MOBILE SOURCE EMISSION INVENTORY

CALIFORNIA AIR RESOURCES BOARD

CONTRACT NOS. ARB 4-956 & ARB 5-434

MARCH 1977

Prepared by:

OLSON LABORATORIES, INC.
An Envirodyne Company

421 E. Cerritos Avenue • Anaheim, California 92805

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ABSTRACT

This final report documents the methodology and results of the Mobile Source Emission Inventory Project performed by Olson Laboratories, Inc., for the California Air Resources Board under Contract Nos. ARB 4-956 and ARB 5-434. The objectives of this project included characterization of driving patterns of light-duty passenger cars throughout California's South Coast Air Basin (SCAB), development of driving cycles, and the estimation and measurement of emissions from pre-catalyst vehicles. Exhaust C_1 to C_{10} hydrocarbon composition was also determined for 10 vehicles driven on the EPA Surveillance Schedule and 15 vehicles driven on the composite derived driving cycle.

An instrumented chase vehicle was used to emulate and record driving patterns. Nine routes were selected which provided various freeway and nonfreeway driving conditions. The routes were driven on different days of the week and time of day. The recorded driving pattern data were subsequently computer processed to derive matrices of mode frequency and time-in-mode. Average speeds and mode frequency were similar to previous data obtained in the CRC-APRAC-CAPE-10 Vehicle Operation Survey (VOS) conducted in 1970. However, considerably more time was spent in cruise modes in the current study than in the VOS.

Based on the driving pattern data, driving cycles were developed. One statistically representative cycle was chosen for each of freeway, nonfreeway and composite driving. The driving cycles were plotted and emissions measured from 15 vehicles using the composite cycle. Emissions were also estimated for all three cycles using EPA computer programs and modal emission data bases. Measured emissions agreed well with the estimated emissions. Over 2,000 driving

cycles were selected which, while not statistically representative, provided a range of average speeds. Emission factors for the range of speeds were calculated using the EPA program and data bases for each route and season. This data was transmitted to TRW for use in calculating speed correction factors.

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Section 1

SUMMARY

This report documents the methodology and results of the Mobile Source Emission Inventory Project performed for the California Air Resources Board under Contract Nos. ARB 4-956 and ARB 5-434. This project involved the use of an instrumented chase vehicle to emulate and record the driving patterns of light-duty vehicles on various roads and highways in the South Coast Air Basin (SCAB). The recorded driving pattern data were subsequently computer processed to derive matrices of mode frequency and time-in-mode. Based on these matrices, a Monte Carlo simulation model was used to generate driving cycles. A driving cycle statistically representative of composite freeway and nonfreeway driving in the SCAB (SCAB cycle) was then used to test the emissions of 15 vehicles on a chassis dynamometer. Emission factors were also estimated using an EPA computer program for driving cycles with various average speeds. A set of magnetic tapes containing edited data, initial speed versus delta speed matrices, and punched cards with estimated emission factors and average speeds for cycles generated over a range of average speeds were provided to the TRW Environmental Engineering Division.

This section contains a summary of major findings, study objectives, chase vehicle operations, and vehicle emissions by route and driving cycle. Section 2 describes the chase vehicle Digital Data Acquisition System and the routes selected for on-the-road data acquisition. Section 3 describes the analysis of the chase vehicle data, development of driving cycles, and estimation and measurement of emission factors based on the derived driving cycles. Additional supporting information is presented in the appendices.

1.1 SUMMARY OF MAJOR FINDINGS

The following major findings resulted from this study:

- Average driving patterns in the SCAB included more time spent in cruise (52 percent versus 34 percent) and less time spent in acceleration/deceleration (37 percent versus 55 percent) than were shown in the original CRC-APRAC-CAPE-10 Vehicle Operation Survey (VOS) conducted in 1970 (Ref. 1, 2, 3). The frequencies of mode occurrence, however, were similar for the VOS and for this study.

- Average nonfreeway driving patterns in the SCAB exhibited less time spent in idle (14 percent versus 18 percent), acceleration (25 percent versus 28 percent), and deceleration (21 percent versus 24 percent) but more time spent in cruise (40 percent versus 30 percent) than the LA-4 driving cycle. Average driving patterns which included both freeway and nonfreeway operation accentuated these differences. However, differences in frequency of mode occurrence were small (±1-4 percent).

- Average speed in the SCAB (31 mph) was similar to the average speed shown in the VOS (29 mph) but was substantially higher than shown in the LA-4 cycle (20 mph).

- Seasonal (i.e., winter and spring) variations in driving patterns were not significant.

- Three statistically representative driving cycles (freeway, nonfreeway, and composite) were developed from the SCAB driving pattern data. These cycles were 17.7 miles, 8.5 miles, and 10.5 miles in length, respectively. The average speeds of the cycles were 51 mph, 24 mph, and 31 mph, respectively. Each cycle was approximately 20 minutes in duration.

- Concentrations of individual species in diluted exhaust were highly variable and did not relate clearly to type of vehicle or control system. Total identifiable C_1 to C_{10} hydrocarbon concentration ranged from 0.64 to 130 mg/m^3 or 0.69 ppm to 141 ppm by mass. This compares to a range of 113 ppmC to 430 ppmC by volume for total hydrocarbons in the diluted exhaust measured using a standard flame ionization detector. The SCAB driving cycle produced a larger fraction of parafinic hydrocarbon emissions than the EPA Surveillance Cycle.

- The composite SCAB driving cycle tended to produce higher mass emissions of HC and CO, but similar mass emissions of NO_x compared to the EPA Surveillance Driving Schedule.

- Using the composite SCAB driving cycle, the estimated emissions agreed well with the measured emissions. The estimated emissions of all three pollutants were within the 95 percent confidence intervals of the measured emissions for the 15 vehicle fleet. The estimated emissions were generally within ±10 percent of the measured emissions.

1.2 STUDY OBJECTIVES

The objectives of the study included the following:

- Record driving characteristics in the SCAB as a function of route, type of road, day of week, time of day, and season.

- Characterize driving patterns in the SCAB by operating mode, time-in-mode, mode frequency and initial speed versus delta speed.

- Derive chassis dynamometer driving cycles representative of driving patterns in the SCAB (the SCAB cycles).

- Determine emission factors from 15 vehicles operated on a chassis dynamometer to follow a representative composite SCAB cycle.

- Calculate estimated emission factors from EPA modal emission data and the individual modes of each representative driving cycle.

- Determine specific C_1 to C_{10} hydrocarbon emissions from 25 vehicles.

- Provide matrices of initial speed versus delta speed for each route, time of day, and season, and estimated emission factors as a function of average cycle speed to TRW.

1.3 STUDY SCOPE

The scope of the study included the following:

- Instrument one chase vehicle to acquire in-use driving pattern data for light-duty vehicles.

- Collect data by pursuing vehicles with the chase vehicle under various traffic conditions over two road design types classified as either freeway or nonfreeway.

- Process the collected data to obtain matrices of average time-in-mode, total time-in-mode, mode frequency of occurrence, transition probability and initial speed versus delta speed for the two road design types, nine routes, winter and spring seasons, time of day, and day of week.

- Process the collected data to obtain approximately 500 driving cycles for each of nine freeway and nine nonfreeway routes for the winter and spring samples. Select from these driving cycles, ten cycles with various average speeds. Calculate emissions from six EPA modal emission data bases applicable to California vehicles for each cycle and provide to TRW.

- Process the collected data to obtain ten driving cycles statistically representative of all freeway, all nonfreeway and all composite SCAB driving patterns. Select a representative cycle of each type and estimate emissions from 18 EPA modal emission data bases.

- Measure the mass emissions from 15 vehicles driven over the selected composite SCAB driving cycle.

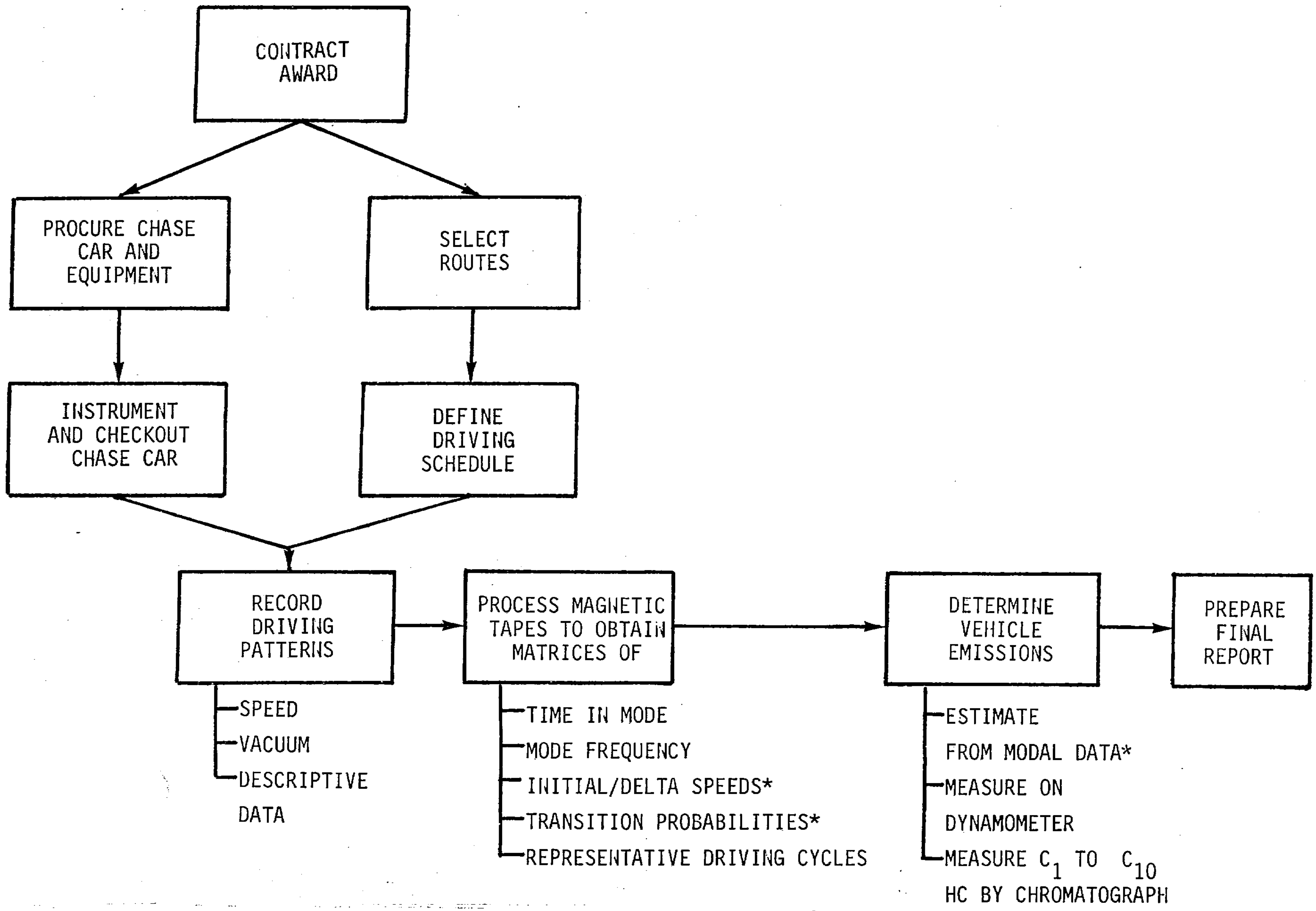
- Measure C_1 to C_{10} hydrocarbons using gas chromatography to determine diluted exhaust hydrocarbon composition from 25 vehicles.

Figure 1-1 summarizes the tasks of this study.

1.4 CHASE VEHICLE INSTRUMENTATION AND OPERATION

The chase vehicle was a 1975 Ford station wagon equipped with a 460 CID engine to ensure adequate acceleration capability. A station wagon was selected to provide sufficient storage and load capacity to hold all required equipment. Supplementary power was supplied by a battery pack, second alternator, inverter, and voltage regulator.

The chase vehicle was equipped with a Digital Data Acquisition System (DDAS) similar to the system used on the CRC-APRAC-CAPE-10 Vehicle Operations Survey (VOS) (Ref. 1). The data acquisition system provided IBM-compatible tapes containing data which was accumulated and recorded once each



*Delivered to TRW Transportation and Environmental Engineering Operations for use in Mobile Source Emission Inventory, Contract No. ARB 4-1236. Modal emission data applicable to California vehicle were available in only six data bases at time of delivery to TRW.

Figure 1-1. MOBILE SOURCE EMISSION INVENTORY PROJECT - CONTRACT NO. ARB 4-956 AND ARB 5-434 second for vehicle speed and manifold vacuum. In addition to the continuously varying data, the following descriptive information was recorded once per second from thumbwheel switches:

- day-of-year
- time-of-day in hours, minutes, and seconds
- car-chased code (make)
- weather code
- road-type code
- route-identification code
- traffic-condition code
- traffic-density code

Detailed description of the chase vehicle and its operation are presented in Section 2.1.

1.5 CHASE ROUTES AND DRIVING PATTERNS

Data on typical driving patterns were collected using the instrumented chase vehicle. Data were collected during two separate 6-week periods in the winter and spring of 1975-1976. Nine routes were designed to cover principal traffic flows in the SCAB. Each route was then divided into four segments: two freeway segments and two nonfreeway segments. Routes were constructed so that the same route was driven at different times of day and on different days of the week.

A total of 480 hours of chase vehicle operation was performed. From these data, over 35,000 driving cycles were generated and filtered to yield ten representative cycles each for freeway, nonfreeway, and combined operation. One cycle of each type was selected and plotted. Eighteen thousand cycles were generated but not filtered to provide a variety of cycles for each route, road type and season. The specific chase vehicle routes are described more fully in Section 2.2. The procedures used to process the vehicle operation data and generate driving cycles are described in Sections 3.1 and 3.2, respectively. Table 1-1 summarizes observed driving patterns and several key parameters of the derived cycles.

1.6 VEHICLE EMISSIONS

Coefficients relating emissions to average speed which had been derived (Ref. 6) from EPA Emission Factor and Surveillance test program data were used to estimate emissions for driving cycles generated from chase vehicle data. Estimated emissions by route, season, and average speed were provided to TRW and are shown in Appendix E. Actual CVS emission data for a statistically representative composite SCAB cycle were collected from 15 vehicles operated on the chassis dynamometer. These data included HC, CO, and NO_x emissions in grams per mile and fuel consumption in miles per gallon. The actual emission data were compared to the calculated emission data to validate the estimated emission factors. Table 1-2 summarizes the actual and estimated average emissions of the 15 vehicles for HC, CO, NO_x and fuel economy. As can be seen, the estimated emissions generally were within ±10 percent of the measured emissions and always were within the 95 percent confidence intervals about the measured emissions.

In addition to tests with the composite SCAB driving cycle, tests early in the program were performed using the EPA Surveillance Driving Schedule. These tests were performed to determine exhaust hydrocarbon composition and to characterize the test fleet's emissions with respect to surveillance data. Table 1-3 summarizes the difference

Table 1-1. SUMMARY OF DRIVING PATTERNS IN THE SOUTH COAST AIR BASIN

CHARACTERISTIC	FREEWAY	NONFREEWAY	COMPOSITE	LA VOS[1]	LA-4 CYCLE[2]	EPA SURVEILLANCE[3]
Mode Occurrence						
Idle (%)	1.73	9.30	8.20	7.60	12.0	13.04
Cruise (%)	59.09	41.96	44.45	42.40	38.0	36.23
Acceleration (%)	18.64	24.78	23.89	25.04	26.7	26.09
Deceleration (%)	20.55	23.95	23.46	24.96	23.3	24.64
Time In Mode						
Idle (%)	0.79	14.17	10.74	10.13	18.2	10.25
Cruise (%)	87.89	40.17	52.42	34.28	30.2	40.51
Acceleration (%)	5.77	24.68	19.82	29.78	27.7	27.13
Deceleration (%)	5.55	20.98	17.02	25.82	23.9	22.11
Most Common Mode						
Cruise (mph)	55	35	35	1-30	-	-
Acceleration (mph)	50-55	0-35	0-35	30-35	-	-
Deceleration (mph)	55-50	35-0	35-0	35-30	-	-
Other Properties						
Average Speed (mph)	50.70*	24.48*	30.97*	29.3	19.6	33.43
Length (miles)	17.71	8.48	10.49	-	7.5	9.79
Stops Per Mile	0.06	1.18	0.67	-	2.4	0.92
Stops Per Cycle	1.00	10.00	7.00	-	18.0	9.00

*These cycles are plotted in Appendix C along with tables of speed versus time.

[1]References 1 and 3.

[2]Reference 2.

[3]Calculated from table of speed versus time for EPA Surveillance Cycle.

Table 1-2. COMPARISON OF MEASURED AND ESTIMATED EMISSION FACTORS USING THE COMPOSITE SCAB DRIVING CYCLE

MODEL YEAR	MEASURED EMISSIONS[1]					ESTIMATED EMISSIONS[2]			
	N	HC	CO	NO_x	MPG	HC	CO	NO_x	MPG
1955-1965	1	4.08	34.73	3.44	23.67	5.39	54.94	4.28	18.04
1972	5	1.86	19.38	4.92	18.64	2.24	21.02	5.06	18.18
1973-1974	9	2.13	21.37	4.33	19.52	2.05	18.73	3.45	16.31
1972-1974	14	2.13	20.66	4.54	18.68	2.12	19.55	4.03	16.98
All	15	2.16	21.60	4.47	19.02	2.34	21.91	4.05	17.05

[1]Measured mass emissions from hot start CVS tests using the composite freeway and nonfreeway SCAB driving cycle.

[2]Estimated mass emissions from modal emissions data bases weighted by time-in-mode from the composite SCAB driving cycle.

Table 1-3. COMPARISON OF HOT START MASS EMISSIONS USING EPA SURVEILLANCE DRIVING SCHEDULE AND COMPOSITE SCAB DRIVING CYCLE

TEST FLEET AND STATISTICAL PARAMETERS	EPA SURVEILLANCE CYCLE			COMPOSITE SCAB CYCLE		
	HC	CO	NO_x	HC	CO	NO_x
6 Vehicles Tested on Both Cycles						
Mean	1.39	13.01	4.93	2.26	18.76	4.82
Standard Deviation	0.44	4.99	2.13	0.74	6.51	1.54
Upper 95% Confidence Limit	1.85	18.25	7.16	3.04	25.59	6.44
Lower 95% Confidence Limit	0.93	7.77	2.70	1.48	11.93	3.20
15 Vehicles Tests on SCAB Cycle 10 Vehicles Tested on EPA Cycle						
Mean	1.37	17.22	4.42	2.16	21.60	4.47
Standard Deviation	0.34	7.91	1.81	0.81	9.35	1.78
Upper 95% Confidence Limit	1.61	22.88	5.71	2.61	26.78	5.46
Lower 95% Confidence Limit	1.13	11.56	3.13	1.71	16.42	3.48

between six vehicles which were tested on both the composite SCAB and the EPA Surveillance driving cycles. As shown in Table 1-3, the average emissions of HC and CO were higher for the composite SCAB driving cycle than for the EPA Surveillance Driving Cycle, although NO_x emissions were similar. Using a paired t-test for the six vehicles tested on both cycles, the differences in emissions of HC and CO were significant at the 95 percent level of confidence.

Gas chromatographic analyses of bag samples of the diluted exhaust were performed to characterize the concentrations of specific C_1 to C_{10} hydrocarbons. Table 1-4 presents the average hydrocarbon composition for the 15 vehicles tested on the composite SCAB driving cycle and the eight vehicles tested earlier on the EPA Surveillance Driving Schedule. In general, the SCAB cycle emissions showed significantly lower percentage of olefins and aromatics than did the EPA Surveillance Driving Schedule emissions. Since the ratio of olefins to aromatics was generally unchanged, the increased parafin fraction was attributable to higher parafinic mass emissions from vehicles operated on the SCAB cycle than on the EPA Surveillance Cycle. The reason for this shift was not identified.

Table 1-4. WEIGHT PERCENT COMPOSITION OF EXHAUST HYDROCARBONS FROM PRE-CATALYST VEHICLES

SPECIES		SCAB COMPOSITE CYCLE			EPA SURVEILLANCE CYCLE		
		MEAN[a]	95% CONFIDENCE LIMITS		MEAN[a]	95% CONFIDENCE LIMITS	
			Upper	Lower		Upper	Lower
C_1	Methane				3.17	3.97	2.37
C_2	Ethane/Acetylene	20.59[c]	25.53[c]	15.65[c]	11.06	14.36	7.76
C_3	Propylene	5.80	7.34	4.25	6.72	8.74	4.70
C_4	Isobutane	1.55	3.31	-0.21	2.81	4.63	0.99
C_4	Butane	4.76	7.88	1.65	0.65	1.56	-0.27
C_4	Isobutene	-	-	-	0.85	1.32	-0.38
C_4	Butene	8.62	10.79	6.45	2.57	4.03	1.11
C_5	Isopentane	8.52	10.49	6.55	4.04	5.10	2.97
C_5	Alkene	0.72	1.01	0.44	6.82	8.55	5.09
C_5	Alkane	-	-	-	0.27	0.50	0.04
C_5	Pentane	4.89	6.74	3.05	0.27	0.74	-0.20
C_6	Alkene	2.50	3.29	1.71	5.77	8.30	3.23
C_6	Alkane	-	-	-	3.15	5.24	1.05
C_6	Hexane	6.77	10.86	2.67	1.33	1.86	0.79
C_7	Alkene	2.07	2.67	1.47	3.34	4.76	1.92
C_7	Alkane	3.66	4.67	2.64	3.05	4.59	1.61
C_7	Heptane	1.76	2.64	0.89	-	-	-
C_8	Alkene	-	-	-	5.11	9.17	1.06
C_8	Alkane	5.54	9.39	1.68	3.15	6.38	0.09
C_8	Benzene	16.00	19.65	12.35	8.22	11.16	5.26
C_8	Octane	1.18	2.23	0.39	-	-	-
C_8	Xylene	1.41	2.68	0.14	1.00	1.74	0.46
C_9	Alkene	3.08	4.49	1.67	0.41	4.86	-4.04
C_9	Toluene	9.36	11.49	1.65	7.77	12.21	3.32
C_9	Aromatic	-	-	-	6.63	9.63	3.63
C_{10}	Ethylbenzene	0.90	1.66	0.13	15.04	26.29	3.78
C_{11}	Undecane	3.49	6.77	0.21	-	-	-
$C_{10}+$	Aromatic	1.32	9.53	-6.90	7.41	8.43	6.39
	Parafins	54.07	59.22	48.93	30.93	35.95	25.90
	Olefins	19.81	22.16	17.46	28.81	32.33	25.29
	Aromatics	26.16	31.34	20.97	40.34	45.53	35.16

[a] Fifteen vehicles tested on SCAB composite driving cycle.

[b] Eight vehicles tested on EPA Surveillance Driving Schedule.

[c] Analysis on these samples did not resolve C_1 from C_2 hydrocarbons.

Section 2

CHASE VEHICLE OPERATIONS

This section presents a detailed description of the chase vehicle and the routes used to characterize driving patterns in the South Coast Air Basin (SCAB). Separate paragraphs are devoted to the following topics:

- <u>Chase Vehicle</u>
  Vehicle Description
  Digital Data Acquisition System
  System Calibration and Checkout
  Driver and Observer Responsibilities

- <u>Chase Routes</u>
  Route Selection
  Route Description
  Chase Hours and Distribution

2.1. CHASE VEHICLE

2.1.1 Vehicle Description

The chase vehicle, shown in Figure 2-1, was a 1975 Ford station wagon equipped with heavy-duty suspension, air conditioning, 460 CID engine and automatic transmission. The vehicle was modified as follows to accommodate the instruments and Digital Data Acquisition System (DDAS):

Figure 2-1. INSTRUMENTED CHASE VEHICLE FOR ARB MOBILE SOURCE EMISSION INVENTORY

- Installed heavy-duty alternator to provide additional power (see Figure 2-2).

- Installed two 12-volt 60 amp-hr truck batteries to serve as primary power source to the inverter (see Figure 2-3).

- Installed 110 VAC inverter to supply line voltage to DDAS.

- Installed voltage regulator to provide clean power to DDAS.

- Installed DDAS remote control/display panel in dashboard in front of passenger seat (see Figure 2-4).

- Installed Viatron manifold vacuum transducer (see Figure 2-5).

- Installed tee in speedometer cable to drive rotary pulse generator in parallel with vehicle speedometer (see Figure 2-6).

2.1.2 Digital Data Acquisition System

The DDAS was purchased from Media III and was generally compatible with the CAPE-10 system. The DDAS specifications are shown in Table 2-1. Figure 2-7 presents the system block diagram of the DDAS and sensors. The DDAS consisted of three main units: the data acquisition unit, the remote control/display unit, and the digital magnetic recorder.

The data acquisition unit, shown in Figure 2-8, performed the following functions:

