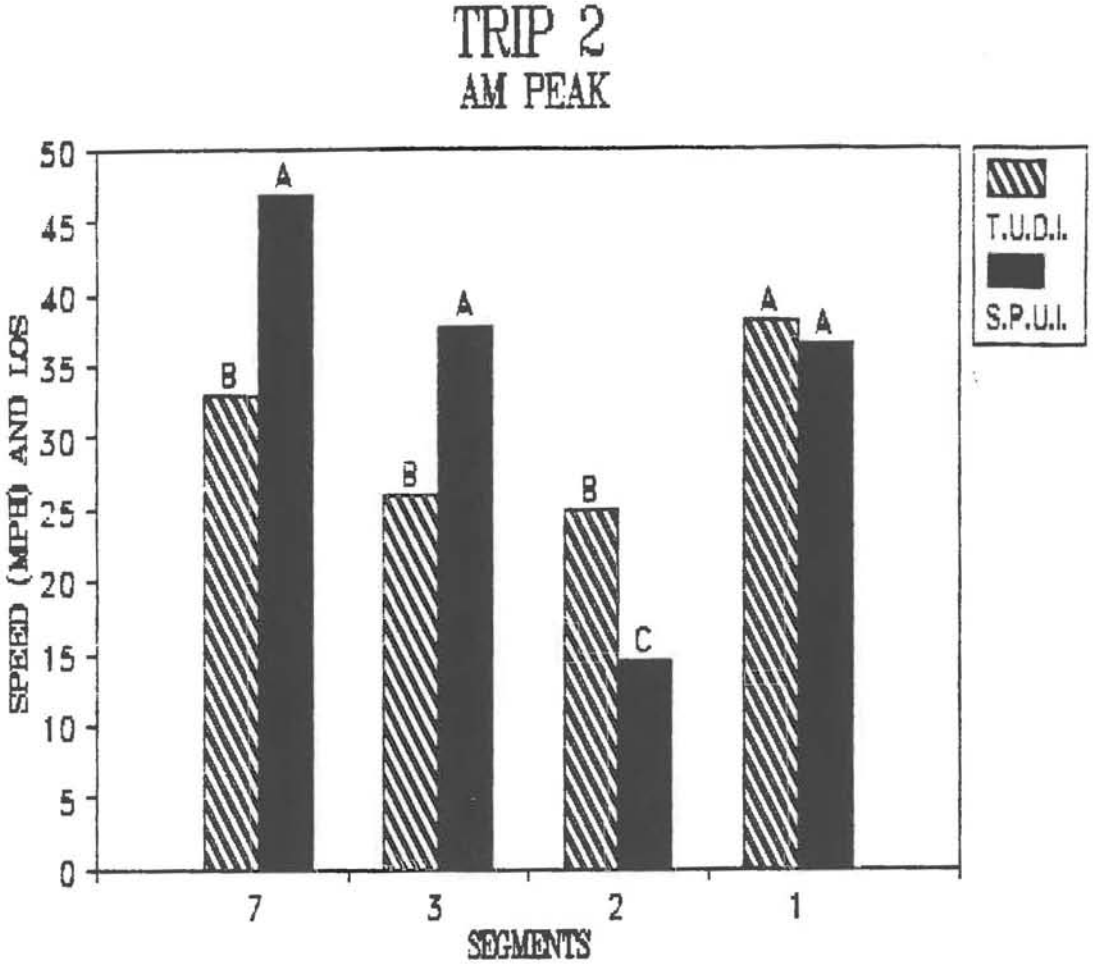


FIGURE 6.6

Arterial LOS

Garden of the Gods

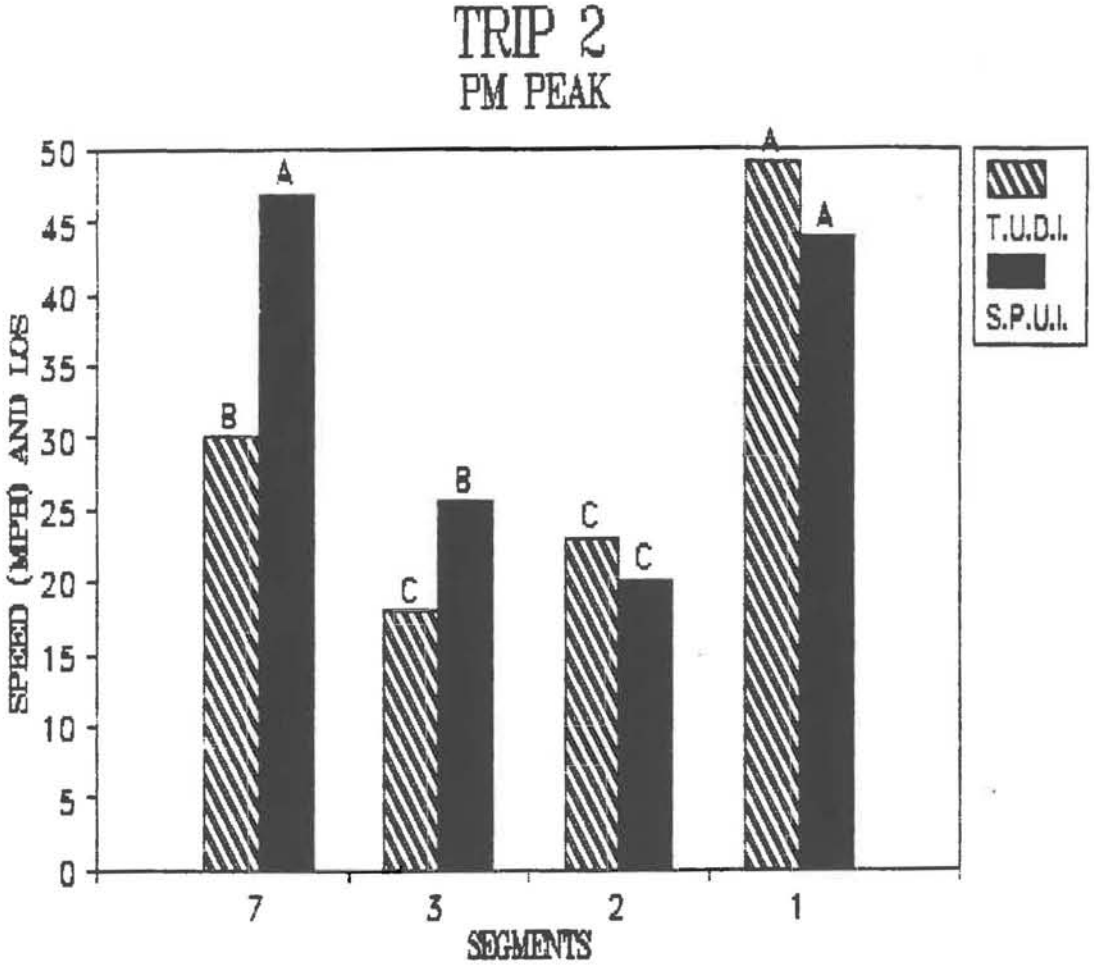


FIGURE 6.7

Arterial LOS

Garden of the Gods

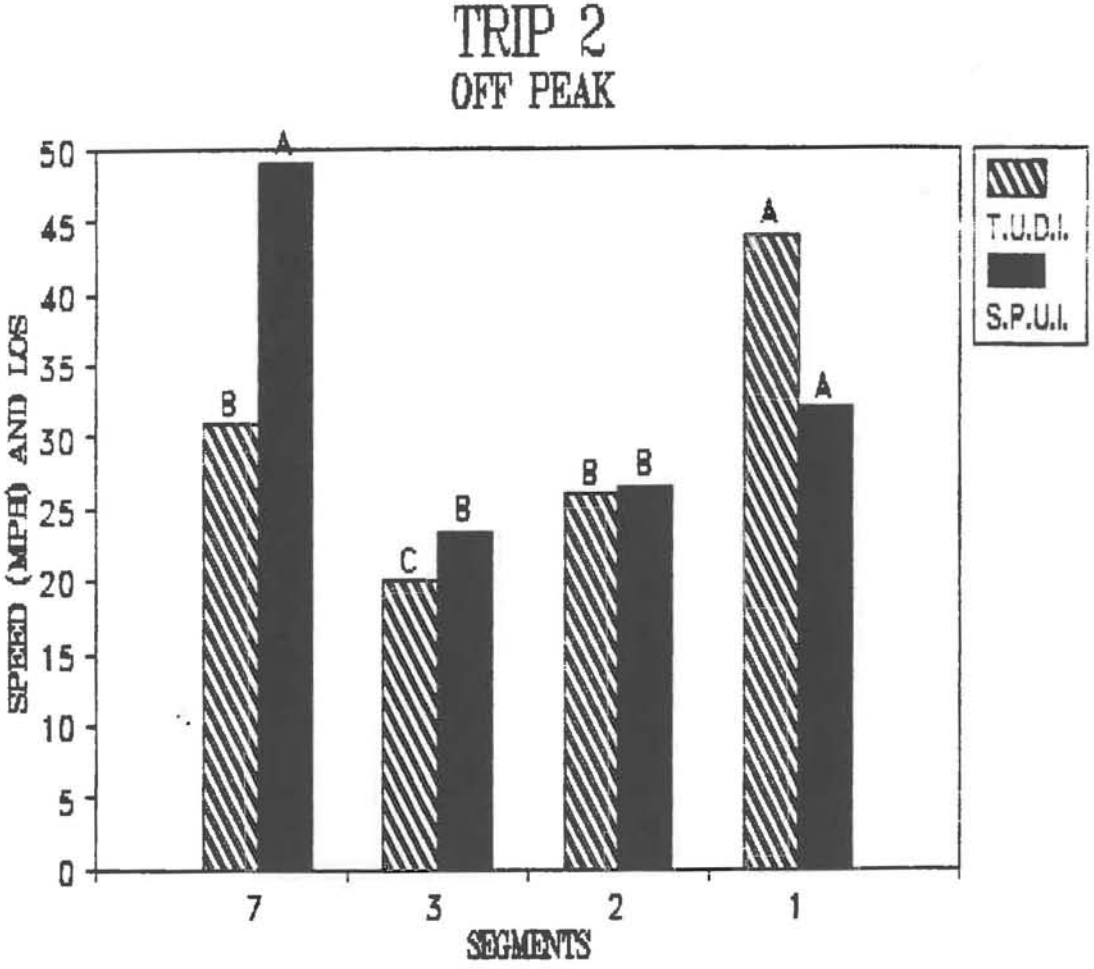


TABLE 6.3

TRIP 3-ARTERIAL LOS COMPARISON
GARDEN OF THE GODS

BEFORE			AFTER		
SEGMENT	OFF PEAK SPEED(MPH)	LOS	SEGMENT	OFF PEAK SPEED(MPH)	LOS
1	40	A	1	38.5	A
2	16	D	2	33.6	A
3	10	E	3	18	C
8	46	A	8	47.6	A
	AM PEAK			AM PEAK	
1	39	A	1	35.1	A
2	7	F	2	43.3	A
3	7	F	3	19.2	C
8	48	A	8	47	A
	PM PEAK			PM PEAK	
1	38	A	1	42.6	A
2	10	E	2	34.2	A
3	5	F	3	10.9	E
8	45	A	8	45.7	A

