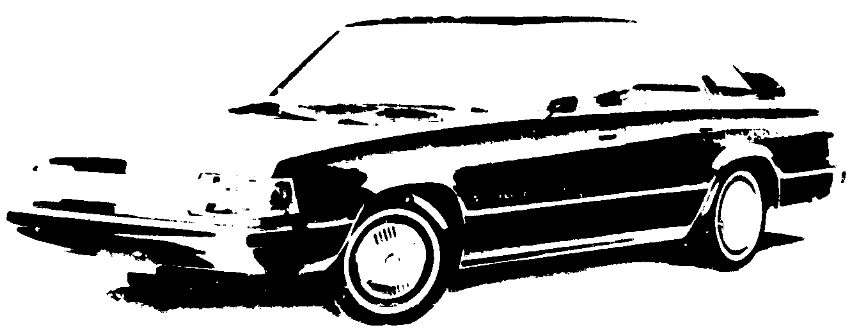
NEAR-TERM HYBRID VEHICLE PROGRAM

FINAL REPORT — PHASE I

Appendix A - Mission Analysis and Performance

Specification Studies Report



Contract No. 955190

Submitted to

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91103

Submitted by

General Electric Company
Corporate Research and Development
Schenectady, New York 12301

October 8, 1979

GENERAL ELECTRIC

FOREWORD

The Electric and Hybrid Vehicle (EHV) Program was established in DOE in response to the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976. Responsibility for the EHV Program resides in the Office of Electric and Hybrid Vehicle Systems of DOE. The Near-Term Hybrid Vehicle (NTHV) Program is an element of the EHV Program. DOE has assigned procurement and management responsibility for the Near-Term Hybrid Vehicle Program to the California Institute of Technology, Jet Propulsion Laboratory (JPL).

The overall objective of the DOE EHV Program is to promote the development of electric and hybrid vehicle technologies and to demonstrate the validity of these systems as transportation options which are less dependent on petroleum resources.

As part of the NTHV Program, General Electric and its subcontractors have completed studies leading to the Preliminary Design of a hybrid passenger vehicle which is projected to have the maximum potential for reducing petroleum consumption in the near term (commencing in 1985). This work has been done under JPL Contract 955190, Modification 3, Phase I of the Near-Term Hybrid Vehicle Program.

This volume is part of Deliverable Item 7, Final Report, of the Phase I studies. In accordance with Data Requirement Description 7, the following documents are submitted as appendices to the Final Report.

APPENDIX A is the Mission Analysis and Performance Specification Studies Report that constitutes Deliverable Item 1 and reports on the work of Task 1.

APPENDIX B is a three-volume set that constitutes Deliverable Item 2 and reports on the work of Task 2. The three volumes are:

- Volume I -- Design Trade-Off Studies Report
- Volume II -- Supplement to Design Trade-Off Studies Report, Volume I
- Volume III -- Computer Program Listings

APPENDIX C is the Preliminary Design Data Package that constitutes Deliverable Item 3 and reports on the work of Task 3.

APPENDIX D is the Sensitivity Analysis Report that constitutes Deliverable Item 8 and reports on Task 4.

The three classifications - Appendix, Deliverable Item, and Task number - may be used interchangeably in these documents. The interrelationship is tabulated below:

Appendix	Deliverable Item	Task	Title
A	1	1	Mission Analysis and Performance Specification Studies Report
B	2	2	Vol. I - Design Trade-Off Studies Report
			Vol. II - Supplement to Design Trade-Off Studies Report
			Vol. III - Computer Program Listings
C	3	3	Preliminary Design Data Package
D	8	4	Sensitivity Analysis Report

This is Appendix A, Mission Analysis and Performance Specification Studies Report, which reports on Task 1 and is Deliverable Item 1. It presents the study methodology, vehicle characterizations, mission description, characterization, and impact on potential sales, rationale for selection of the ICE Reference Vehicle, primary results of the study, and conclusions and recommendations.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

Section 1

INTRODUCTION AND SUMMARY

Section 1

INTRODUCTION

1.1 INTRODUCTION

This is Appendix A, Mission Analysis and Performance Specification Studies Report (Deliverable Item 1) of the Phase I Final Report (Deliverable Item 7). This Appendix A reports on Task 1 of the Near-Term Hybrid Vehicle Program and is part of Deliverable Item 7, Final Report, which is the summary report of a series which documents the results of Phase I of the Near-Term Hybrid Vehicle Program. Phase I of the program was a study leading to the preliminary design of a five-passenger hybrid vehicle utilizing two energy sources (electricity and gasoline/diesel fuel) to minimize petroleum usage on a fleet basis.

The Near-Term Hybrid Vehicle Program is sponsored by the U.S. Department of Energy (DOE) and the California Institute of Technology, Jet Propulsion Laboratory (JPL). Responsibility for this program at DOE resides in the Office of Electric and Hybrid Vehicle Systems. Work on the Phase I portion of the Program was done by General Electric Company Corporate Research and Development and its subcontractors under JPL Contract 955190.

This report presents the study methodology; the vehicle characterizations; the mission description, characterization, and impact on potential sales; the rationale for the selection of the Reference Internal Combustion Engine (ICE) Vehicle, the primary results; and conclusions and recommendations of the mission analysis and performance specification report.

1.2 OBJECTIVES OF MISSION ANALYSIS AND PERFORMANCE SPECIFICATION STUDIES (TASK 1)

The major objectives of Task 1 - Mission Analysis and Performance Specification Studies are to:

- Perform an analysis of missions appropriate for a hybrid vehicle which meets or exceeds specified minimum constraints and performance requirements,
- Identify vehicle characteristics associated with these missions,
- Identify the mission or sets of missions which maximize the potential for reduction of petroleum consumption by a single hybrid design, and to
- Conduct performance specification studies directed at defining the performance requirements the vehicle should meet to safely and efficiently perform the mission or missions identified in the mission analysis.

The Task 1 report consists of the following major sections:

- Study Methodology
- Vehicle Characterizations
- Mission Description and Characterization
- Rationale for the Selection of the Reference ICE Vehicle
- Primary Results of Mission Analysis and Performance Specifications Study
- Conclusions and Recommendations for Continuing Work on Mission Analysis

1.3 SUMMARY

The results of the mission analysis and performance studies are briefly summarized in this subsection. A complete description of the approach to the studies and the results and conclusions are presented in later sections.

1.3.1 VEHICLE CHARACTERIZATIONS

For purposes of this analysis, four passenger car size classes were defined:

Class	Passenger Capacity
Small	2 front plus 2 rear with reduced comfort
Compact	4
Mid	5
Full	6

Vehicle performance was specified in terms of:

- Top Speed
- Acceleration
- Gradability
- Passing Capability

Conventional Internal Combustion Engine (ICE) passenger cars were characterized by size class for the years 1978 and were projected for 1985. These data were used to estimate the required and acceptable performance for the hybrid/electric car and also served as criteria for selecting the Reference ICE Vehicle.

1.3.2 SUMMARY OF MISSION DESCRIPTION AND CHARACTERIZATION

Personal transportation needs vary markedly from locality to locality and from region to region in the United States. This study has examined the differences in regional characteristics as they relate to hybrid/electric vehicle use and marketability. Two distinct types of areas are defined in terms of inside and outside Standard Metropolitan Statistical Areas (SMSAs). Urban areas are taken to be inside SMSAs. Small cities/towns/rural communities are taken to be outside SMSAs. Based on 1970 population data, about 60% of the US population lives inside SMSAs. Data on household ownership of vehicles in 1974 indicates that about 70% of passenger cars are owned by people living inside or on the fringe of SMSAs. A sales mix for 1977 for inside SMSAs and outside SMSAs was developed from new car sales data and was assumed to apply to 1985 even though the actual size of cars in each size class will be decreasing during the 1977 to 1985 time period. Four mission sets were specified and analyzed for each of the two distinct regions.

Mission Sets

Personal business travel only

Personal business plus trips to work

All-purpose (except trips of 100 or more miles per day)

All purposes

In order to characterize the mission sets, three main factors are required:

- Annual mileage
- Daily travel requirements
- Driving cycles

These are discussed in Section 4.3. The annual mileage and trip length data is used as inputs to a Monte Carlo trip simulation computer program to calculate annual driving statistics. The results of the Monte Carlo computer program calculations were analyzed to determine the effect of hybrid/electric vehicle range solely on the battery, on the fraction of days and vehicle miles for which the vehicle can be operated primarily on stored electrical energy. Typical correlations for personal travel plus trips to work inside an SMSA area are shown in Figures 1-1 and 1-2. A summary of the travel statistics and hybrid/electric range implications is given in Table 1-1.

Three driving cycles were considered:

- EPA urban, Federal Urban Driving Cycle (FUDC)
- EPA highway, Federal Highway Driving Cycle (FHDC)
- SAE J227a Schedules B,C,D

It was concluded that the EPA urban and highway cycles could be adapted for use in the hybrid/electric vehicle design. The SAE J227 cycles were defined as a means of comparing all-electric vehicles of differing design and capability and do not represent actual driving conditions even in congested urban areas.