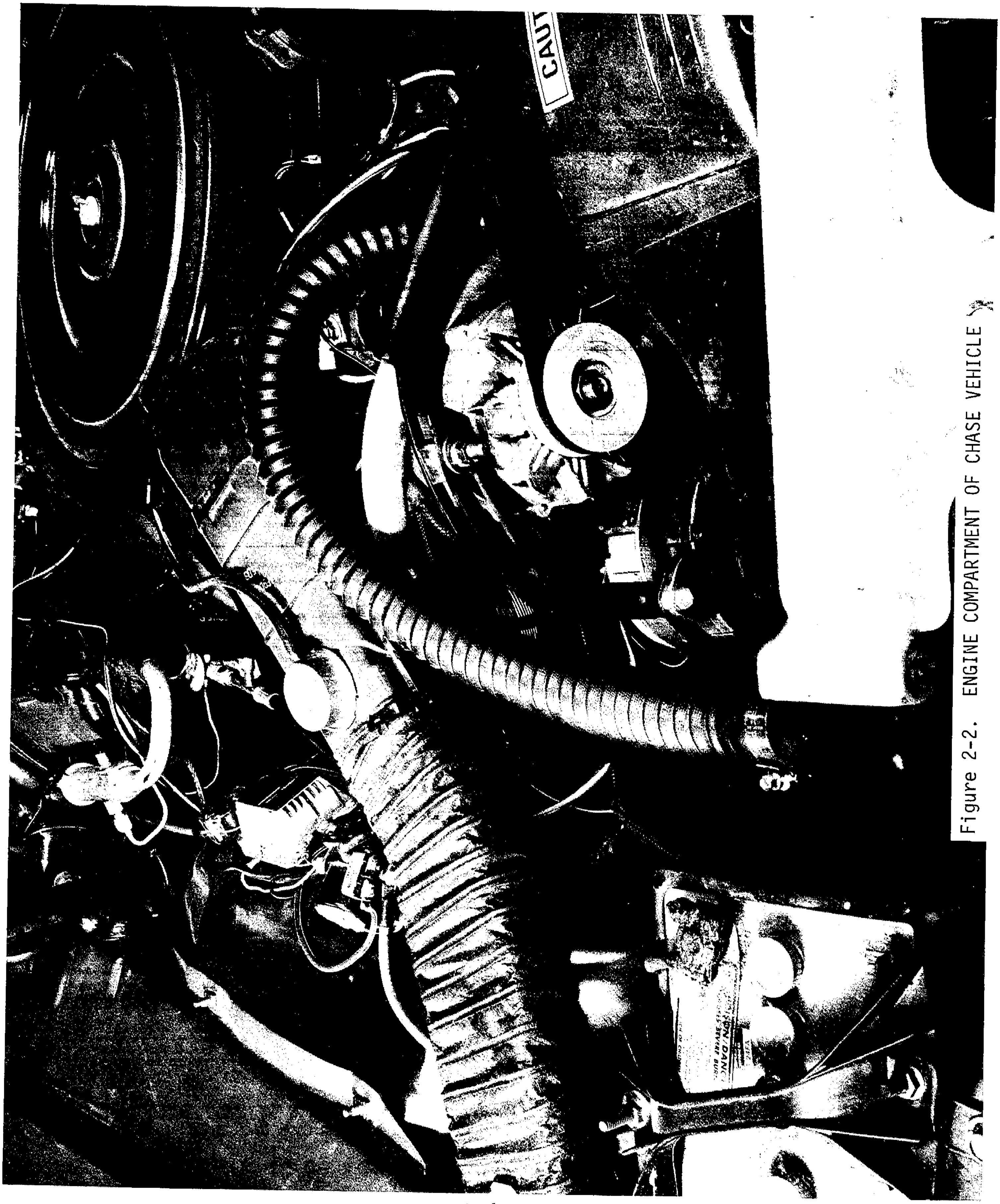


Figure 2-2. ENGINE COMPARTMENT OF CHASE VEHICLE

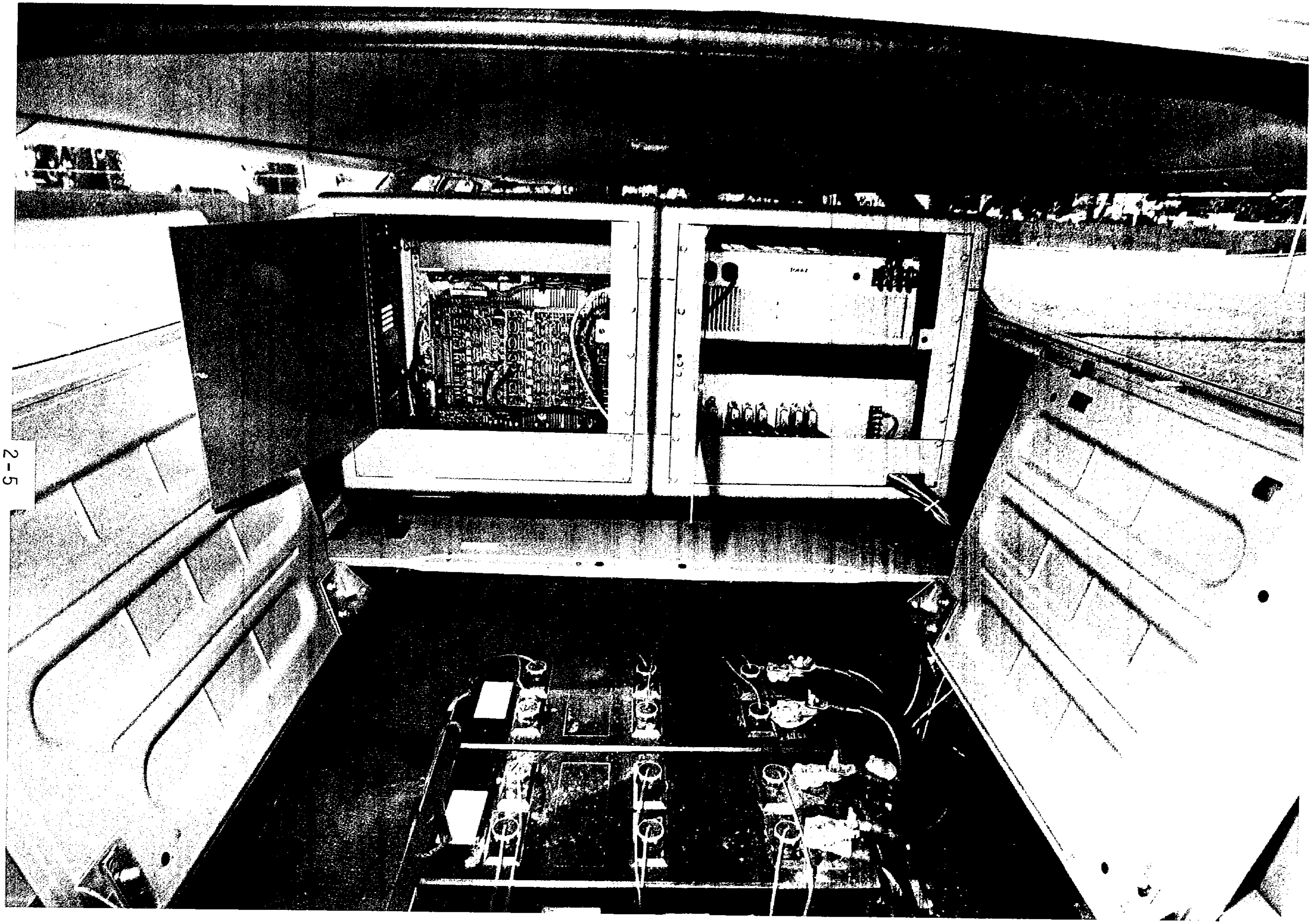


Figure 2-3. REAR VIEW OF CHASE VEHICLE SHOWING DATA ACQUISITION SYSTEM AND AUXILIARY BATTERIES

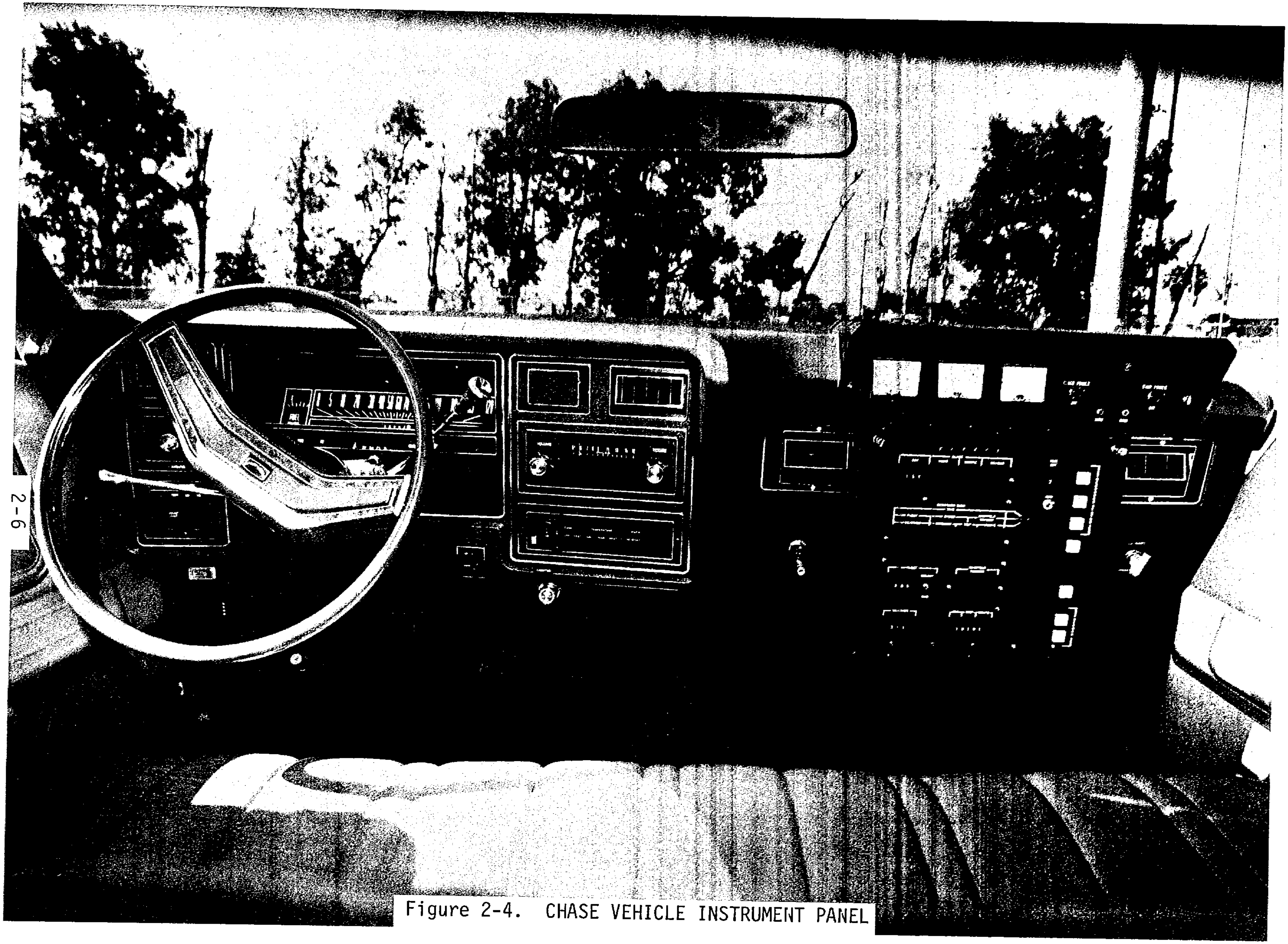


Figure 2-4. CHASE VEHICLE INSTRUMENT PANEL

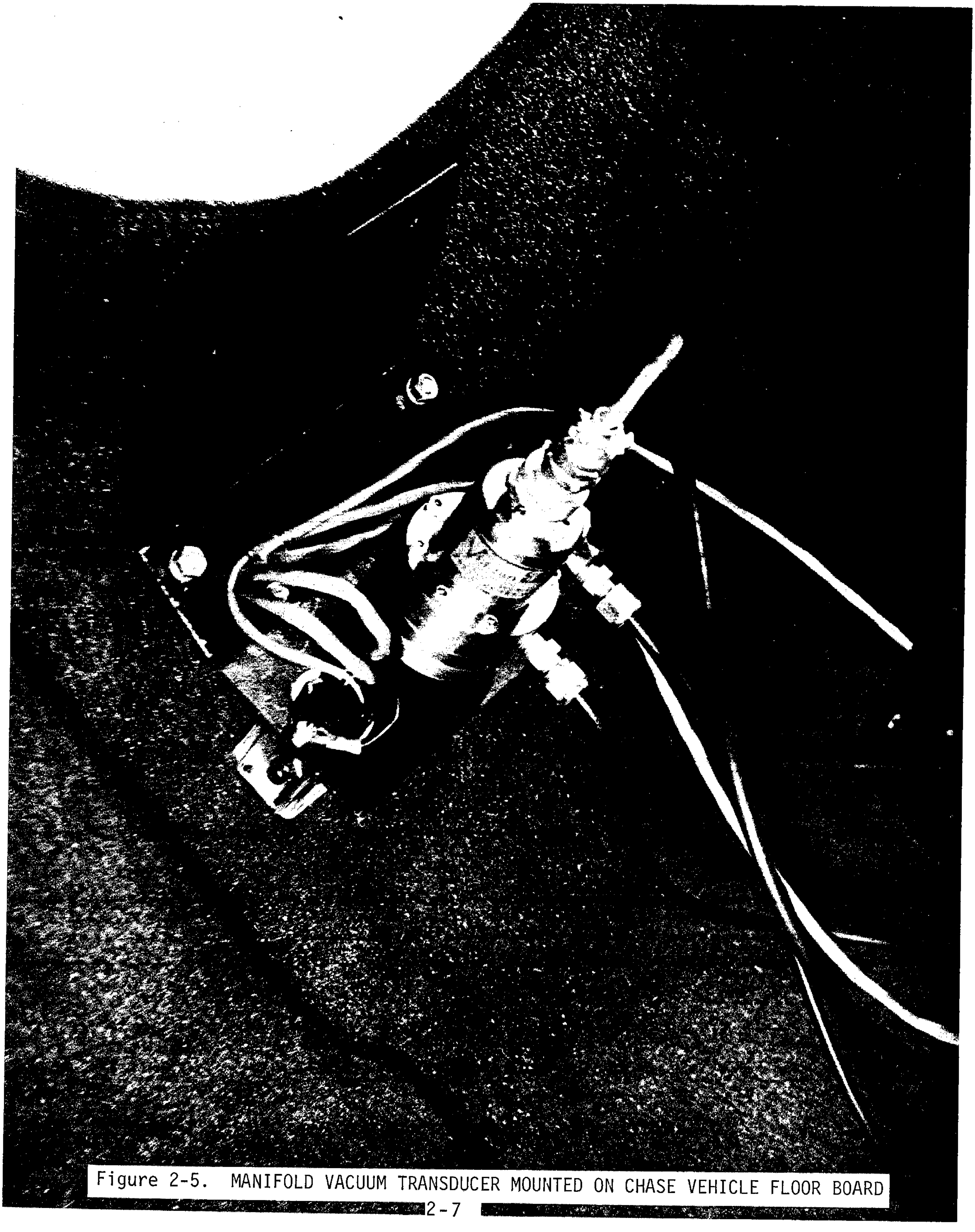


Figure 2-5. MANIFOLD VACUUM TRANSDUCER MOUNTED ON CHASE VEHICLE FLOOR BOARD

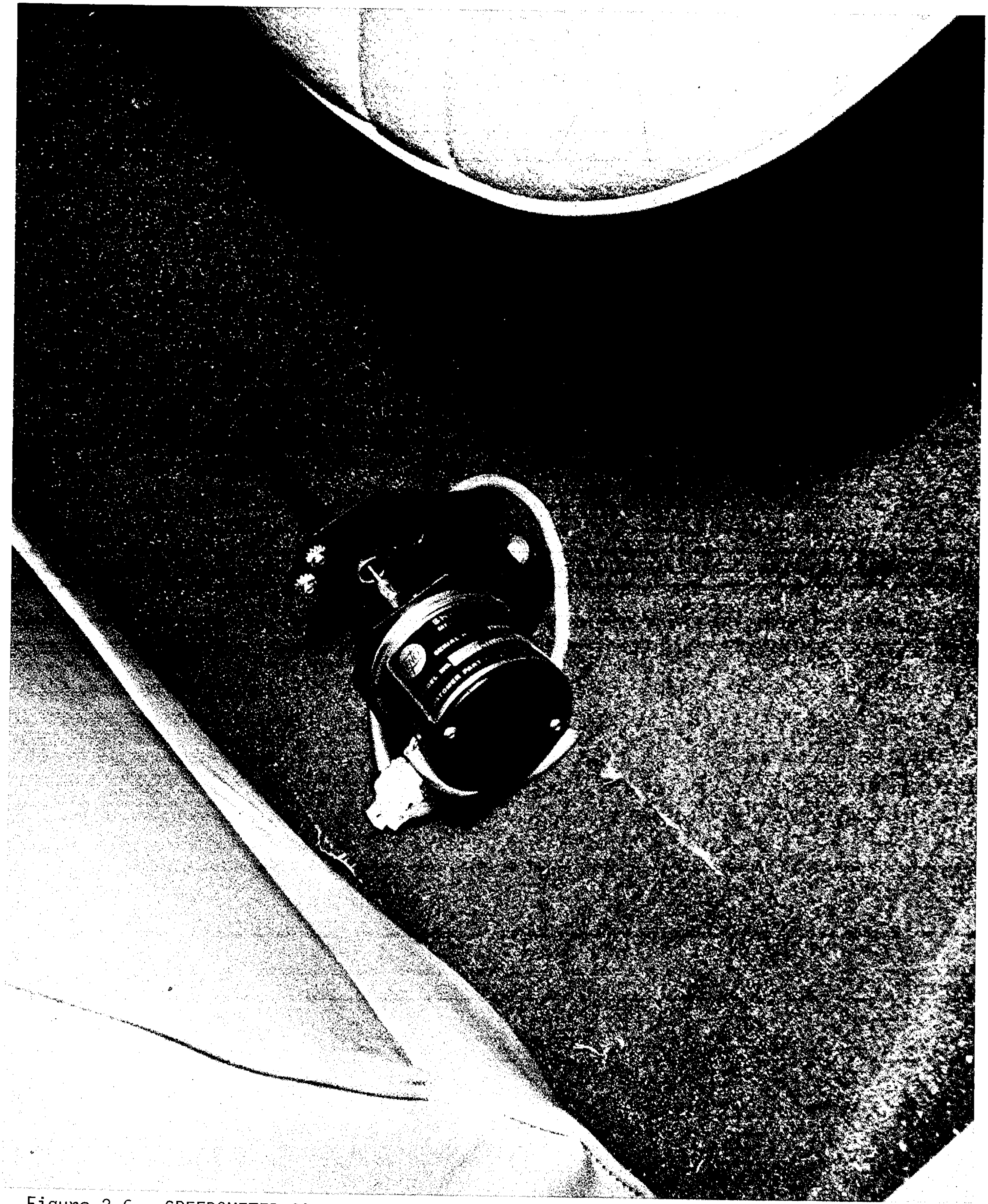


Figure 2-6. SPEEDOMETER CABLE DRIVEN PULSE GENERATOR MOUNTED ON CHASE VEHICLE FLOOR BOARD

Table 2-1. DIGITAL DATA ACQUISITION SYSTEM (DDAS) SPECIFICATIONS

PARAMETER	SPECIFICATION
Analogue Data (Manifold Vacuum)	1 Channel with ADC
Analogue Input Range	±5V for a display of 00.0 to ±99.9 inches Hg
Digital Data (Vehicle Speed)	1 Channel
Digital Input Range	10^6 square wave pulses per mile for a display of 00.0 to 99.9 mph
Digital Clock	Time display in hours, minutes, and seconds accurate to 1 part in 10^5 per day
Thumbwheel Set Data	6 Channels Day of Year — 3 digits Vehicle Description — 3 digits Weather Data — 3 digits Segment Data — 2 digits Trip Data — 2 digits Route Data — 2 digits
Recording Media	IBM Compatible 9-Track - 800 BPI Tape
Record Size	27 Characters
Recording Rate	1 record per second
Power Requirements	115 VAC 60 Hz 3.5 amp

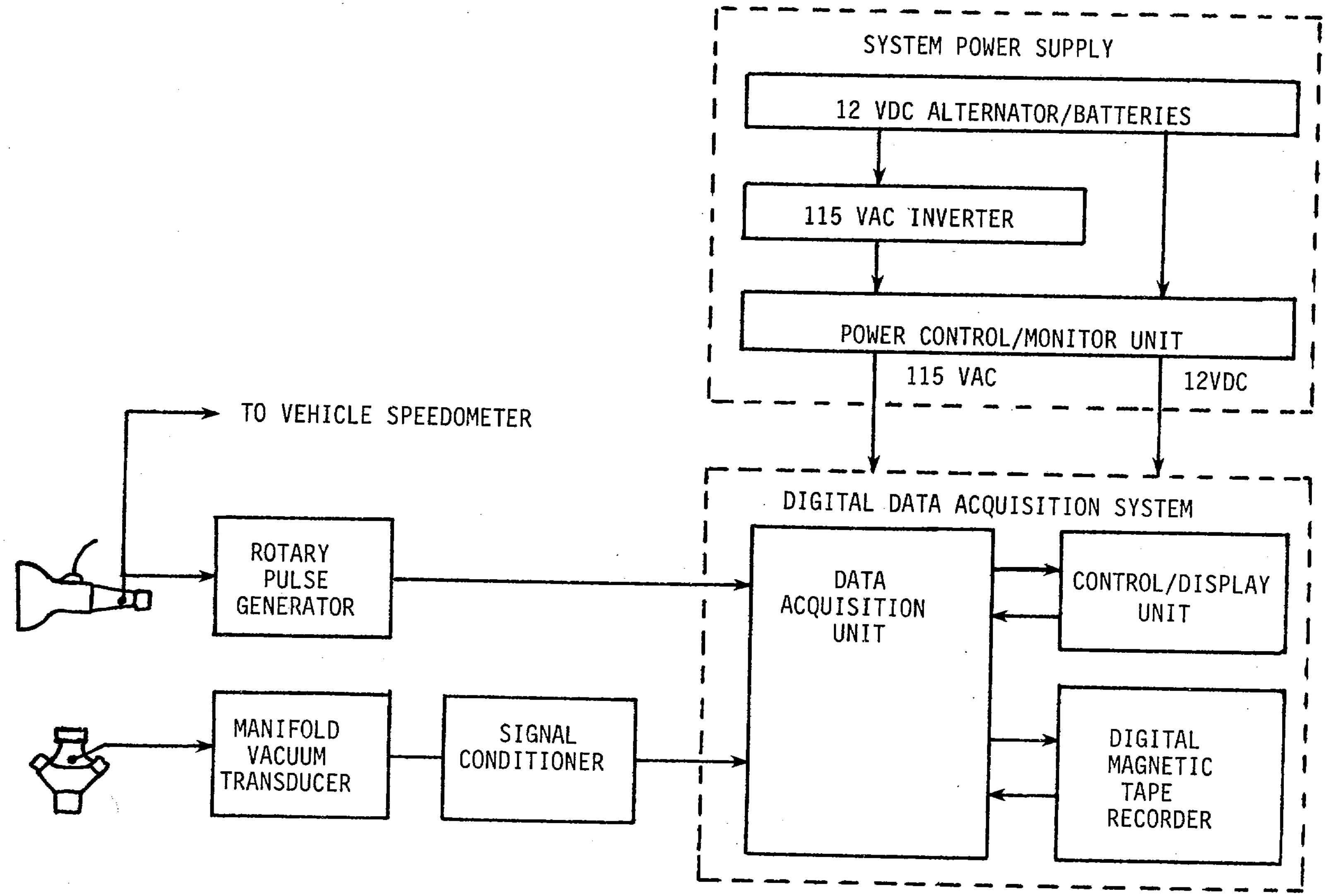


Figure 2-7. ARB MOBILE SOURCE EMISSION INVENTORY CHASE VEHICLE INSTRUMENTATION SYSTEM BLOCK DIAGRAM

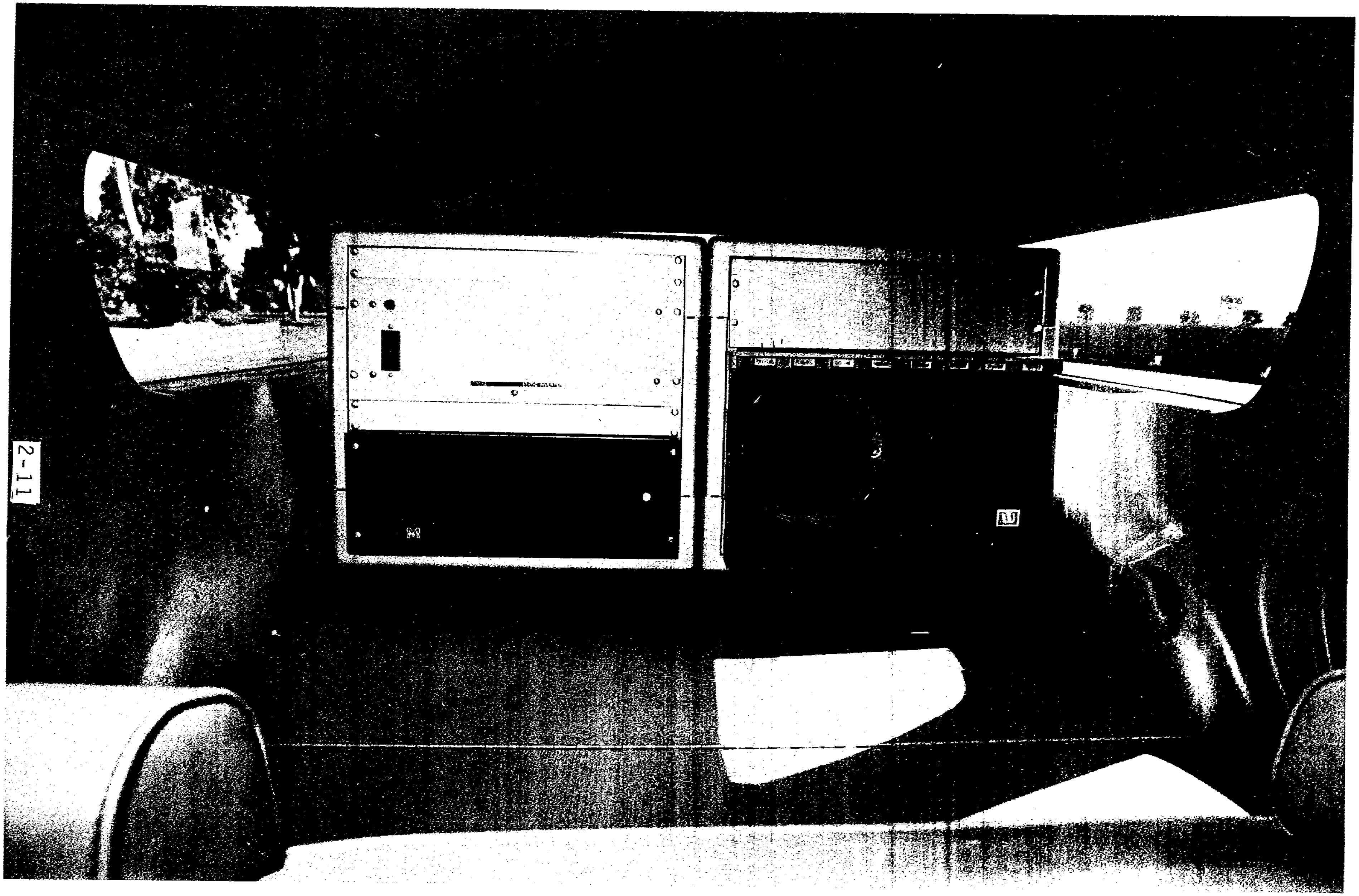


Figure 2-8. CHASE VEHICLE DIGITAL DATA ACQUISITION SYSTEM AND TAPE TRANSPORT

- Accumulated speed pulse data to obtain speed resolved to 0.01 mph.

- Generated digital time-of-day data from a 1-MHz clock oscillator.

- Received digitally-coded thumbwheel data from the control/display unit.

- Time-multiplexed day-of-year, time-of-day, car chased, speed, manifold vacuum, weather, road type, and route data into a BCD serial format and presented these data to the tape recorder at a sample rate of one complete scan per second.

- Received read-back data from the recorder once each second, de-multiplexed, and provided it to the control/display unit for display.

- Processed and generated all system control signals.

The remote control/display unit, shown in Figure 2-9, provided the following functions:

- A read-out of all recorded data.

- Thumbwheel switches for manually coding the day, car chased, weather, road, and route data.

- Pushbutton switches to set the clock.

Figure 2-9. CHASE VEHICLE DIGITAL DATA ACQUISITION SYSTEM REMOTE CONTROL/DISPLAY UNIT

- System status indication.

- CRC and LRC end-of-file characters on tape.

The magnetic tape recorder, previously shown in Figure 2-8, was a 9-track, 800-bpi, IBM-compatible, synchronous recorder which received 27 characters of BCD data in serial format once each second from the data acquisition unit multiplexer. The order in which the data was recorded, the characters per parameter, and the range of possible values for each parameter are shown in the Table 2-2. The parameter codes are described in Appendix A.

Table 2-2. CHASE VEHICLE DDAS RECORDED PARAMETERS

PARAMETER	NUMBER OF CHARACTERS	PARAMETER RANGE
Day of year	3	0 to 365
Hour	2	0 to 23
Minute	2	0 to 59
Second	2	0 to 59
Car Chased	3	0 to 999
Speed (mph)	3	0 to 99.9
Manifold Vacuum (in Hg)	3	0 to 30.0
Traffic Density	1	0 to 9
Traffic Condition	1	0 to 9
Weather Code	1	0 to 9
Segment Code	2	0 to 99
Road Type Code	2	0 to 99
Route Code	2	0 to 99

2.1.3 System Calibration and Checkout

Calibration of the two externally generated signals (speed and manifold vacuum) was accomplished after installation in the vehicle. Both external channels were provided with potentiometric adjustments to enable transducer calibration. The speed signal was calibrated by comparing the indicated DDAS speed to an independently calibrated fifth wheel. The speed was calibrated at 60 mph and then checked at 40 mph, 20 mph, 10 mph, and 0 mph. The signals agreed within the resolution of the two transducers.

The manifold vacuum signal was calibrated using an external vacuum source and precision manometer. The vacuum transducer was provided with a two-way valve which connected it either to the calibration source or to the engine manifold vacuum source.

During the chase operations, the transducer calibration was checked before and after each series of road runs. No adjustments to the calibration were required, however.

The operation of each channel could be monitored during road operation. The monitored information was obtained from read heads on the tape recorder located after the write heads. Therefore, a complete functional check of the external signals, internally generated signals, I/O circuits, and recorder operation was possible during chase operations.

The chase drivers were trained prior to beginning chase operation. It was necessary to ensure that the chase vehicle faithfully replicated the driving pattern of the target vehicle. Therefore, the fifth wheel used to calibrate the chase vehicle speed signal was installed in an Olson vehicle and connected to a strip chart recorder. The chase vehicle speed signal was also connected to a strip chart recorder. Several runs were then made until the chase vehicle dirver was nearly able to replicate the speed trace generated by the lead vehicle driver. At this point, it was concluded that the chase vehicle driver was sufficiently trained to emulate the vehicle being pursued.

After the initial test runs were completed, the data tapes were submitted for processing. However, these tapes could not be read due to an encoding error in the MEDIA-III electronics. These tapes were eventually transcribed into a coding format compatible with existing software.

The electronic problem was also corrected prior to proceeding with chase operations.

2.1.4 Driver and Observer Responsibilities

The chase vehicle required two operators: the driver and the DDAS operator who also served as an observer of test and traffic conditions. The basic responsibility of the driver was to emulate the operation of the pursued vehicle.

The observer/DDAS operator was responsible for starting/monitoring/stopping the DDAS and directing the driver. As the run began, the descriptive information was set up on the thumbwheel switches. During the run, the observer was responsible for appropriate changes in the thumbwheel switches to reflect changes in the pursued vehicle, road traffic or weather conditions.

The complete step-by-step operating procedure is presented in Appendix A.

2.2 CHASE ROUTES

2.2.1 Route Selection

The chase routes were selected to survey representative driving patterns throughout the SCAB. The routes included predominately freeway and predominately nonfreeway driving. The specific routes were selected using the following criteria.

- Select freeways and nonfreeways which were typical routes used by vehicles in the areas of interest.

- Segment each route into portions of freeway and nonfreeway roads to allow variations in driving patterns.

- Sequence segments of each route so that the starting point of one segment was the ending point of the previous segment.

- Plan each segment to take approximately 2 hours under the normal traffic and route conditions experienced.

Routes were selected using road maps of the SCAB. Tentative routes were developed along the major freeway and arterial roads throughout the SCAB. Routes did not necessarily lead into or out of the Los Angeles central business district so that completely suburban driving patterns could also be characterized. Maps of the chase vehicle routes are presented in Appendix B. Table 2-3 summarizes the nine routes ultimately selected. Each route segment was specified in advance. The chase vehicle followed the specified route and emulated any convenient vehicle which moved with the general flow of traffic. If the pursued vehicle left the route segment, the next vehicle ahead became the new pursued vehicle.

2.2.2 Route Descriptions

A brief description of each route is presented in this paragraph. In general, routes were replicated reasonably well from day-to-day in terms of distance and average speed. On occasion, however, traffic, road condition or DDAS problems caused an unanticipated deviation from the specified route. Each route segment generally included periods of peak as well as nonpeak traffic conditions. Traffic condition was

Table 2-3. DESCRIPTION OF CHASE VEHICLE ROUTES

ROUTE	SEGMENT	ROAD TYPE	MILEAGE (MILES)	AVERAGE ROUTE SPEED (MPH)		
				Peak	Nonpeak	Total
A	1	NF	52	27	27	27
	2	F	101	-	54	54
	3	F	49	-	54	54
	4	NF	36	-	24	24
B	1	F	96	44	55	46
	2	NF	37	-	25	25
	3	NF	20	22	23	23
	4	F	95	45	55	53
C	1	NF	44	-	27	27
	2	F	78	-	49	49
	3	F	81	51	53	52
	4	NF	32	-	26	26
D	1	F	95	-	55	55
	2	NF	36	-	25	25
	3	NF	36	26	25	25
	4	F	101	48	55	53
E	1	NF	40	30	25	26
	2	F	94	51	53	53
	3	NF	38	27	22	26
	4	F	86	44	54	53
F	1	NF	39	-	24	24
	2	F	148	-	56	56
	3	NF	36	-	23	23
	4	F	74	-	54	54
G	1	F	85	48	51	49
	2	NF	46	30	30	30
	3	F	100	-	55	55
	4	NF	23	-	25	25
H	1	F	68	40	51	48
	2	NF	32	20	-	20
	3	F	108	50	54	53
	4	NF	44	-	27	27
I	1	F	136	44	54	46
	2	NF	33	-	18	18
	3	F	42	-	52	52
	4	NF	46	-	25	25

NF - Nonfreeway
F - Freeway

defined as "peak" on a segment if most of the segment mileage was driven in the direction of major traffic flow during the hours of 6:00 a.m. to 9:00 a.m. or 4:00 p.m. to 7:00 p.m.

Route A consisted of nonfreeway driving on major surface streets in Orange County and freeway driving on various freeways throughout Orange County, West Los Angeles, the San Gabriel Valley and South Central Los Angeles. Driving was performed on several different days of the week but was always under nonpeak conditions. Average speeds were 24 to 27 mph on nonfreeway routes and 54 mph on freeway routes.

Route B consisted of freeway driving on the Santa Ana, Golden State, and Hollywood Freeways during morning peak traffic and nonpeak freeway driving on the Santa Monica, San Diego, Long Beach, and Artesia Freeways. Nonfreeway driving was performed during nonpeak periods in the South Bay - Torrance area of Los Angeles County. Average speeds were 46 mph for segment B-1 which included morning peak driving. Average speeds for nonfreeway segments B-2 and B-3 were 23 to 25 mph. Average speed for nonpeak freeway segment B-4 was 53 mph.

Route C consisted of nonfreeway driving in Orange County and freeway driving along the San Diego, Ventura, Hollywood, and Long Beach Freeways. Except for peak afternoon driving along the Santa Ana, Long Beach and San Diego Freeways, Route C represented nonpeak traffic conditions. Average route speeds were 26 to 27 mph for the nonfreeway driving segments, 49 mph for peak traffic the freeway driving segments, and 52 mph for the nonpeak freeway segments.

Route D consisted of nonpeak freeway driving on the Santa Ana, Hollywood, Ventura, San Bernardino, Pomona, San Gabriel River, and the Orange Freeways and nonpeak nonfreeway driving on surface streets in the El Monte, Rosemead and Alhambra areas of the San Gabriel Valley of Los Angeles County. Average speeds for freeway driving segments were 53 to 55 mph and for nonfreeway driving segments were 25 mph.