FIGURE 6.8
Arterial LOS
Garden of the Gods

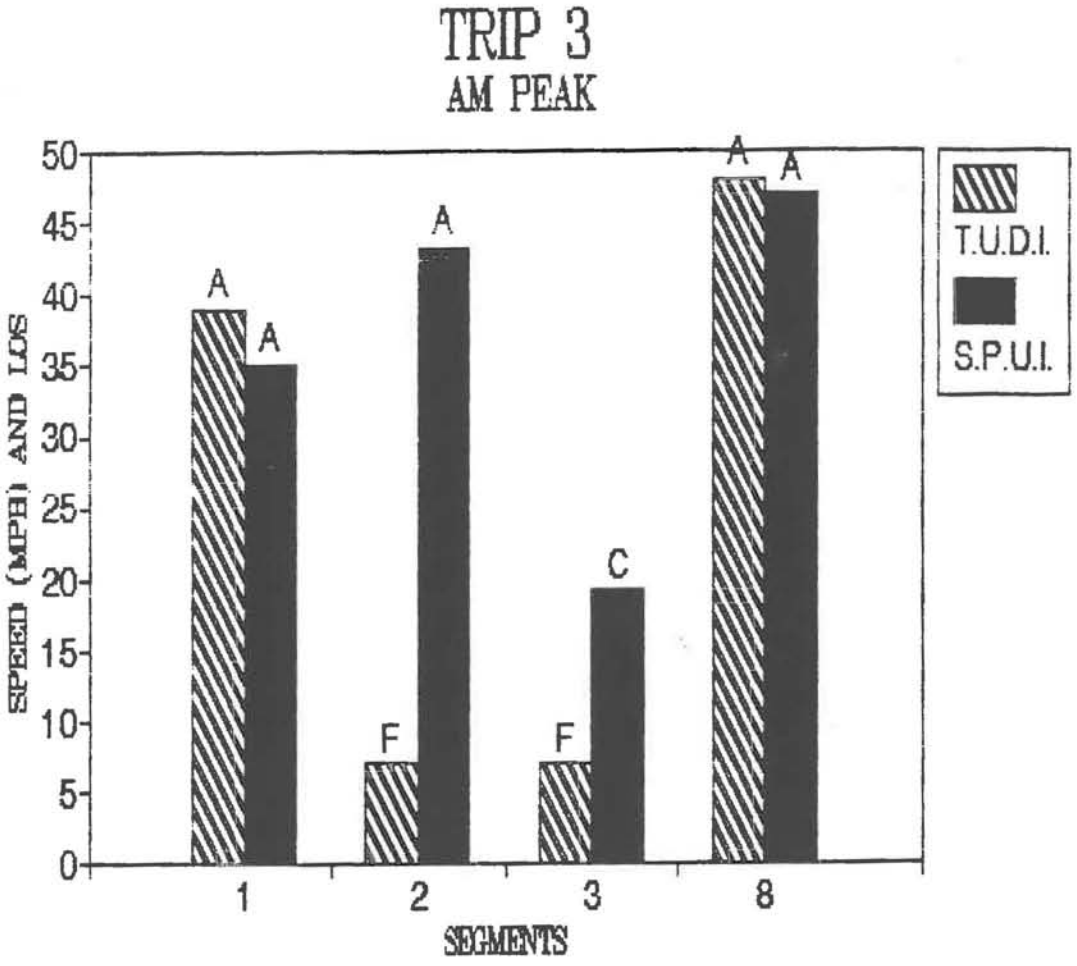


FIGURE 6.9
Arterial LOS
Garden of the Gods

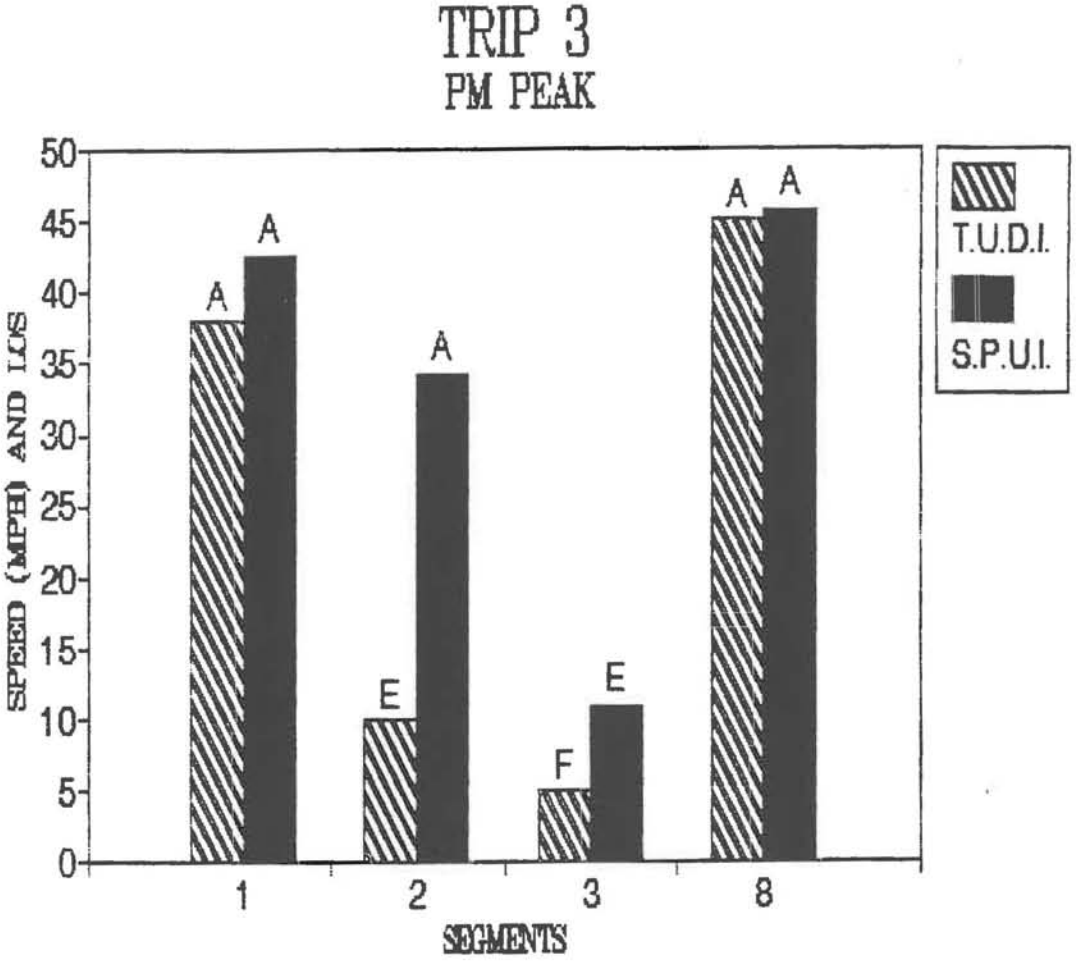


FIGURE 6.10

Arterial LOS

Garden of the Gods

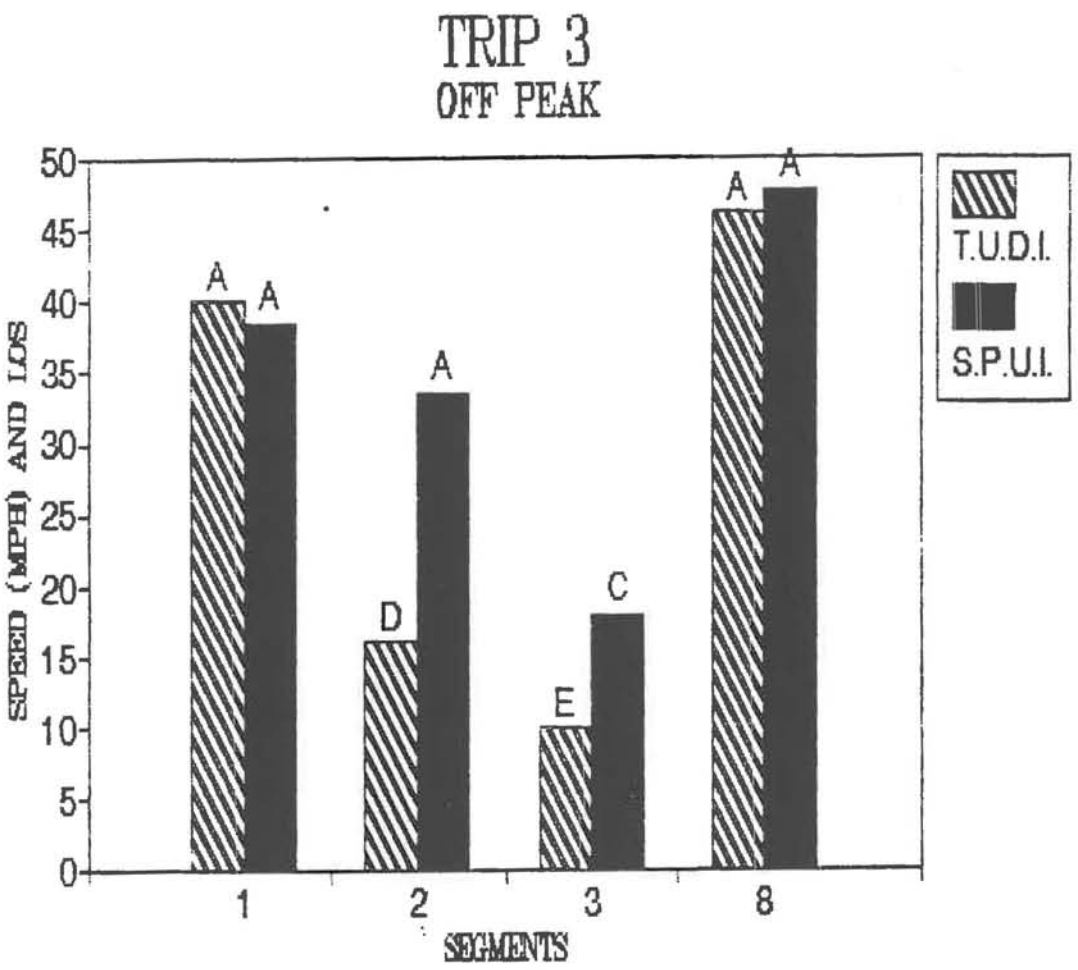


TABLE 6.4

TRIP 4-ARTERIAL LOS COMPARISON
GARDEN OF THE GODS

BEFORE			AFTER		
SEGMENT	OFF PEAK SPEED(MPH)	LOS	SEGMENT	OFF PEAK SPEED(MPH)	LOS
9	45	A	9	43	A
3	22	C	3	8.6	F
4	31	A	4	13.9	E
5	34	A	5	28.2	B
6	43	A	6	36.4	A
	AM PEAK			AM PEAK	
9	30	B	9	43.5	A
3	30	A	3	9.4	F
4	31	A	4	10.7	E
5	31	A	5	31.4	A
6	38	A	6	45.5	A
	PM PEAK			PM PEAK	
9	51	A	9	36.9	A
3	18	C	3	10.7	E
4	31	A	4	10.1	E
5	35	A	5	25.4	B
6	39	A	6	36.9	A