1.3.3 SUMMARY OF RATIONALE FOR THE SELECTION OF THE ICE REFERENCE VEHICLE

Selection of a conventional internal combustion engine (ICE) passenger vehicle is needed for comparison with the hybrid/electric vehicle. A contract specification for the hybrid/electric is that it must carry at least 5 adults. To maximize the potential fuel saving, the hybrid/electric has been targeted to be in the mid-size car class. The criteria for selection of the ICE Reference Vehicle were:

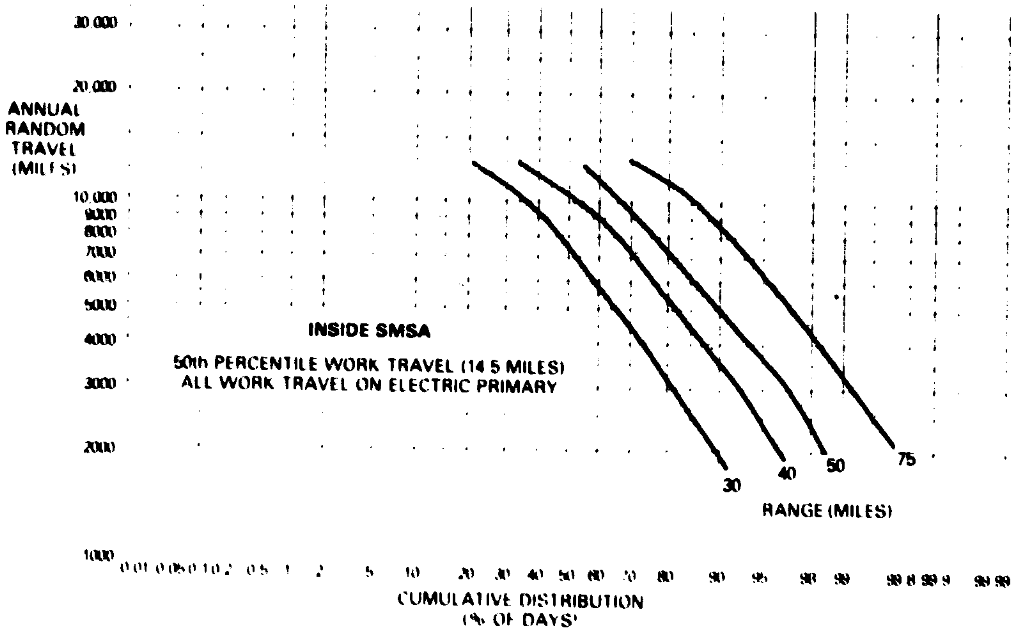


Figure 1-1. Effect of Electric Vehicle Range on All-Electric Vehicle Travel Inside SMSA as a Percentage of Number of Days in a Year

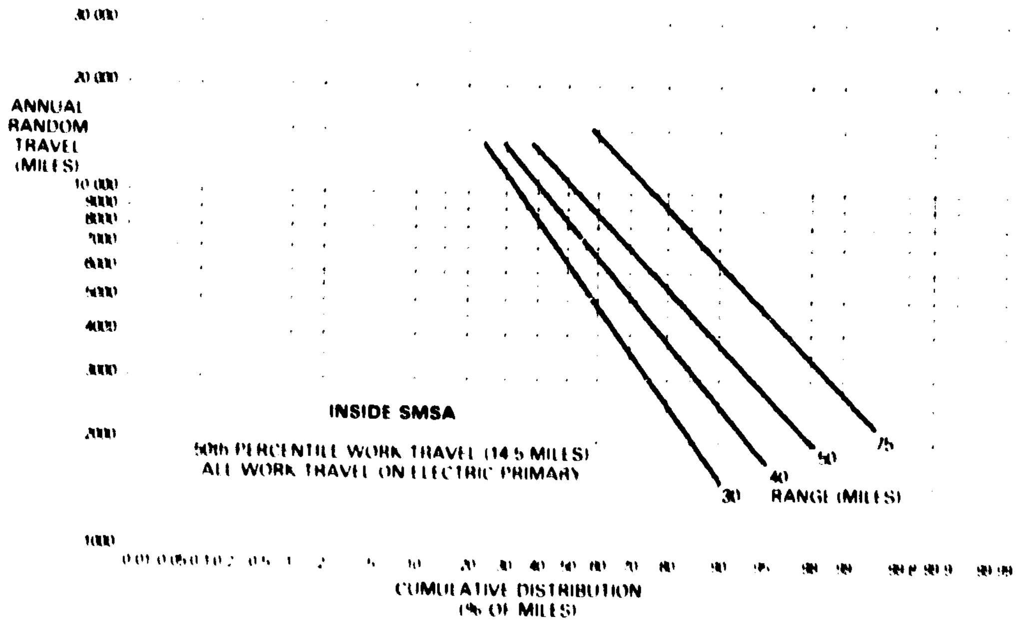


Figure 1-2. Effect of Electric Vehicle Range on All-Electric Vehicle Travel Inside SMSA as a Percentage of Annual Miles

Table 1-1

DAILY AND ANNUAL TRAVEL DISTANCES INSIDE SMSAs FOR VARIOUS MISSIONS

Mission	Annual Distance (miles)	Daily Distance (miles) Percentile *		
		50	75	90
Personal business only				
50th percentile	3,000	20	29	39
75th percentile	4,500	25	38	49
90th percentile	6,500	32	49	66
Personal business plus work trips				
50th percentile	6,625	21	32	43
75th percentile	8,125	26	39	57
90th percentile	10,125	32	51	76
All-purpose (excluding intercity travel)				
50th percentile	6,400	34	52	69
75th percentile	9,200	52	74	99
90th percentile	11,600	>100	>100	>100
All-purpose (including intercity travel)				
50th percentile	7,000	36	61	>100
75th percentile	11,300	50	84	>100
90th percentile	17,000	70	>100	>100

*Percentiles are for vehicle miles

- Capacity for 5 adults
- High sales volume
- Acceptable acceleration

Both the General Motors Malibu/Cutlass and the Ford Motor Company Fairmont/Zephyr meet the above criteria. The Chevrolet Malibu using a V-6, 231 CID engine was selected as the ICE Reference Vehicle primarily because General Electric and its subcontractors have better access to information on the General Motors than on the Ford cars. A brochure on the Chevrolet Malibu is included in the Appendix.

1.3.4 SUMMARY OF PRIMARY RESULTS

The format used in presenting the results follows that given in Exhibit I of Contract No. 955190.

Vehicle Performance Specifications

P1, Minimum Nonrefuelable Range

Urban, Suburban	-- 55 to 65 km (35-40 miles) on battery;* 110-130 km (70-80 miles) without any recharging of the battery by the heat engine
Highway	-- 400 km (250 miles) **

P2, Cruise Speed

Electric Drive Only	-- 88 km/h (55 mph)
ICE Engine Only	-- 105 km/h (65 mph)
P3, Maximum Speed	-- 120 km/h (75 mph)
P4, Acceleration	-- 0-96 km/h (0-60 mph) in 16 seconds

P5, Gradability (minimum continuous)

5%	-- 88 km/h (55 mph)
15%	-- 35 km/h (20 mph)
P6, Passenger Capacity	-- 5 adults
P7, Cargo Capacity	-- 0.5 m^3 (17.7 ft^3); 100 kg (220 lb)

* Heat engine used only to meet peak power demand.
** Depends on size of fuel tank; no battery recharging by heat engine in 500 miles.

Mission Specifications

M1, Daily Travel	-- see Tables 6-1 and 6-2
M2, Payload	-- passenger and cargo loads not assigned to specific type trips
M3, Trip Length, Frequency and Purpose	-- see Section 4.3
M4, Driving Cycles	-- EPA Urban (FUDC) and EPA Highway (FHDC)
M5, Annual Vehicle Miles	-- see Figures 4-7 through 4-10 for annual mileage statistics
M6, Potential Number of Hybrid/Electric Vehicles in Use	-- will be analyzed in later task
M7, ICE Reference Vehicle	-- Chevrolet Malibu with V-6, 231 CID engine
M8, Reference ICE Vehicle Annual Fuel Consumption	-- in 1985 all mid-size passenger cars estimated to use 27% of fuel used for personal transportation

Section 2

STUDY METHODOLOGY

Section 2

STUDY METHODOLOGY

A study methodology was devised which would provide the information needed to define the hybrid/electric car which will be designed in Task 2 and Task 3. In addition, the information developed will serve as a guide in the selection of the ICE Reference Vehicle. The study methodology consists of three major activities:

- Vehicle Characterizations
- Mission Description and Characterization
- Rationale for the Selection of the ICE Reference Vehicle

The Work Flow Diagram for this study is shown in Figure 2-1.

2.1 METHODOLOGY FOR VEHICLE CHARACTERIZATIONS

In the present study, passenger cars are categorized by size and passenger capacity. Four size classes are defined: small, compact, mid-size, and full-size. Vehicle weight for each size class is estimated but is not used in defining the size class. Vehicle performance specifications are examined in terms of the following:

- Top Speed
- Acceleration
- Gradability
- Low- and High-Speed Passing Capability

Performance (acceleration) required for safe operation was differentiated from performance required for ready acceptance in the marketplace. Performance requirements for the 1985 cars were then estimated based primarily on safe operation. Performance specifications for the hybrid/electric vehicle were proposed and compared to the minimum requirements specified in Exhibit 1 of the contract.