Route E consisted of nonfreeway driving in the Orange County, and East Los Angeles County areas followed freeway driving to the San Fernando Valley. Nonpeak, nonfreeway driving in the San Fernando Valley of Los Angeles County followed by freeway driving back to Anaheim completed Route E. Route E was generally representative of nonpeak driving except for nonfreeway driving in the San Fernando Valley. The average speed for nonfreeway segments was 26 mph. Average speed for freeway segments were 49 to 53 mph.

Route F consisted of nonfreeway driving in the Long Beach area of Los Angeles County and freeway driving in the East Los Angeles County, Orange County, San Bernardino County and Riverside County areas. All driving represented nonpeak traffic conditions. Average speeds were 23 to 24 mph for nonfreeway driving segments and 54 to 56 mph for freeway driving segments.

Route G consisted of freeway driving to the San Fernando Valley, nonfreeway driving in the San Fernando Valley, freeway driving to Fountain Valley, and nonfreeway driving in the Fountain Valley and Anaheim areas of Orange County. Route G consisted of morning peak driving on the Santa Ana, Artesia, and San Diego Freeways and generally nonpeak nonfreeway driving. Afternoon freeway driving was during nonpeak traffic conditions. Average freeway speeds were 49 mph on the morning peak segment, 55 mph on the nonpeak afternoon segment and 25 to 30 mph on the nonfreeway segments.

Route H consisted of freeway driving along the Garden Grove, San Gabriel Valley, Santa Ana, Long Beach, San Diego, Harbor, and Hollywood Freeways into the Hollywood area of Los Angeles County, and nonfreeway driving in the Central Los Angeles and Hollywood areas. Route H was completed by freeway driving back to Orange County and nonfreeway driving in the Whittier, Fullerton, and Yorba Linda areas of Orange County. Route H generally represented peak traffic conditions for both freeway and nonfreeway driving. Average speeds on the peak freeway segment were 48 mph. Average speed in the Los Angeles central business district during peak hours was 20 mph which agreed well with the LA-4 route average speed. The nonpeak freeway and nonfreeway segments, H-3 and H-4, respectively) had average speeds of 53 and 27 mph, respectively.

Route I consisted of freeway driving in the Orange and Los Angeles counties and nonfreeway driving in Los Angeles central business district in the Anaheim, Fullerton areas of Orange County. The first freeway segment (H-1) represented peak traffic. All other segments represented nonpeak traffic. Average speeds for peak freeway driving were 46 mph. The average speed in the Los Angeles central business district was 18 mph compared to 25 mph in the Orange County suburbs. The average speed on nonpeak freeway driving was 52 mph.

2.2.3 Chase Hours and Distribution

Each route was driven on several days and times of day. Table 2-4 shows the chase vehicle hours of operation on the different road segments described above. A large concentration of chase hours between 1300 and 1500 (1:00 to 3:00 p.m.) was due to the following:

- Earliest start time was 6:00 a.m. such that nine consecutive hours of operations, stop time occurs at 3:00 p.m.

- Latest stop time was 10:00 p.m. such that with nine consecutive hours of operation, start time occurs at 1:00 p.m.

Table 2-4. CHASE VEHICLE HOURS DISTRIBUTION

LOCAL TIME	WINTER OPERATIONS			SPRING OPERATIONS		
	Non Freeway	Freeway	Combined	Non Freeway	Freeway	Combined
0600-0700	3	5	8	2	2	4
0700-0800	4	9	13	2	6	8
0800-0900	6	7	13	4	7	11
0900-1000	8	8	16	6	9	15
1000-1100	9	6	15	10	7	17
1100-1200	8	4	12	11	6	17
1200-1300	11	7	18	7	10	17
1300-1400	14	14	28	14	11	25
1400-1500	15	13	28	16	10	26
1500-1600	9	11	20	11	11	22
1600-1700	7	8	15	11	10	21
1700-1800	5	6	11	5	8	13
1800-1900	4	7	11	5	9	14
1900-2000	8	5	13	6	6	12
2000-2100	6	5	11	7	4	11
2100-2200	3	5	8	3	4	7
Total Hours	120	120	240	120	120	240

Section 3

DATA ANALYSIS

This section describes the analysis of the driving pattern tapes, the development of specific driving cycles, and the estimation and collection of vehicle emissions data. Separate paragraphs are devoted to the following topics:

- <u>Chase Vehicle Data Processing</u>
  Editing
  Data Reduction

- <u>Driving Cycle Development</u>
  Mathematical Model
  Driving Pattern Selection

- <u>Vehicle Emission Estimates</u>
  Modal Emission Data Bases
  Estimated Mass Emissions
  Measured Mass Emissions
  Determination of C_1 to C_{10} Hydrocarbons

3.1 CHASE VEHICLE DATA PROCESSING

All data processing was accomplished using an IBM System 360 Model 50 (MVT) Computer with OS JCL and a Hasp operating system. A flowchart depicting the data processing phase is given in Figure 3-1.

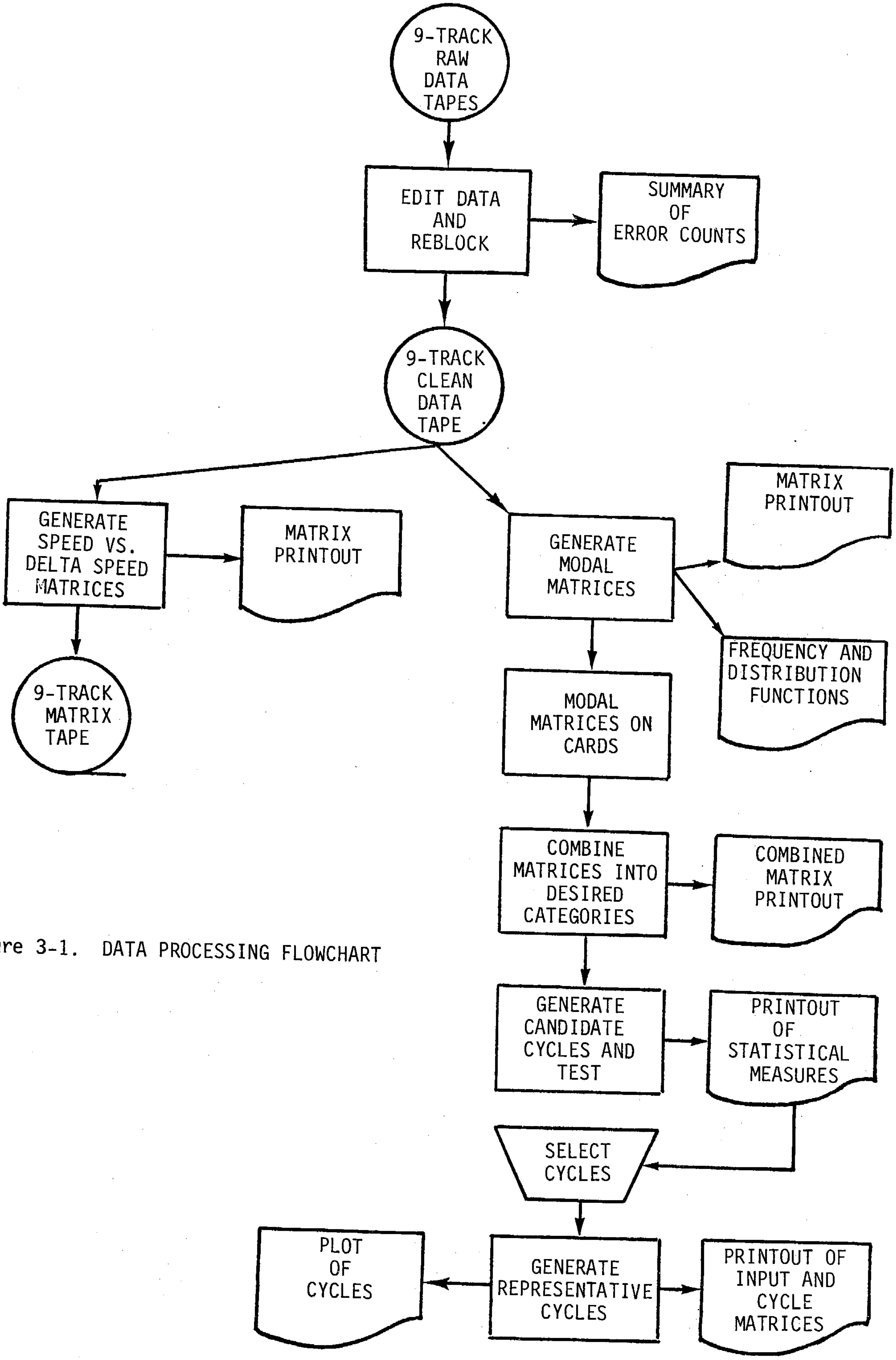


Figure 3-1. DATA PROCESSING FLOWCHART

The data processing steps consisted of editing the raw data tapes and the reduction of the data into matrices.

3.1.1 Editing

The raw data was first passed through an editing program to determine and correct any errors from the Digital Data Acquisition System. Before writing the edit program, selected tapes from the winter sample were dumped to determine the nature and extent of any errors. From this study it was found that the recorder would intermittently write a nonnumeric character instead of a valid digit code. In operation, however, there were very few errors.

Each byte of a raw data tape represented one digit of a data field. Initially all fields were written in binary coded decimal (BCD) digits. When the recorder modification mentioned in Section 2.1.3 was made, the field format was changed to extended binary coded decimal interchange code (EBCDIC).

For editing purposes the data fields were divided into three groups. The purpose of this classification was to group the data fields according to the edit logic necessary to eliminate the nonnumeric characters. Below is a description of the edit logic pertaining to each of the data groups:

- <u>Day, Segment, and Route</u>
  The field in error was replaced by its corresponding input value.

- <u>Fleet, Traffic Density and Condition, Weather, and Road Code</u>
  The value of the corresponding field from the previous record was substituted for the field in error.

- <u>Time, Speed and Manifold Vacuum</u>
  A linear interpolation was taken from the corresponding fields of the previous and next records and this value was then substituted for the field in error.

Because fast efficient processing was desired and because the detection of the nonnumeric characters involved bit manipulation, the edit program was written in IBM 360 Level G assembler language. For each segment of data, an error count for each field was printed. These error counts indicated a very low incidence of nonnumeric characters over the total data sample.

The edited data were output to 800 BPI magnetic tape. All fields were converted to the equivalent of a Fortran integer 4 variable and the records written in variable blocked-spanned (VBS) format. One day's accumulation of data comprised a file.

3.1.2 Data Reduction

Data reduction consisted of generating two-dimensional matrices from the edited chase vehicle data including initial speed versus delta speed and modal matrices.

3.1.2.1 Initial Speed Versus Delta Speed Matrices

Initial speed versus delta speed matrices were developed at the request of TRW. For the initial speed versus delta speed matrices, the speed range was 0 to 70 mph in increments of 1 mph and the delta speed range was ±10 mph per second in increments of 1 mph per second. Columns 1 through 10 represented deceleration, column 11 represented cruise while columns 12 through 21 represented accelerations. By summing the appropriate column totals, acceleration, deceleration, and cruise frequencies of a given matrix were determined. Idle frequency was the frequency of the cell marked I in Figure 3-2.

Initial speed versus delta speed matrices were developed for 432 categories broken down as follows:

- Routes: 1-9

- Road type: 3
  Freeway, nonfreeway including both major arterial and collector

- Time of Day: 4
  0600-0900
  0900-1500
  1500-1800
  1800-2200

- Weekday/weekend: 2

- Winter/spring: 2

An IBM Level H Fortran program was written to accomplish the desired matrix development. After a record pair was read, the speed field from the first record determined the row index of the cell to be incremented. The column index was obtained by subtracting the speed field of the first record from the speed field of the second record and using an appropriate algorithm to convert the resulting delta speed to an index. Having determined a particular initial speed-delta speed mode, the corresponding cell of the matrix was incremented.

The above matrices were output to 800 BPI magnetic tape. Each matrix row was written as a record and a set of 24 matrices for each route comprised a field. Winter and

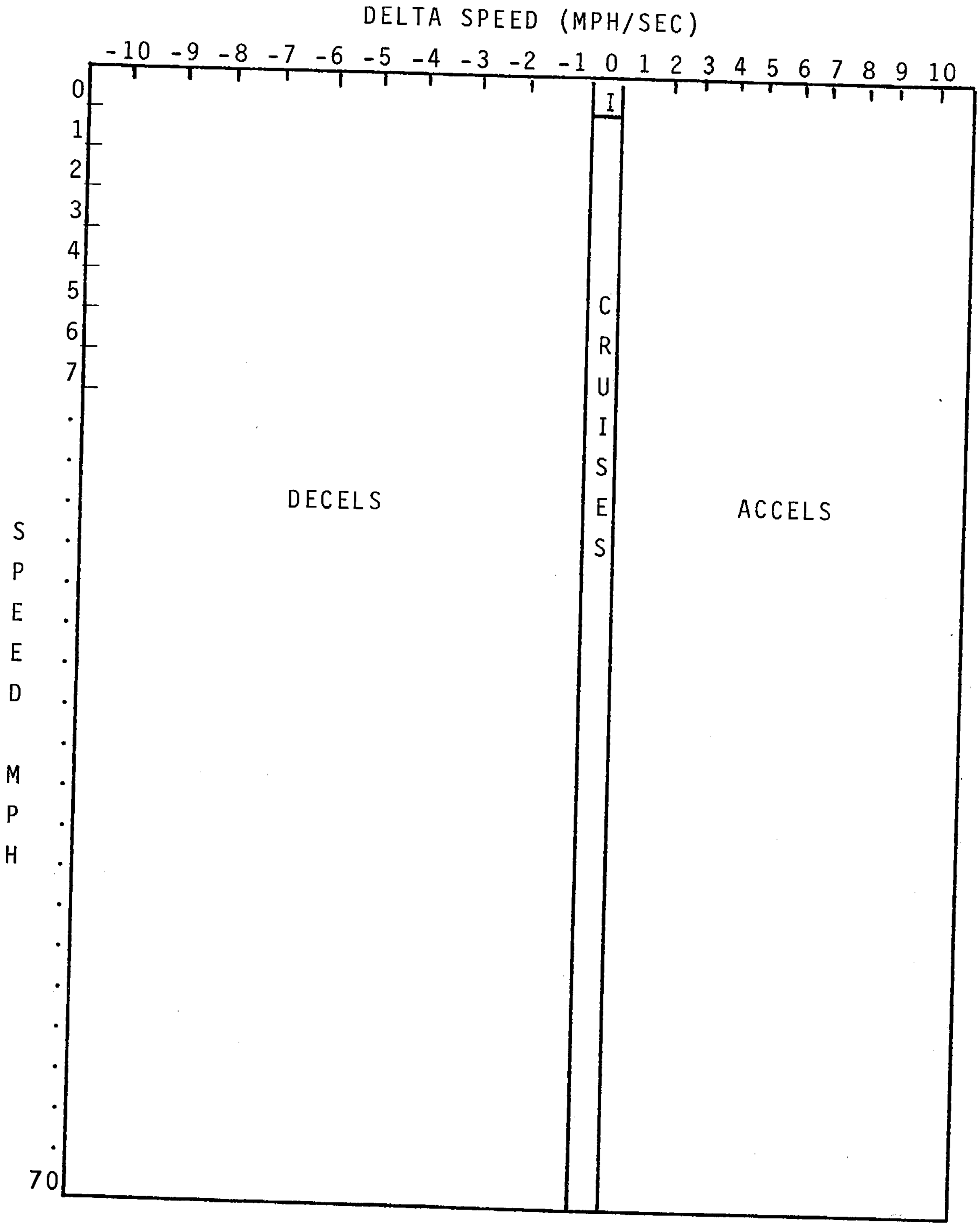


Figure 3-2. INITIAL SPEED VS. DELTA SPEED MATRIX

spring data were written on separate tapes. These tapes were then transmitted to TRW.

3.1.2.2 Modal Matrices

The following modal matrices were developed to define parameters for driving cycle development.

- Time-in-mode
- Mode frequency
- Transition-probability

Normalized Time-in-Mode Matrix

The time spent in executing each mode was accumulated to yield the two-dimensional total-time-in-mode matrix, formatted as shown schematically in Figure 3-3. Each entry was the total accumulated observed time, normalized by dividing each element by the total of all elements so that the sum of all entries was 100 percent.

Normalized Mode-Frequency Matrix

This two-dimensional matrix, also formatted as in Figure 3-3, was derived from the distribution-of-time-in-mode matrix by simply tallying the number of times each mode occurred and then normalizing by dividing each element by the sum of all occurrences so that the sum of all entries was 100 percent.

Transition-Probability Matrix

This matrix was obtained by row-normalization of the mode-frequency-of-occurrence matrix. The nondiagonal elements in each row of the mode-frequency-of-occurrence matrix were

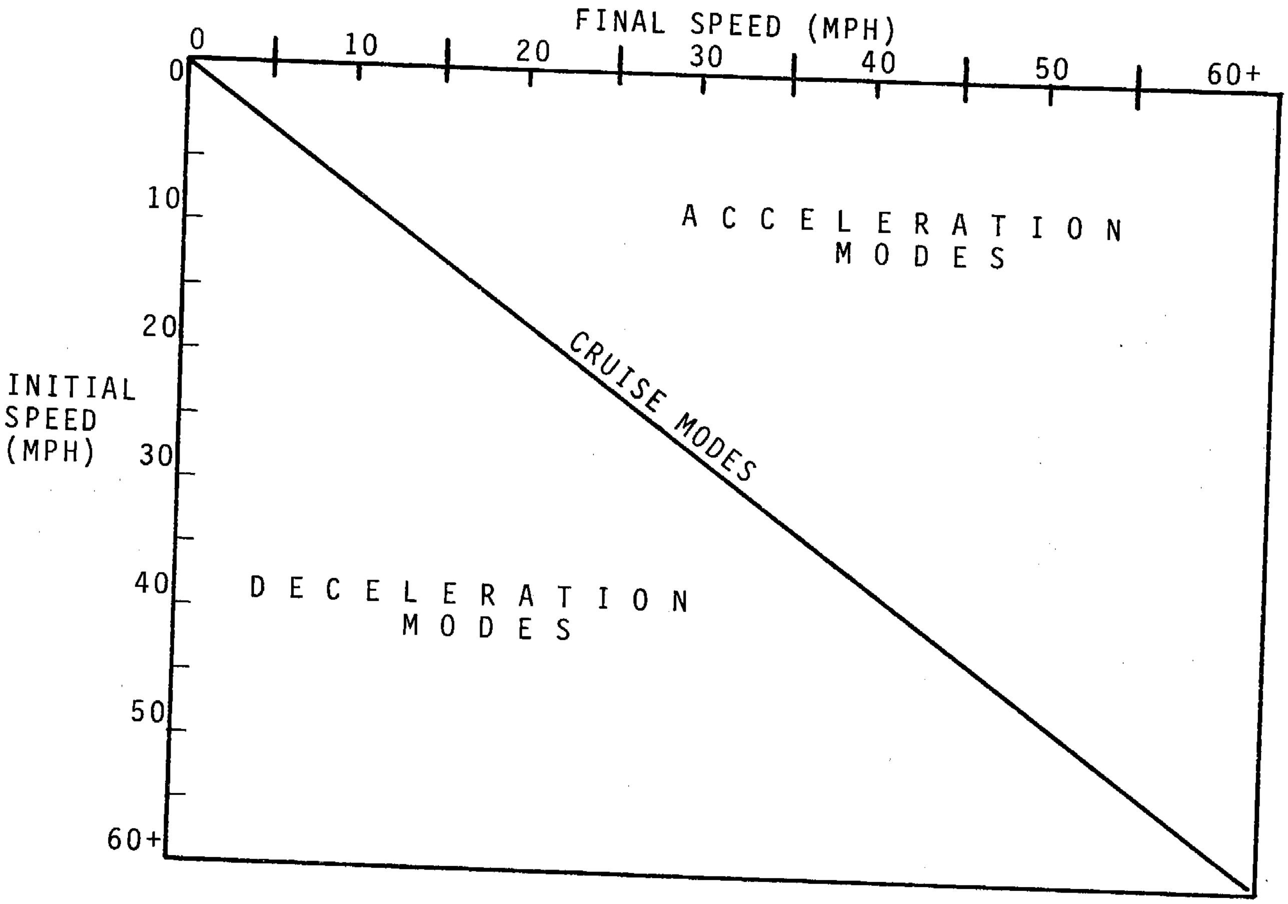


Figure 3-3. TIME-IN-MODE AND MODE FREQUENCY MATRIX FORMATS

first summed, and each nondiagonal row element was then divided by the row total. The off-diagonal entries in any row were, therefore, the conditional probabilities of making transitions from the row's cruise mode (diagonal element) to those acceleration or deceleration modes. The diagonal elements in the transition probability matrix remained undefined, of course, since no transition occurred while cruising. Table 3-1 illustrates the transition probability matrix.

Tables 3-2 through 3-4 show the normalized time-in-mode matrices for the freeway, nonfreeway, and combined data bases. The tables define modes as shown in Figure 3-3. Tables 3-5 through 3-7 show the normalized mode frequency matrices for freeway, nonfreeway, and combined data bases. The freeway and nonfreeway matrices were weighted in proportion to vehicle miles travelled during the CAPE-10 VOS study (41.83 percent freeway). The actual percentage of vehicle miles traveled on freeways was 43.88 percent in the SCAB (Ref. 5).

3.2 DRIVING CYCLE DEVELOPMENT

The matrices of driving patterns developed in the preceding paragraph were the basis for developing representative driving cycles. The basic matrices used in the construction of driving cycles included the following:

- Normalized time-in-mode
- Normalized mode-frequency
- Average time-in-mode
- Transition-probability.

The mathematical model and procedures for developing driving cycles are described in this paragraph. The mathematical model and procedures for statistically filtering the cycles are described in Section 3.3.2.

Table 3-1. TRANSITION-PROBABILITY MATRIX (PERCENT)

INITIAL SPEED	FINAL SPEED												
	0	5	10	15	20	25	30	35	40	45	50	55	60+
0	--	13.9	7.1	5.3	7.3	13.1	18.8	19.1	10.9	3.60	0.7	0.1	0.1
5	37.4	--	14.6	7.1	6.8	7.6	9.2	9.7	5.2	1.8	0.4		
10	15.6	18.3	--	15.5	12.9	13.1	12.2	7.9	2.8				
15	11.4	6.5	14.9	--	20.0	15.0	13.5						
20	17.0	6.0	8.2	15.7	--								
25	20.1	5.8	6.4										
30	20.5												

Table 3-2. NORMALIZED TIME-IN-MODE MATRIX OF FREEWAY DRIVING PATTERNS

	0	5	10	15	20	25	30	35	40	45	50	55	60
0	0.79	0.14	0.10	0.07	0.06	0.07	0.05	0.09	0.03	0.04	0.03	0.03	0.05
5	0.11	0.67	0.07	0.07	0.03	0.03	0.01	0.00	0.01	0.01	0.00	0.01	0.01
10	0.07	0.07	0.64	0.10	0.07	0.05	0.03	0.02	0.01	0.01	0.01	0.02	0.02
15	0.05	0.06	0.07	0.70	0.12	0.08	0.07	0.05	0.03	0.02	0.00	0.04	0.05
20	0.05	0.02	0.06	0.08	0.81	0.12	0.09	0.06	0.04	0.01	0.01	0.01	0.01
25	0.06	0.03	0.04	0.07	0.09	0.86	0.11	0.09	0.08	0.04	0.04	0.06	0.06
30	0.03	0.02	0.02	0.05	0.05	0.09	0.67	0.10	0.08	0.04	0.04	0.05	0.02
35	0.06	0.01	0.02	0.02	0.06	0.05	0.07	0.78	0.11	0.11	0.06	0.05	0.02
40	0.05	0.02	0.01	0.02	0.03	0.04	0.05	0.08	1.16	0.18	0.11	0.07	0.05
45	0.05	0.01	0.01	0.02	0.02	0.08	0.05	0.10	0.14	3.05	0.31	0.26	0.05
50	0.03	0.00	0.00	0.02	0.03	0.03	0.02	0.08	0.12	0.38	12.05	0.68	0.16
55	0.02	0.01	0.01	0.01	0.02	0.05	0.03	0.05	0.08	0.27	0.89	37.30	0.56
60	0.04	0.0	0.00	0.0	0.01	0.01	0.01	0.00	0.02	0.06	0.21	0.76	29.18

Table 3-3. NORMALIZED TIME-IN-MODE MATRIX OF NONFREEWAY DRIVING PATTERNS

	0	5	10	15	20	25	30	35	40	45	50	55	60
0	14.17	0.27	0.16	0.42	0.71	1.24	2.00	3.31	2.96	1.65	0.25	0.05	0.02
5	0.21	0.47	0.04	0.10	0.17	0.28	0.41	0.45	0.38	0.22	0.05	0.00	0.0
10	0.13	0.04	0.38	0.08	0.14	0.21	0.28	0.46	0.26	0.20	0.03	0.00	0.0
15	0.23	0.07	0.06	0.75	0.16	0.23	0.35	0.49	0.41	0.20	0.04	0.02	0.01
20	0.56	0.12	0.13	0.12	1.34	0.28	0.45	0.52	0.30	0.17	0.03	0.01	0.01
25	1.10	0.23	0.19	0.19	0.19	3.18	0.61	0.59	0.35	0.11	0.02	0.0	0.00
30	1.81	0.35	0.27	0.28	0.31	0.42	6.58	0.75	0.37	0.15	0.01	0.01	0.0
35	3.04	0.47	0.36	0.34	0.33	0.43	0.65	10.95	0.57	0.21	0.02	0.00	0.00
40	2.60	0.41	0.21	0.20	0.25	0.27	0.33	0.64	9.70	0.23	0.03	0.01	0.0
45	1.38	0.18	0.11	0.11	0.08	0.10	0.12	0.20	0.30	4.85	0.07	0.02	0.0
50	0.28	0.03	0.01	0.03	0.02	0.02	0.02	0.02	0.05	0.09	1.33	0.02	0.00
55	0.07	0.01	0.01	0.01	0.02	0.02	0.01	0.00	0.01	0.03	0.02	0.50	0.01
60	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.0	0.0	0.00	0.01	0.01	0.16

Table 3-4. NORMALIZED TIME-IN-MODE MATRIX OF COMPOSITE DRIVING PATTERNS

	0	5	10	15	20	25	30	35	40	45	50	55	60
0	10.74	0.24	0.15	0.33	0.54	0.94	1.50	2.48	2.21	1.23	0.20	0.04	0.03
5	0.19	0.52	0.05	0.09	0.13	0.22	0.31	0.34	0.29	0.16	0.04	0.01	0.00
10	0.12	0.05	0.44	0.08	0.12	0.17	0.21	0.35	0.20	0.15	0.03	0.01	0.01
15	0.19	0.07	0.06	0.74	0.15	0.19	0.28	0.38	0.32	0.16	0.03	0.02	0.02
20	0.43	0.10	0.11	0.11	1.20	0.24	0.36	0.40	0.24	0.13	0.02	0.01	0.01
25	0.83	0.18	0.15	0.16	0.16	2.58	0.48	0.46	0.28	0.05	0.03	0.01	0.02
30	1.35	0.27	0.20	0.22	0.25	0.33	5.06	0.58	0.29	0.12	0.02	0.02	0.01
35	2.28	0.36	0.27	0.26	0.26	0.33	0.50	8.34	0.45	0.18	0.03	0.01	0.01
40	1.95	0.31	0.16	0.16	0.20	0.21	0.26	0.50	7.50	0.22	0.05	0.03	0.01
45	1.04	0.14	0.09	0.09	0.07	0.09	0.10	0.17	0.26	4.35	0.13	0.08	0.01
50	0.22	0.02	0.01	0.03	0.03	0.02	0.02	0.04	0.07	0.16	4.08	0.19	0.04
55	0.05	0.01	0.01	0.01	0.02	0.03	0.01	0.02	0.03	0.05	0.24	9.95	0.15
60	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.06	0.20	7.61

Table 3-5. NORMALIZED MODE FREQUENCY MATRIX OF FREEWAY DRIVING PATTERNS

	0	5	10	15	20	25	30	35	40	45	50	55	60
0	1.73	0.69	0.32	0.18	0.13	0.13	0.08	0.11	0.04	0.04	0.02	0.03	0.03
5	0.64	1.48	0.36	0.22	0.07	0.05	0.02	0.01	0.01	0.01	0.00	0.01	0.01
10	0.26	0.45	1.67	0.43	0.22	0.12	0.05	0.02	0.01	0.01	0.01	0.02	0.02
15	0.16	0.22	0.36	1.94	0.51	0.25	0.14	0.08	0.04	0.02	0.01	0.03	0.04
20	0.16	0.07	0.23	0.44	2.04	0.54	0.25	0.12	0.07	0.01	0.01	0.01	0.01
25	0.13	0.07	0.10	0.26	0.46	2.30	0.48	0.21	0.13	0.07	0.06	0.07	0.06
30	0.07	0.04	0.03	0.12	0.18	0.39	1.82	0.40	0.19	0.07	0.07	0.06	0.02
35	0.10	0.02	0.04	0.04	0.15	0.15	0.30	2.01	0.46	0.29	0.11	0.07	0.02
40	0.07	0.03	0.01	0.04	0.07	0.10	0.16	0.34	2.56	0.89	0.25	0.13	0.07
45	0.06	0.02	0.01	0.02	0.03	0.14	0.12	0.28	0.70	5.26	1.61	0.64	0.09
50	0.04	0.01	0.00	0.02	0.04	0.05	0.04	0.18	0.35	1.94	10.91	3.02	0.37
55	0.01	0.01	0.01	0.01	0.02	0.07	0.04	0.08	0.17	0.78	4.23	17.37	3.07
60	0.03	0.0	0.00	0.0	0.01	0.01	0.01	0.01	0.03	0.14	0.57	3.75	9.73

Table 3-6. NORMALIZED MODE FREQUENCY MATRIX NONFREEWAY DRIVING PATTERNS

	0	5	10	15	20	25	30	35	40	45	50	55	60
C	9.30	0.82	0.32	0.63	0.83	1.14	1.50	2.14	1.67	0.87	0.12	0.02	0.01
5	0.70	1.81	0.13	0.18	0.23	0.29	0.34	0.32	0.22	0.12	0.03	0.00	0.0
1C	0.27	0.14	1.64	0.20	0.24	0.27	0.27	0.37	0.18	0.12	0.02	0.00	0.0
15	0.35	0.14	0.20	2.47	0.40	0.35	0.39	0.43	0.30	0.13	0.02	0.01	0.00
20	0.68	0.20	0.27	0.34	3.35	0.63	0.60	0.50	0.24	0.12	0.02	0.01	0.00
25	1.12	0.29	0.28	0.38	0.53	5.04	1.27	0.73	0.31	0.08	0.01	0.0	0.00
30	1.59	0.35	0.31	0.38	0.53	1.00	7.09	1.57	0.43	0.12	0.01	0.00	0.0
35	2.29	0.40	0.34	0.36	0.42	0.64	1.41	9.06	1.30	0.25	0.02	0.00	0.00
40	1.78	0.29	0.17	0.18	0.24	0.31	0.44	1.43	6.97	0.59	0.04	0.01	0.0
45	0.87	0.12	0.08	0.09	0.07	0.09	0.12	0.26	0.72	3.44	0.20	0.03	0.0
50	0.15	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.07	0.22	0.84	0.04	0.00
55	0.04	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.03	0.04	0.21	0.02
60	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.00	0.01	0.02	0.05

Table 3-7. NORMALIZED MODE FREQUENCY MATRIX COMPOSITE DRIVING PATTERNS

	0	5	10	15	20	25	30	35	40	45	50	55	60
0	8.20	0.80	0.32	0.56	0.73	1.00	1.29	1.84	1.43	0.75	0.11	0.02	0.01
5	0.69	1.77	0.16	0.19	0.21	0.25	0.30	0.27	0.19	0.11	0.02	0.00	0.00
10	0.27	0.19	1.65	0.23	0.23	0.25	0.24	0.32	0.16	0.11	0.02	0.00	0.00
15	0.33	0.15	0.22	2.39	0.41	0.34	0.35	0.38	0.27	0.12	0.02	0.01	0.01
20	0.61	0.18	0.26	0.35	3.16	0.61	0.55	0.45	0.22	0.10	0.02	0.01	0.00
25	0.98	0.26	0.26	0.37	0.52	4.64	1.15	0.65	0.29	0.08	0.02	0.01	0.01
30	1.37	0.30	0.27	0.34	0.48	0.91	6.32	1.40	0.40	0.12	0.02	0.01	0.00
35	1.97	0.35	0.29	0.32	0.38	0.57	1.25	8.03	1.18	0.25	0.03	0.01	0.01
40	1.53	0.26	0.15	0.16	0.22	0.28	0.40	1.27	6.33	0.63	0.07	0.03	0.01
45	0.75	0.11	0.07	0.08	0.06	0.10	0.12	0.26	0.72	3.71	0.40	0.11	0.01
50	0.13	0.01	0.01	0.02	0.02	0.02	0.02	0.04	0.11	0.47	2.30	0.47	0.06
55	0.03	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.03	0.14	0.65	2.70	0.47
60	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.09	0.56	1.45

3.2.1 Mathematical Model

A Monte Carlo simulation model was used since that technique allows for rapid generation of large numbers of driving patterns from which the most representative cycles may be selected. The Monte Carlo technique was ideal for predicting a sequence of events each of which had its own probability of occurrence, such as a driving pattern. The driving patterns or cycles were generated by randomly selecting modes and mode durations using their respective distribution functions. Modes and allowable mode sequences were defined as follows:

- A cruise mode was either an idle mode or a nonzero constant-speed mode.
- Every other mode in a cycle was a cruise mode; i.e., every acceleration or deceleration was followed by a cruise mode; zero-time cruises were admissible, but were not utilized for this program.