FIGURE 6.11

Arterial LOS

Garden of the Gods

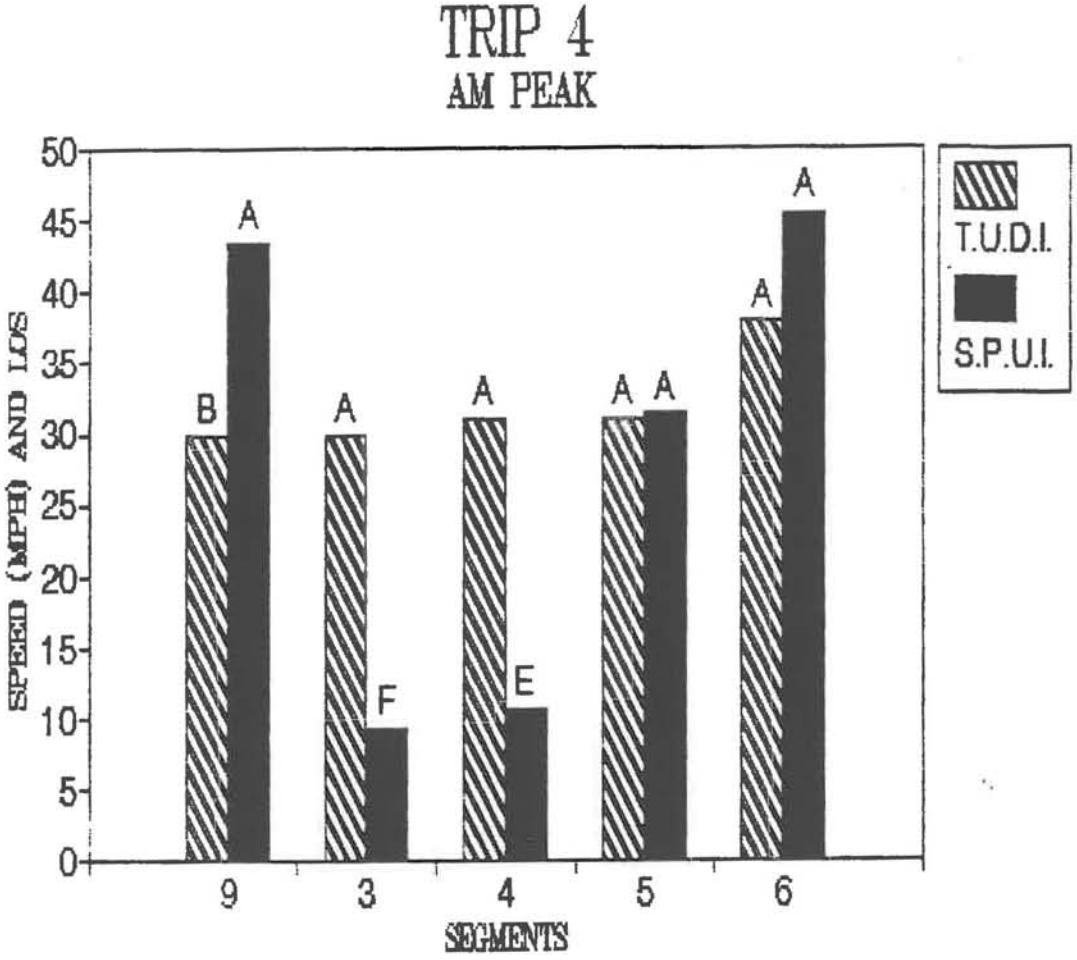


FIGURE 6.12

Arterial LOS

Garden of the Gods

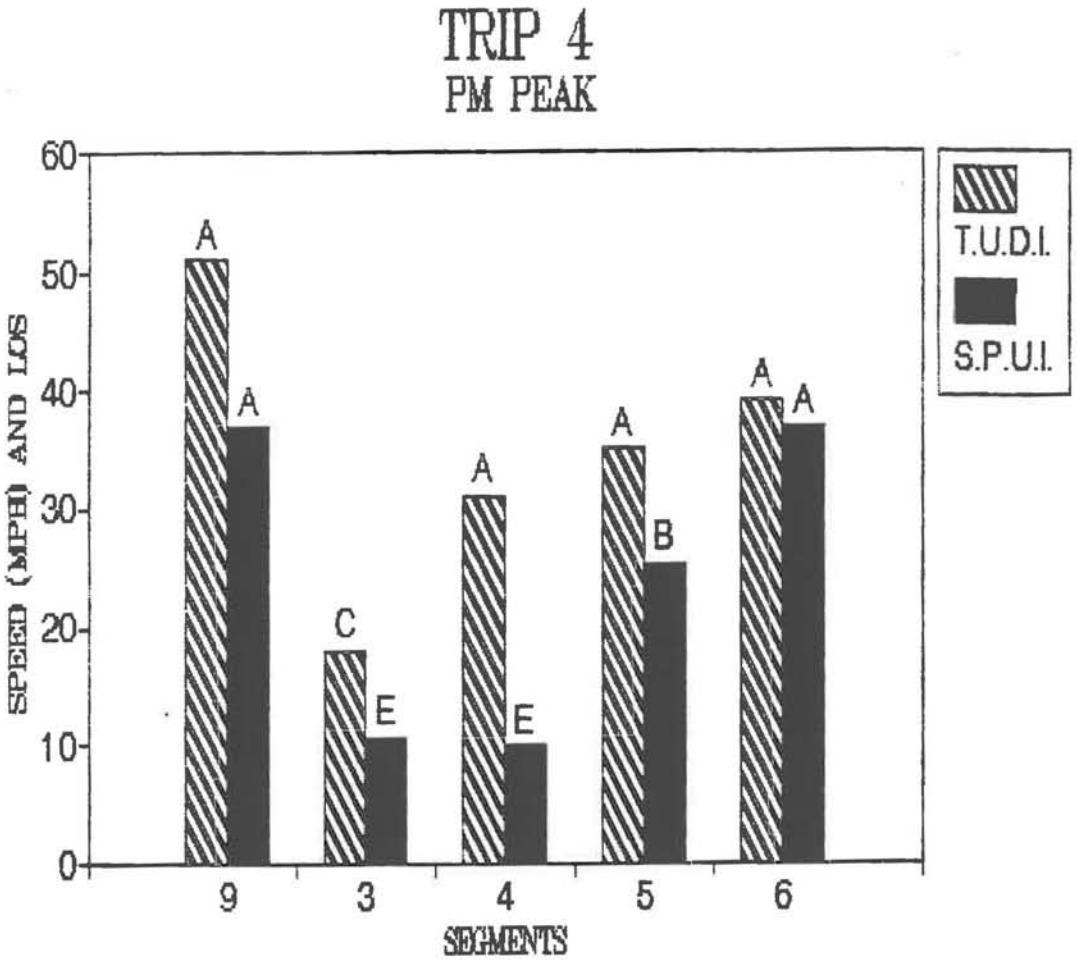


FIGURE 6.13

Arterial LOS

Garden of the Gods

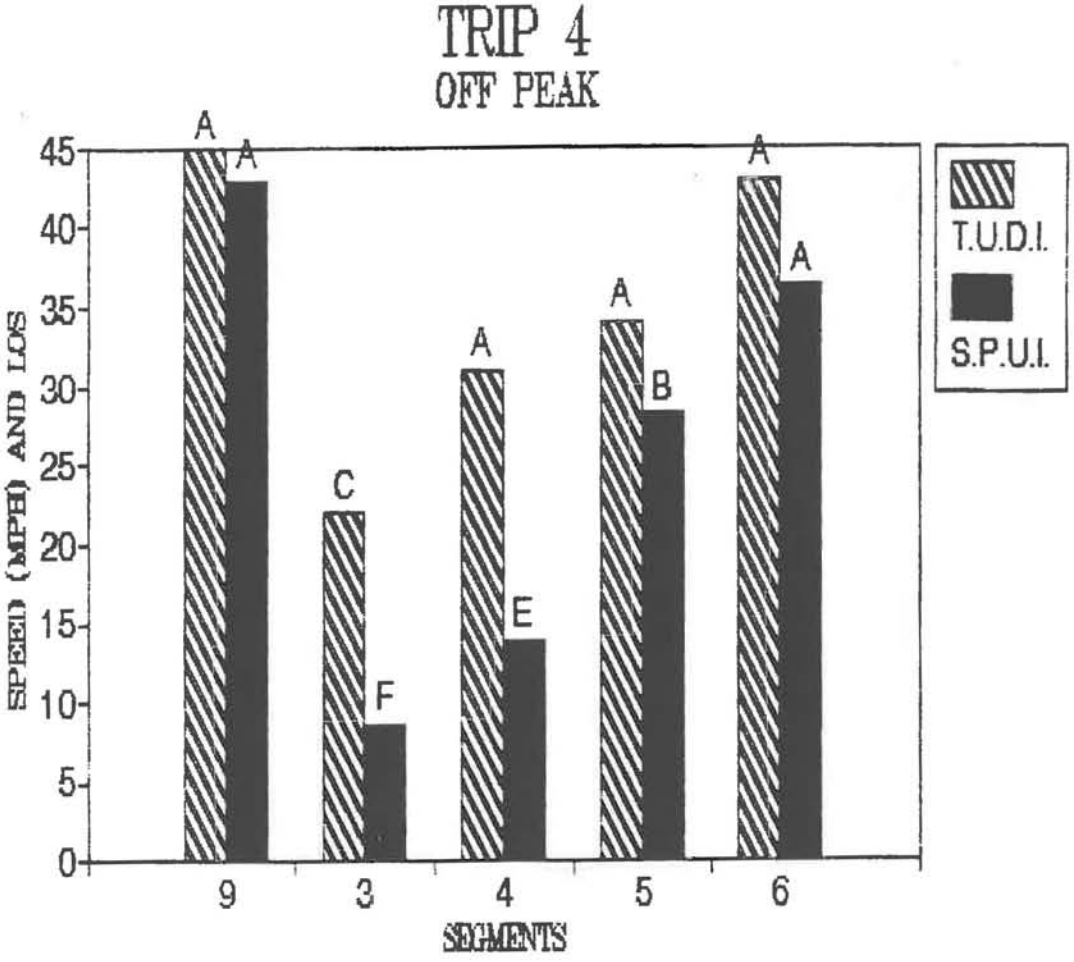


TABLE 6.5

TRIP 5-ARTERIAL LOS COMPARISON
GARDEN OF THE GODS

BEFORE			AFTER		
SEGMENT	OFF PEAK SPEED(MPH)	LOS	SEGMENT	OFF PEAK SPEED(MPH)	LOS
6	39	A	6	39.2	A
5	37	A	5	33.8	A
4	19	C	4	31.6	A
3	38	A	3	27.9	C
2	24	B	2	28.2	B
1	43	A	1	41.9	A
	AM PEAK			AM PEAK	
6	27	B	6	36.2	A
5	35	A	5	43	A
4	21	C	4	21	C
3	34	A	3	41	A
2	23	C	2	26	C
1	36	A	1	39	A
	PM PEAK			PM PEAK	
6	35	A	6	23.7	C
5	28	B	5	38.2	A
4	22	C	4	40.3	A
3	30	A	3	42.7	A
2	28	B	2	20.4	C
1	47	A	1	45.5	A