Projected characteristics of conventional ICE passenger cars were collected and examined. The characteristics of particular interest were:

- Exterior Dimensions
- Curb Weight
- Fuel Economy
- Exhaust Emission Standards

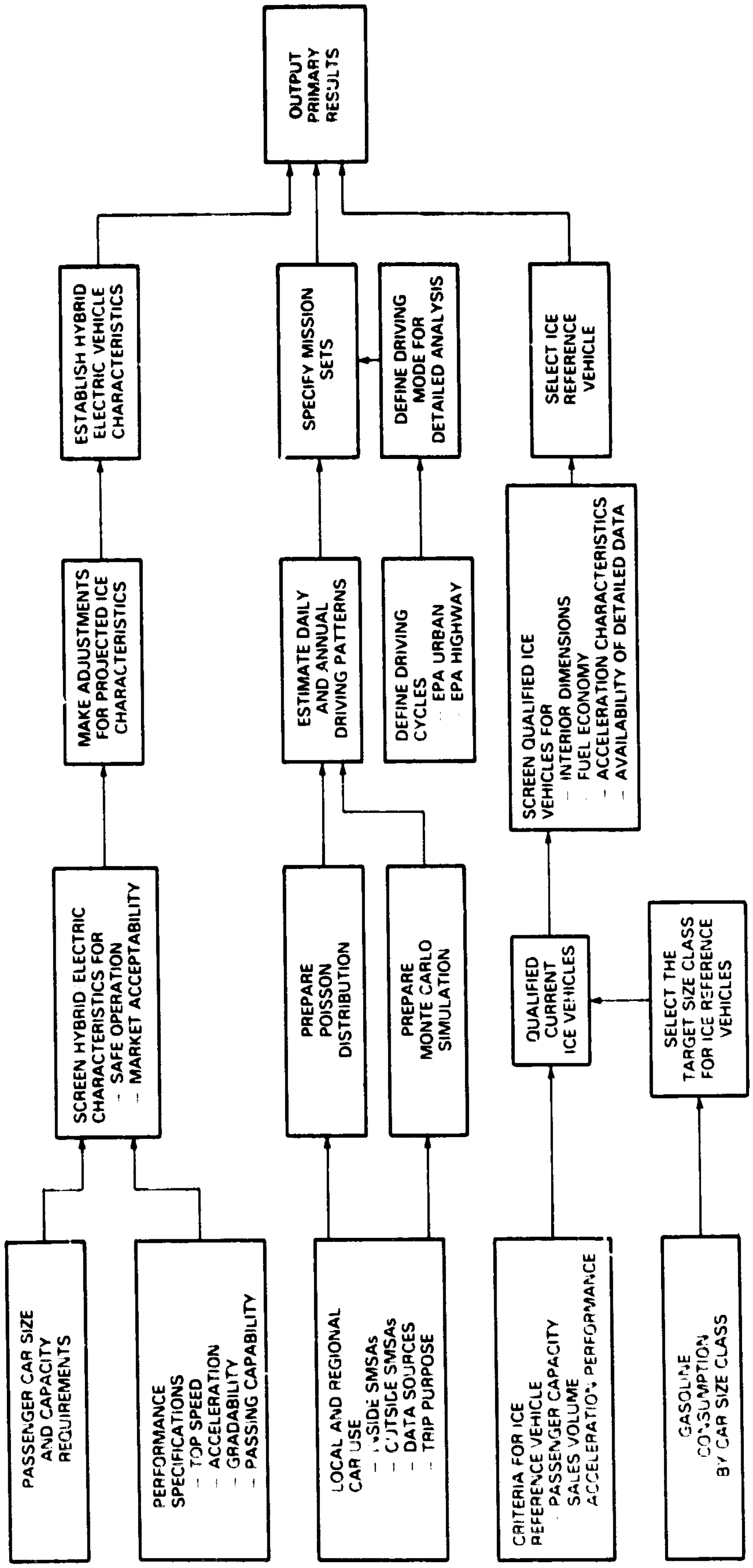


Figure 2-1. Work Flow Diagram for Task 1

Data were correlated for both 1978 model cars and cars projected for 1985. The EPA urban and highway driving cycles were assumed to be representative of urban and highway driving in 1985 and were used to determine vehicle composite fuel economy for the conventional cars. The 1977 sales mix of four size classes was used as the basis for the 1985 sales mix in order to target the size class for the hybrid/electric vehicle.

2.2 METHODOLOGY FOR MISSION DESCRIPTION AND CHARACTERIZATION

In order to assess the effects of mission analysis on hybrid/electric vehicle design and marketability, local and regional car use was studied. Two regions were considered:

- Inside Standard Metropolitan Statistical Areas (SMSAs)
- Outside Standard Metropolitan Statistical Areas (SMSAs)

Data sources used include (1) national census surveys, (2) national transportation use-pattern surveys, and (3) car registration statistics. It was assumed that the sales mix by size class would be about the same during the next decade even though the actual size of the cars will be smaller in the future than at present.

The use pattern of the automobile varies over a wide range in terms of trip length, trip frequency, and trip purpose. Four general categories of trip purpose are often defined:

- Earning a Living (Work Travel)
- Family Business
- Civic, Educational, or Religious
- Social or Recreational

The last three trip purposes were consolidated and called Personal Business. Use patterns of automobiles were characterized in terms of regular travel (e.g., work travel) and random travel (e.g., personal business). Mission sets were then described in terms of both random and non-random trips. A total of eight mission sets were specified and analyzed (four each for travel inside SMSAs and outside SMSAs).

Characterization of automobile travel requires the following main factors:

- Annual Mileage (statistical distributions)
- Daily Travel (statistical distribution of trip length and number)
- Driving Mode

Since data pertinent to some of these factors are very limited, considerable judgement had to be used in developing inputs for the travel analysis. In the absence of data, for example, an estimate had to be made for annual mileage versus percent automobiles. Daily travel patterns were determined when at all possible through use of the Nationwide Personal Transportation Study. A computer program was written to simulate daily travel by using a Poisson distribution and a Monte Carlo simulation. The Poisson distribution determines both the number of days per year in which a specified number of trips are taken as well as the total number of trips per year. The Poisson distribution requires as input data the average number of trips per day and the average trip length. The Monte Carlo simulation uses a random number generator to predict trip length and requires the use of distribution functions for percent trips and percent vehicle miles in terms of the trip length. The results of the Monte Carlo trip simulation are used to determine the fraction of days and vehicle miles for which a hybrid/electric vehicle having a specified "electric" range can be operated primarily on the battery. Such correlations are developed for each of the mission sets.

Driving mode is usually described by a driving cycle or combinations of driving cycles. The EPA urban (FUDC) and the EPA highway (FHDC) driving cycles were examined as the means to represent urban and highway travel. The two parts (transient and stabilized) of the FUDC are used individually and in combination to describe city and suburban trips, and the FHDC is used to describe intercity travel which is considered as trips of over 100 miles.

2.3 METHODOLOGY USED IN THE SELECTION OF THE ICE REFERENCE VEHICLE

In order to properly assess the hybrid/electric car it is necessary to identify a conventional internal combustion engine (ICE) passenger car having the same passenger carrying capacity and performance. The criteria for selection of the ICE Reference Vehicle were:

- Passenger Capacity
- Sales Volume
- Acceleration Performance

Selection of the ICE Reference Vehicle was directed to mid-size cars because hybrid/electric cars of that size class were judged to have the greatest potential for reducing gasoline consumption. Interior dimensional criteria noted by Consumers Union (April 1978) were used to identify several 1978/1979 model mid-size cars which would be acceptable as ICE Reference Vehicles. Fuel economy and acceleration characteristics were used for further narrowing of the list of potential ICE Reference Vehicles. The final selection of the ICE Reference Vehicle was based on the availability of detailed information on the ICE vehicle which was selected.

2.4 PRESENTATION OF RESULTS

The results of the study are presented as:

- Vehicle Performance Specifications
- Mission Description and Daily Travel
- Mission Specifications
- ICE Reference Vehicle and Its Characteristics

Section 3

VEHICLE CHARACTERIZATIONS

In this section, vehicle passenger carrying capacity, acceleration performance, safe operation, and market acceptability are considered as they relate to 1985 cars. Based on those considerations, hybrid/electric vehicle specifications are proposed for use in this program. Conventional ICE passenger car size, weight, fuel economy, and sales mix are summarized and used to target the size class for the hybrid/electric vehicle to be designed in Tasks 2 and 3.

3.1 PASSENGER CAR SIZE CLASSES

Passenger cars will be categorized in this report in terms of four classes: small, compact, mid, and full. The primary distinguishing factor for each class is the interior size of the vehicle, and thus its capacity for carrying a specified number of adult passengers in comfort over a reasonable distance. In these terms, the four size classes are defined as follows:

Class	Passenger Capacity
Small	2 front plus 2 rear with reduced comfort
Compact	4
Mid	5
Full	6

The US auto industry is currently engaged in an extensive program of passenger car downsizing, which, in essence means reducing the exterior dimensions and the weight of the vehicle while maintaining a specified passenger carrying capacity. Thus, within a passenger car class, the size of the vehicle is being reduced, but not its passenger carrying capacity. The weight and exterior dimensions of selected car models, which are typical of downsized designs, are given in Table 3-1, grouped by size class. The data shown in the table will be used in Section 3.3 to project the size and weight characteristics of conventional ICE passenger cars marketed from 1980 to 1985. The electric/hybrid vehicles in each size class would by definition have the same passenger carrying capacity as conventional ICE vehicles in that class, but not the same weight or necessarily the same exterior dimensions.

3.2 PERFORMANCE SPECIFICATIONS

By vehicle performance specifications are meant the following: (1) top speed, (2) acceleration, (3) gradability, and (4) low- and high-speed passing capability. Vehicle performance depends both on the power-to-weight ratio of the vehicle and its gearing (i.e., axle ratio, transmission gear ratios, and shift logic). In determining the performance requirements, it seems advisable to differentiate between the performance required (1) for safe operation of the vehicle on streets, freeways, and highways as they are currently structured and trafficked and (2) for ready acceptance of a new vehicle design by potential buyers. Both of these aspects of setting performance specifications will be considered in the subsequent paragraphs.