In order to provide a basis for the mode selection process, the transition-probability matrix was recast in the form of running sums to the right on a row-by-row basis. This new matrix, the cumulative transition-probability matrix, is shown in Table 3-8. In all that follows, the random numbers generated were uniformly distributed on the unit probability interval; i.e., .000 to 1.000.

Execution of a cruise mode defined the matrix row from which to select the next mode by virtue of the mode-sequence logic. A random number on the unit interval was then generated to sample the distribution function for that row and thus select the next mode. Examination of Table 3-8 shows, for example, that if an idle had just been executed

Table 3-8. CUMULATIVE TRANSITION-PROBABILITY MATRIX (PERCENT)

INITIAL SPEED \ FINAL SPEED	0	5	10	15	20	25	30	35	40	45	50	55	60+
0	0.0	13.9	21.0	26.3	33.6	46.7	65.5	84.6	95.5	99.1	99.8	99.9	100.
5	37.4	37.4	52.0	59.1	65.9	73.5	82.7	92.4	97.6	99.4	99.9		
10	15.6	33.9	33.9	49.4	62.3	75.4	87.6	95.5	98.3				
15	11.4	17.9	32.8	32.8	52.8	67.8	81.3						
20	17.0	23.0	31.2	46.9	46.9								
25	20.1	25.9	32.3										
30	20.5												

and a random number of 0.539 (53.9 percent) generated, then the mode selected is an acceleration from 0 to 30 mph because this random number is contained within the probability space defined for 0 to 30 mph.

During the APRAC-CAPE-10 Vehicle Operations Survey (VOS) (Ref. 1, 2, 3), it was found that virtually all decelerations followed the same normalized curve, independently of initial and final speeds. The accelerations, however, could not be accurately represented by a single normalized curve, but rather required classification into three distinct normalized acceleration curves. The acceleration characteristics were found to be functions of both initial speed and net change in speed. The computer was thus programmed with polynomials fitting the curve shapes observed in the VOS. The transitions made between cruise modes in the test cycles were, therefore, representative of those observed from actual pattern data. These polynomials were not redetermined for the current project.

The time-in-mode-matrix yielded, for each mode, a frequency distribution such as that illustrated in Figure 3-4. By creating equal intervals along the abscissa of the time distribution curve, stepwise integration lead to a histogram as shown. After normalizing the area under the histogram, the Monte Carlo technique was applied to time-in-mode selection. It should be noted that probability was again reflected along the random number axis, and that the most probable time-in-mode was the average time-in-mode.

The sequence in which the selections were made is shown in the condensed functional flow diagram of Figure 3-5. The total-time-in-mode and mode-frequency-of-occurrence matrices were input to the computer. The average-time-in-mode matrix and cumulative transition-probability matrices were then created. The program then passed through reference point one, which denoted the point at which mode selections

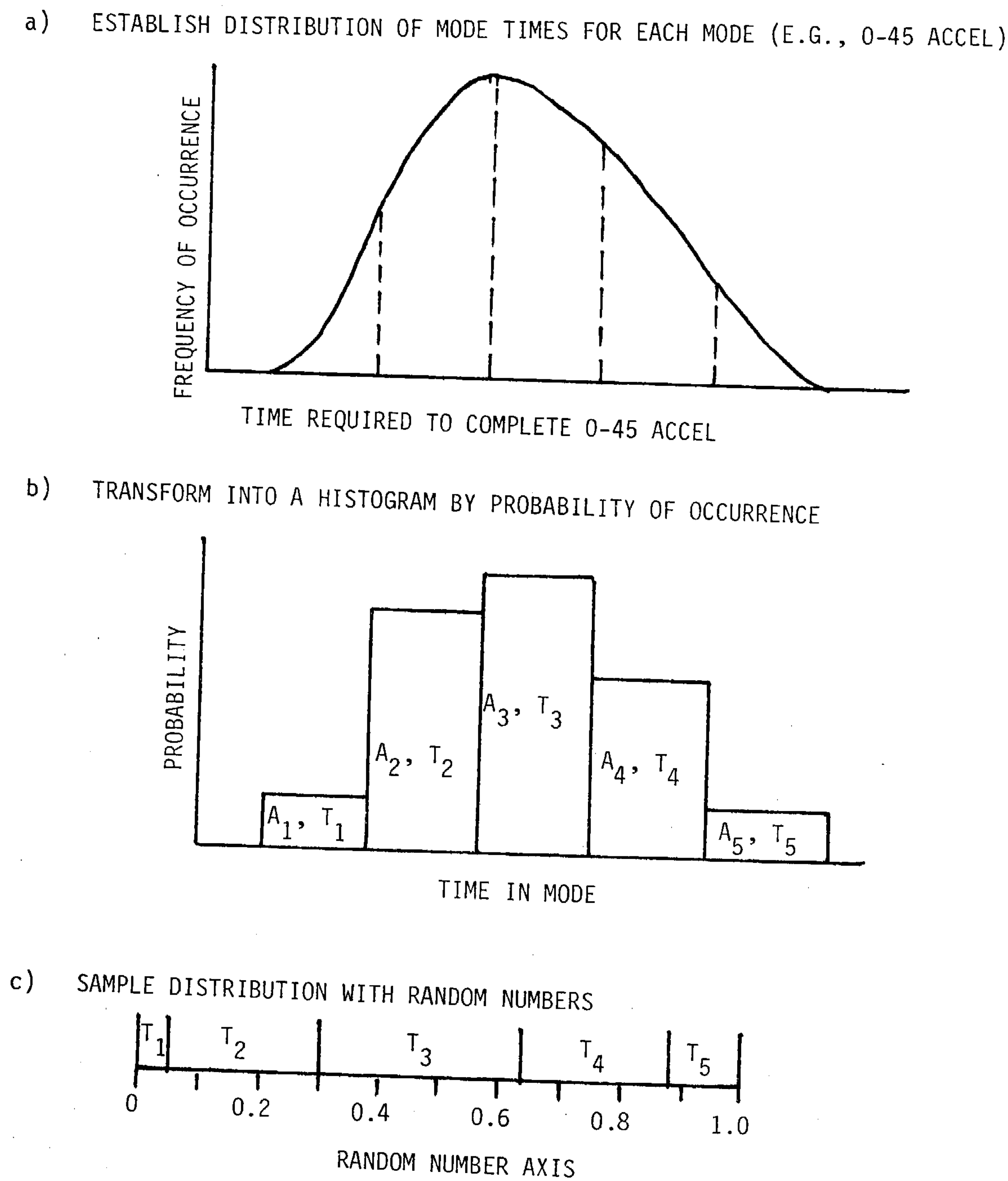


Figure 3-4. DESCRIPTION OF MONTE CARLO SELECTION OF TIME-IN-MODE

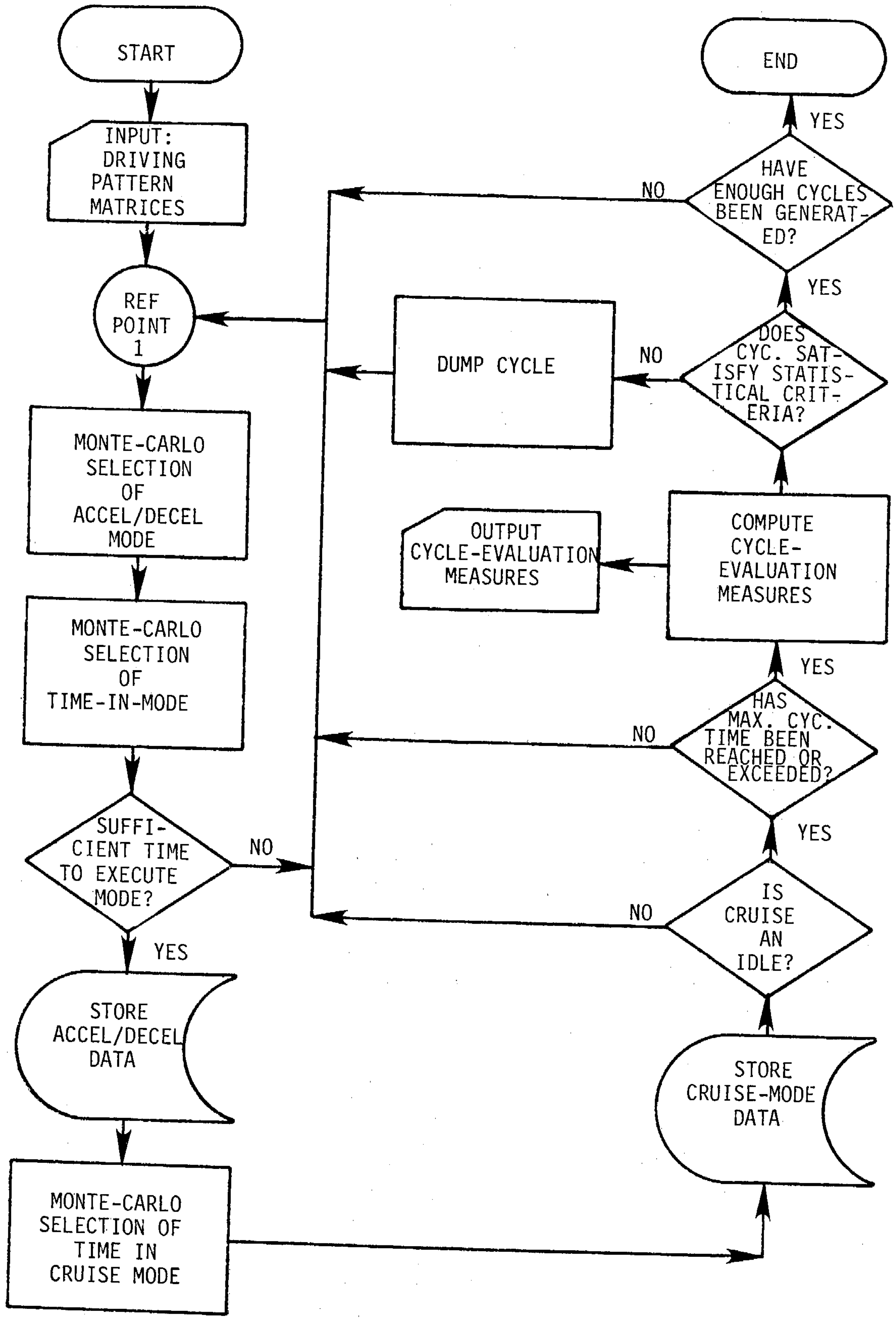


Figure 3-5. COMPUTER PROGRAM FLOWCHART FOR DRIVING CYCLE GENERATION

were initiated by random numbers and completed using the mode sequence logic defined above.

Since patterns must be of finite duration and it was desirable to end them with an idle mode, the program tested each cruise mode to determine if it was an idle. If it was not, the program returned to reference point one. If it was an idle, the program tested the pattern duration to that point to determine whether the desired duration had been either reached or exceeded. If the duration was less than desired, the program returned to reference point one. If the desired duration had been exceeded, the process was terminated when the specified number of cycles were generated.

If the duration was within the established time limits, the pattern was tested to determine whether it was representative of (similar to) the observed vehicle operation patterns used as inputs. If certain criteria were met, the pattern was retained in storage. If it was found not to satisfy the criteria, the pattern was erased from storage after the pattern-evaluation data were stored for statistical purposes. After each such test, the program was either terminated or returned to reference point one to generate another pattern.

3.2.2 Driving Pattern Selection

The Monte Carlo cycle generation procedure described above can generate highly nonrepresentative cycles. Therefore, pattern evaluation measures, summarized in Table 3-9, were used to identify representative cycles.

Table 3-9. DRIVING PATTERN EVALUATION CRITERIA

- Kolmogorov-Smirnov Difference Test
  Acceleration
  Deceleration
  Cruise
  Overall

- Figure of Merit

- Summary Measures
  Percent Acceleration
  Percent Deceleration
  Percent Cruises
  Percent Idle
  Average Speed

Since a basic goal of this project was to generate driving patterns representative of observed driving habits, the problem of matrix similarity was of prime importance. Although it would be ideal to generate a driving pattern which, for example, had a normalized mode-frequency matrix identical to that of the corresponding input matrix, it was not possible to do so because of the short duration of the pattern relative to the large amount of time reflected in the input matrices.

Since the problem was that of comparing two sets of numbers to determine how close the numbers were in magnitude, it was natural to consider the set of statistical techniques generally used to make comparisons; i.e., to do significance testing. An attractive feature of statistical testing was the provision of criterion levels which permitted the acceptance or rejection of hypotheses at any desired confidence level. This process was referred to as cycle filtering.

For these reasons, it was first decided to apply the Kolmogorov-Smirnov Difference Test (KS-Test) for matrix-comparison. The KS one-sample test is a test of goodness of fit and is concerned with the degree of agreement between a set of sample values (observed scores) and a specified theoretical distribution. It determines whether the sample values can reasonably be considered to have come from a population having the theoretical distribution.

Acceptance or rejection of the null hypothesis (i.e., that the matrices are not significantly different) with the KS-test was referenced to a criterion level depending only on the number of degrees of freedom and the selected Type I error confidence level (80 percent). The 80 percent confidence level was selected to minimize the Type II error probability. Application of the KS-test involved formulating a distribution function (cumulative percent table) of the modes to be tested of both the input matrix and the corresponding cycle matrix. The greatest difference between corresponding cells of the distribution function was then determined. The KS-test was satisfied; i.e., the cycle was representative of the input data, if the largest difference was less than the statistical criterion.

For pattern evaluation purposes, KS-tests were performed between the input matrices and driving pattern matrices for the acceleration, deceleration, and cruise modes, and for the composite of all modes. Consequently, eight KS-tests were computed for each cycle: four for the normalized time-in-mode matrix and four for the normalized mode-frequency-of-occurrence matrix. For a cycle to be accepted as statistically representative, all eight KS-tests had to be satisfied.

A figure of merit was then defined which consisted of a linear combination of the eight KS differences. The smaller the value of the figure of merit, the more representative the pattern. The statistical data for each pattern meeting the desired criteria were computer-sorted and outputted in ascending order of figure of merit.

Finally, the idle, cruise, acceleration, and deceleration data were summed by category to yield the percent of time spent in each of the four mode types and the percent frequency of occurrence of each of the mode types. Statistical tests were not performed. However, the summary measures for the cycles were compared to the input matrices to insure similarity.

Five hundred unfiltered driving cycles were generated for each of the nine freeway and nine nonfreeway routes from the winter and spring data samples. From these 18,000 cycles, ten unfiltered unrepresentative cycles for each route, road type, and season were selected between the highest to lowest speeds of the generated cycles on the route. Emission factors were then developed for each driving cycle as described in Section 3.3. These data were transmitted to TRW.

Some 35,000 driving cycles were generated for freeway, nonfreeway, and composite freeway and nonfreeway driving. From these, ten statistically representative cycles were selected by the KS-test for each of freeway, nonfreeway, and composite driving. The 30 driving cycles were then plotted and visually inspected to select one of each which appeared to have a reasonable sequence of modes and rates of transitions. Plots of the three cycles and tables of speed versus time for the three cycles are shown in Appendix C.

3.3 VEHICLE EMISSION ESTIMATES

Vehicle emissions were estimated using a modal emission data base and interpolation program supplied by the EPA (Ref. 6). Modal emission factors were time integrated using the driving cycles derived according to the procedures described in the preceeding paragraph. A small test fleet was utilized in an effort to validate the emissions estimates by measuring mass emissions while driving the composite SCAB cycle. Finally, specific C_1 to C_{10} hydrocarbon species were identified by gas chromatography of diluted exhaust collected while the vehicles were driven over the composite cycle.

3.3.1 Modal Emission Data Bases

Modal emission data has been collected for several years as part of the EPA emission factor, in-use compliance, and surveillance vehicle test programs. Eighteen data bases, distinguished by vehicle model-year and city, have been established to date and are shown in Table 3-10.

Table 3-10. MODAL EMISSION DATA BASES (REF 6)

DATA BASE	MODEL YEAR	LOCATION
1	1957 - 1967	Denver
2	1957 - 1967	Low Altitude, No 1966, 1967 California
3	1966 -1967	California
4	1968	Low Altitude
5	1969	Low Altitude
6	1970	Low Altitude
7	1971	Low Altitude
8	1968	Denver
9	1969	Denver
10	1970	Denver
11	1971	Denver
12	1972	Denver
13	1972	Los Angeles
14	1972	Low Altitude
15	1973 - 1974	Denver
16	1973 - 1974	Los Angeles
17	1973 - 1974	Low Altitude
18	1975	Low Altitude

Of these data bases only the first 11 were available from EPA at the time emission factors were calculated for TRW. Only data bases 2 through 7 were applicable to California. Therefore, the emission factors provided to TRW only include data for 1957 to 1971 model-year vehicles.

3.3.2 Estimated Mass Emissions

After selection of typical driving patterns at the various average route speeds, an EPA-supplied computer program (Ref. 6) was utilized to estimate the emissions over each pattern for each vehicle group. The driving pattern generation computer program was modified by computing and storing speed data on a second-by-second basis and incorporating the EPA-supplied program. The model interpolates for cruise or acceleration/deceleration modes which were not included in the original data bases by the use of polynomial regression functions. The emissions for HC, CO, and NO_x were calculated for the ten driving cycles for each data base (a total of 360 cycles). The emissions and average speed for each pattern and vehicle group combination were then output on punched cards for transmittal to TRW. An overview of the process is shown in the flow diagram of Figure 3-6. The three representative SCAB driving cycles (freeway, nonfreeway and combined) were also used to estimate emissions and fuel economy. These estimates are presented in Table 3-11 for all 18 data bases which were available as of September, 1976.

3.3.3 Measured Mass Emissions

Fifteen dynamometer tests were performed to determine whether the estimated emissions were comparable to actual emissions. All dynamometer tests were hot start CVS tests using the composite freeway and nonfreeway driving

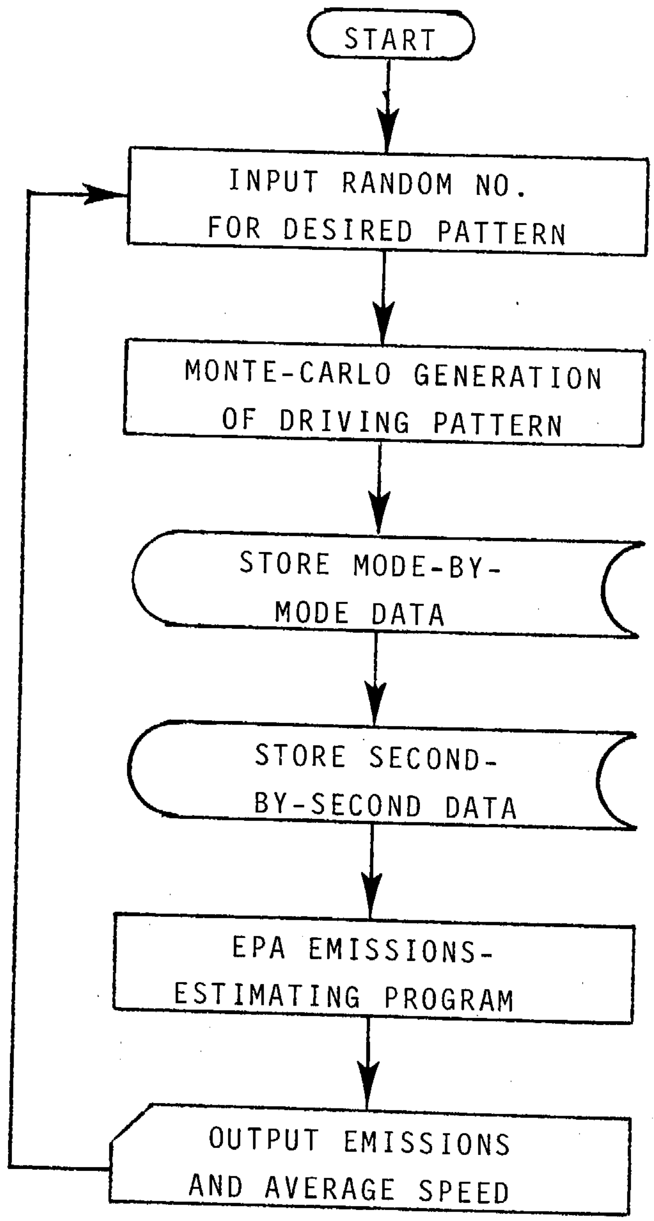


Figure 3-6. CYCCRUD PROGRAM FLOWCHART FOR CALCULATING EMISSION FACTORS

Table 3-11. ESTIMATED EMISSION FACTORS BASED ON EXISTING DATA BASES[1] AND DERIVED SCAB DRIVING CYCLES

NO.	DATA BASE		FREEWAY CYCLE				NONFREEWAY CYCLE				COMPOSITE CYCLE			
	Vehicle Yr.	Location	HC	CO	NO_x	MPG	HC	CO	NO_x	MPG	HC	CO	NO_x	MPG
1	1957-1967	Denver	4.89	83.54	3.52	18.61	7.16	112.00	2.27	17.83	6.38	103.80	2.75	17.97
2*	1957-1967	Low Alt.	3.97	40.15	4.98	19.74	6.16	63.01	3.75	17.32	5.39	54.94	4.28	18.04
3	1966-1967	Los Angeles	2.79	26.26	4.57	20.14	4.50	39.36	3.49	16.88	3.86	34.40	3.99	17.94
4	1968	Low Alt.	2.27	30.16	5.54	19.87	4.06	51.05	4.49	16.57	3.42	43.42	4.99	17.57
5	1969	Low Alt.	2.22	18.62	7.18	19.36	3.75	38.69	5.96	16.33	3.21	31.00	6.57	17.26
6	1970	Low Alt.	1.92	14.44	7.13	19.89	2.87	31.34	5.54	16.43	2.54	24.98	6.28	17.50
7	1971	Low Alt.	1.55	14.86	6.49	19.82	2.42	31.95	5.06	16.32	2.12	25.78	5.73	17.39
8	1968	Denver	3.61	75.51	3.85	18.81	4.64	94.48	2.60	18.30	4.32	90.22	3.07	18.33
9	1969	Denver	2.89	56.81	4.07	20.33	3.59	65.13	2.95	19.60	3.36	64.66	3.41	19.73
10	1970	Denver	3.06	56.63	4.97	18.78	4.35	82.13	3.26	17.61	3.92	75.53	3.92	17.85
11	1971	Denver	2.73	51.91	4.77	18.51	3.78	82.67	3.27	15.56	3.45	74.41	3.86	16.37
12	1972	Denver	2.86	57.04	5.19	19.48	4.05	78.41	3.24	16.42	3.66	72.61	3.99	17.32
13*	1972	Los Angeles	1.72	10.96	5.63	21.68	2.46	25.75	4.53	16.81	2.24	21.02	5.06	18.18
14	1972	Low Alt.	1.83	19.32	5.96	19.40	2.95	35.00	4.24	15.88	2.57	29.65	4.97	16.98
15	1973-1974	Denver	2.46	51.96	3.08	18.31	3.41	69.85	2.01	16.06	3.11	65.45	2.44	16.68
16*	1973-1974	Los Angeles	1.40	10.40	3.60	19.17	2.33	22.22	3.19	15.20	2.05	18.73	3.45	16.31
17	1973-1974	Low Alt.	0.30	6.92	3.68	18.99	0.68	14.44	2.82	16.36	0.55	12.09	3.24	17.10
18	1975	Low Alt.	0.26	6.50	3.02	17.78	0.54	11.68	2.10	15.45	0.46	10.65	2.51	16.11

[1]Data bases include In-Use Compliance, Surveillance, and Emission Factor Programs (Ref. 6).

*Vehicles representative of these data bases were tested to compare emission levels.

cycle shown in Appendix C. All vehicles were consumer-owned 1972 to 1974 model-year vehicles, except for one 1965 Ford Mustang. The emissions data in grams per mile and fuel economy in miles per gallon are shown in Table 3-12. Although the test fleet size was small, the 95 percent confidence intervals for both the entire fleet and for the 1972 to 1974 model-year vehicles enclosed the estimated emissions based on the two Los Angeles data bases (13 and 16). In general, the estimated fleet emissions agreed well with the measured fleet emissions, except for 1965 model-year vehicle.

3.3.4 Determination of C_1 to C_{10} Hydrocarbons

Samples of the diluted exhaust were collected and sent to Analytical Research Laboratories, Inc., for determination of C_1 to C_{10} hydrocarbon composition by gas chromatography. In addition to the 15 vehicles tested on the composite SCAB driving cycle, ten vehicles were tested earlier in the program using the standard EPA Surveillance Driving Cycle. The mass emission data for these vehicles are presented in Table 3-13. Table 3-14 identifies the test numbers and vehicles which were tested on both cycles.

Vehicles tested on both driving cycles exhibited considerable variation in total hydrocarbon emissions and in hydrocarbon composition. Appendix D presents the diluted concentration data in mg/m^3 for each specie. Since the individual emissions varied so much, the percent composition was calculated for each identified specie for each test. These data are presented in Tables 3-15 and 3-16, respectively for the EPA Surveillance Driving Cycle and the derived SCAB composite cycle. The mean of the percent composition and the 95 percent confidence intervals are also presented. In general, the hydrocarbon percentage composition of parafinic compounds was higher for vehicles tested using the SCAB cycle than for vehicles tested using the Surveillance Driving Schedule.