FIGURE 6.14

Arterial LOS
Garden of the Gods

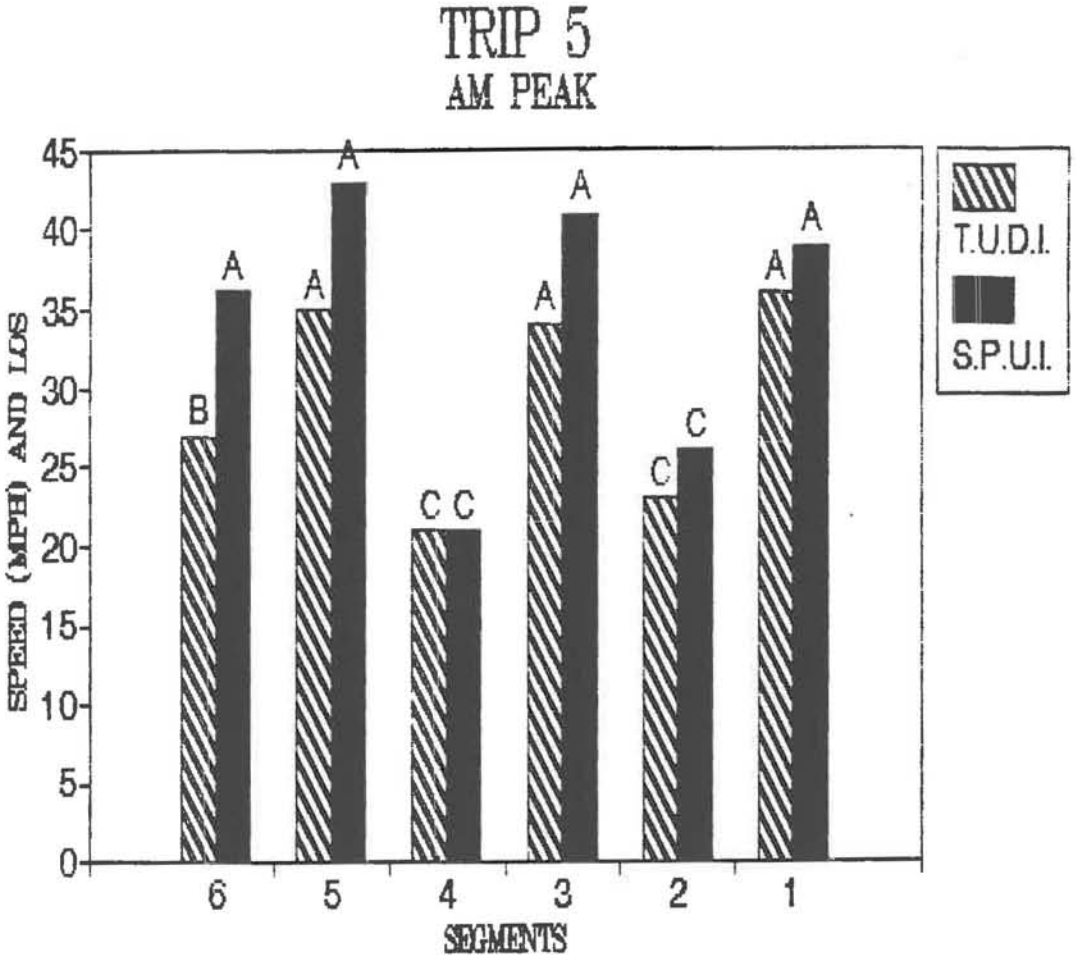


FIGURE 6.15

Arterial LOS

Garden of the Gods

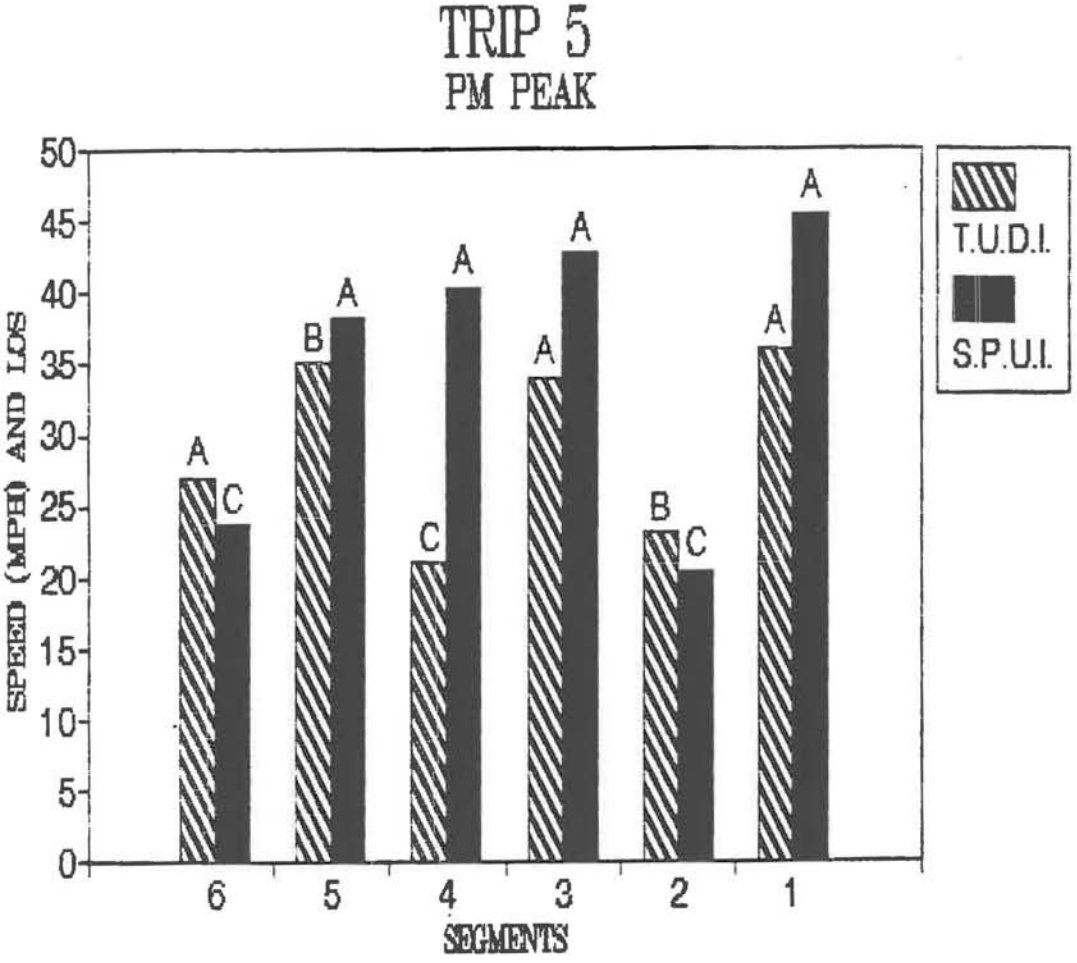


FIGURE 6.16

Arterial LOS

Garden of the Gods

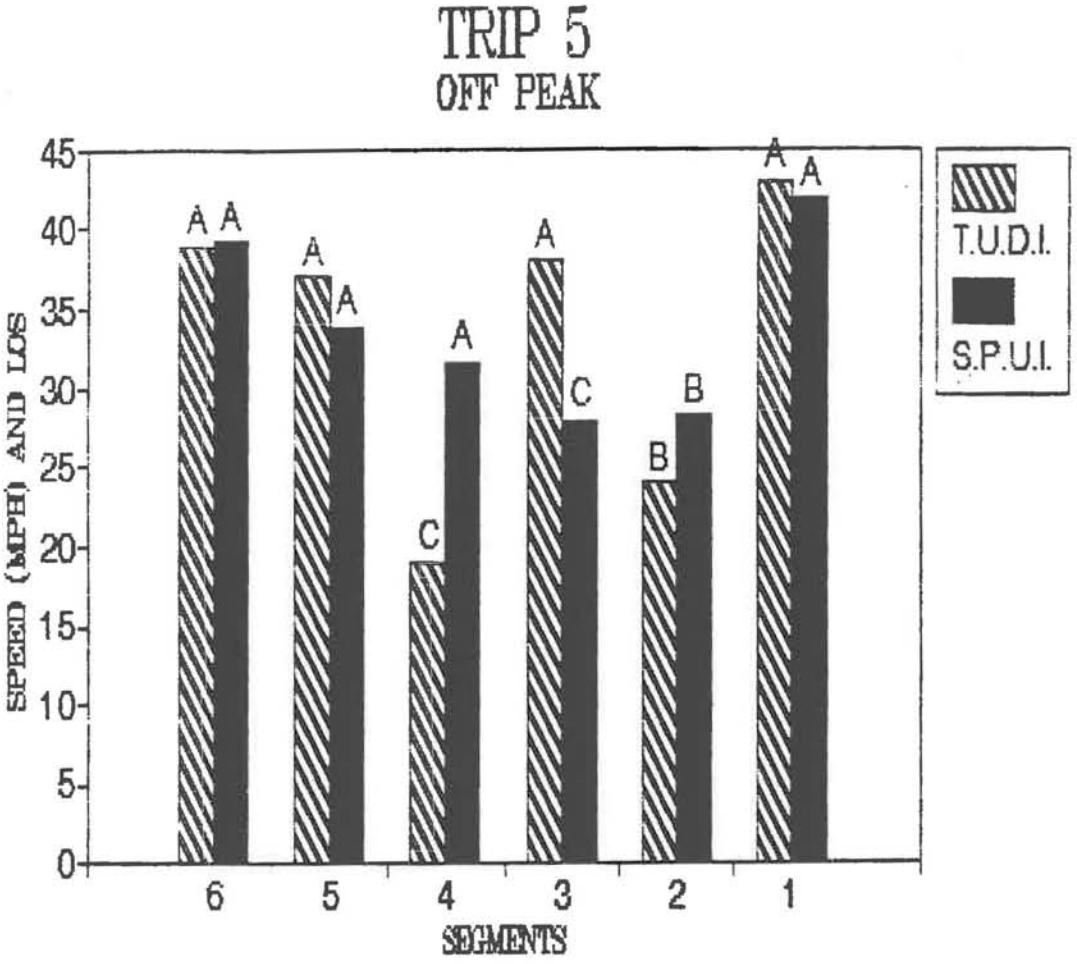


TABLE 6.6

TRIP 6-ARTERIAL LOS COMPARISON
GARDEN OF THE GODS

BEFORE			AFTER		
SEGMENT	OFF PEAK SPEED(MPH)	LOS	SEGMENT	OFF PEAK SPEED(MPH)	LOS
1	40	A	1	35.6	A
2	15	D	2	39.2	A
3	25	B	3	34.6	A
4	27	B	4	33.9	A
5	34	A	5	35.1	A
6	39	A	6	36	A
	AM PEAK			AM PEAK	
1	37	A	1	38.9	A
2	6	F	2	41	A
3	34	A	3	9.2	F
4	34	A	4	35.2	A
5	26	B	5	46.6	A
6	39	A	6	42.6	A
	PM PEAK			PM PEAK	
1	25	B	1	35.5	A
2	6	F	2	40.2	A
3	26	B	3	28.5	B
4	31	A	4	33.9	A
5	22	C	5	39.9	A
6	40	A	6	39.9	A