Table 3-1

WEIGHTS AND EXTERIOR DIMENSIONS OF DOWNSIZED PASSENGER CARS

Manuf.	Model	Year Introd.*	Curb Weight kg (lb)	Vehicle Dimensions cm (in.) L	W	H
			Vehicle Class: Small			
VW	Rabbit	1976	843.7 (1860)	393.7 (155)	160.0 (63)	139.7 (55)
Chevrolet	Chevette	1976	929.9 (2050)	411.5 (162)	15[illegible].5 (62)	132.1 (52)
Honda	Civic	1972	799.2 (1762)	381.0 (150)	149.9 (59)	132.1 (52)
Ford	Fiesta	1978	805.1 (1775)	373.4 (147)	157.5 (62)	132.1 (52)
Mazda	GLC	1977	891.3 (1965)	391.2 (154)	160.0 (63)	137.2 (54)
Toyota	Corolla		932.1 (2055)	419.1 (165)	157.5 (62)	139.7 (55)
Datsun	B-210		916.3 (2020)	411.5 (162)	154.9 (61)	137.2 (54)
Volvo	66	1977	839.2 (1850)	391.2 (154)	154.9 (61)	137.2 (54)
			Vehicle Class: Compact			
Audi	Fox		952.5 (2100)	442.0 (174)	165.1 (65)	137.2 (54)
VW	Dasher	1976	997.9 (2200)	439.4 (173)	160.0 (63)	137.2 (54)
Toyota	Corona		1149.9 (2535)	439.4 (173)	162.6 (64)	137.2 (54)
Honda	Accord	1977	915.4 (2018)	414.0 (163)	162.6 (64)	132.1 (52)
Renault	12		997.[illegible] (2200)	442.0 (174)	165.1 (65)	144.8 (57)
Volvo	343	1977	997.0 (2154)	421.6 (166)	165.1 (65)	139.7 (55)
Saab	99		1179.4 (2600)	444.5 (175)	167.6 (66)	142.2 (56)
Chrysler	Horizon	1978	969.3 (2137)	419.1 (165)	167.6 (66)	137.2 (54)
			Vehicle Class: Mid-Size			
Ford	Fairmont	1978	1247.4 (2750)	492.8 (194)	177.8 (70)	137.2 (54)
Chevrolet	Malibu	1978	1406.2 (3100)	490.2 (193)	182.9 (72)	137.2 (54)
Ford	Granada	1975	1478.7 (3260)	502.9 (198)	188.0 (74)	134.6 (53)
Dodge	Aspen	1976	1474.2 (3250)	500.4 (197)	185.4 (73)	139.7 (55)
Audi	5000	1978	1236.0 (2725)	482.6 (190)	177.8 (70)	137.2 (54)
Volvo	264		1437.9 (3170)	490.2 (193)	170.2 (67)	142.2 (56)
Merc. B.	230		1451.5 (3200)	485.1 (191)	177.8 (70)	142.2 (56)
			Vehicle Class: Full-Size			
Chevrolet	Impala	1977	1678.3 (3700)	538.5 (212)	193.0 (76)	142.2 (56)
Chrysler	LeBaron	1977	1633.0 (3600)	523.2 (206)	185.4 (73)	139.7 (55)
Ford	LTD	1979	1637.9 (3611)	530.9 (209)	198.1 (78)	[illegible]
Oldsmobile	Toronado	1979	1746.4 (3850)	523.2 (206)	182.9 (72)	[illegible]

* The year of introduction is noted if the model represented a significant new design for the manufacturer rather than an evolution from previous designs.

From Reference 4.

Consider first the performance required for ready acceptance of a new vehicle design in the marketplace. As indicated in Figure 3-1, there is little doubt concerning the acceleration performance preferred by the majority of car buyers at the present time. In 1977, cars having a 0-60 mph acceleration capability of greater than 16 seconds represented only 16% of General Motor's sales and those having a 0-60 mph acceleration capability of less than 13 seconds represented about 65% of sales. Whether this acceleration capability is needed for safe operation or is preferred for purely emotional reasons will be considered later. According to Table 3-2, taken from Ref. (1), it is likely that conventional ICE cars marketed in 1985 by the US auto industry will exhibit significantly lower acceleration performance than those marketed in 1978. This lowering of performance would, of course, occur gradually over the next 5 years and would result in a lowering of the expectations of car buyers regarding car performance. Hence, it seems quite likely that the acceleration performance required of a new design in 1985 will be significantly less than that expected in 1978. Another factor to consider is that the speed limit is currently 55 mph and travel at speeds in excess of 65-70 mph is likely to result in a traffic citation even with the current rather lax enforcement of the 55 mph speed limit. Over a period of years the reduced speed limit may also tend to lower consumer interest in high performance cars as there will be less need for highway passing capability much in excess of 60 to 65 mph. Hence, from a consumer acceptance point-of-view, it seems likely that by 1985, a 0-60 mph acceleration capability of 15 seconds will be considered attractive and a 0-60 mph acceleration in 20 seconds acceptable.

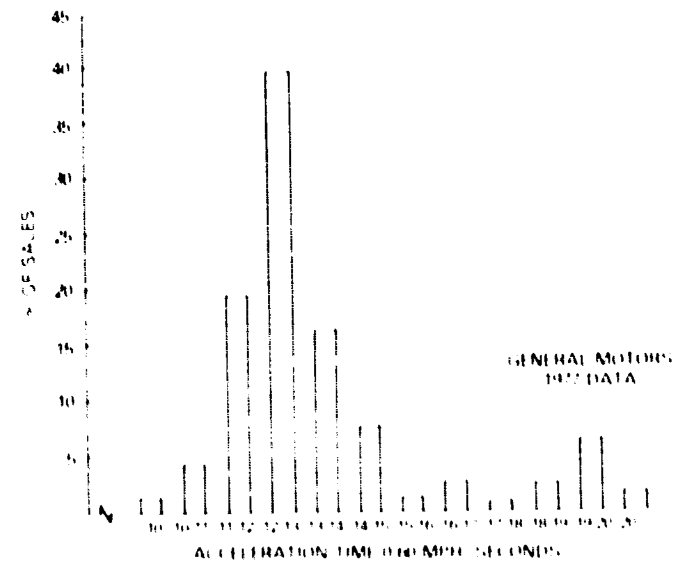


Figure 3-1. GM 1977 Sales Relation to Acceleration Characteristics (Reference 1)

Table 3-2

ACCELERATION CHARACTERISTICS(1)

Size Class	0-60 mph (0-96.5 km/h) (Automatic Transmission) 1977 (Seconds)	1985 (Seconds)
Small (Sub Compact)	11 - 24	17 - 21
Compact	12 - 19	17 - 18
Mid-Size	11 - 20	18 - 19
Large (Full-Size)	10 - 20	15 - 18

Next, consider the vehicle performance capability required for safe operation on urban streets/freeways and intercity highways. In order to be operated safely, a car must be able to (1) keep up with traffic on level roads and grades, (2) merge with flowing traffic on entering freeways and expressways, and (3) pass slower moving traffic at speeds up to the speed limit. Since the highway system in the mid-1980s will be essentially the same as that of today, the vehicles marketed in 1985 must be capable of safe operation on the roads as presently constructed. Today's highways were designed following the policies set forth in Reference 2 concerning maximum grades, expressway merging lane lengths, and required passing distances (Table 3-3). It will be assumed that the EPA urban and highway cycles will be representative of urban and highway driving in 1985 and that, if a vehicle can follow those cycles, it is capable of keeping up with traffic on level roads. Based on the highway design information given in Table 3-3, the minimum performance requirements set forth in Table 3-4 are suggested. These requirements should permit safe operation of the electric/hybrid vehicle in city/suburban and highway driving on the highway system as presently constructed and marked (i.e., designation of no-passing zones, etc.). For reasons of convenience, Table 3-4 specifies vehicle performance in terms of acceleration at a given speed or distance in which a specified speed change is to take place rather than the more familiar standing-start acceleration times (e.g., 0-30 mph or 0-60 mph in so-many seconds).

As noted above, the performance capability of conventional ICE cars is often stated in terms of the 0-60 mph acceleration time. In a sense, that acceleration time has acted as a proxy for the more meaningful performance capabilities listed in Table 3-4. It is of interest to ascertain the maximum 0-60 mph acceleration time for which all the performance requirements for safe operation of the vehicle in all types of driving are met. This could then be

Table 3-3

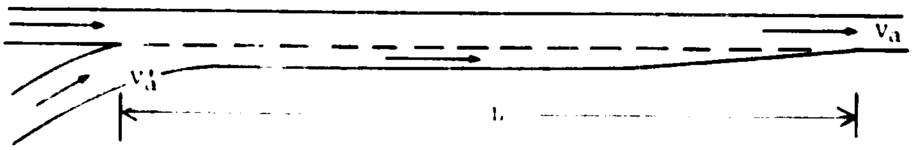
RELATION OF MAXIMUM GRADES TO DESIGN SPEED MAIN HIGHWAYS

Type of Topography	Design speed, mph 30	40	50	60	65	70	75	80
Flat	6	5	4	3	3	3	3	3
Rolling	7	6	5	4	4	4	4	4
Mountainous	9	8	7	6	6	5	-	-

ELEMENTS OF SAFE PASSING SIGHT DISTANCE-2-LANE HIGHWAYS

Speed group, mph Average passing speed, mph	30-40 34.9	40-50 43.8	50-60 52.6	60-70 62.0
Initial maneuver:				
a = average acceleration, mphps	1.40	1.43	1.47	1.50
t_1= time, seconds	3.6	4.0	4.3	4.5
d_1= distance traveled, feet	145	215	290	370
Occupation of left lane:				
t_2= time, seconds	9.3	10.0	10.7	11.3
d_2= distance traveled, feet	475	640	825	1030
Clearance length:				
d_3= distance traveled, feet	100	180	250	300
Opposing vehicle:				
d_4= distance traveled, feet	315	425	550	680
Total distance, $d_1+d_2+d_3+d_4$, feet	1035	1460	1915	2380

DERIVATION OF LENGTHS FOR ACCELERATION LANES



Highway		L-Length of Acceleration Lane-Feet for Entrance Curve Design Speed, MPH								
Design Speed, MPH	Speed Reached (V_a), MPH	Stop Condition	15	20	25	30	35	40	45	50
		And Initial Speed (V_a'), MPH								
		0	14	18	22	26	30	36	40	44
30	23	190	--	--	--	--	--	--	--	--
40	31	380	320	250	220	140	--	--	--	--
50	39	760	700	630	580	500	380	160	--	--
60	47	1,170	1,120	1,070	1,000	910	800	590	400	170
70	53	1,590	1,540	1,500	1,410	1,330	1,230	1,010	830	580

Note: Where lengths exceed 1,300 feet, or design speeds exceed 70 mph, uniform 50:1 tapers are recommended.