Table 3-12. MEASURED EMISSIONS DURING COMPOSITE SCAB DRIVING CYCLE

TEST NO.	VEHICLE DESCRIPTION					HC	CO	NO_x	F.C
	Year	Make	Cylinder	Weight	Air	gm/mi	gm/mi	gm/mi	mpg
11	73	Buick	8	5500	Yes	3.23	18.65	5.95	11.69
12	73	Pinto	4	2750	No	1.62	24.04	4.52	28.74
13	72	Vega	4	2500	No	2.41	33.85	3.81	23.88
14	73	Vega	4	2500	No	1.38	16.49	3.23	25.40
15	65	Mustang	6	2750	No	4.08	34.73	3.44	23.67
16	72	Toyota	4	2750	Yes	1.65	26.49	5.39	24.00
17	74	Plymouth	8	3000	Yes	2.57	39.25	1.17	18.95
18	73	Mercury	8	5000	Yes	1.84	18.21	7.44	14.55
19	74	Buick	8	4000	Yes	2.15	16.10	3.23	13.88
20	73	Comet	6	3000	Yes	2.29	11.81	3.76	16.91
21	73	Pinto	4	2750	Yes	1.72	20.03	6.91	23.51
22	72	Hornet	8	3000	Yes	2.79	18.97	7.08	18.76
23	72	Pontiac	8	4500	Yes	1.06	6.25	3.45	13.99
24	72	Pontiac	8	4000	Yes	1.22	11.34	4.85	12.57
25	73	Ford	8	4000	Yes	2.41	27.75	2.75	15.08

Table 3-13. MEASURED EMISSIONS DURING EPA SURVEILLANCE DRIVING CYCLE

TEST NO.	VEHICLE DESCRIPTION					HC	CO	NO_x	F.C
	Year	Make	Cylinder	Weight	Air	gm/mi	gm/mi	gm/mi	mpg
1	72	Mustang	8	3,000	Yes	1.30	14.93	3.84	21.39
2	72	Pontiac	8	4,000	Yes	1.20	11.44	5.19	18.99
3	72	Buick	8	5,500	Yes	0.83	8.43	2.59	15.46
4	72	Hornet	8	3,000	Yes	1.92	12.79	8.30	24.19
5	73	Ford	8	4,000	Yes	1.89	21.68	2.80	18.72
6	72	Pinto	4	2,250	No	1.27	30.60	3.03	32.18
7	73	Pinto	4	2,750	No	1.12	15.28	5.99	30.96
8	72	Chevrolet	8	4,000	Yes	1.21	17.28	4.99	18.92
9	73	Comet	6	3,000	Yes	1.37	8.44	4.69	21.51
10	74	Duster	6	3,500	Yes	1.59	29.37	2.74	23.08

Table 3-14. VEHICLES TESTED ON BOTH DRIVING CYCLES

VEHICLE DESCRIPTION					EPA SURVEILLANCE CYCLE TEST NO.	SCAB CYCLE TEST NO.
Year	Make	Cylinder	Weight	Air		
72	Pontiac	8	4,000	Yes	2	24
72	Buick	8	5,500	Yes	3	11
72	Hornet	8	3,000	Yes	4	22
73	Ford	8	4,000	Yes	5	25
73	Pinto	4	2,750	No	7	12
73	Comet	6	3,000	Yes	9	20

Table 3-15. SUMMARY OF EXHAUST HYDROCARBON PERCENT COMPOSITION DURING EPA SURVEILLANCE DRIVING CYCLE

SPECIES			TEST NUMBER												
Carbon	Name	Class	1	2	3	4	5	6	7	8	9*	10*	CONFIDENCE LIMITS Mean	+95%	-95%
C_1	Methane	P	2.91	3.08	2.98	2.93	3.31	4.15	4.03	3.47	0.39	4.40	3.17	3.97	2.37
C_2	Ethane/Acetylene	P	11.25	12.85	12.86	14.93	10.93	11.43	13.17	16.53	7.67	0.79	11.06	14.36	7.76
C_3	Propylene	O	7.31	9.54	8.01	8.65	7.45	8.37	7.20	7.40	2.61	0.63	6.72	8.74	4.70
C_4	Isobutane	P	5.31	1.66	1.43	0.51	0.17	7.10	4.67	2.72	-	1.73	2.81	4.63	0.99
C_4	Butane	P	-	-	-	0.08	1.35	0.87	-	-	0.29	-	0.65	1.56	-0.27
C_4	Isobutene	O	-	-	0.20	-	-	-	0.35	0.57	2.02	1.10	0.85	1.32	-0.38
C_4	Butene	O	5.48	1.79	0.15	1.19	0.55	5.09	2.13	3.37	3.39	-	2.57	4.03	1.11
C_5	Isopentane	P	5.06	3.45	3.93	4.45	2.42	6.82	2.21	4.05	-	3.93	4.04	5.10	2.97
C_5	Alkene	O	10.53	6.08	8.56	5.33	3.69	7.12	4.88	5.84	9.34	-	6.82	8.55	5.09
C_5	Alkane	P	0.11	0.06	0.31	0.36	0.13	-	0.77	0.14	-	-	0.27	0.50	0.04
C_5	Pentane	P	-	0.02	0.20	0.11	-	0.94	-	-	0.10	-	0.27	0.74	-0.20
C_6	Alkene	O	3.59	3.95	5.36	5.91	7.66	-	7.88	4.85	12.24	0.47	5.77	8.30	3.23
C_6	Alkane	P	9.44	4.40	2.36	3.98	2.33	3.36	0.99	0.63	0.84	-	3.15	5.24	1.05
C_6	Hexane	P	0.85	1.94	1.21	1.90	1.16	1.00	-	0.34	-	2.20	1.33	1.86	0.79
C_7	Alkene	O	5.85	5.83	3.18	5.21	0.41	1.02	3.27	3.65	3.88	1.10	3.34	4.76	1.92
C_7	Alkane	P	5.17	1.13	6.64	2.12	1.59	1.23	4.05	4.77	3.00	0.79	3.05	4.59	1.61
C_8	Alkene	O	0.18	2.46	4.66	1.72	1.54	1.77	13.46	14.36	5.85	-	5.11	9.17	1.06
C_8	Alkane	P	0.98	2.37	-	1.32	0.27	1.68	2.65	1.66	14.11	3.30	3.15	6.38	0.09
C_8	Benzene	A	8.93	11.57	9.33	12.82	10.64	12.26	6.49	0.91	1.97	7.23	8.22	11.16	5.26
C_8	Xylene	A	0.49	0.89	2.46	1.13	0.62	0.76	1.32	0.30	0.20	2.83	1.00	1.74	0.46
C_9	Alkene	O	-	0.06	-	-	-	-	-	0.76	-	-	0.41	4.86	-4.04
C_9	Toluene	A	8.17	12.76	11.46	11.40	-	13.05	4.16	0.90	0.25	-	7.77	12.21	3.32
C_9	Aromatic	A	5.97	0.89	4.97	7.58	11.32	7.43	10.50	-	10.23	0.79	6.63	9.63	3.63
C_{10}	Ethylbenzene	A	-	-	2.70	-	25.12	-	-	11.57	13.18	22.64	15.04	26.29	3.78
$C_{10}+$	Aromatic	A	2.69	13.21	7.04	6.42	7.32	4.54	5.83	11.20	8.46	46.54	7.41	8.43	6.39
C_1-C_8	Parafins	P	41.08	30.96	31.93	32.69	23.66	38.58	32.54	34.31	26.40	17.14	30.93	35.95	25.90
C_3-C_9	Olefins	O	32.94	29.71	30.12	28.01	21.30	23.37	39.17	40.80	39.33	3.30	28.81	32.33	25.29
C_8+	Aromatic	A	26.25	39.32	37.96	39.35	55.02	38.04	28.30	24.88	34.29	80.03	40.34	45.53	35.16

*Samples collected in Tedlar bags had substantially different composition and were not included in mean.

Table 3-16. SUMMARY OF EXHAUST HYDROCARBON PERCENT COMPOSITION DURING COMPOSITE SCAB DRIVING CYCLE

SPECIES			TEST NUMBER															CONFIDENCE LIMITS		
Carbon	Name	Class	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Mean	+95%	-95%
C_1	Methane	P																		
C_2	Ethylene	P																		
C_2	Acetylene	P	19.52	16.73	17.71	5.06	32.00	34.39	28.15	11.10	15.24	13.47	31.97	16.98	29.77	24.04	12,80	20.59	25.53	15.65
C_3	Propylene	O	3.35	3.61	4.60	2.88	6.02	11.90	9.98	4.88	5.46	5.10	6.93	2.43	5.61	9.86	4.31	5.80	7.34	4.25
C_4	Isobutane	P	0.89	0.79	0.85	7.63	-	-	-	-	0.43	0.86	1.01	0.77	-	-	0.71	1.55	3.31	-0.21
C_4	Butane	P	3.90	4.27	2.99	24.90	3.43	3.12	2.43	5.21	2.29	3.06	3.46	3.92	2.85	2.47	4.00	4.76	7.88	1.65
C_4	Butene	O	9.48	9.84	3.45	1.48	9.91	16.93	10.75	11.72	4.57	10.41	7.99	8.25	12.51	6.78	5.23	8.62	10.79	6.45
C_5	Isopentane	P	9.34	7.22	5.98	19.05	7.62	6.61	8.70	9.77	5.46	8.98	6.93	8.40	5.61	5.24	12.93	8.52	10.49	6.55
C_5	Alkene	O	0.75	-	-	1.09	0.49	-	-	-	0.41	-	-	0.99	-	-	0.62	0.72	1.01	0.44
C_5	Pentane	P	5.58	6.89	3.22	14.01	2.82	2.65	0.56	2.44	0.41	6.53	5.33	7.84	4.27	1.05	6.77	4.89	6.74	3.05
C_6	Alkene	O	1.67	3.90	-	5.05	2.59	-	1.51	-	2.20	2.00	1.28	3.19	1.38	-	2.77	2.50	3.29	1.71
C_6	Hexane	P	2.79	5.25	18.17	2.33	1.52	-	1.00	-	15.25	3.47	3.73	7.09	2.98	10.96	3.39	6.77	10.86	2.67
C_7	Alkene	O	1.65	2.10	-	2.33	3.05	-	1.80	-	0.94	2.02	1.42	4.14	1.16	-	2.22	2.07	2.67	1.47
C_7	Alkane	P	5.58	3.64	-	3.58	2.82	-	1.66	-	2.80	5.51	2.93	5.60	2.47	-	-	3.66	4.67	2.64
C_7	Heptane	P	1.39	1.99	-	0.78	0.53	-	-	-	0.85	2.86	1.63	4.18	1.68	-	-	1.76	2.64	0.89
C_8	Alkane	P	0.91	-	-	1.60	12.88	6.88	4.99	11.72	-	2.16	-	-	-	3.14	-	5.54	9.39	1.68
C_8	Benzene	A	16.73	17.39	20.47	3.66	8.38	7.67	10.88	23.11	17.79	18.58	11.19	17.54	16.82	20.96	28.93	16.00	19.65	12.35
C_8	Octane	P	0.60	-	-	-	-	-	-	-	-	1.08	-	0.91	-	-	2.12	1.18	2.23	0.39
C_8	Xylene	A	0.99	-	-	-	-	-	1.60	2.44	0.61	-	-	-	-	-	-	1.41	2.68	0.14
C_9	Alkene	O	2.17	3.94	7.59	1.38	0.62	-	2.55	-	2.03	-	4.53	3.56	-	-	2.43	3.08	4.49	1.67
C_9	Toluene	A	11.57	8.53	7.59	3.19	5.33	9.79	11.00	16.60	9.66	13.88	9.59	4.48	12.94	5.49	10.77	9.36	11.49	1.65
C_{10}	Ethylbenzene	A	0.54	-	-	-	-	-	0.50	1.01	1.52	-	-	-	-	-	-	0.90	1.66	0.13
C_{11}	Undecane	P	0.68	3.94	7.36	-	-	-	1.28	-	6.99	-	-	1.21	-	-	-	3.49	6.77	0.21
C_{10}^+	Aromatic	A	-	-	-	-	-	-	0.67	-	1.94	-	-	-	-	-	-	1.32	9.53	-6.90
C_1-C_{11}	Parafins	P	51.18	50.72	56.28	78.94	63.62	53.65	48.77	40.24	53.09	47.98	61.52	55.84	49.63	56.90	42.72	54.07	59.22	48.93
C_3-C_9	Olefins	O	19.07	23.39	15.64	14.21	22.68	28.83	26.59	16.60	15.72	19.53	17.62	22.35	20.66	16.64	17.58	19.81	22.16	17.46
C_8^+	Aromatic	A	29.83	25.93	28.06	6.85	13.71	17.46	24.65	43.16	31.72	32.46	20.78	21.82	29.76	26.45	39.70	26.16	31.34	20.97

Note: Analysis on these samples did not distinguish between C_1 and C_2 hydorcarbons.

Section 4

DISCUSSION AND CONCLUSIONS

The results of this study, which have been presented in the preceding sections and subsequent appendices, provide a data base for refining the light-duty vehicle emission inventory in the South Coast Air Basin (SCAB). Specific contributions included the following:

- Updated and expanded driving pattern data base to include more areas of the SCAB.
- Processed data to derive driving cycles representative of driving patterns throughout the SCAB.
- Estimated emission factors based on SCAB driving patterns using an EPA computer model.
- Measured emissions from a fleet of vehicles driven on a representative derived driving cycle to validate the estimated emission factors.
- Characterized the composition of C_1 to C_{10} hydrocarbon emissions.

Data from the chase vehicle indicated that the mode frequency of average driving patterns has not changed significantly since the original CAPE-10 Vehicle Operation Survey conducted in 1971. The amount of time spent in cruises has increased, however, while the time spent in acceleration and deceleration has decreased. This has been accompanied by a slight increase in average speed from approximately 29 miles per hour to 31 miles per hour. These results confirm the original VOS conclusion that the LA-4 driving cycle does not represent typical driving patterns in the SCAB.

Three driving cycles were selected as representative of driving patterns in the SCAB. The first cycle included only freeway driving patterns. The second cycle included only nonfreeway driving patterns on principle city streets. The third cycle included both freeway and nonfreeway driving and represented average or typical driving throughout the SCAB. These cycles were used to estimate emission factors for 18 vehicle groups using an EPA supplied computer program. Emission factors were estimated for 1957-1975 model-year vehicles in several cities. Only eleven of the data bases were applicable to the Los Angeles vehicle population, however.

The third driving cycle, representing composite freeway and nonfreeway driving, was plotted and used to measure emissions from a fleet of 15 vehicles. The estimated emissions were within the upper and lower 95 percent confidence limits of the measured emissions indicating that the EPA computer model accurately predicted actual emissions.

In addition to these three driving cycles, ten driving cycles were generated for each SCAB survey route by road type and season. These 360 cycles differed from the three discussed above in that they were not statistically representative of the driving survey data base. Rather they were randomly generated combinations of modes derived from the driving survey data. They, therefore, represented possible, although not necessarily typical driving cycles.

Emission factors were also estimated for these driving cycles using the EPA modal emission model. These emission factors were not analyzed by Olson but were provided to TRW for development of speed correction factors. The NO_x data were observed to be highly variable for different derived driving cycles while HC and CO data were relatively independent of the driving cycle. Since NO_x emissions tend to be speed or load dependent, i.e., vacuum advance and EGR modulation, changing the cycle may have significant effect on emissions even though the average speed is unchanged. The HC and CO emissions, however, were apparently independent of the cycle and correlated well with average speed. As expected, the cycle average emissions of NO_x tended to be higher for freeway cycles than for nonfreeway cycles.

Emissions were also measured using the EPA Surveillance Driving Schedule for six of the same vehicles used in the above test fleet. These emissions were significantly lower for HC, somewhat lower for CO and generally similar for NO_x as the emissions measured using the SCAB composite driving cycle. The reason for these differences were not identified, although the EPA Surveillance Driving Schedule does not have as much cruise operation as the SCAB composite cycle.

The C_1 to C_{10} hydrocarbon emission composition was measured using both the EPA Surveillance Driving Schedule and the SCAB composite cycle. The difference in total hydrocarbon emissions noted above was also reflected in differences in hydrocarbon composition. In general, the SCAB driving cycle resulted in more C_1, C_2 and parafinic hydrocarbons and benzene than the EPA Surveillance Driving Schedule. However, there was substantial vehicle-to-vehicle variation in hydrocarbon emissions and composition for both cycles.

In summary, the following conclusions have resulted from this study:

- Nonfreeway driving patterns in the SCAB are similar to those found in the original CAPE-10 Vehicle Operation Survey (VOS).

- Composite driving patterns in the SCAB which include both freeway and nonfreeway driving are similar to the VOS in the mode frequency but include more time spent in cruise and less time spent in acceleration or deceleration.

- The average speed in the SCAB has increased slightly since the VOS (29 mile per hour to 31 miles per hour).

- Measured emissions agreed well with the emissions estimated from a computer model for 1972 to 1974 model year vehicles.

- Hydrocarbon emissions from the derived SCAB driving cycle are higher than from the EPA Surveillance Driving Cycle.

- Hydrocarbon composition is highly variable although the composite SCAB driving cycle tended to produce more parafinic hydrocarbons than the EPA Surveillance Driving Schedule.

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Appendix A

CHASE VEHICLE OPERATIONAL PROCEDURES

Appendix A

OPERATING PROCEDURE FOR ARB CHASE VEHICLE

A.1 VEHICLE AND SYSTEM PREPARATION

1. The day's recording should normally be started with a full gas tank and the vehicle refilled during the lunch or dinner break as need dictates.

2. At least three blank tapes should be in the vehicle when starting out. One spare is recommended in case a tape should break or prove defective.

3. All the magnetic tape reels must contain a write ring to record data on the tape. The write ring is a 3-inch diameter black plastic ring pressed into a groove located on the backside of the tape reel. (If a ring is not present, the file protect indicator on the tape transport (recorder) will illuminate and data cannot be recorded on the tape.)

4. Verify that the Calibrate/Operate valve for the manifold vacuum transducer valve is in the Operate position.

5. Verify that gasoline credit cards are in the possession of either the driver or observer.

6. Verify that appropriate maps, log sheets and other necessary items are present in the

vehicle before leaving for the start of the route.

A.2 SYSTEM STARTUP

1. Turn the Main Power switch "on."

2. Turn the Clock Power switch "on."

3. Observe that Display and Transport power is "on."

A.3 TAPE LOADING

1. Install a fresh data tape on the tape transport.

2. Label the tape with the day and Segment numbers 1 and 2.

3. Thread the tape by following Steps 4 through 11 and referring to the diagram on the face of the transport.

4. Lead the end of the tape down and around the fixed guide; then around the left side of the buffer arm guide.

5. Continue across the head assembly from left to right by passing over the fixed guide, tape cleaner, head, and second fixed guide to the capstan.

6. At the capstan end of the head assembly, lead the tape below and around the right side of the capstan.

7. Pass the tape around the left side and over the top of the other buffer guide.

8. Lead the tape below and around the right side of the fixed takeup reel.

9. Press the tape end against the top of the hub.

10. Holding the tape against the hub, turn the reel until the end of the tape is overlapped and secured by the next tape layer.

11. To complete the loading operation, firmly press the LOAD pushbutton. Both buffer arms will move to their normal operating positions and the capstan will pull the tape forward until the beginning-of-tape (BOT) marker reaches the photosensor assembly.

12. Observe that the Power, Load, and On Line indicators are illuminated.

13. If all three indicators are "on" the transport is ready; if not, recheck the loading and correct the problem.

A.4 OPERATORS CONSOLE SETUP

1. Set the current day of the year into the three thumbwheel switches labeled DAY.

2. Place the clock Run/Hold switch in the "Hold" position (down).

3. The time of day clock is set to a desired number using the Time Set thumbwheel. Depress the pushbutton switch above the selected display to load that particular display. Repeat this operation for each clock position (Hours, Minutes, Seconds).

4. Place the Run/Hold switch in the "Run" position.

5. Observe that the clock increments at 1-second intervals from the present correct time.

6. Set the Weather switches to the desired pattern (see Table A-1).

7. Set the Segment switch to "1."

8. Set the Trip switch as shown in Table A-1.

9. Set the Route switch to the appropriate route number to be run that day (see Table A-1 and calendar schedule).

10. Set the Fleet Select toggle switch to the "000" position.

A.5 DATA COLLECTION PROCEDURE

A.5.1 Segment 1*

1. Drive the chase vehicle to the route starting point and park.

2. Dial in the appropriate trip selection number (see Table A-1).

3. At start time, press the Record Start pushbutton and proceed on the route.

4. Observe that the tape moves off the load point and proceeds forward in 1-second increments.

5. Log the starting time, mileage, dial in the make of vehicle being chased (see Table A-1 and A-2) and proceed on the route.

6. Throughout the route refer to Table A-1 and dial in any required data such as traffic density, condition, visibility, and type of road (trip selection number).

7. Select the Recorded Data display and observe that data is being recorded correctly.

*NOTE: All data collection must be started with the vehicle completely stopped (0 MPH) and terminated after the vehicle has come to a complete stop. This applies to all recorded segments.

8. Follow Step 7 frequently during the route to verify correct system performance so that a minimum of data is lost due to a system malfunction or operator error.

9. Upon completion of the first segment, stop the vehicle, press the Record Stop pushbutton, and log the time and mileage.

A.5.2 Segment 2

1. Drive the chase vehicle to the route starting point and park.

2. Dial in "2" in the Segment switch.

3. Dial in the appropriate trip selection number (see Table A-1).

4. At start time press the Record Start pushbutton and proceed on the route.

5. Observe that the tape proceeds forward in 1-second increments.

6. Log the starting time, mileage, dial in the make of vehicle being chased and proceed on the route.

7. Throughout the route refer to Table A-1 and dial in any required data such as traffic density, condition, visibility, and type of road (trip selection number).

8. Select the Recorded Data display and observe that data is being recorded correctly.

9. Follow Step 8 frequently during route to verify correct system performance so that a minimum of data is lost due to system malfunction or operator error.

10. Upon completion of Segment 2, stop the vehicle, press the Record Stop pushbutton and log the time and mileage.

11. Press the End of File pushbutton and observe that the tape moves forward approximately 1 inch.

12. Repeat Step 11.

13. Press Reset on the tape transport.

14. Press Rewind and observe that the tape goes into the rewind mode until the load point foil is detected then proceeds forward and stops at the foil load point tab.

15. Press Rewind again and the tape will unload.

16. Remove the tape from the transport and place it in it's container.

17. During lunch or dinner break (normally after Segment 2) the data system can be turned off (Main Power to "Off" position) and the Clock Power should remain "on." This is especially important if the vehicle is to be closed and unattended as the data system may overheat.

A.5.3 Segment 3

1. Turn "on" Main Power switch.

2. Load a fresh data tape (see "Tape Loading Procedure").

3. Label tape with day and Segment numbers 3 and 4.

4. Set the thumbwheel Segment switch to "3."

5. Dial in the appropriate trip selection number.

6. Proceed to the route starting point and park.

7. At start time press the Record Start pushbutton and proceed on the route.

8. Observe that the tape moves off load point and proceeds forward in 1-second increments.

9. Log the starting time, mileage, dial in the make of vehicle being chased and proceed on the route.

10. Throughout the route refer to Table A-1 and dial in any required data such as traffic density, condition, visibility, and type of road (trip selection number).

11. Select the Recorded Data display and observe that data is being recorded correctly.

12. Follow Step 11 frequently during the route to verify correct system performance so that a minimum of data is lost due to system malfunction or operator error.

13. Upon completion of Segment 3, stop the vehicle, press the Record Stop pushbutton and log the time and mileage.

A.5.4 Segment 4

1. Drive the vehicle to the route starting point and stop.

2. Set the thumbwheel Segment switch to 4.

3. Dial in the appropriate trip selection number.

4. At start time, press the Record Start pushbutton and proceed on the route.

5. Observe that the tape moves forward in 1-second increments.

6. Log the time, mileage, and dial in the make of vehicle.

7. Dial in any required data as done in the previous segments.

8. Select Pecorded Data and observe correct data as done in previous segments.

9. Upon completion of Segment 4, stop the vehicle, press the Record Stop pushbutton and log the time and mileage.

10. Press the End of File pushbutton and observe that the tape moves forward approximately 1 inch.

11. Repeat Step 10.

12. Unload the tape as done previously (Segment 2, Steps 13 through 16).

13. Turn the Main Power and Clock Power "off."

14. The two tapes containing the day's recorded data should now be removed from the vehicle and stored in an appropriate place.

A.5. DESCRIPTIVE INFORMATION AND DEFINITIONS

Route - There are nine (9) survey routes identified. During any given day, one and only one route will be followed.

Segment - There are four (4) segments for each route. These segments will be followed in sequence, no exception. The starting time of each segment is significant. Thus, if the preceding segment is completed and the next segment is not due to start, the driver will park and wait at a convenient location. This applies only to segment start time.

Trip - The trip indicator will be used to denote the type of road traveled. There are freeway, major arterial, and collector roads which are defined as follows:

> Freeway - Only roads designated as freeways on street maps will be coded as such.

Major Arterials - Major surface streets, usually with highway number assigned, will be coded as major arterials. See route maps for coding.

Collectors - All streets not designated as freeways or major arterials will be coded as collectors.

Traffic Density - A general indication of the amount of vehicles on the road going in the same direction as the chase vehicle will be recorded using the first digit of the Weather switches. The following definitions will be used:

Light - Usually encountered during early morning or late night, typically very few vehicles on the road travelled.

Moderate - Usually encountered during mid-morning and mid-day, number of vehicles about normal for type of road and area.

Heavy - Usually encountered during peak-hour traffic, morning and evening, with many vehicles on road travelled.

Stop and Go - Extremely heavy traffic due to peak-hour congestion, special event traffic congestion, road construction, or traffic accident.

Traffic Conditions - A general indication of traffic flow conditions will be recorded using the second digit of the Weather switches. The following definitions will be used:

Normal - Traffic flow as expected for type of road, time of day, day of week.

Obstruction - Traffic flow impeded due to weather, visibility, unusual circumstances such as dog on road, buildings or large objects being transported, etc.

Accident - Traffic flow impeded by accident or stalled vehicles.

Road Construction - Traffic flow impeded due to construction, land painting, etc.

Visibility and Precipitation - A general indication of weather conditions as they affect traffic flow will be recorded using the third digit of the Weather switches. The following criteria will apply:

Visibility Normal - Visibility obscured by light rain or light fog.

Visibility Moderate - Visibility obscured by light rain or light fog.

Visibility Greatly Reduced - Visibility greatly impaired by heavy rain or heavy fog.

Precipitation Light - Light fog, light rain, or heavy dew.

Precipitation Moderate - Moderate rain of intermittent nature, normally requiring low speed windshield wiper action.

Precipitation Heavy - Heavy continuous rain, normally requiring high speed windshield wiper action.

Table A-1. INPUT CODE DEFINITIONS

WEATHER

	1 TRAFFIC DENSITY	2 TRAFFIC CONDITION	3 VISIBILITY PRECIPTIATION
0	-	-	-
1	Light	Normal	Visibility Normal
2	Moderate	Obstruction	Visibility Moderately Reduced
3	Heavy	Accident	Visibility Greatly Reduced
4	Stop & Go	Road Construction	Precipitation Light
5			Precipitation Moderate
6			Precipitation Heavy
7			
8			
9			

SEGMENT	TRIP		ROUTE		
1	2	3	4	5	
-	-	-	-	-	
1	1 Freeway			1	(A)
2	2 Major Arterial			2	(B)
3	3 Collector			3	(C)
4				4	(D)
				5	(E)
				6	(F)
				7	(G)
				8	(H)
				9	(I)

Table A-1. INPUT CODE DEFINITIONS (Continued)

FLEET CODE

CODE	VEHICLE CHASED
001	Chevrolet Chevrolet, Chevelle, Corvair, Chevy II, Nova, Corvette, Camaro, Vega, El Camino, Monte Carlo
002	Ford Ford Galaxie, Fairlane, Torino, Mustang, Falcon, Maverick, Pinto, Thunderbird, Ranchero, LTD
003	Pontiac Pontiac, Tempest, Le Mans, GTO, Firebird, Grand Prix, Bonneville
004	Plymouth Fury, Belvedere, VIP, GTX, Valiant, Barracuda, Swinger, Duster
005	Buick Buick, Special, Riviera, Electra, Apollo, Wildcat
006	Oldsmobile Oldsmobile, F-85, Cutlass, Toronado, Ninety-Eight
007	Dodge Coronet, Monaco, Charger, Dart, Challenger, Polara
008	Mercury Mercury, Montego, Cyclone, Cougar, Lincoln Continental, Comet Meteor
009	Chrysler Chrysler, Imperial, New Yorker
010	American Motors Ambassador, Rebel, Rambler, Javelin, AMX, Gremlin

Table A-1. INPUT CODE DEFINITIONS (Continued)

CODE	VEHICLE CHASED
011	Cadillac Cadillac, El Dorado
012	Other American Checker, Edsel, DeSota, International, Jeep, G.M.C., Kaiser, Nash, Studebaker, etc.
013	Volkswagen
014	Other Foreign Cars Toyota, Datsun, Jaguar, MG, Porsche, etc.

NOTE: The fleet switch is to be in the "000" position when no vehicle is being followed.

Table A-2. SAMPLE ARB CHASE VEHICLE LOG SHEET

DAY ______________

ROUTE ______________

SEGMENT ______________

START MILEAGE ______________ START TIME ______________

END MILEAGE ______________ END TIME ______________

SEGMENT ______________

START MILEAGE ______________ START TIME ______________

END MILEAGE ______________ END TIME ______________

SEGMENT ______________

START MILEAGE ______________ START TIME ______________

END MILEAGE ______________ END TIME ______________

SEGMENT ______________

START MILEAGE ______________ START TIME ______________

END MILEAGE ______________ END TIME ______________

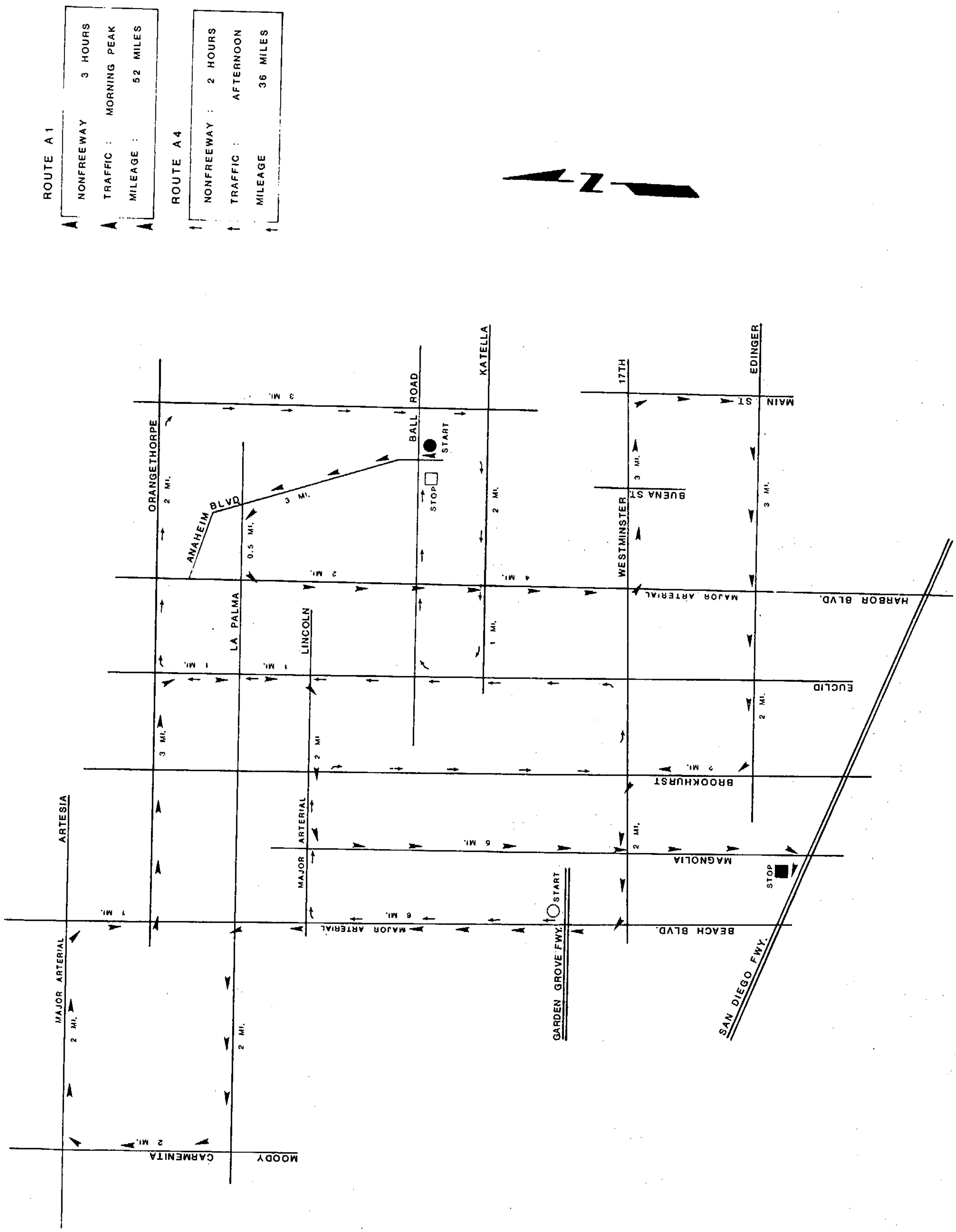
GAS: GALLONS ______ MILEAGE ______ PRICE ______ TIME ______