FIGURE 6.17

Arterial LOS

Garden of the Gods

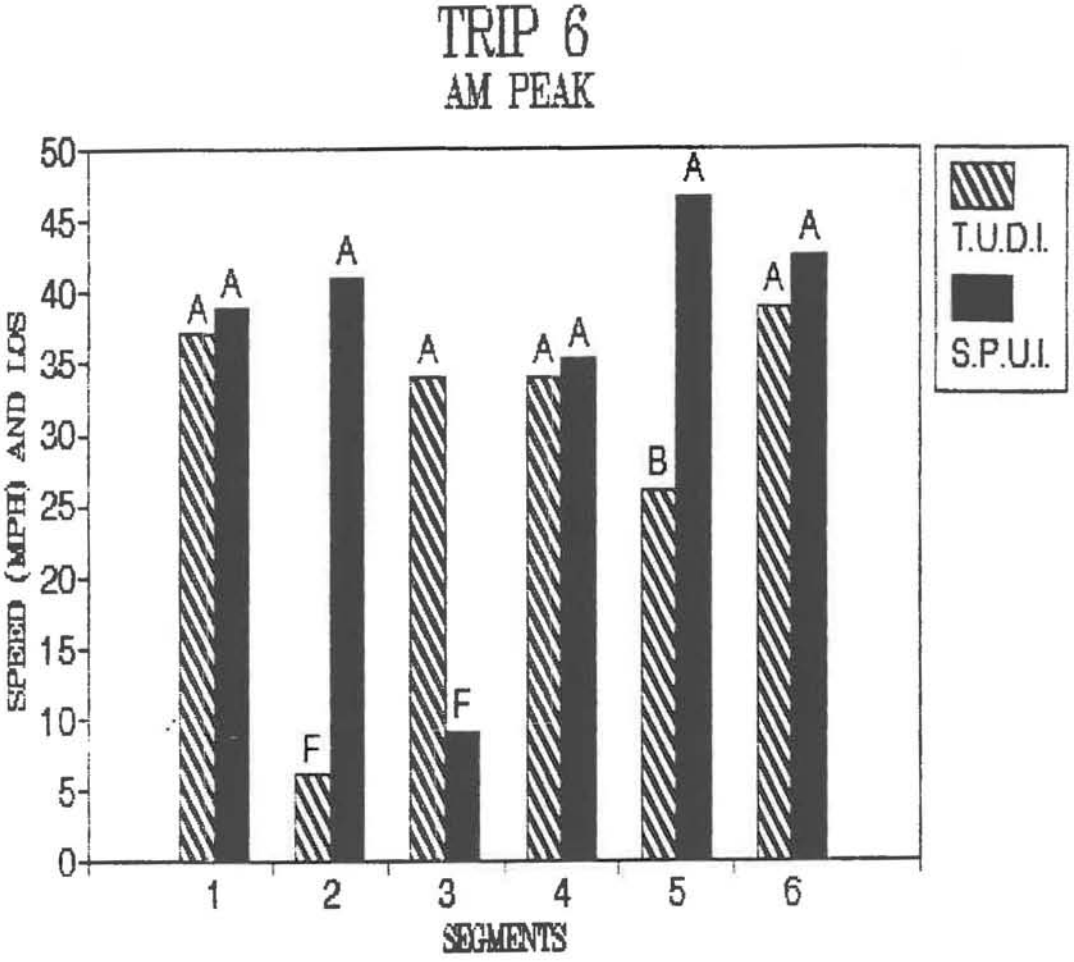


FIGURE 6.18

Arterial LOS

Garden of the Gods

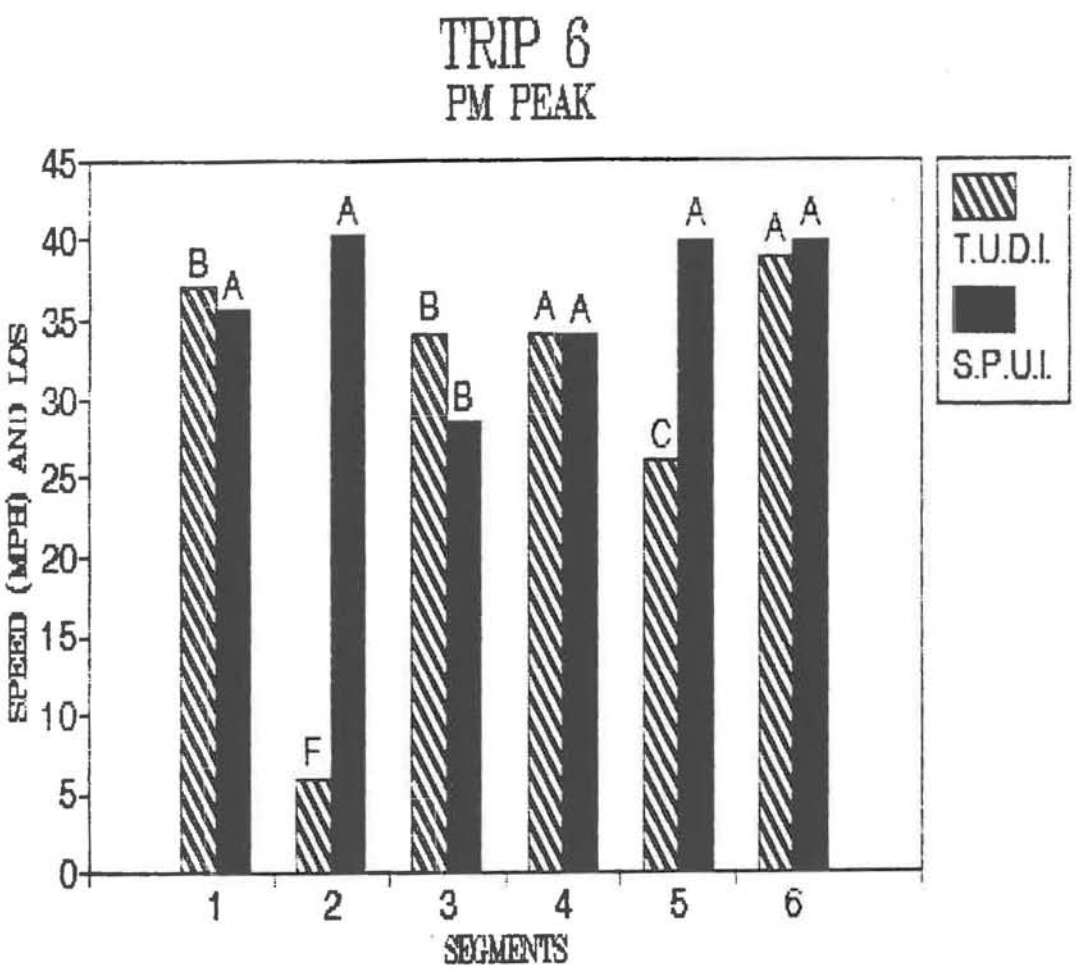


FIGURE 6.19

Arterial LOS

Garden of the Gods

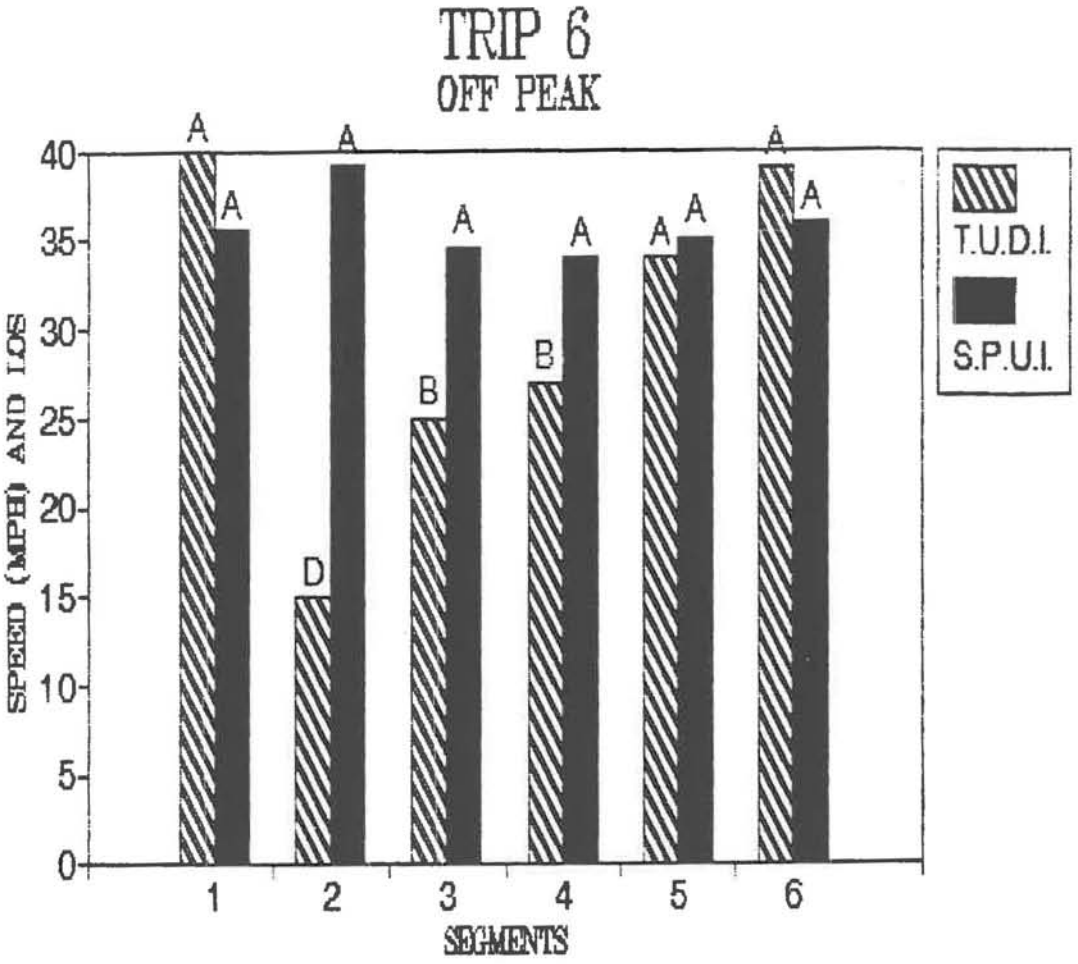


TABLE 6.7

TRIP 7-ARTERIAL LOS COMPARISON
GARDEN OF THE GODS

BEFORE			AFTER		
SEGMENT	OFF PEAK SPEED(MPH)	LOS	SEGMENT	OFF PEAK SPEED(MPH)	LOS
6	39	A	6	34	A
5	35	A	5	40.5	A
4	12	D	4	24	B
3	13	D	3	18	C
10	54	A	10	49	A
	AM PEAK			AM PEAK	
6	27	B	6	35	A
5	37	A	5	39	A
4	18	C	4	36	A
3	20	C	3	18	C
10	54	A	10	42	A
	PM PEAK			PM PEAK	
6	23	C	6	30	A
5	35	A	5	43	A
4	17	D	4	35	A
3	14	D	3	5	F
10	46	A	10	50	A