From Reference 2.

Table 3-4

MINIMUM PERFORMANCE REQUIREMENTS

Situation	Requirement	Basis
Acceleration		
City/Suburban Driving	3.2 mph/s at 31 mph (5.15 km/h/s at 49.88 km/h)	EPA Urban Cycle
Expressway Merging	0-35 mph in 300 ft (0-56.32 km/h in 91.44 m)	AASHO Design Policy
Passing on a 2-lane Road (55 MPH Speed Limit)	45-55 mph in 225 ft (72.41-88.5 km/h in 68.58 m)	AASHO Design Policy
<u>Gradability</u>	55 mph (88.5 km/h) on a 5% grade	Maintain Speed Limit on Grades in Rolling Terrain
<u>Top Speed</u>	Sustained Operation at 60 mph (96.54 km/h); speeds up to 70 mph (112.63 km/h) for passing	Speed Limit of 55 mph

used to determine the minimum power-to-weight ratio to consider in designing passenger cars. The power-to-weight ratios required at the wheels for various vehicle driving maneuvers are shown in Figure 3-2. The values given in Figure 3-2 were calculated using a variety of approximations including average rates of accelerations and times based on average speeds (e.g., $\bar{v} = v_{final} + v_{initial}/2$). Except for steady-state maneuvers such as driving on a grade, the effective acceleration parameter $(a/g)_{eff}$ was assigned to an intermediate speed between $\bar{v}$ and v_{final} based on available detailed calculations or engineering judgement. Fortunately, it appears that the critical conclusions can be extracted from Figure 3-2 without the need for precise calculations. It seems clear from Figure 3-2 that the high-speed passing maneuver on a 2-lane road is the most demanding relative to power required. Gradability and lower speed accelerations, including freeway merging, require much less power at the wheels. The differences when translated to engine (or powertrain) maximum power rating are smaller because it is possible to attain a greater fraction of the peak engine rated power at high vehicle speeds such as 50-60 mph than at vehicle speeds near 30-35 mph (see the ICE limit power curve in the upper left-hand corner of Figure 3-2). Note from Figure 3-2 that the 0-60 mph acceleration time corresponding to the 2-lane road passing requirement is about 15 seconds. Without a detailed study of 2-lane road passing, it would seem difficult to justify vehicle power-to-weight ratios much less than those resulting in 0-60 mph acceleration times of 15 or 16 seconds.

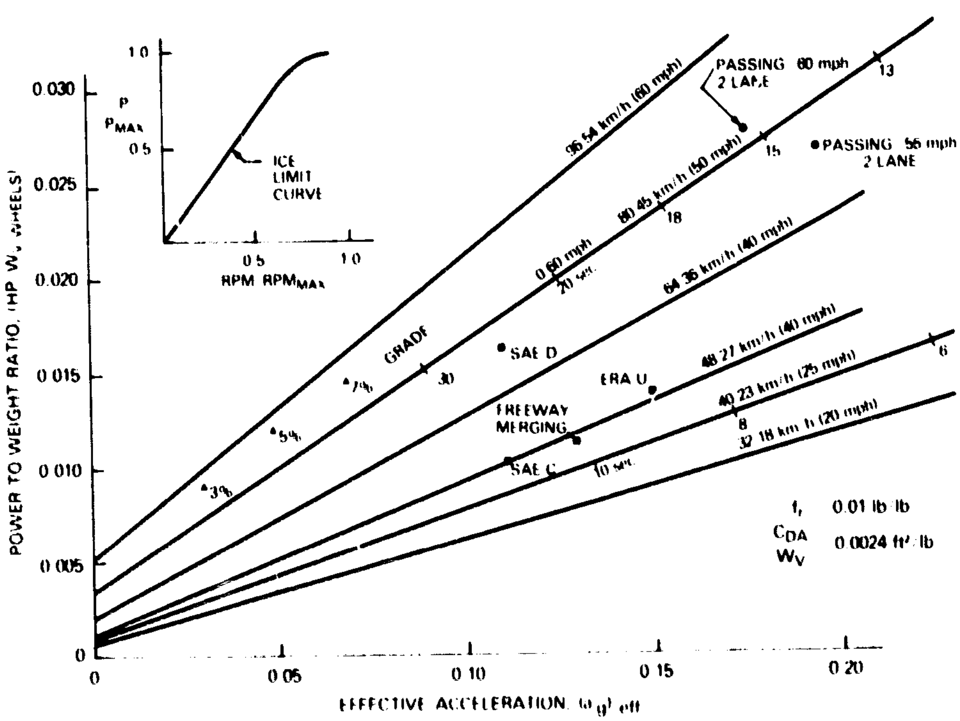


Figure 3-2. Power-to-Weight Ratio Requirements

The minimum JPL performance requirements (Exhibit 1 of RFP) and the hybrid vehicle design goals (Reference 3) are shown in Table 3-5. Direct comparisons between the JPL performance specifications and those proposed in Table 3-4 can only be made for gradability and the inferred 0-60 mph acceleration time. Unfortunately, the JPL acceleration time for minimum performance is given for a 0-56 mph acceleration rather than for the customary 0-60 mph acceleration. Using available vehicle acceleration profile test data (see Figure 3-3), a 0-56 mph acceleration time of 15 seconds was found to be equivalent to a 0-60 mph acceleration time of 17 seconds which is within the range (15-19 seconds) projected for 1985 by the US auto industry for 5- and 6-passenger cars (Table 3-2). The power requirement inferred from Figure 3-2 in the present analysis is only slightly greater than that corresponding to a 0-60 mph acceleration time of 17 seconds, and is also within the range projected by the auto industry. The JPL acceleration goal of 0-60 mph in 14 seconds would certainly be attractive to potential hybrid vehicle buyers, but that much power does not seem to be needed for safe operation and would likely exceed that available in conventional ICE cars in 1985. There does not appear to be significant differences between the JPL minimum acceleration specification and those developed in the present study so that the power-to-weight of the hybrid design will be such that the minimum performance requirements set forth in Table 3-4 will be met yielding an equivalent 0-60 mph acceleration time of 15-16 seconds. It can be expected that the gradability of the hybrid vehicle will be better than the JPL minimum requirement (55 mph on a 3% grade) and probably also better than 55 mph on a 5% grade, at least for some distance, depending on the state-of-charge of the battery. Maintaining a gradability of 55 mph on a 7% grade would certainly be desirable and would appear to be a strong possibility.

3.3 CHARACTERIZATION OF CONVENTIONAL ICE PASSENGER CARS BY SIZE CLASS

At various times during the electric/hybrid study program, it will become necessary to obtain projected characteristics of the conventional ICE passenger cars marketed in the mid-1980s in the various size classes. The characteristics of particular interest are exterior dimensions, curb weight, and fuel economy (urban and highway). Projection of these characteristics for 1985 model passenger cars is clearly subject to some uncertainty. Fortunately, the uncertainty is considerably reduced by the necessity of the auto industry to meet the legally mandated CAFE* of 27.5 mpg in 1985. In addition to the fleet fuel economy standard, the passenger cars must also meet exhaust emission standards. The fuel economy and emission standards which must be met between 1978 and 1985 are summarized in Table 3-6.

Table 3-5

JPL - MINIMUM SPECIFICATIONS

Acceleration	Time (Seconds)
0 - 31 mph (49.88 km/h)	6
0 - 56 mph (90.1 km/h)	15
25 - 56 mph (passing) (40.23 - 90.1 km/h)	12

Grade (%)	Speed km/h	(mph)
3	90.1	(56)
8	49.88	(31)
15	25.74	(16)

JPL - GOAL SPECIFICATIONS

Acceleration	Time (Seconds)
0 - 30 mph (48.27 km/h)	6
0 - 60 mph (96.54 km/h)	14
19 - 35 mph (passing) (30.57 - 56.32 km/h)	4
37 - 55 mph (passing) (59.53 - 88.50 km/h)	9

Grade (%)	Speed km/h	(mph)
5	88.50	(55)
7	48.27	(30)
20	19.31	(12)

*Corporate Average Fuel Economy

Table 3-6

MANDATORY FUEL ECONOMY AND EMISSIONS STANDARDS

Year	Sales Weighted Average mpg[(a)]
1978	18
1979	19
1980	20
1981	22
1982	24
1983	26
1984	27
1985	27.5

(a) Composite - 55% urban cycle, 45% highway cycle.

LIGHT-DUTY VEHICLE EMISSION STANDARDS

Year	49 - States (Fed.) grams/mile			California grams/mile		
	HC	CO	NO_x	HC	CO	NO_x
1973[(a)]	3.2	39	3	3.2	39	3
1974	3.2	29	3	3.2	39	3
1975[(b)]	1.5	15	3	0.9	9	2
1976	1.5	15	3	0.9	9	2
1977	1.5	15	2	0.4	9	1.5
1978	1.5	15	2	0.4	9	1.5
1979	1.5	15	2	0.4	9	1.5
1980	0.4	15	2	0.4	9	1.0
1981	0.4	7	1[(c)]	0.4	9	1.0
1982	0.4	3.4	1	0.4	9[(d)]	0.4[(e)]
1983	0.4	3.4	1	0.4	9	0.4
1984	0.4	3.4	1	0.4	9	0.4
1985	0.4	3.4	1	0.4	9	0.4

(a) 1972 CVS-C test procedures used for 1973-74.
(b) 1975 CVS-CH test procedure used for 1975 and beyond.
(c) Diesels and cars with other innovative fuel-saving engines could qualify for a NO_x standard of 1.5 grams/mile (1977 amendments to the 1970 Clean Air Act).
(d) California is considering a CO standard of 7 grams/mile.
(e) California is considering an NO_x standard of 1 gram/mile if vehicle can be certified for 100,000 mi rather than 50,000 mi.