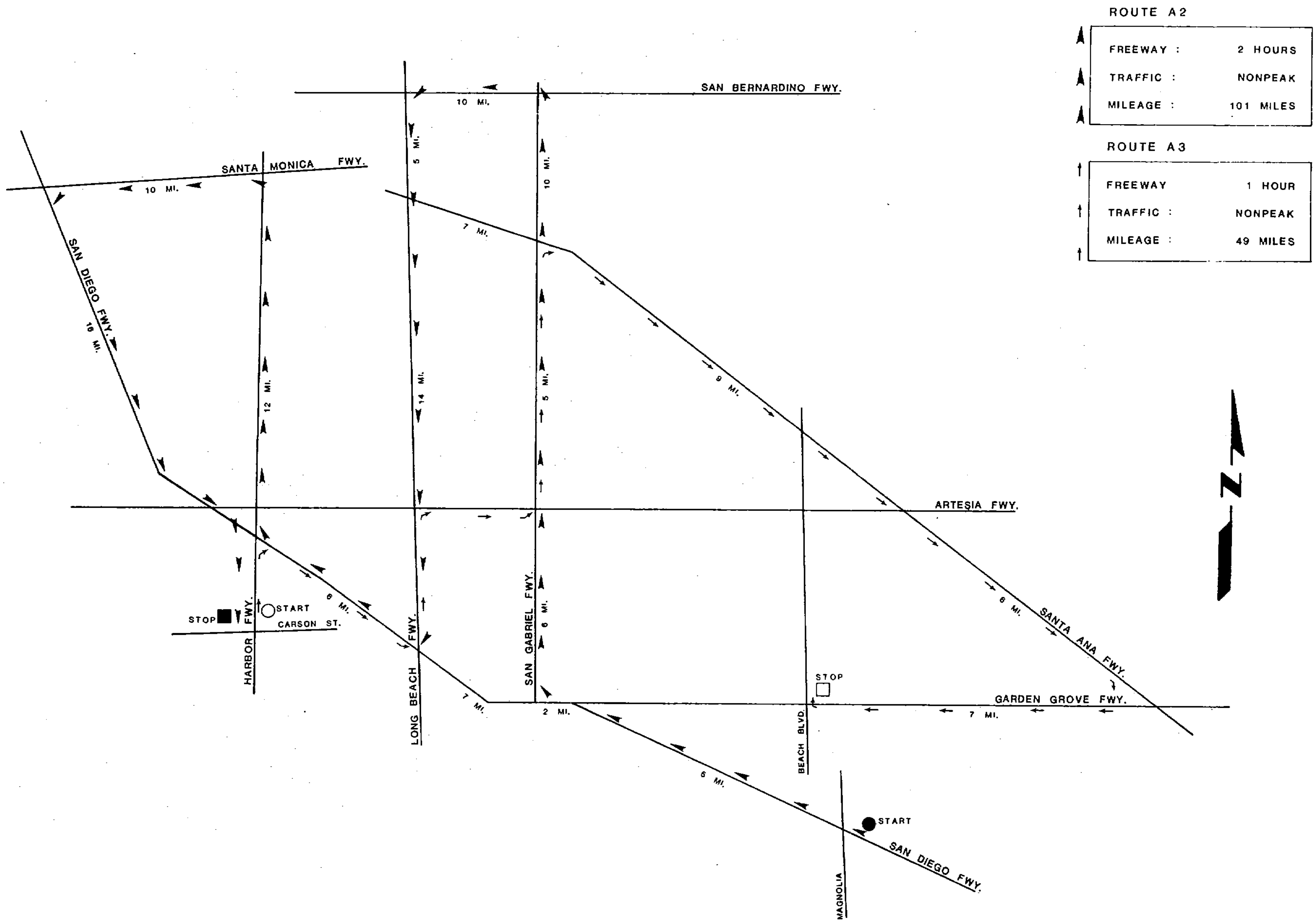
OIL: ______________

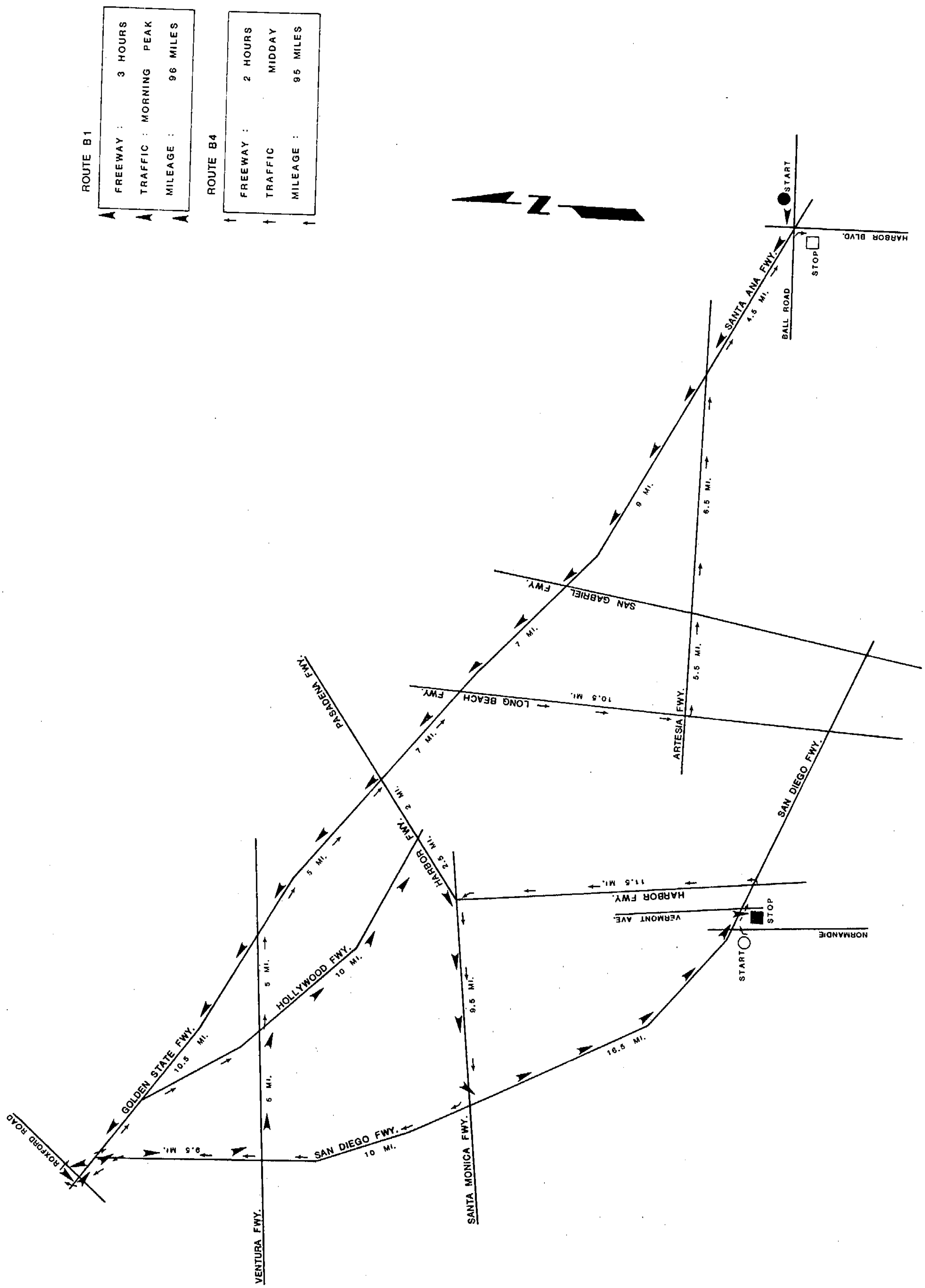
NOTES:

Appendix B

CHASE VEHICLE ROUTE MAPS


ROUTE A1
NONFREEWAY 3 HOURS
TRAFFIC : MORNING PEAK
MILEAGE : 52 MILES
ROUTE A4
NONFREEWAY : 2 HOURS
TRAFFIC : AFTERNOON
MILEAGE 36 MILES
N
ORANGETHORPE
BALL ROAD
KATELLA
17TH
EDINGER
MAIN ST
START
STOP
ANAHEIM BLVD
BUENA ST
WESTMINSTER
LA PALMA
LINCOLN
HARBOR BLVD.
MAJOR ARTERIAL
EUCLID
BROOKHURST
ARTESIA
MAGNOLIA
BEACH BLVD.
GARDEN GROVE FWY.
SAN DIEGO FWY.
MOODY
CARMENITA


ROUTE A2
FREEWAY : 2 HOURS
TRAFFIC : NONPEAK
MILEAGE : 101 MILES
ROUTE A3
FREEWAY 1 HOUR
TRAFFIC : NONPEAK
MILEAGE : 49 MILES
N
SAN BERNARDINO FWY.
SANTA MONICA FWY.
SAN DIEGO FWY.
ARTESIA FWY.
HARBOR FWY.
LONG BEACH FWY.
SAN GABRIEL FWY.
SANTA ANA FWY.
GARDEN GROVE FWY.
BEACH BLVD.
MAGNOLIA
CARSON ST.
START
STOP
10 MI.
7 MI.
9 MI.
6 MI.
16 MI.
12 MI.
14 MI.
5 MI.
2 MI.

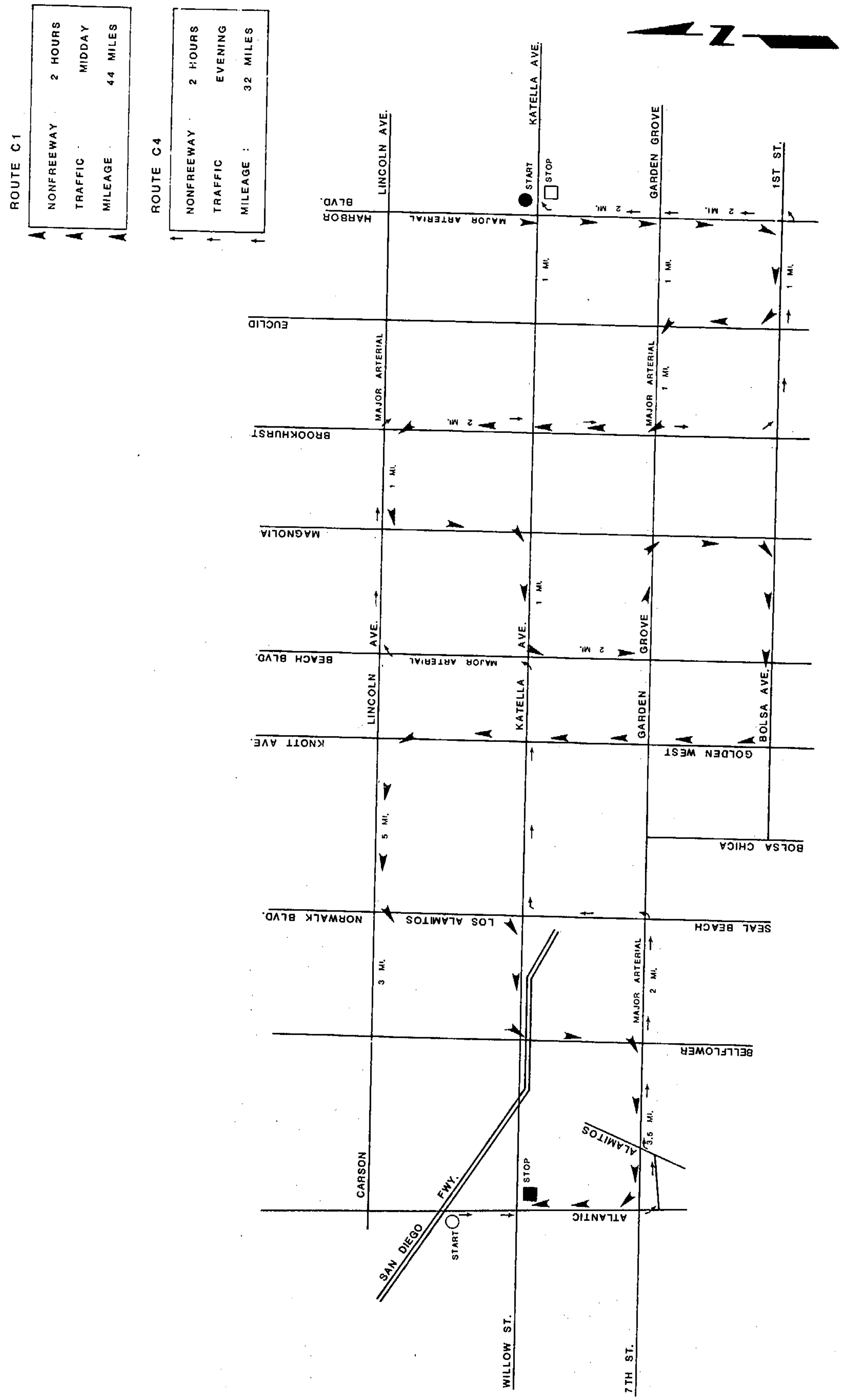

ROUTE B1
FREEWAY : 3 HOURS
TRAFFIC : MORNING PEAK
MILEAGE : 96 MILES
ROUTE B4
FREEWAY : 2 HOURS
TRAFFIC : MIDDAY
MILEAGE : 95 MILES
N
START
STOP
HARBOR BLVD.
BALL ROAD
SANTA ANA FWY.
4.5 MI.
9 MI.
6.5 MI.
SAN GABRIEL FWY.
7 MI.
5.5 MI.
LONG BEACH FWY.
10.5 MI.
ARTESIA FWY.
SAN DIEGO FWY.
PASADENA FWY.
7 MI.
2 MI.
HARBOR FWY.
2.5 MI.
11.5 MI.
HARBOR FWY.
VERMONT AVE.
STOP
NORMANDIE
START
5 MI.
HOLLYWOOD FWY.
10 MI.
5 MI.
9.5 MI.
GOLDEN STATE FWY.
10.5 MI.
16.5 MI.
6 MI.
ROXFORD ROAD
9.5 MI.
SAN DIEGO FWY.
10 MI.
SANTA MONICA FWY.
VENTURA FWY.

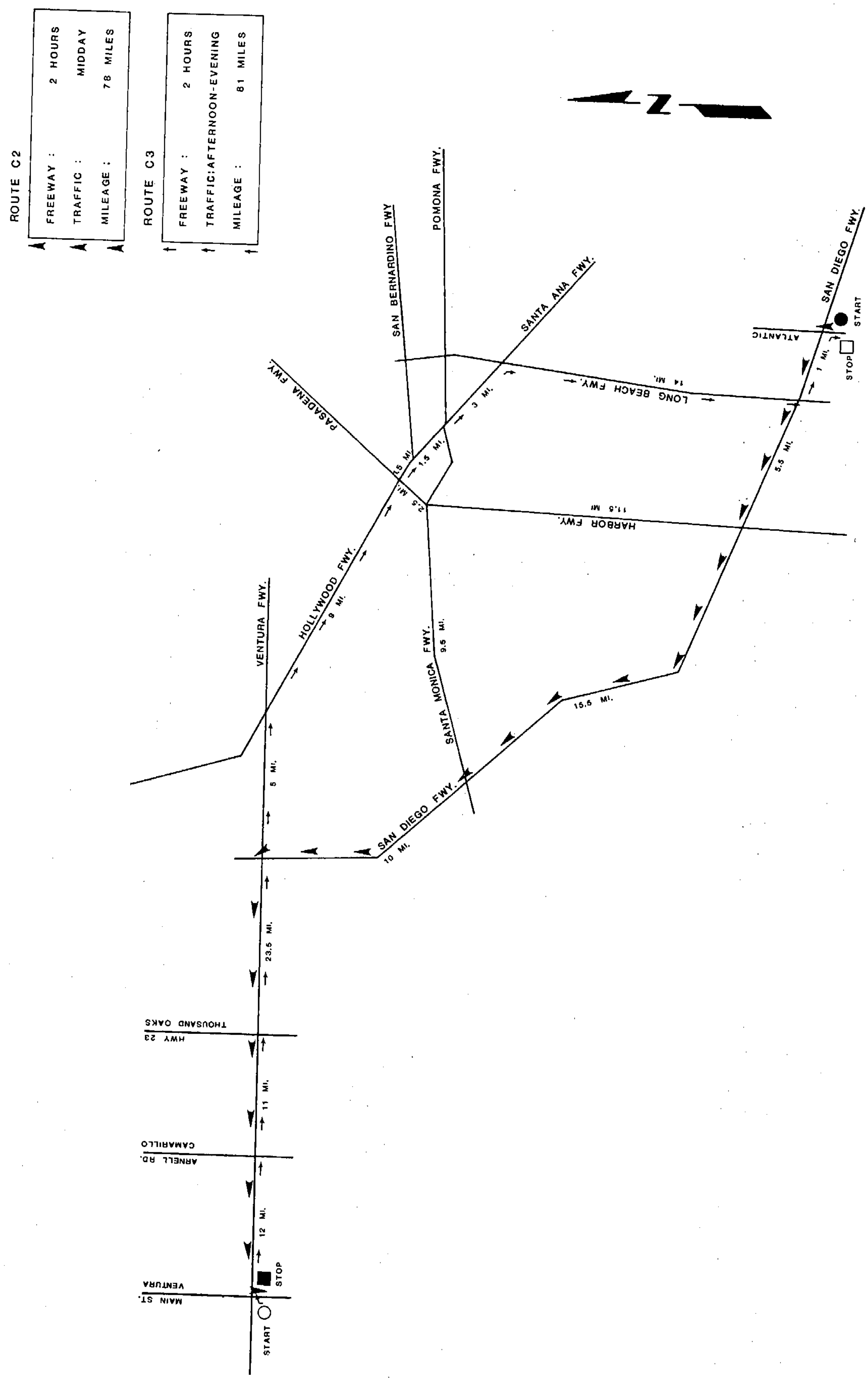
ROUTE B2

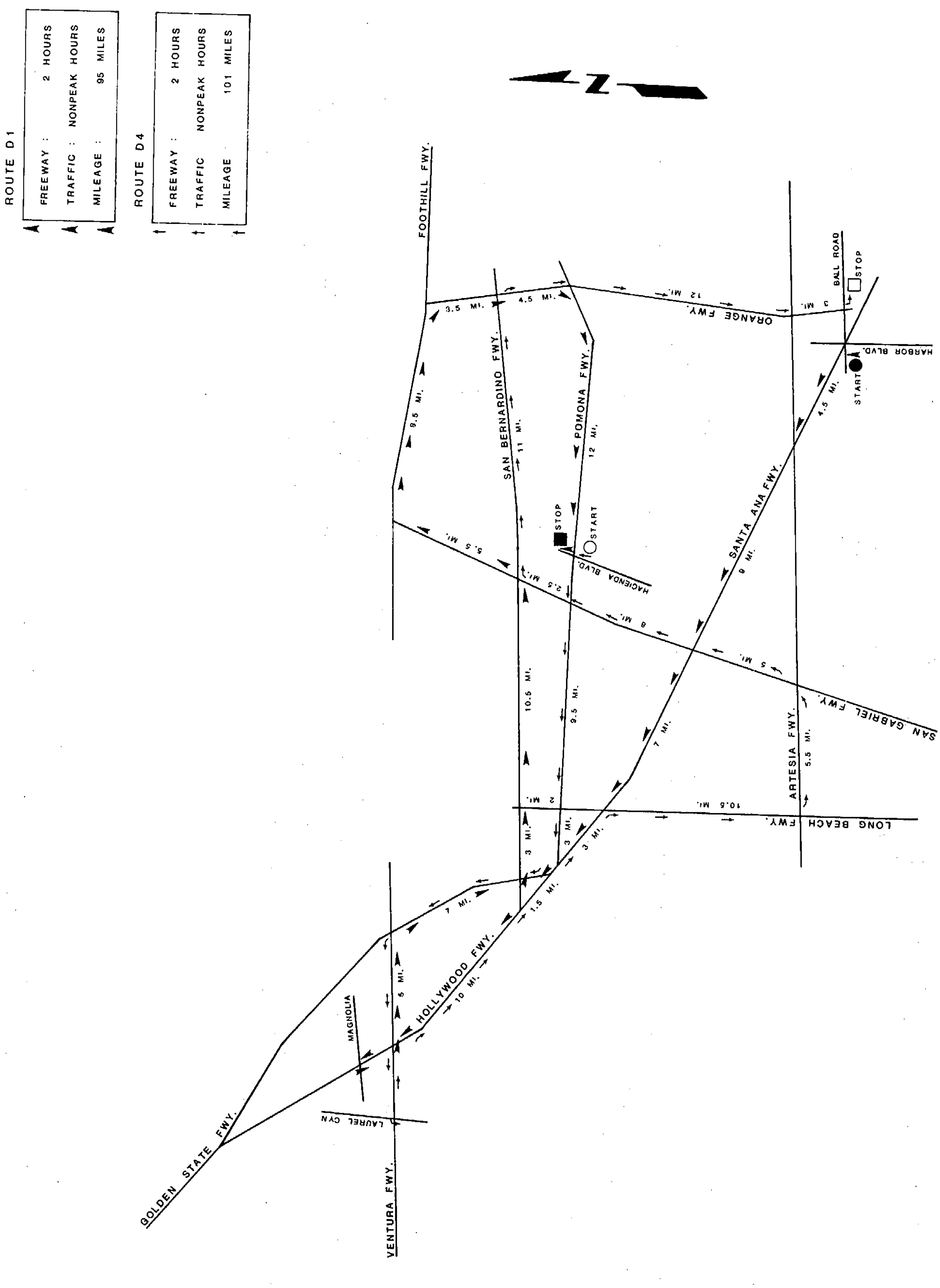
NONFREEWAY :		2 HOURS
TRAFFIC	MORNING NON-PEAK	
MILEAGE :		37 MILES

ROUTE B3

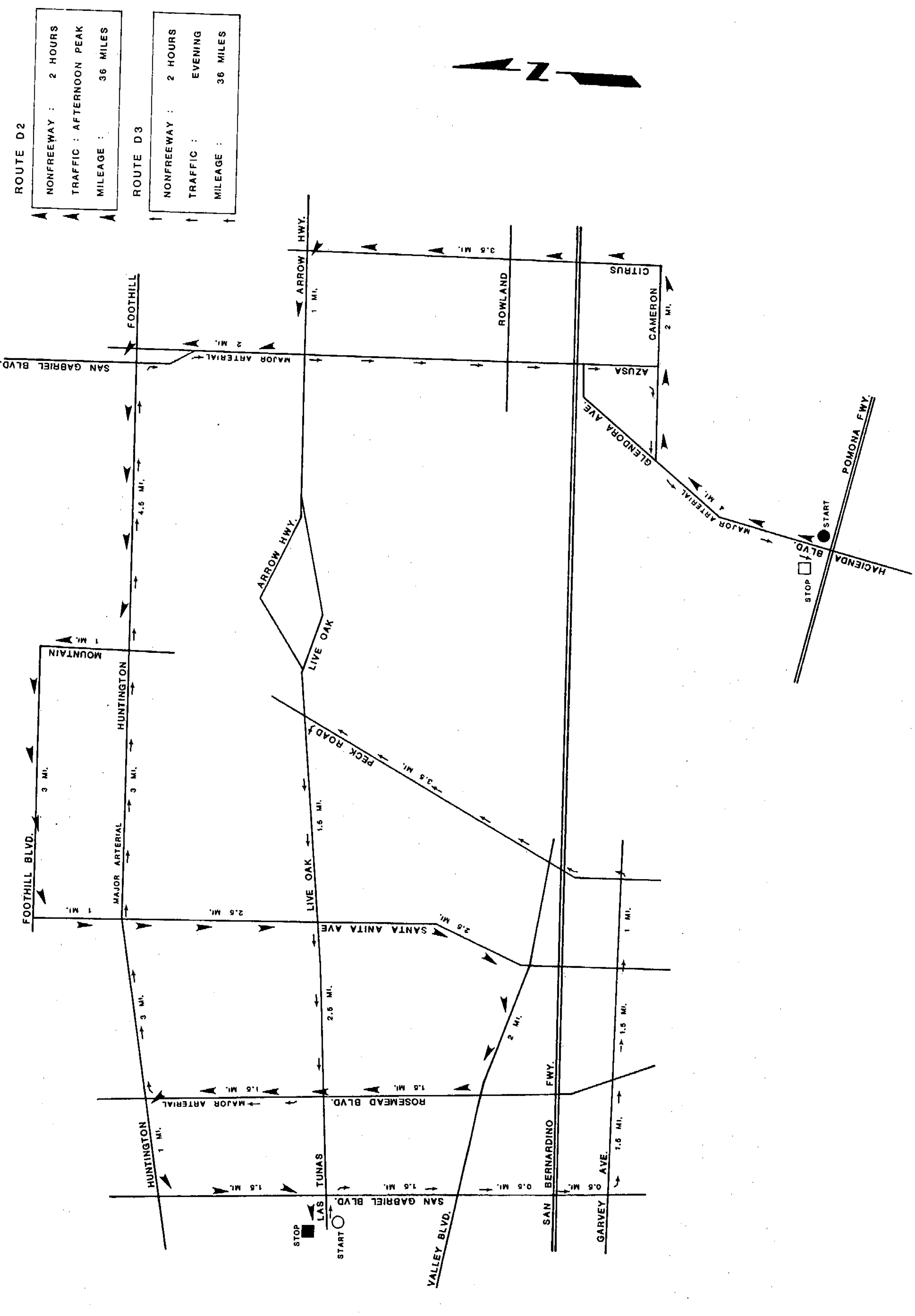
NONFREEWAY :		1 HOUR
TRAFFIC :		NOON
MILEAGE :		20 MILES

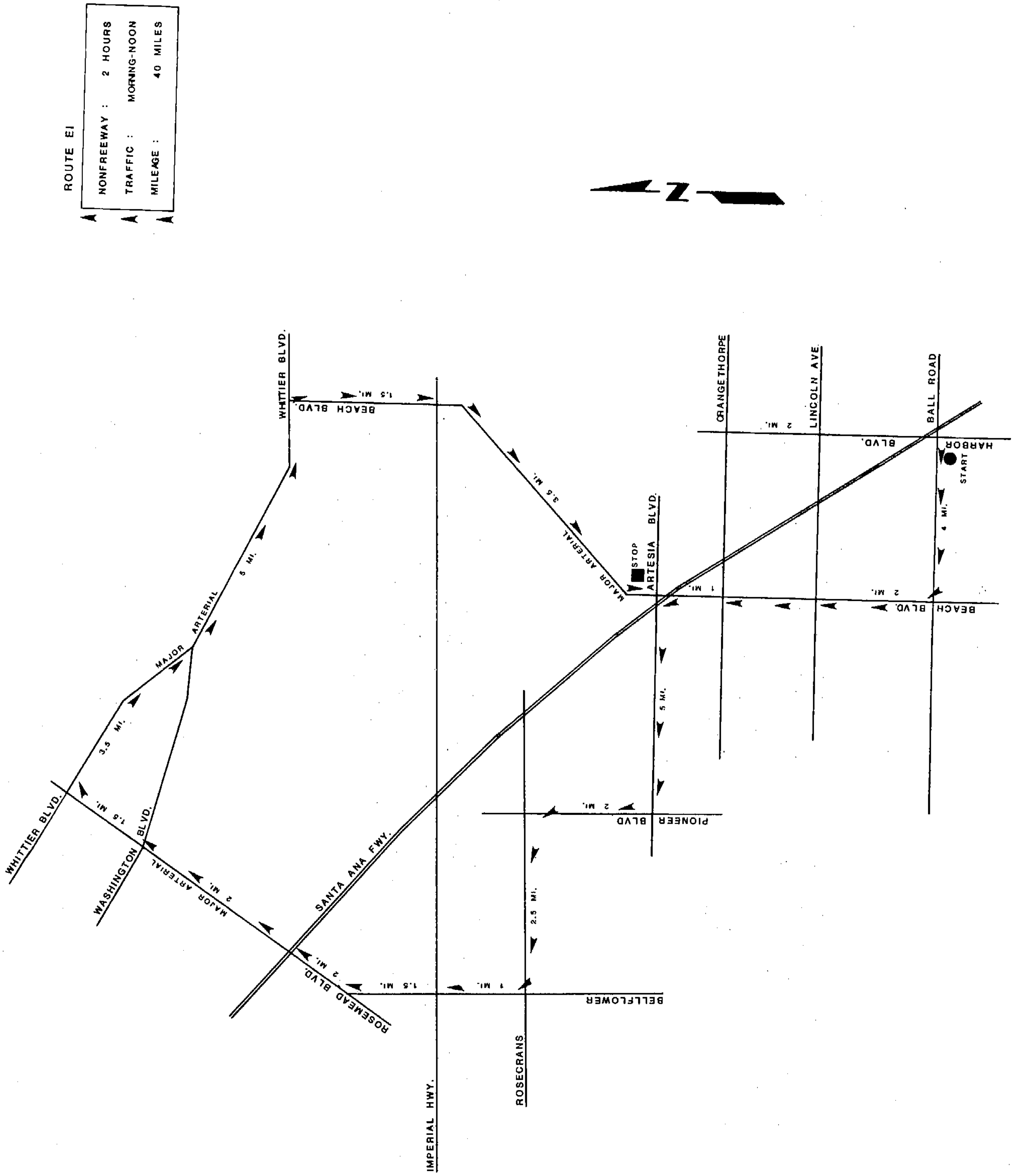

ROUTE C1
NONFREEWAY 2 HOURS
TRAFFIC MIDDAY
MILEAGE 44 MILES
ROUTE C4
NONFREEWAY 2 HOURS
TRAFFIC EVENING
MILEAGE : 32 MILES
N
LINCOLN AVE.
KATELLA AVE.
GARDEN GROVE
1ST ST.
START
STOP
HARBOR BLVD.
MAJOR ARTERIAL
EUCLID
BROOKHURST
MAGNOLIA
BEACH BLVD.
KNOTT AVE.
GOLDEN WEST
BOLSA AVE.
BOLSA CHICA
NORWALK BLVD.
LOS ALAMITOS
SEAL BEACH
BELLFLOWER
ALAMITOS
ATLANTIC
CARSON
SAN DIEGO FWY.
WILLOW ST.
7TH ST.
1 MI.
2 MI.
3 MI.
5 MI.
3.5 MI.