FIGURE 6.20

Arterial LOS

Garden of the Gods

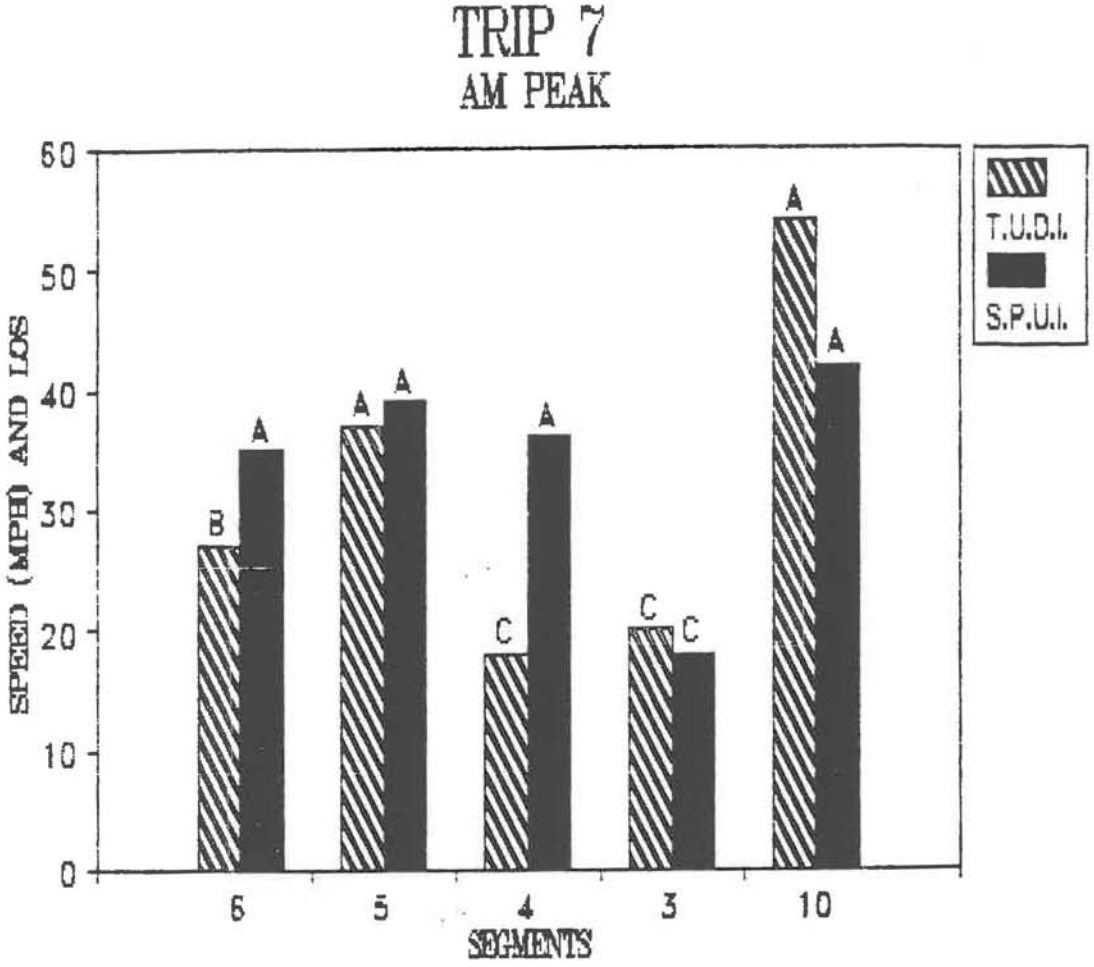


FIGURE 6.21

Arterial LOS

Garden of the Gods

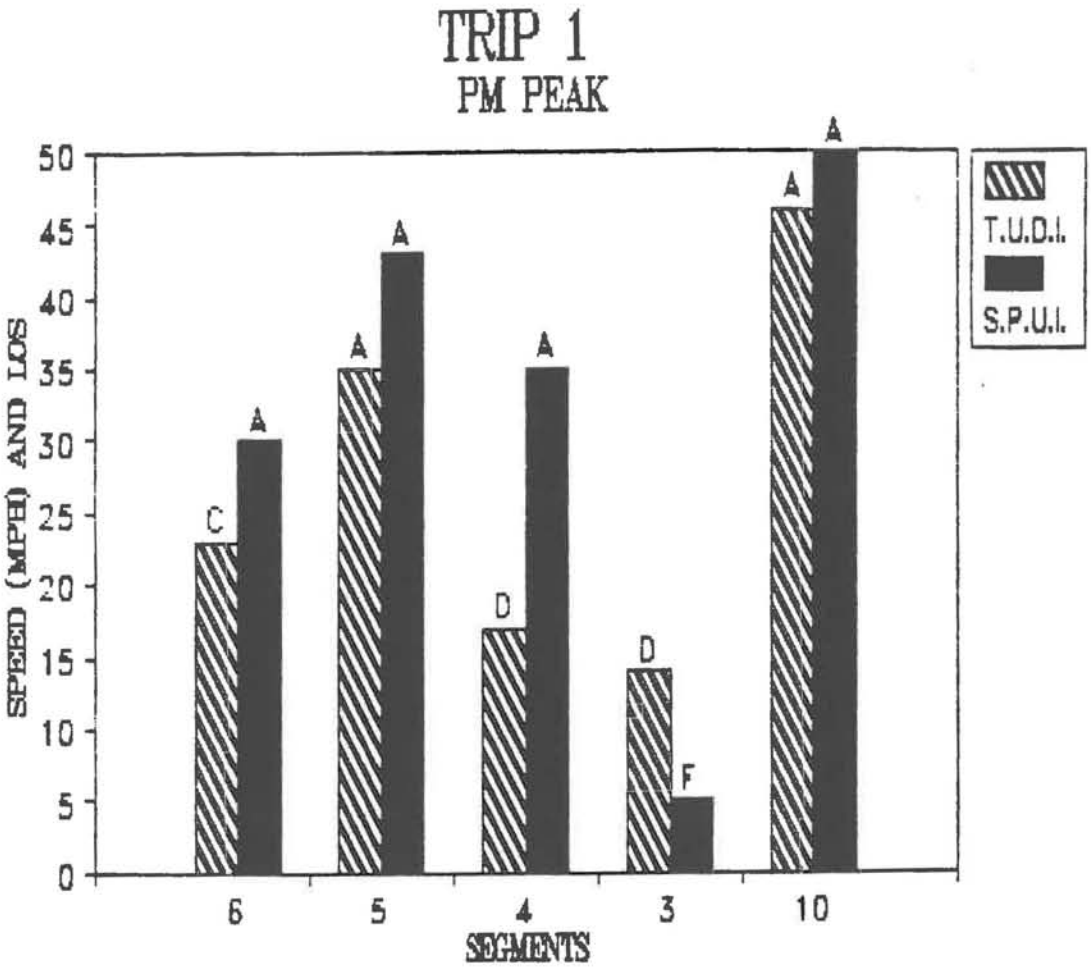


FIGURE 6.22

Arterial LOS

Garden of the Gods