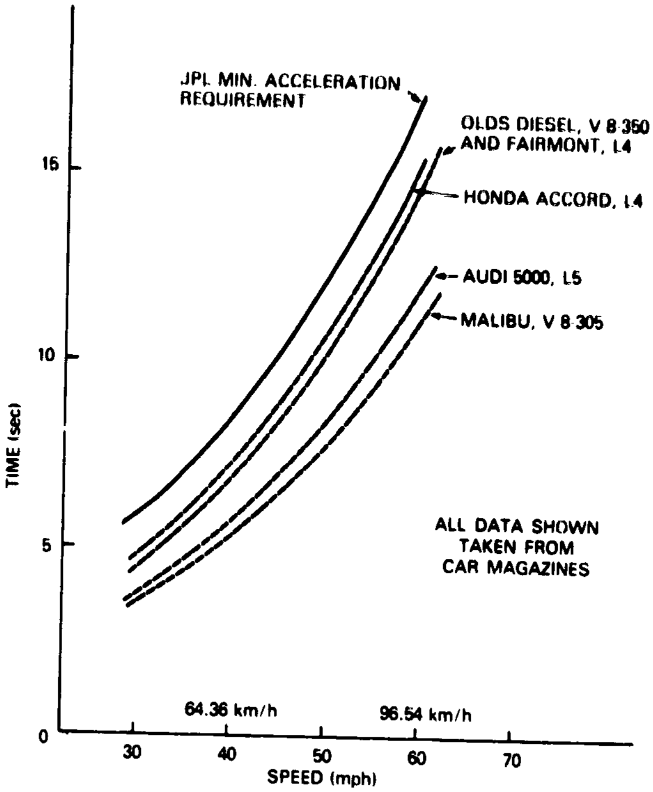


Figure 3-3. Acceleration Profiles

The approach used to obtain the passenger car characterizations given in this section is the same as that presented in Reference 4. In fact, some of the results given in Reference 4 will be used essentially unchanged in the present study because the referenced work is quite recent and little has happened in the interim to influence projections. The projected exterior dimensions and curb weights of downsized designs in the various size classes are summarized in Table 3-7. In the case of the US auto industry, 1978/79 designs are the first in an expected series of downsized designs in each class size. Significant additional size and weight reductions can be expected in subsequent redesigns as the auto industry utilizes extensively front wheel drive and smaller, more compact engines. This is especially true for mid- and full-size cars. Further weight reductions will also occur in all size classes with the use of lighter weight materials. Vehicle weights much less than those projected for 1985 would require a drastic change in structural design, such as the use of fiberglass, graphite composite, or foam-filled sandwich-type body construction. There is no reason to believe this will happen within the mid-1980 time period, because of the very large retooling investment required.

The fuel economy of the downsized 1985 passenger cars has been projected using 1978 EPA fuel economy results as the baseline. Fuel economy (urban and highway) using 1978 engine technology is shown in Figures 3-4 and 3-5 as a function of vehicle inertia weight for both gasoline and diesel engines. Improvements in fuel economy between 1978 and 1985 can result from a number of technological developments and/or styling changes. A breakdown of projected improvements from

Table 3-7

PROJECTED CAR WEIGHTS AND EXTERIOR DIMENSIONS

Car Class and Year	Curb Weight kg	(lb)	Length cm	(in.)	Width cm	(in.)	Height cm	(in.)
Small								
1978	798.3-932.2	(1760-2055)	381.0-411.5	(150-162)	149.9-160.0	(59-63)	132.1-139.7	(52-55)
1985	725.8	(1600)	381.0	(150)	152.4	(60)	132.1	(52)
Compact								
1978	916.3-1179.4	(2020-2600)	414.0-444.5	(163-175)	160.0-167.6	(63-66)	137.2-142.2	(54-56)
1985	907.2	(2000)	431.8	(170)	162.6	(64)	137.2	(54)
Mid-Size								
1978	1236.1-1478.7	(2725-3260)	482.6-500.4	(190-197)	177.8-188.0	(70-74)	134.6-142.2	(53-56)
1985	1179.4	(2600)	469.9	(185)	185.4	(73)	137.2	(54)
Full-Size								
1978	1633.0-1814.4	(3600-4000)	523.2-546.1	(206-215)	188.0-198.1	(74-78)	134.6-142.2	(53-56)
1985	1451.5	(3200)	508.0	(200)	190.5	(75)	139.7	(55)

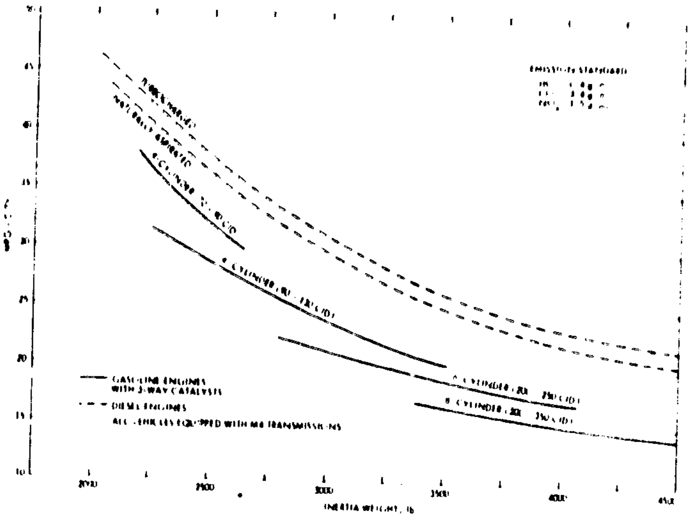


Figure 3-4. Baseline Fuel Economy - 1978 Technology, Urban Cycle(4)

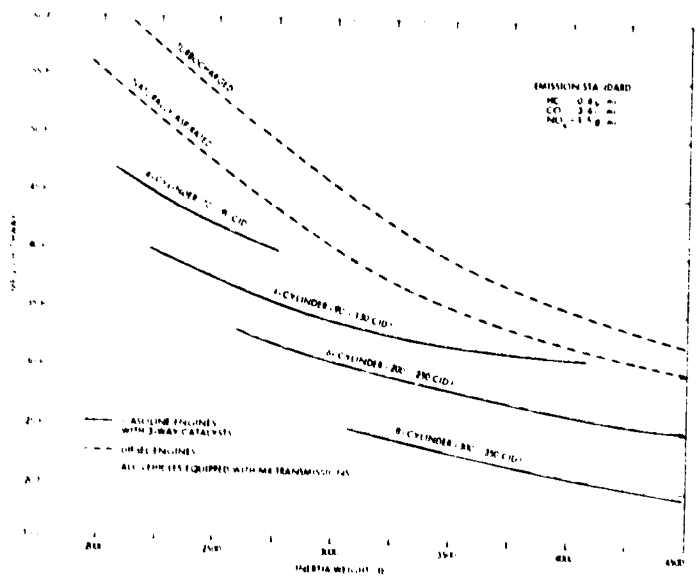


Figure 3-5. Baseline Fuel Economy - 1978 Technology, Highway Cycle(4)

various sources is given in Table 3-8. It has been assumed that the improvements indicated can be achieved along with meeting the 1985 statutory emission standards of 0.4 gram/mile HC, 3.4 grams/mile CO, and 1.0 gram/mile NO_x. This will doubtlessly require a refined 3-way catalyst system with microprocessor logic and control. The fuel economy for the 1985 vehicles is obtained by simply multiplying the baseline 1985 values by the fuel economy improvement factors in the table. The resultant 1985 fuel economy projections are shown in Figures 3-6, 3-7, and 3-8. The present results for

Table 3-8

PROJECTED FUEL ECONOMY IMPROVEMENTS (1978 to 1985)

Source	% Improvement City	% Improvement Highway
Engine Development	10%	10%
Lower C_D (0.5 to 0.38)	3%	7%
Improved Lubricants	2%	2%
Transmission Developments	3%	5%
Total	18%	24%