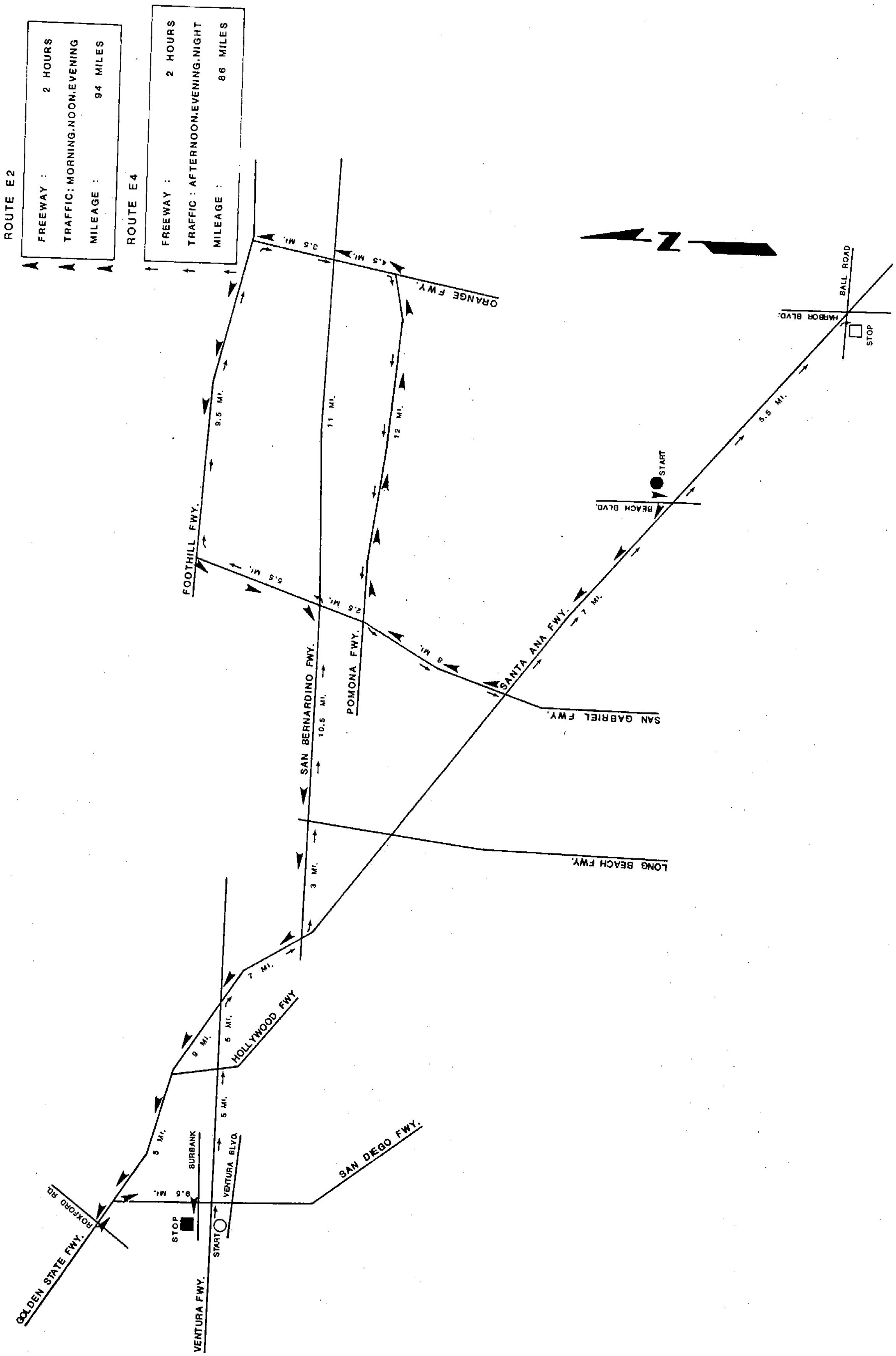

ROUTE C2
FREEWAY : 2 HOURS
TRAFFIC : MIDDAY
MILEAGE : 78 MILES
ROUTE C3
FREEWAY : 2 HOURS
TRAFFIC: AFTERNOON-EVENING
MILEAGE : 81 MILES
N
SAN DIEGO FWY.
START
STOP
ATLANTIC
1 MI.
LONG BEACH FWY.
14 MI.
SANTA ANA FWY.
3 MI.
POMONA FWY.
SAN BERNARDINO FWY
PASADENA FWY.
1.5 MI.
2.5 MI.
HARBOR FWY.
11.5 MI
5.5 MI.
HOLLYWOOD FWY.
9 MI.
SANTA MONICA FWY.
9.5 MI.
15.5 MI.
SAN DIEGO FWY.
10 MI.
VENTURA FWY.
5 MI.
23.5 MI.
THOUSAND OAKS
HWY 23
11 MI.
CAMARILLO
ARNELL RD.
12 MI.
VENTURA
MAIN ST.
STOP
START



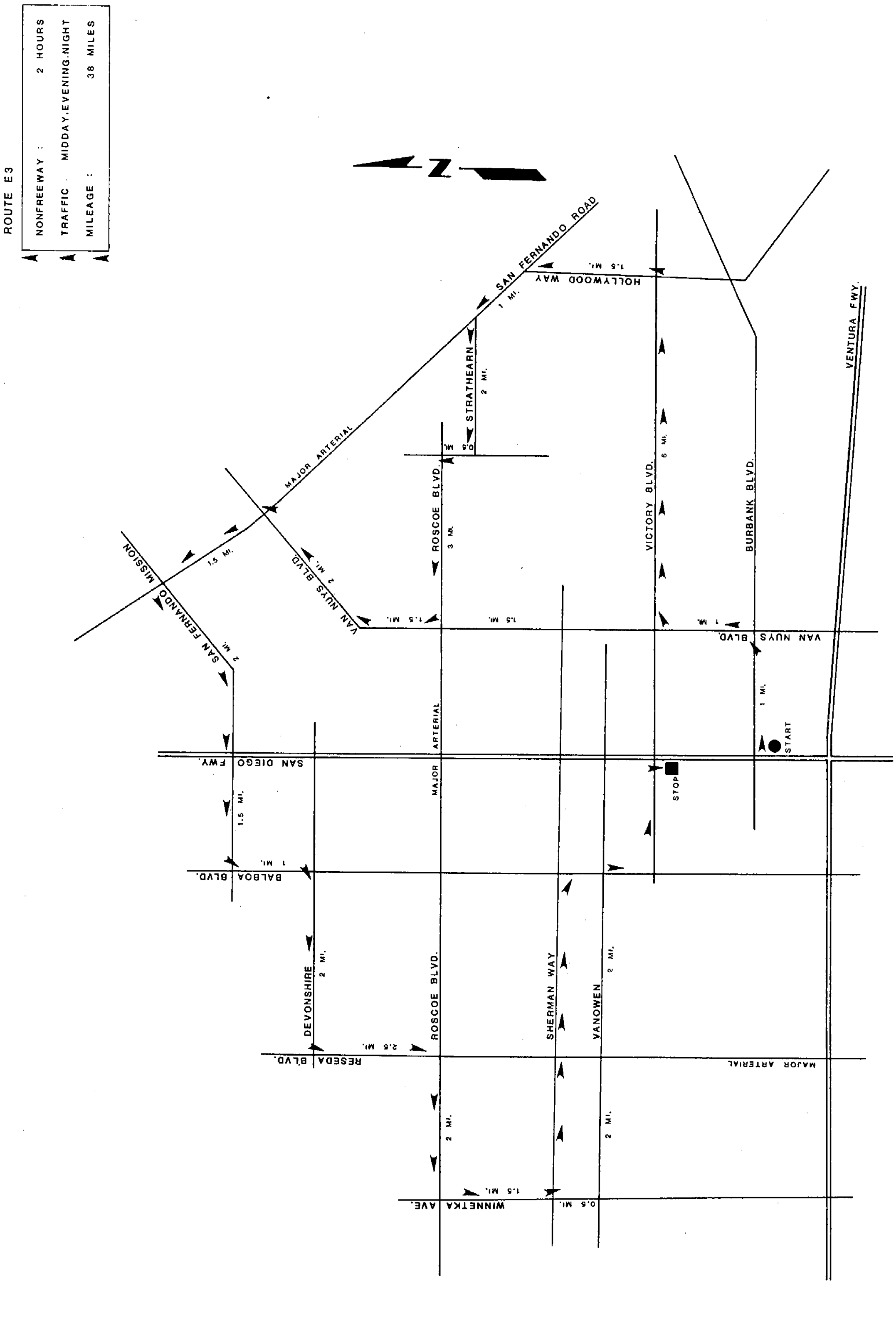
ROUTE D1
FREEWAY : 2 HOURS
TRAFFIC : NONPEAK HOURS
MILEAGE : 95 MILES
ROUTE D4
FREEWAY : 2 HOURS
TRAFFIC : NONPEAK HOURS
MILEAGE : 101 MILES
N
FOOTHILL FWY.
SAN BERNARDINO FWY.
POMONA FWY.
ORANGE FWY.
BALL ROAD
STOP
HARBOR BLVD.
START
SANTA ANA FWY.
HACIENDA BLVD.
STOP
START
SAN GABRIEL FWY.
ARTESIA FWY.
LONG BEACH FWY.
HOLLYWOOD FWY.
GOLDEN STATE FWY.
VENTURA FWY.
MAGNOLIA
LAUREL CYN
3.5 MI.
4.5 MI.
12 MI.
3 MI.
4.5 MI.
9.5 MI.
11 MI.
12 MI.
9 MI.
5.5 MI.
2.5 MI.
8 MI.
5 MI.
10.5 MI.
9.5 MI.
7 MI.
5.5 MI.
2 MI.
10.5 MI.
3 MI.
3 MI.
3 MI.
1.5 MI.
7 MI.
10 MI.
5 MI.

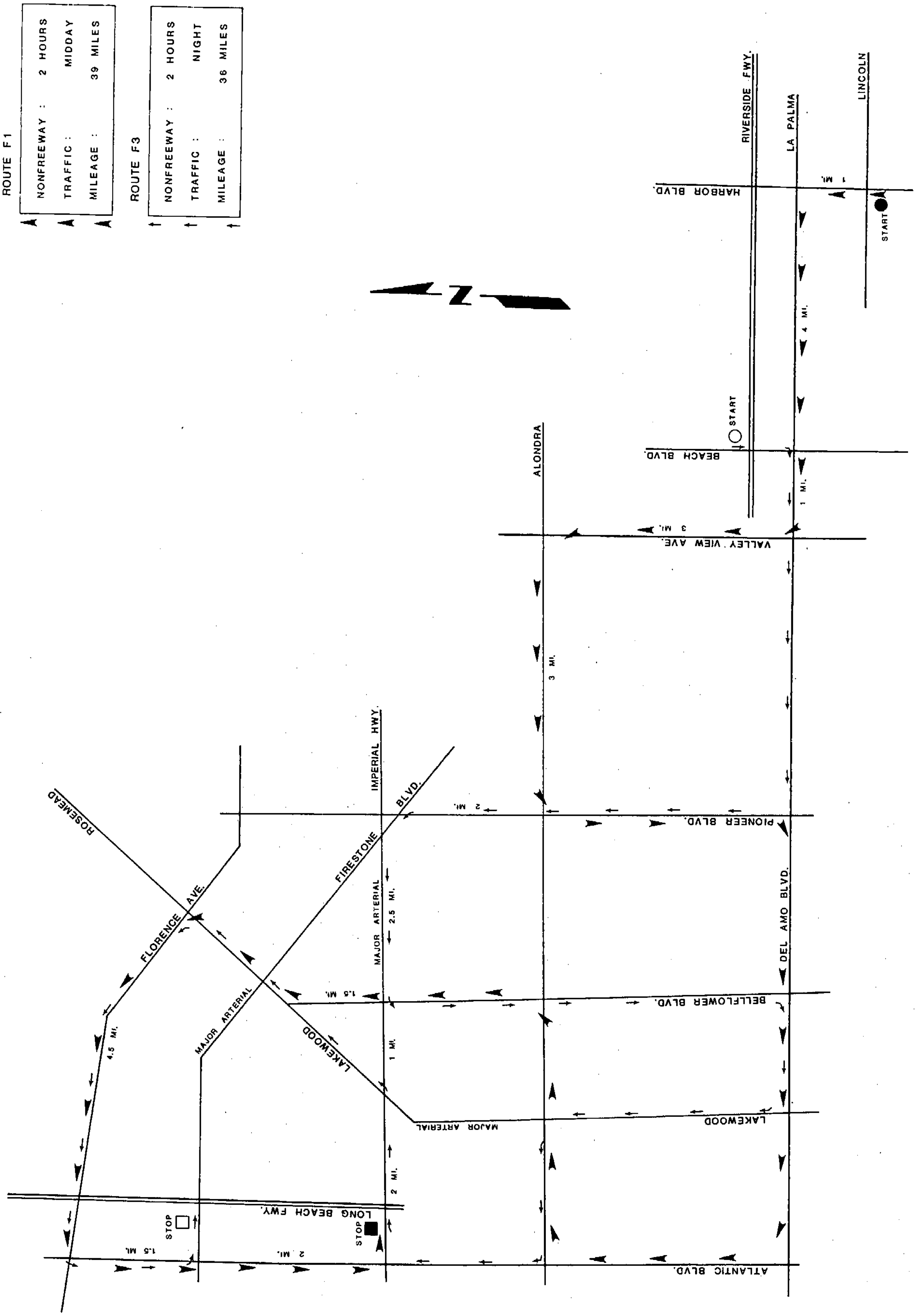

ROUTE D2
NONFREEWAY : 2 HOURS
TRAFFIC : AFTERNOON PEAK
MILEAGE : 36 MILES
ROUTE D3
NONFREEWAY : 2 HOURS
TRAFFIC : EVENING
MILEAGE : 36 MILES
N
ARROW HWY.
3.5 MI.
CITRUS
ROWLAND
CAMERON
2 MI.
1 MI.
FOOTHILL
SAN GABRIEL BLVD.
MAJOR ARTERIAL
2 MI.
AZUSA
GLENDORA AVE.
MAJOR ARTERIAL
4 MI.
POMONA FWY.
START
STOP
HACIENDA BLVD.
4.5 MI.
ARROW HWY.
LIVE OAK
MOUNTAIN
1 MI.
HUNTINGTON
PECK ROAD
3.5 MI.
3 MI.
FOOTHILL BLVD.
MAJOR ARTERIAL
3 MI.
1.5 MI.
LIVE OAK
1 MI.
2.5 MI.
SANTA ANITA AVE
2.5 MI.
1 MI.
3 MI.
2.5 MI.
2 MI.
1.5 MI.
ROSEMEAD BLVD.
MAJOR ARTERIAL
1.5 MI.
1.5 MI.
FWY.
HUNTINGTON
1 MI.
1.5 MI.
LAS TUNAS
SAN GABRIEL BLVD.
1.5 MI.
0.5 MI.
SAN BERNARDINO
0.5 MI.
GARVEY AVE.
1.5 MI.
STOP
START
VALLEY BLVD.


ROUTE EI
NONFREEWAY : 2 HOURS
TRAFFIC : MORNING-NOON
MILEAGE : 40 MILES
N
WHITTIER BLVD.
BEACH BLVD.
1.5 MI.
3.5 MI.
MAJOR ARTERIAL
STOP
ARTESIA BLVD.
ORANGETHORPE
LINCOLN AVE.
BALL ROAD
HARBOR BLVD.
START
4 MI.
2 MI.
1 MI.
5 MI.
PIONEER BLVD
2.5 MI.
BELLFLOWER
ROSECRANS
IMPERIAL HWY.
ROSEMEAD BLVD.
SANTA ANA FWY.
WASHINGTON BLVD.
WHITTIER BLVD.

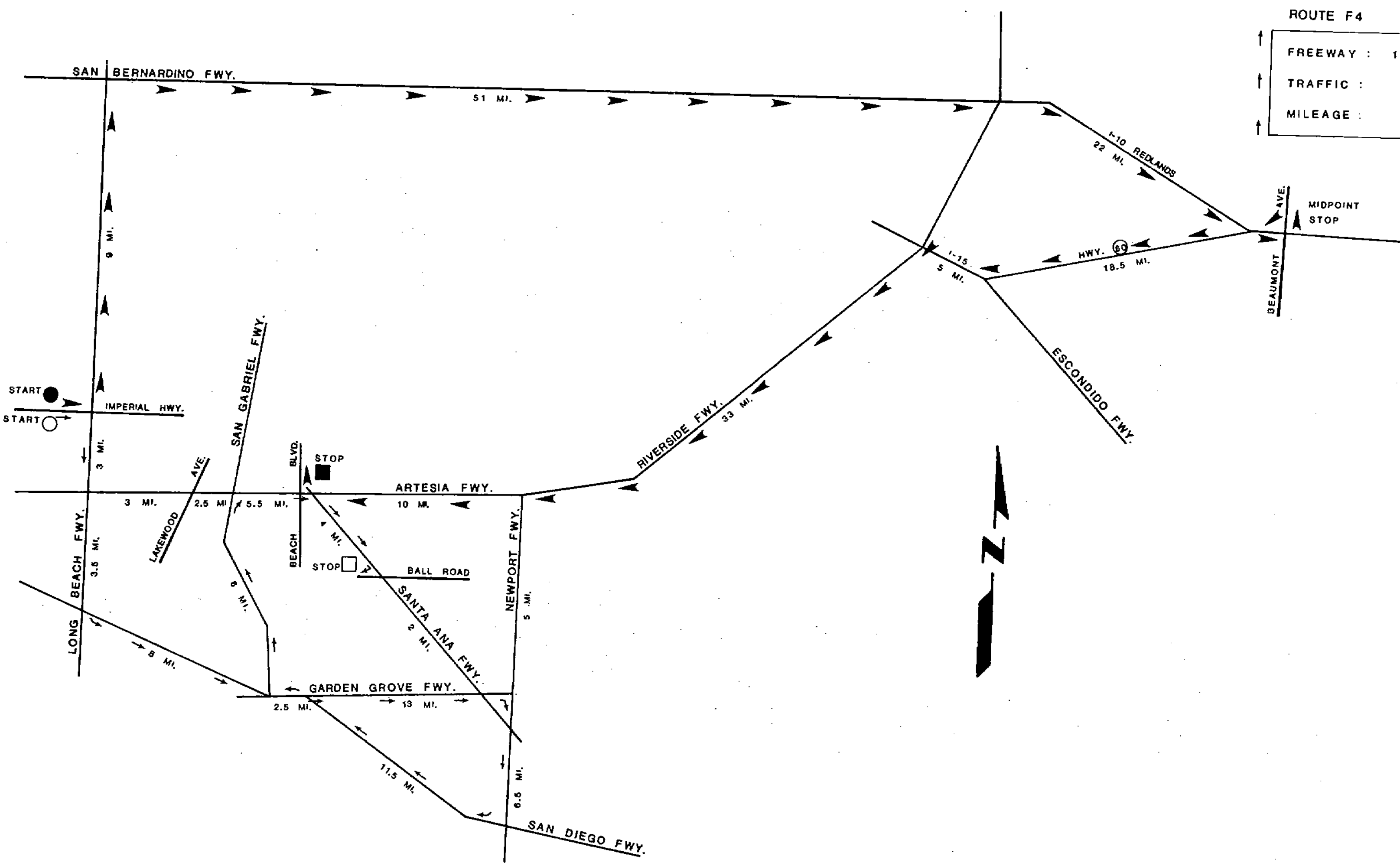


ROUTE E2
FREEWAY : 2 HOURS
TRAFFIC : MORNING, NOON, EVENING
MILEAGE : 94 MILES
ROUTE E4
FREEWAY : 2 HOURS
TRAFFIC : AFTERNOON, EVENING, NIGHT
MILEAGE : 86 MILES
N
ORANGE FWY.
FOOTHILL FWY.
SAN BERNARDINO FWY.
POMONA FWY.
SAN GABRIEL FWY.
SANTA ANA FWY.
LONG BEACH FWY.
HOLLYWOOD FWY
SAN DIEGO FWY.
GOLDEN STATE FWY.
VENTURA FWY.
BALL ROAD
HARBOR BLVD.
BEACH BLVD.
ROXFORD RD.
BURBANK
VENTURA BLVD.
START
STOP
3.5 MI.
4.5 MI.
9.5 MI.
11 MI.
12 MI.
5.5 MI.
2.5 MI.
8 MI.
10.5 MI.
7 MI.
5.5 MI.
3 MI.
7 MI.
9 MI.
5 MI.
5 MI.
5 MI.
9.5 MI.


ROUTE E3
NONFREEWAY : 2 HOURS
TRAFFIC : MIDDAY, EVENING, NIGHT
MILEAGE : 38 MILES
N
SAN FERNANDO ROAD
HOLLYWOOD WAY
1.5 MI.
1 MI.
STRATHEARN
2 MI.
0.5 MI.
MAJOR ARTERIAL
ROSCOE BLVD.
3 MI.
VICTORY BLVD.
6 MI.
BURBANK BLVD.
VENTURA FWY.
MISSION
1.5 MI.
VAN NUYS BLVD
2 MI.
1.5 MI.
1.5 MI.
1 MI.
VAN NUYS BLVD.
SAN FERNANDO
2 MI.
1 MI.
START
SAN DIEGO FWY.
MAJOR ARTERIAL
STOP
1.5 MI.
BALBOA BLVD.
1 MI.
DEVONSHIRE
2 MI.
ROSCOE BLVD.
SHERMAN WAY
VANOWEN
2 MI.
RESEDA BLVD.
2.5 MI.
MAJOR ARTERIAL
2 MI.
2 MI.
WINNETKA AVE.
1.5 MI.
0.5 MI.



ROUTE F1
NONFREEWAY : 2 HOURS
TRAFFIC : MIDDAY
MILEAGE : 39 MILES
ROUTE F3
NONFREEWAY : 2 HOURS
TRAFFIC : NIGHT
MILEAGE : 36 MILES
N
RIVERSIDE FWY.
LA PALMA
LINCOLN
HARBOR BLVD.
START
BEACH BLVD.
ALONDRA
VALLEY VIEW AVE.
IMPERIAL HWY.
PIONEER BLVD.
DEL AMO BLVD.
FIRESTONE BLVD.
ROSEMEAD
FLORENCE AVE.
MAJOR ARTERIAL
BELLFLOWER BLVD.
LAKEWOOD
LONG BEACH FWY.
STOP
ATLANTIC BLVD.
1 MI.
4 MI.
3 MI.
2 MI.
2.5 MI.
1.5 MI.
4.5 MI.

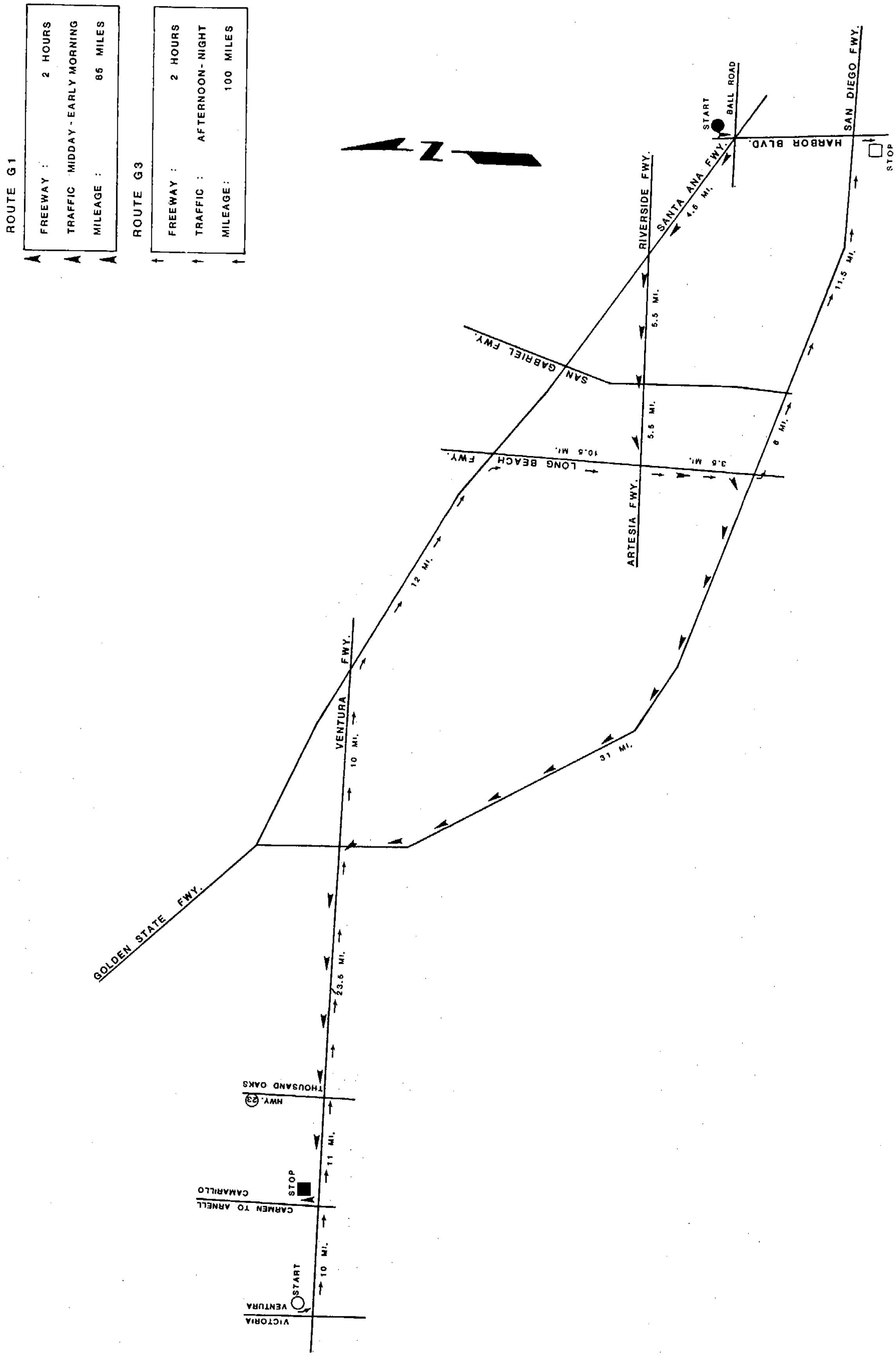


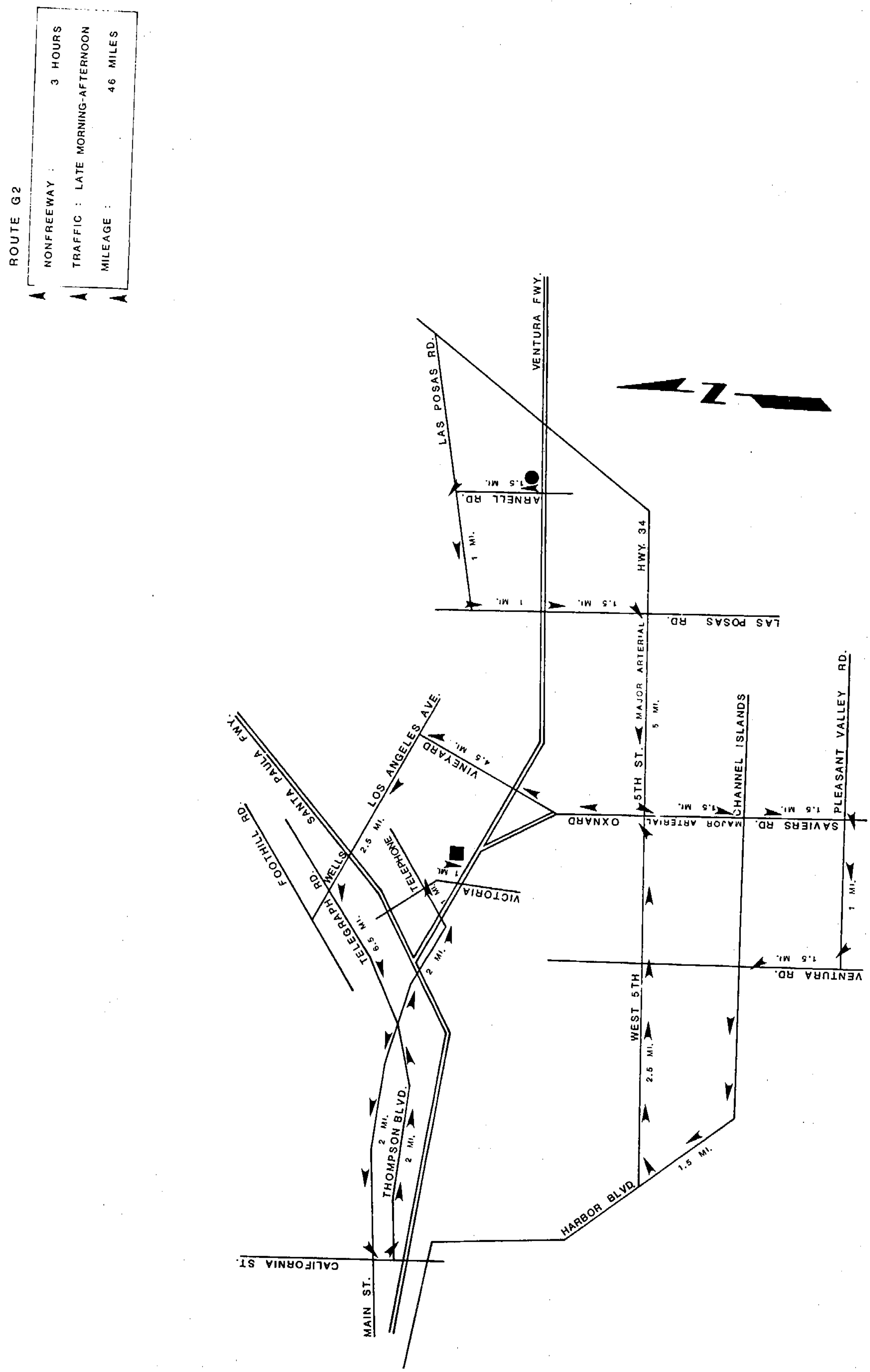
ROUTE F2

FREEWAY :	3 HOURS
TRAFFIC :	AFTERNOON
MILEAGE :	148 MILES

ROUTE F4

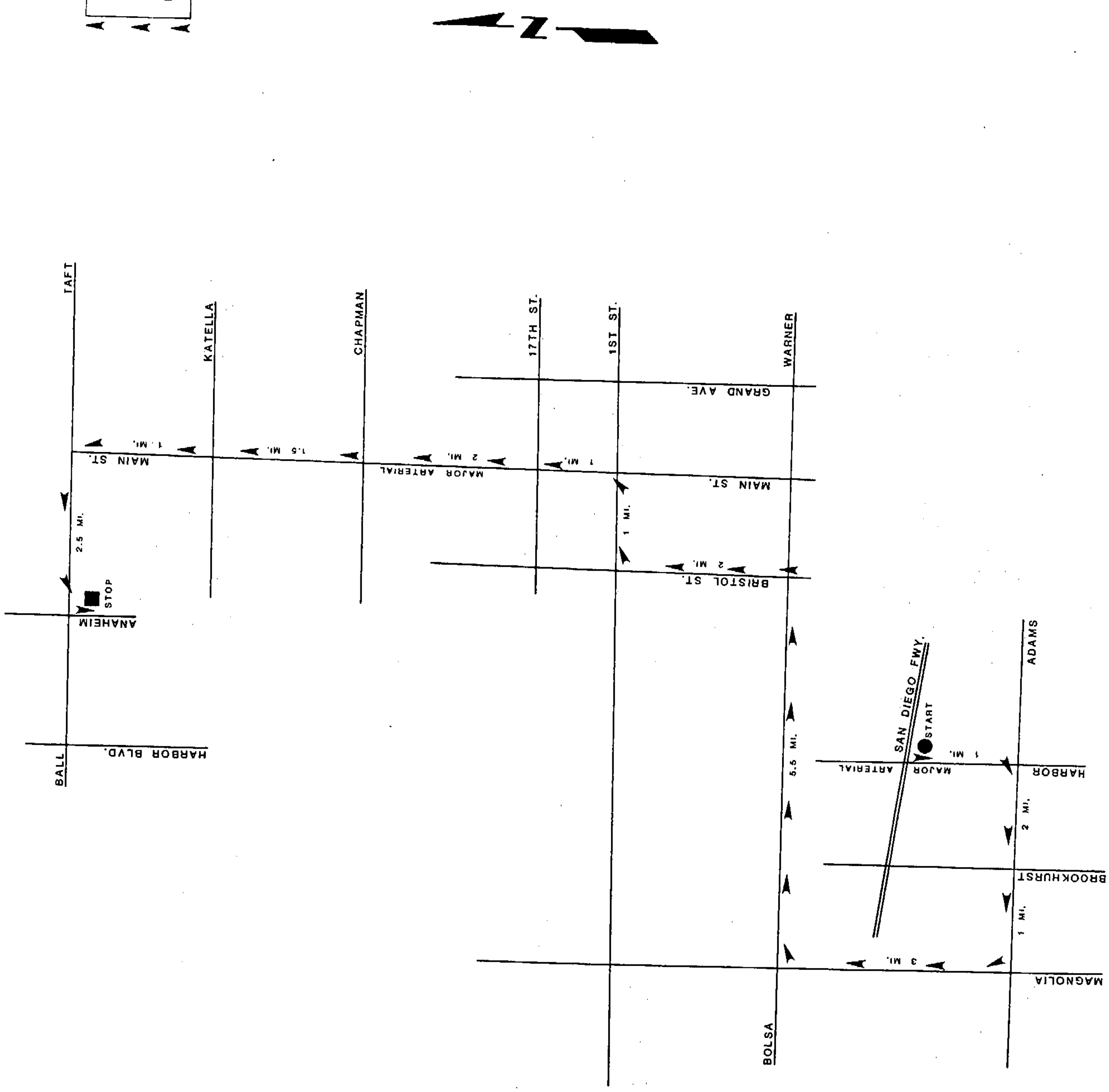
FREEWAY :	1 HOUR 20 MIN.
TRAFFIC :	NIGHT
MILEAGE :	74 MILES