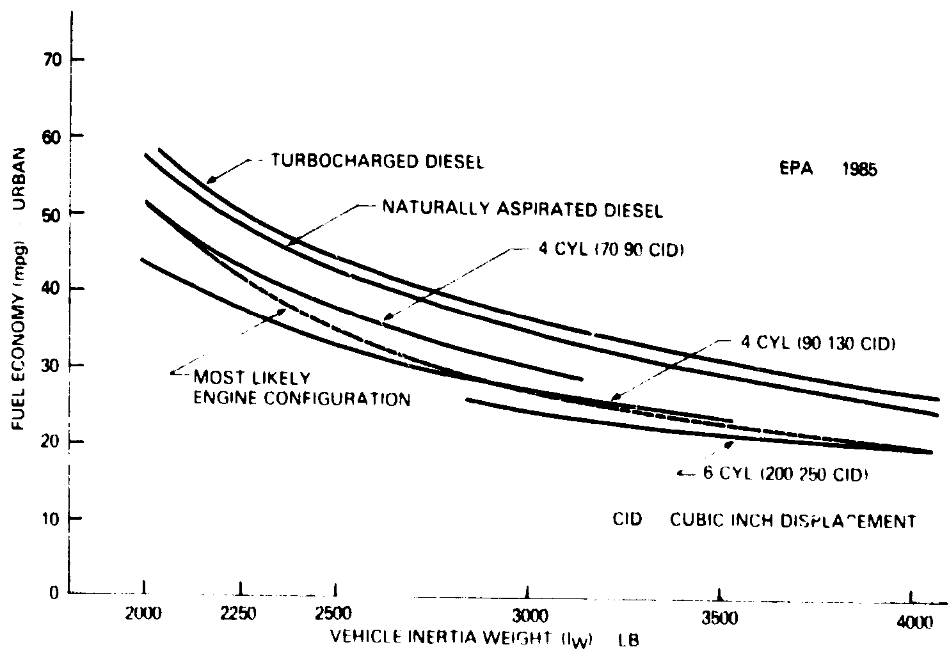


Figure 3-6. Projected 1985 Urban Fuel Economy

the composite fuel economy are compared with the guideline values given by JPL (Assumptions and Guidelines, received 27 Sept. 1978) in Figure 3-9. The JPL projections are, in general, lower than the present results. The differences are about 25% for 2000-lb cars and 15% for 3000 to 4000-lb cars. Reference (5) indicates that on-road fuel economy is somewhat lower than that measured by EPA. Therefore, it seems appropriate to correct the fuel economy projections (Figures 3-6, 3-7, and 3-8) based on the 1978 EPA values to account for this discrepancy. This has been done using the formula

$$(FE)_{cor.} = 0.71\ (FE)_{EPA\ based} + 2.83 \qquad (1)$$

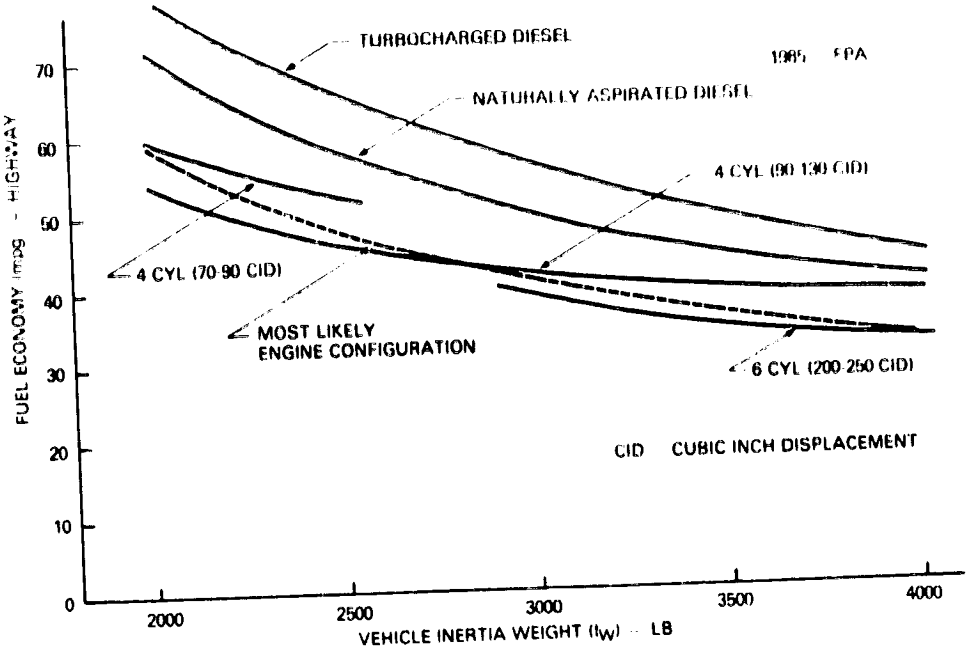


Figure 3-7. Projected 1985 Highway Fuel Economy

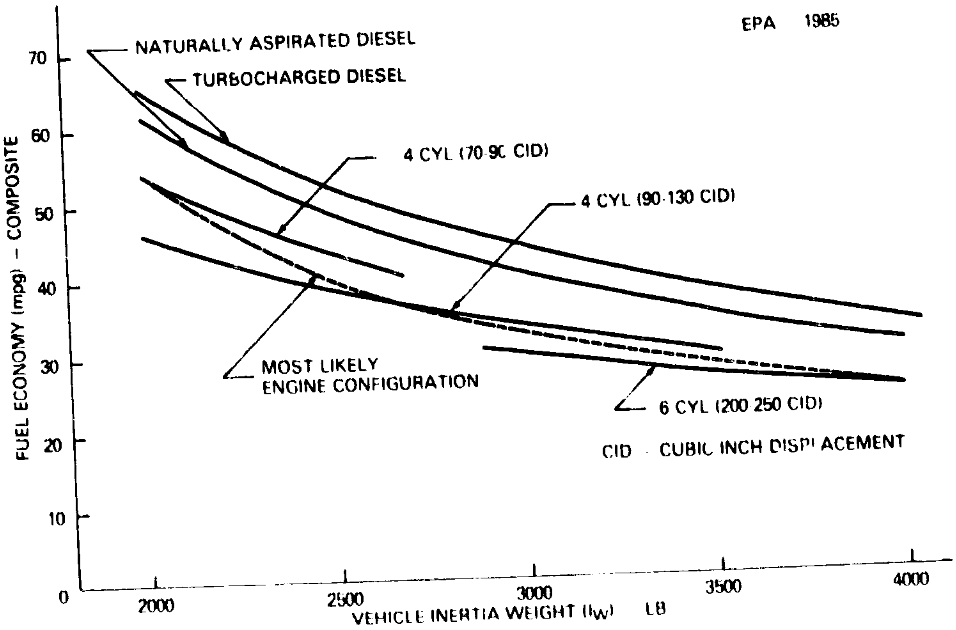


Figure 3-8. Projected 1985 Composite Fuel Economy

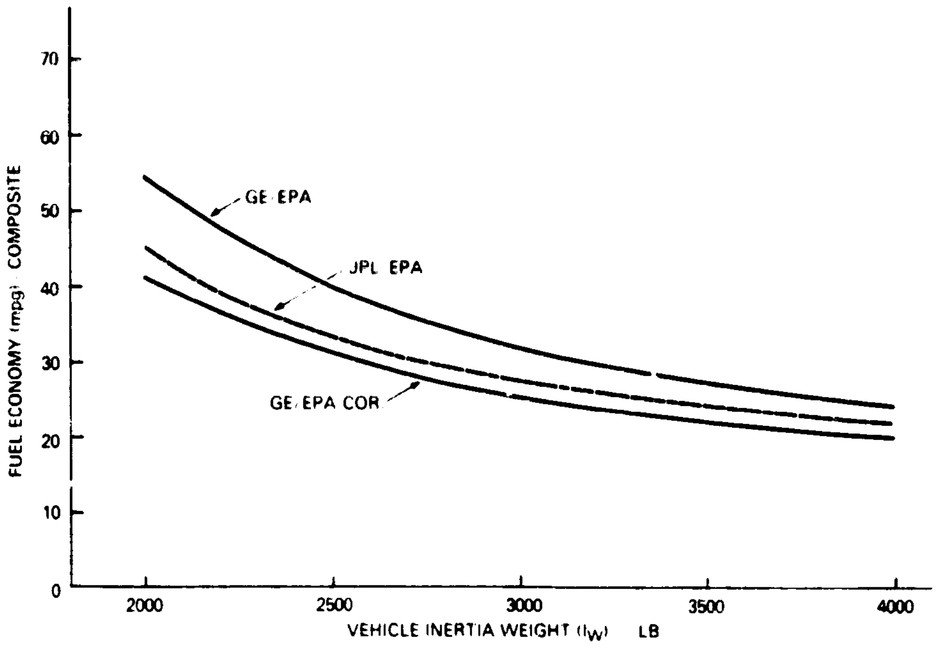


Figure 3-9. Composite Fuel Economy Comparisons

given by JPL in Ref. (6). The corrected composite fuel economy projection for gasoline-powered cars is shown in Figure 3-9. Because data to do otherwise are simply not available[5], the same correction has been made for both urban and highway fuel economy.

Unless directed by JPL to do otherwise, General Electric (GE) plans to use GE fuel economy projections during the hybrid vehicle study rather than those given in Ref. (6). This approach is preferred for a number of reasons. First, the differences between the JPL and GE projections are not really significant in terms of their effect on the conclusions to be drawn from the study. Second, the basis for the GE projections is known in detail whereas the same depth of information relative to the JPL projections was not readily available. Third, the GE projections include separate results for urban and highway driving and for diesel engines. Such information was not supplied by JPL as part of their guidelines/assumptions.[6]

The fuel economy projections and sales mix information discussed in Section 4 can be combined to determine the fraction of the fuel used by the various size classes. Those results for 1985 are given in Table 3-9. It was assumed that the sales mix in 1985 (in terms of size classes) will be the same as in 1977, and that all size classes are driven the same average annual mileage. As would be expected, Table 3-9 indicates that the larger cars use about 64% of the fuel. This simple calculation did not differentiate between urban and highway mileage. Nevertheless, it does indicate that the development of electric/hybrid 5- and 6-passenger cars has a greater potential for reducing national petroleum requirements than similar developments for small and compact size cars. This important point will be discussed later.

Table 3-9

FUEL USE BY SIZE CLASS IN 1985

Size Class	Sales Mix %	Iw, lb	Composite mpg	Fraction of Fuel Used
Small	23.9	1900	43.8	0.16
Compact	23.3	2300	34.5	0.198
Mid-Size	24.3	2900	26.0	0.274
Full-Size	27.6	3500	22.0	0.367
				0.999

Section 4

MISSION DESCRIPTION, CHARACTERIZATION, AND IMPACT ON POTENTIAL SALES

Section 4

MISSION DESCRIPTION, CHARACTERIZATION, AND IMPACT ON POTENTIAL SALES

For the hybrid/electric passenger car to have a significant impact on petroleum conservation, the hybrid/electric car must be designed so that it will meet the transportation needs (i.e., mission requirements) of a significant fraction of potential new car buyers in a convenient and economical manner. In this section of the report, automobile use patterns within and outside metropolitan areas are described statistically so as to target the hybrid/electric vehicle design characteristics to meet the expected uses. From this analysis, various mission sets are defined and the associated vehicle "electric" range requirements for the mission sets are determined.