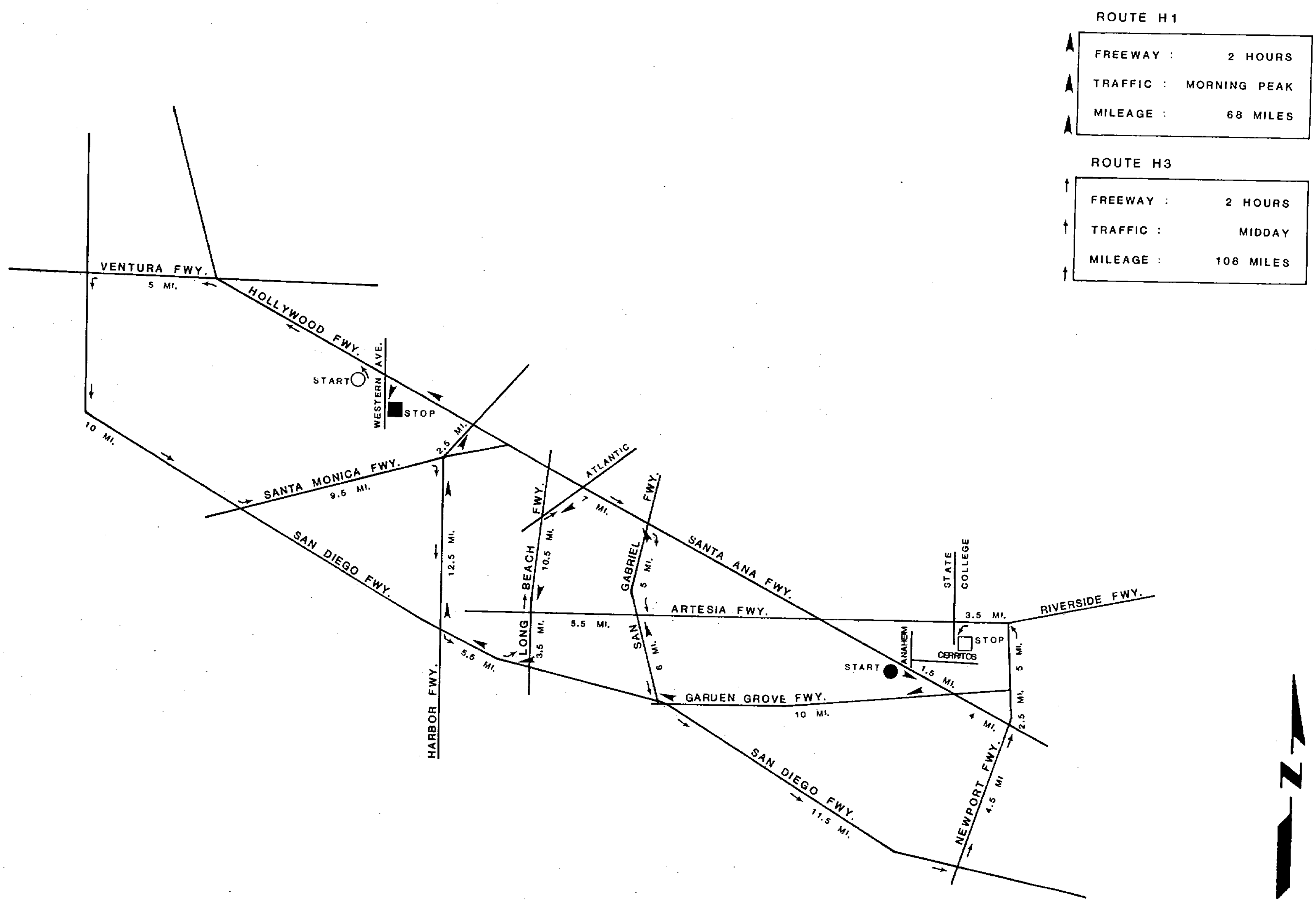

ROUTE G1
FREEWAY : 2 HOURS
TRAFFIC : MIDDAY - EARLY MORNING
MILEAGE : 85 MILES
ROUTE G3
FREEWAY : 2 HOURS
TRAFFIC : AFTERNOON - NIGHT
MILEAGE : 100 MILES
N
START
BALL ROAD
HARBOR BLVD.
SAN DIEGO FWY.
STOP
SANTA ANA FWY.
4.6 MI.
RIVERSIDE FWY.
5.5 MI.
SAN GABRIEL FWY.
5.5 MI.
LONG BEACH FWY.
10.5 MI.
3.5 MI.
ARTESIA FWY.
6 MI.
11.5 MI.
12 MI.
VENTURA FWY.
10 MI.
31 MI.
GOLDEN STATE FWY.
23.5 MI.
THOUSAND OAKS
HWY. 23
11 MI.
STOP
CAMARILLO
CARMEN TO ARNELL
10 MI.
START
VENTURA
VICTORIA

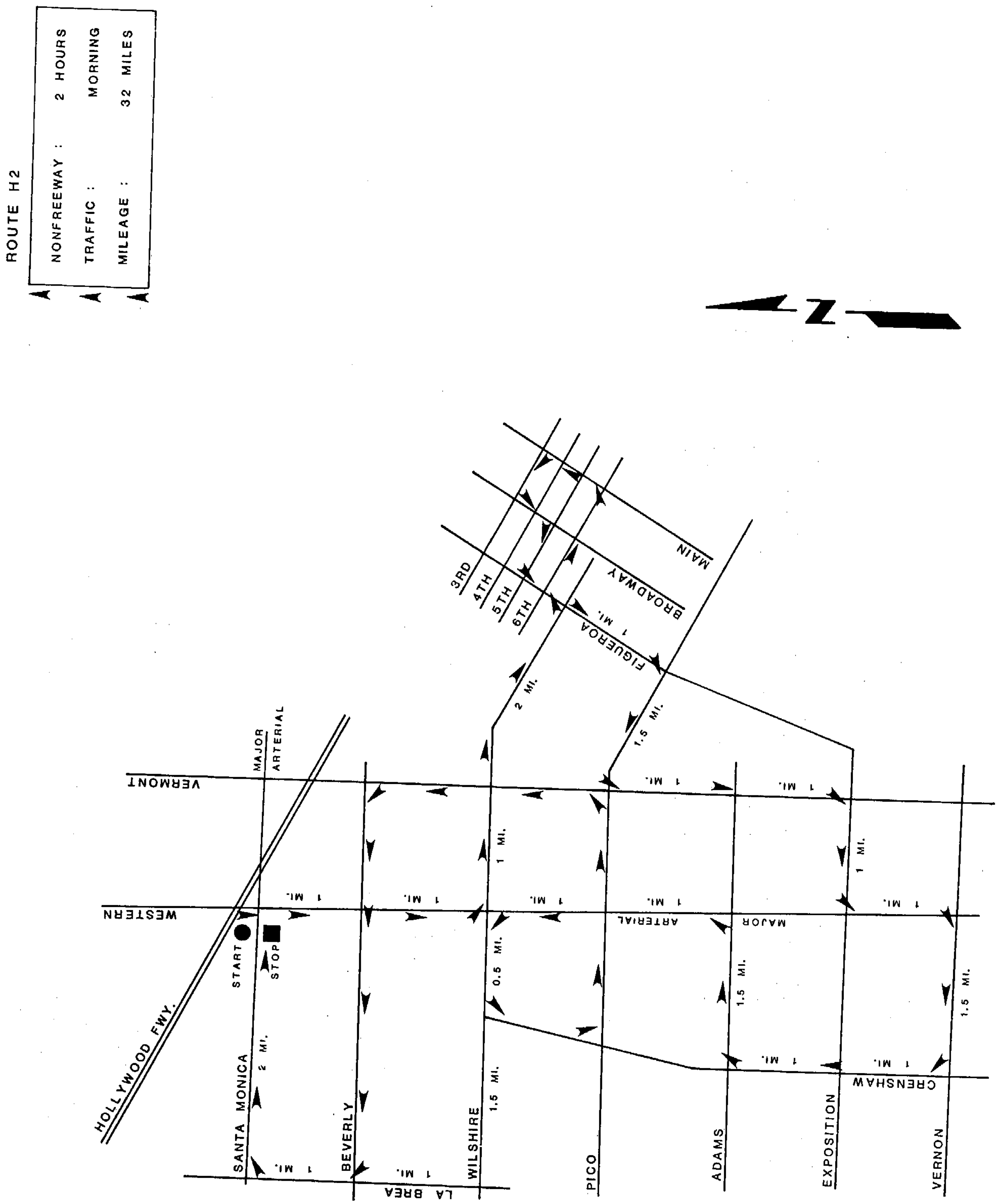

ROUTE G2
NONFREEWAY : 3 HOURS
TRAFFIC : LATE MORNING-AFTERNOON
MILEAGE : 46 MILES
N
VENTURA FWY.
LAS POSAS RD.
ARNELL RD.
1.5 MI.
1 MI.
1 MI.
1.5 MI.
HWY. 34
LAS POSAS RD.
5TH ST.
MAJOR ARTERIAL
5 MI.
PLEASANT VALLEY RD.
CHANNEL ISLANDS
LOS ANGELES AVE.
VINEYARD
4.5 MI.
SANTA PAULA FWY.
OXNARD
MAJOR ARTERIAL
1.5 MI.
SAVIERS RD.
1.5 MI.
FOOTHILL RD.
WELLS RD.
2.5 MI.
TELEPHONE
VICTORIA
1 MI.
TELEGRAPH
6.5 MI.
2 MI.
1 MI.
VENTURA RD.
1.5 MI.
WEST 5TH
2.5 MI.
THOMPSON BLVD.
2 MI.
2 MI.
HARBOR BLVD.
1.5 MI.
CALIFORNIA ST.
MAIN ST.

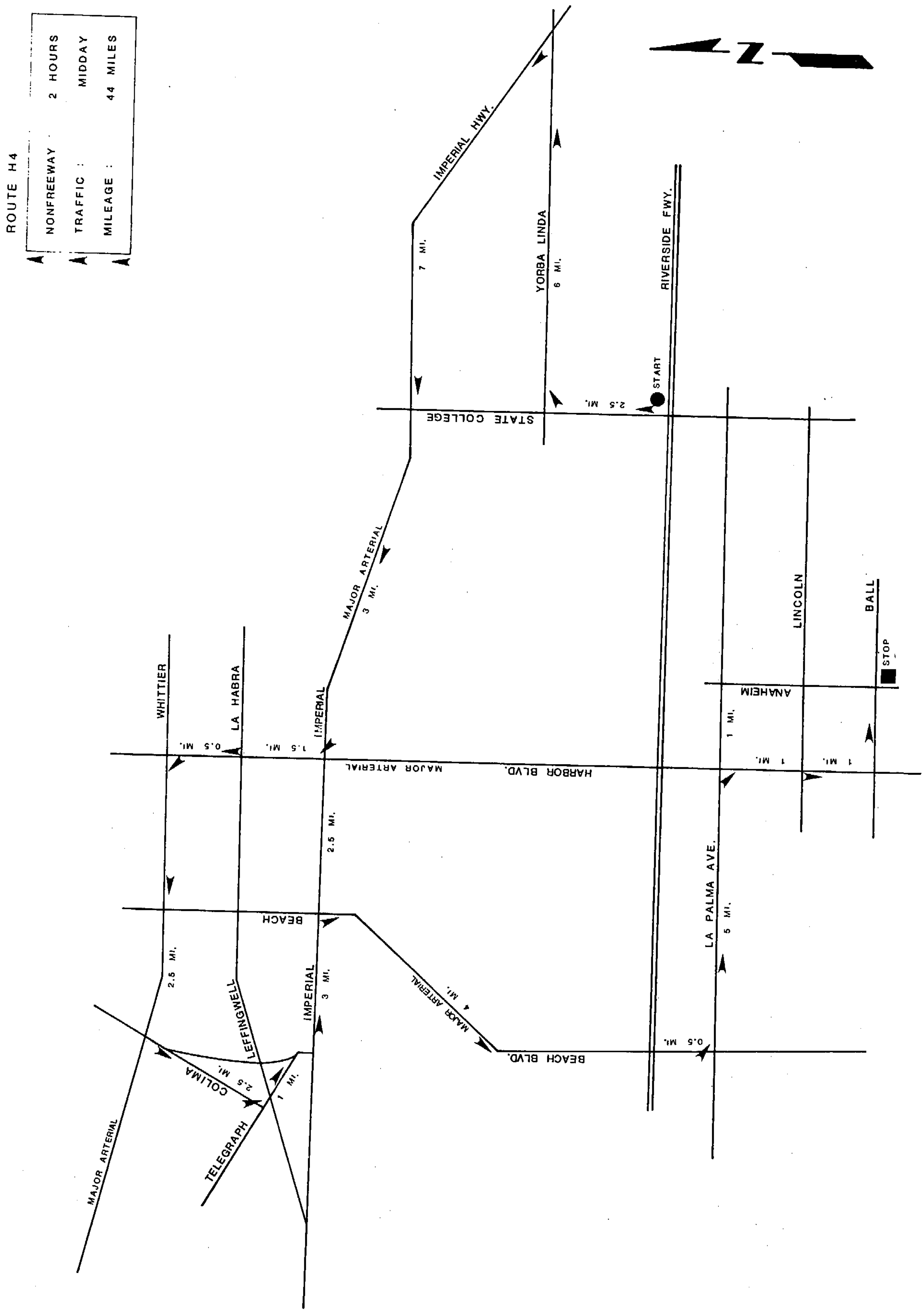
ROUTE G4

NONFREEWAY : 1 HOUR
TRAFFIC : MIDDAY-NIGHT
MILEAGE : 23 MILES




ROUTE H1
FREEWAY : 2 HOURS
TRAFFIC : MORNING PEAK
MILEAGE : 68 MILES
ROUTE H3
FREEWAY : 2 HOURS
TRAFFIC : MIDDAY
MILEAGE : 108 MILES
VENTURA FWY.
5 MI.
HOLLYWOOD FWY.
WESTERN AVE.
START
STOP
10 MI.
2.5 MI.
SANTA MONICA FWY.
9.5 MI.
SAN DIEGO FWY.
12.5 MI.
HARBOR FWY.
5.5 MI.
LONG BEACH FWY.
10.5 MI.
3.5 MI.
ATLANTIC
7 MI.
SAN GABRIEL FWY.
5 MI.
6 MI.
ARTESIA FWY.
5.5 MI.
SANTA ANA FWY.
GARUEN GROVE FWY.
10 MI.
SAN DIEGO FWY.
11.5 MI.
STATE COLLEGE
3.5 MI.
RIVERSIDE FWY.
STOP
CERRITOS
ANAHEIM
START
1.5 MI.
4 MI.
5 MI.
2.5 MI.
NEWPORT FWY.
4.5 MI
N


ROUTE H2
NONFREEWAY : 2 HOURS
TRAFFIC : MORNING
MILEAGE : 32 MILES
N
MAIN
BROADWAY
3RD
4TH
5TH
6TH
FIGUEROA
1 MI.
2 MI.
1.5 MI.
VERMONT
MAJOR ARTERIAL
WESTERN
MAJOR ARTERIAL
HOLLYWOOD FWY.
START
STOP
SANTA MONICA
BEVERLY
WILSHIRE
PICO
ADAMS
EXPOSITION
VERNON
CRENSHAW
LA BREA
0.5 MI.
1.5 MI.

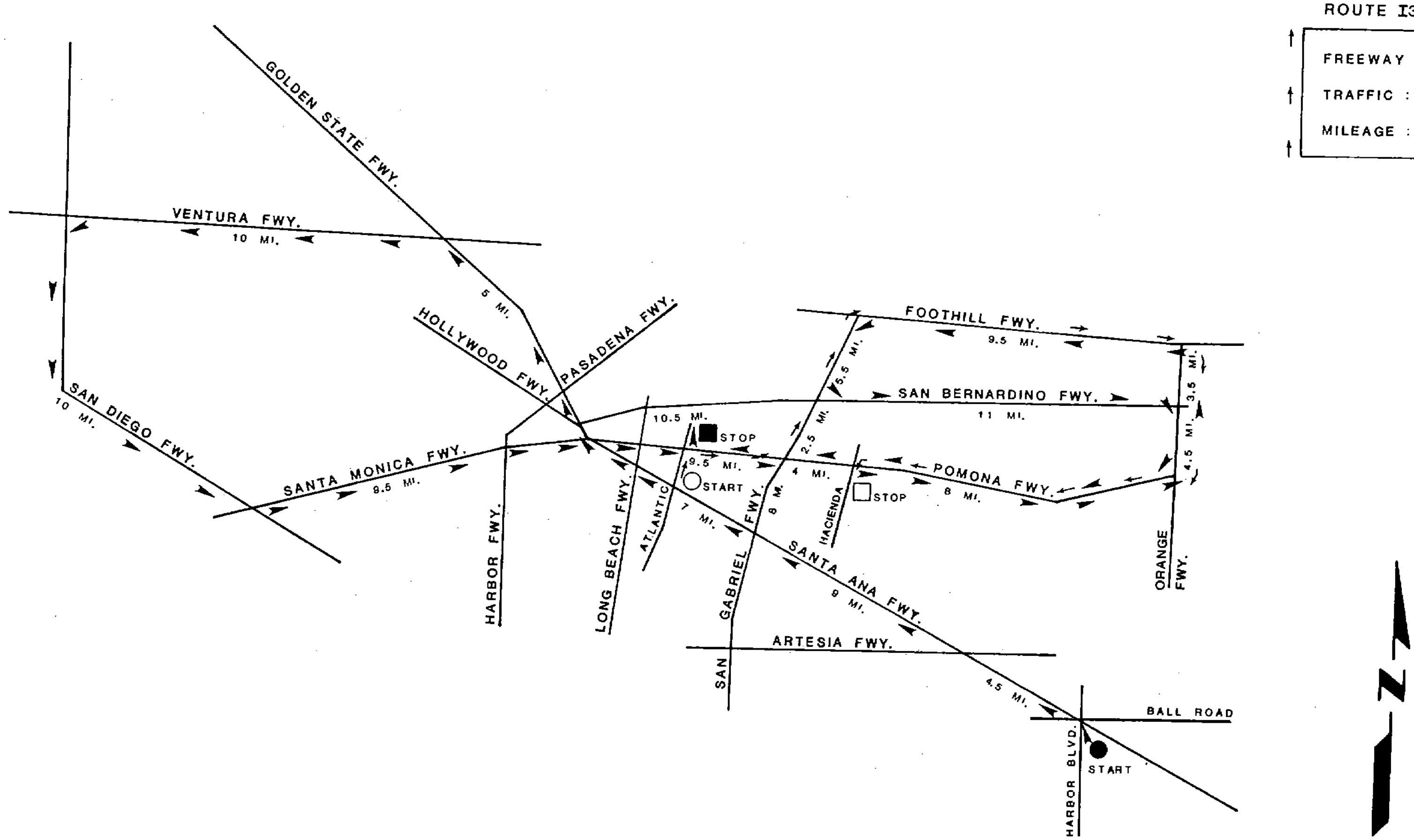

ROUTE H4
NONFREEWAY : 2 HOURS
TRAFFIC : MIDDAY
MILEAGE : 44 MILES
N
IMPERIAL HWY.
7 MI.
YORBA LINDA
6 MI.
RIVERSIDE FWY.
START
2.5 MI.
STATE COLLEGE
MAJOR ARTERIAL
3 MI.
LINCOLN
BALL
STOP
ANAHEIM
1 MI.
WHITTIER
LA HABRA
IMPERIAL
0.5 MI.
1.5 MI.
MAJOR ARTERIAL
HARBOR BLVD.
1 MI.
1 MI.
2.5 MI.
LA PALMA AVE.
5 MI.
BEACH
2.5 MI.
LEFFINGWELL
IMPERIAL
3 MI.
MAJOR ARTERIAL
4 MI.
BEACH BLVD.
0.5 MI.
COLIMA
2.5 MI.
1 MI.
TELEGRAPH
MAJOR ARTERIAL

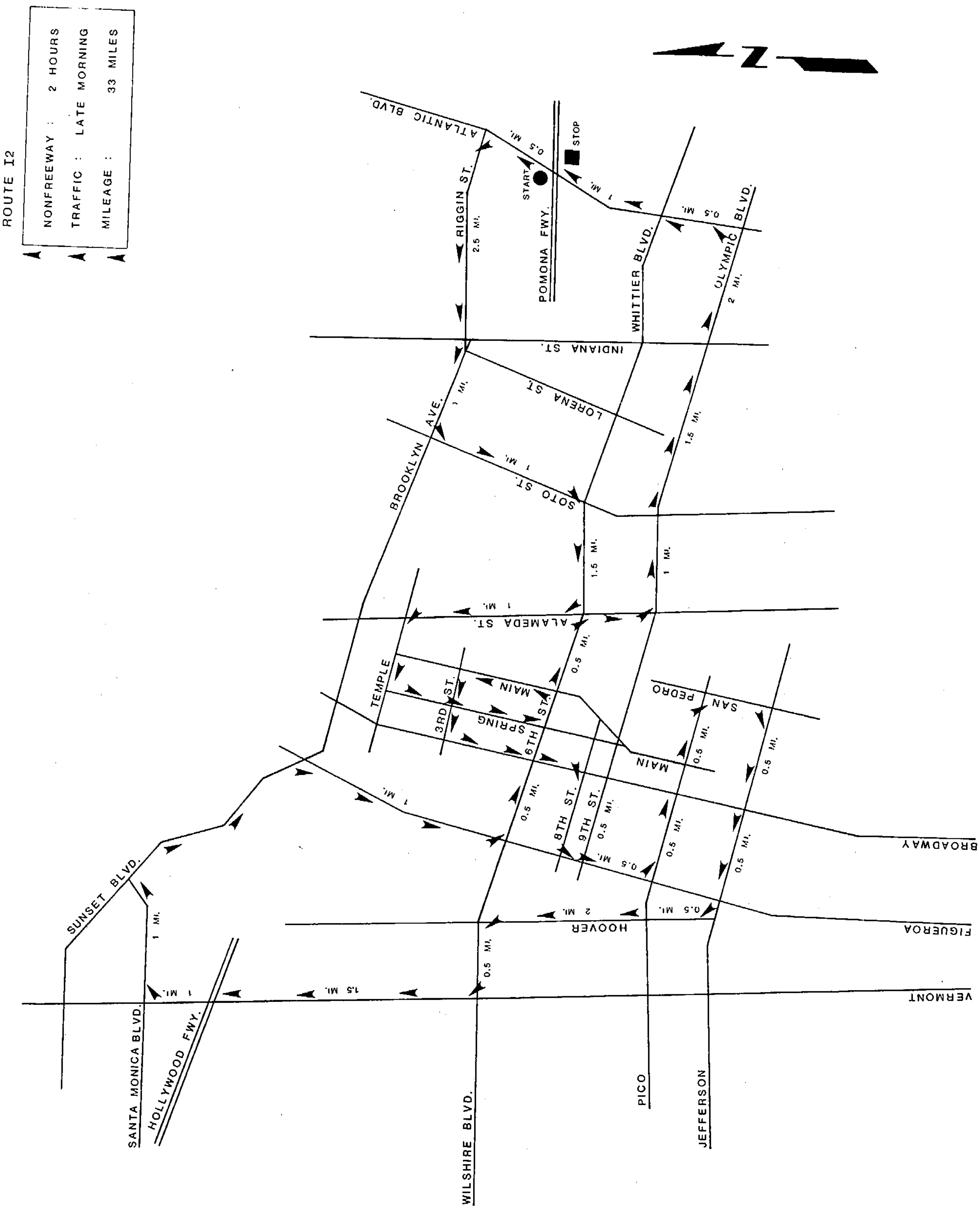
ROUTE I1

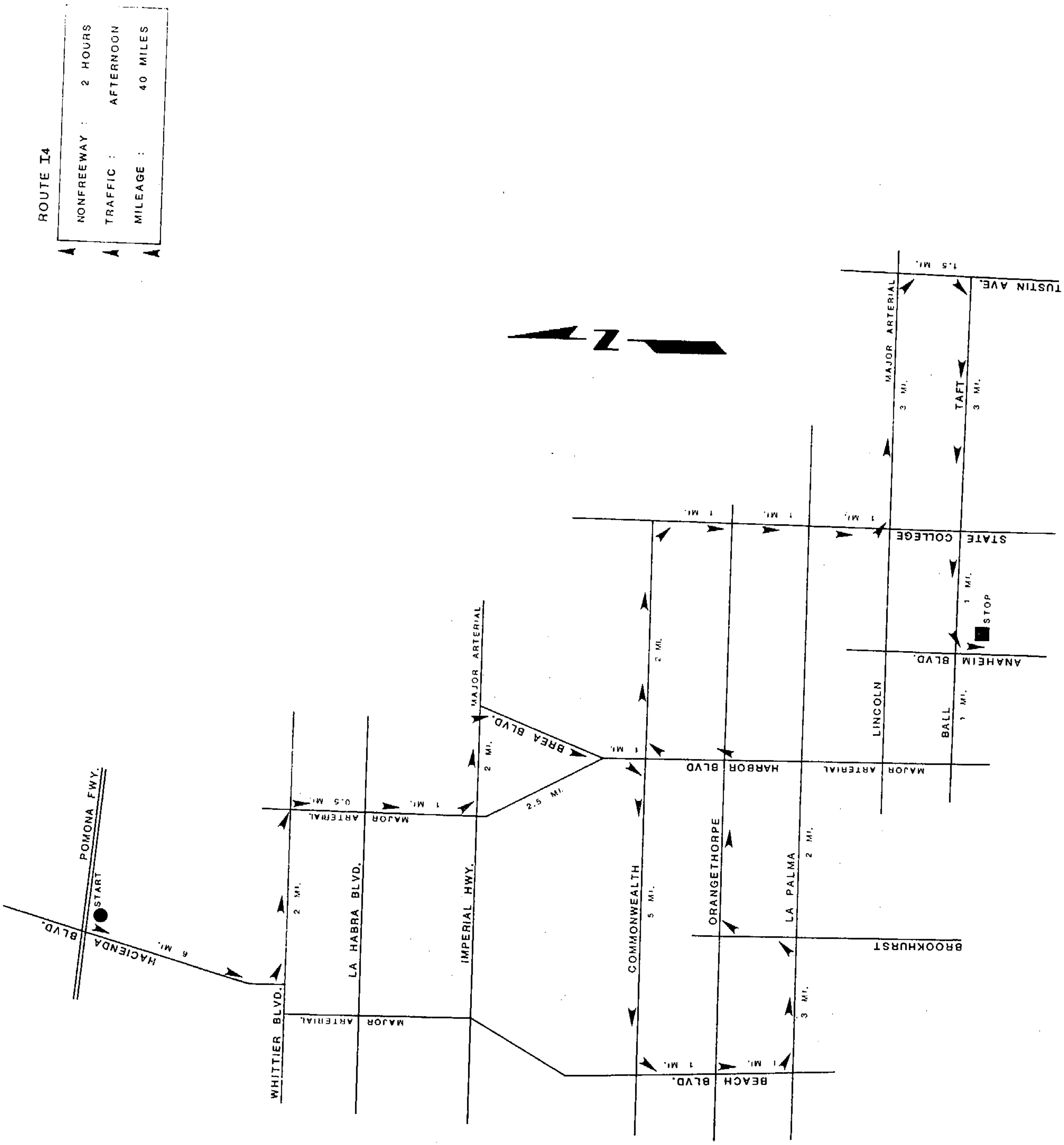
FREEWAY :	3 HOURS
TRAFFIC :	MORNING PEAK
MILEAGE :	136 MILES

ROUTE I3

FREEWAY :	1 HOUR
TRAFFIC :	NOON
MILEAGE :	42 MILES




ROUTE I2
NONFREEWAY : 2 HOURS
TRAFFIC : LATE MORNING
MILEAGE : 33 MILES
N
START
STOP
POMONA FWY.
ATLANTIC BLVD.
RIGGIN ST.
WHITTIER BLVD.
OLYMPIC BLVD.
INDIANA ST.
LORENA ST.
BROOKLYN AVE.
SOTO ST.
ALAMEDA ST.
TEMPLE
3RD ST.
MAIN
SPRING
6TH ST.
SAN PEDRO
MAIN
8TH ST.
9TH ST.
BROADWAY
SUNSET BLVD.
HOOVER
FIGUEROA
VERMONT
SANTA MONICA BLVD.
HOLLYWOOD FWY.
WILSHIRE BLVD.
PICO
JEFFERSON
0.5 MI.
1 MI.
2.5 MI.
1.5 MI.
2 MI.


ROUTE I4
NONFREEWAY : 2 HOURS
TRAFFIC : AFTERNOON
MILEAGE : 40 MILES
N
POMONA FWY.
START
HACIENDA BLVD.
6 MI.
WHITTIER BLVD.
2 MI.
LA HABRA BLVD.
MAJOR ARTERIAL
0.5 MI.
1 MI.
IMPERIAL HWY.
2 MI.
MAJOR ARTERIAL
BREA BLVD.
2.5 MI.
1 MI.
HARBOR BLVD
COMMONWEALTH
5 MI.
2 MI.
ORANGETHORPE
LA PALMA
2 MI.
3 MI.
BROOKHURST
BEACH BLVD.
1 MI.
STATE COLLEGE
LINCOLN
BALL
ANAHEIM BLVD.
STOP
TAFT
3 MI.
MAJOR ARTERIAL
TUSTIN AVE.
1.5 MI.