4.1 REGIONAL / LOCAL USE CONSIDERATIONS

Personal transportation needs vary markedly throughout the United States due to a number of factors including local traffic congestion, the availability of public transportation, commuter distances, shopping locations, etc. Differences in local/regional life styles are reflected in the way people use their cars and, as a result, in the sales mix of cars that are purchased. Hence, in order to assess the effects of mission analysis on electric/hybrid vehicle design and marketability, it is advisable to consider local/regional characteristics in both regards. Much of the previous work in this area centered primarily around national averages -- for example, average trip length, average annual mileage, average fraction of mileage in urban driving, average sales mix, etc.

The present study is structured to consider differences in regional characteristics. A clear distinction will be made according to whether a car user lives within or near a large metropolitan area or in a small city/town or rural community. Considerable data is available from which the differences of interest can be assessed. The data sources include (1) national census surveys, (2) national transportation use-pattern surveys, and (3) state highway and car registration statistics. As discussed in the following sections, significant differences relative to the design and use of electric/hybrid vehicles are readily apparent.

Population data for 1970[7] for urban and rural areas are given in Table 4-1. Those data indicate that about 60% of the US population lives in urban areas (central cities and suburbs) and about 40% lives in small cities/towns and rural communities. Table 4-2 indicates that about the same 60/40 split applies to urban Standard Metropolitan Statistical Areas (SMSAs) and to other areas. Therefore, when no other data is available, information pertinent to those living inside SMSAs is assumed appropriate to urban areas and information pertinent to those living

Table 4-1

POPULATION DISTRIBUTION, 1970[7]

Residence	Percent	
Urban		
Inside urbanized areas		
Central cities	31.5	
Urban fringe	26.8	
Subtotal		58.3
Outside urbanized areas		15.2
Rural		26.5
Total		100.0
Class		
Urban		
Places of 1,000,000 or more	9.2	
Places of 500,000 to 1,000,000	6.4	
Places of 250,000 to 500,000	5.1	
Places of 100,000 to 250,000	7.0	
Places of 50,000 to 100,000	8.2	
Places of 25,000 to 50,000	8.8	
Places of 10,000 to 25,000	10.5	
Places of 5,000 to 10,000	6.4	
Places under 5,000	4.4	
Unincorporated	0.4	
Subtotal		73.5
Rural		
Places of 1,000 to 2,000	3.3	
Places of up to 1,000	1.9	
Other rural	21.3	
Subtotal		26.5
Total		100.0

outside SMSAs is assumed appropriate to small cities/towns/rural communities. Information on the household ownership of vehicles in 1974 is given in Table 4-3. This indicates that approximately 70% of passenger cars are owned by people living in or on the fringe of metropolitan areas. However, only about 27% of the passenger cars are owned by those living in central city areas. This means that almost 75% of the passenger cars are used by people living in the less densely populated suburban, small city/town, and rural areas.

Table 4-2

POPULATION DENSITY, 1970[7]

Residence	Population Density (persons/mi^2)	Percent	
Urban	2760	73.5	
Rural	15	26.5	
		100.0	
Inside SMSAs†	360		
urban	NA*	60.5	
rural	NA	8.1	
Subtotal			68.6
Outside SMSAs†	20		
urban	NA	13.0	
rural	NA	18.4	
Subtotal			31.4
Total			100.0

*NA - Not available
†SMSA - Standard Metropolitan Statistical Area

It is also of interest to consider the differences in the annual vehicle miles driven by people living in various types of areas, and what fraction of their vehicle miles can be classified as urban (or highway). One approach to assess these differences considers the urban and rural miles driven in selected states relative to the number of passenger cars registered in each state.

Table 4-3

HOUSEHOLD OWNERSHIP OF VEHICLES, 1974[7,8]

Residence	Total No. of Households (10^6)	Passenger Cars (%)				Total No. of Pass. Cars (10^6)	One or More Pickup Trucks (%)
		None	One	Two	Three or More		
Metropolitan areas							
Central cities	22.3	28.7	44.9	21.9	4.5	24	7.4
Suburban rings	26.2	11.7	47.2	33.2	7.9	37	15.5
Outside metropolitan areas	22.3	16.2	54.7	24.2	4.9	28	28.7
All households	70.8	18.5	48.8	26.8	5.9	89	17.1

Such statistical data for 1975 is given in Tables 4-4 and 4-5 taken from Refs. 7 and 8. As indicated in the tables, the annual miles per vehicle and the portion of those miles driven in urban areas varies significantly from state-to-state. In general, the vehicle miles per year are lower and the portion of those miles driven in urban areas is higher for the more populous states, especially those in the Northeast (e.g., Connecticut, New York, and Rhode Island). The national averages of about 10,000 vehicle miles/yr and 55% thereof driven in urban areas, respectively, are close to those given in Table 4-4 for all states combined. Since hybrid/electric vehicles are more likely to have greater market potential in more populous areas, the lower annual mileage and higher fraction of urban miles in those areas are particularly noteworthy. The effect of urban population on daily travel patterns will be discussed in a subsequent section of this report.

The differences in regional transportation needs as perceived by car buyers will also be reflected in the sales mix and its variations from State-to-State in the US. Detailed new car sales information is available each year from R.L. Polk. Such data for 1977 for domestic and imported passenger cars (Ref. 9) was used to calculate the sales mix information given in Table 4-6. The domestic cars were assigned to the four market classes -- small, compact, intermediate (or mid), standard (or full) -- according to the designations used by the US auto industry (see Table 4-7 taken from Automotive News, 1977 Market Data Book Issue). It is clear from Table 4-6 that there are significant differences in the sales mix between the various states depending primarily on the transportation needs and conditions in the respective states. A 1977 sales mix for urban and rural/small town areas has been inferred from the State-by-State results as indicated near the bottom of Table 4-6. Further, a sales mix for inside SMSAs and outside SMSAs was developed from the urban/rural sales mixes by using the 1977 national sales mix and 70/30 split between SMSAs and outside SMSAs. The difference between the national sales mix and that inferred for the SMSAs is probably not significant, but outside SMSAs sales mix is certainly significantly different from the national sales mix. As would be expected, persons living in less populous areas tend to buy larger cars than those living in more congested urban areas.

Projections as to how the sales mix will change in the next 5 to 10 years are rather difficult to make for at least three reasons. First, the US auto industry is reducing car sizes in each of the market classes, and the consumer response to these design changes is not yet clear. Second, as the Corporate Average Fuel Economy (CAFE) Standards become more difficult to meet, the pricing strategy of the auto industry can be expected to favor smaller cars. This is already becoming evident in 1979. Third, if the price of gasoline continues to increase at a rate faster than inflation, more car buyers can be expected to purchase cars somewhat smaller than they have been accustomed to. All of these factors will interact making it very difficult to assess

Table 4-4

VEHICLE MILES STATISTICS, 1975, Ref. 8.

State	10^9 Vehicle Miles			Fraction Urban Miles
	Urban	Rural	Total	
Connecticut	14.7	3.5	18.2	0.807
Georgia	17.3	22.0	39.3	0.44
North Carolina	13.4	23.0	36.4	0.368
New York	42.5	22.6	65.1	0.653
New Jersey	38.3	10.2	48.5	0.790
Nebraska	4.7	6.5	11.2	0.420
Ohio	34.6	29.5	64.1	0.54
Pennsylvania	33.3	30.4	63.7	0.523
California	94.8	37.8	132.6	0.715
Massachusetts	23.5	5.6	29.1	0.808
Wisconsin	14.1	14.4	28.5	0.495
Iowa	8.0	11.6	19.6	0.408
Illinois	40.8	20.2	61.0	0.669
Indiana	18.8	18.6	37.4	0.503
Maryland	13.2	12.0	25.2	0.524
Rhode Island	4.7	1.0	5.7	0.825
Virginia	15.7	18.9	34.6	0.454
Michigan	35.3	22.9	58.2	0.607
Minnesota	14.2	11.5	25.7	0.553
All	729.4	600.6	1330.0	0.548

the relative importance of each of the factors even in the 1985 to 1990 time period. In the present report, it will be assumed that the sales mix will not change significantly in terms of the four classes (small, compact, mid, full), but it will be recognized that the size of the car typical of each class will become smaller as the downsizing programs of the auto industry continue. Hence, people will, in fact, be buying smaller cars in the next 5 to 10 years, but the class name assigned to them will be unchanged. For example, the Ford Fairmont is presently designated a compact car by the US Auto Industry, but that size car will be assigned to the mid-size category in future years. As discussed in the next section, classification of car sizes by passenger carrying capacity makes more sense and can more easily be projected into the future than the present system of using primarily car length and weight.

Table 4-5

PASSENGER CAR STATISTICS, 1975, Ref. 8.

State	Total Vehicle Miles (10^9)	Car Registration (10^6)	Miles Per Yr	Fraction Urban Miles
Connecticut	14.4	1.79	8045	0.807
Georgia	31.0	2.51	12350	0.440
North Carolina	28.7	2.86	10035	0.368
New York	51.4	6.74	7626	0.653
New Jersey	38.3	3.74	10241	0.790
Nebraska	8.9	0.82	10854	0.420
Ohio	50.6	6.29	8045	0.540
Pennsylvania	50.3	6.59	7633	0.523
California	104.7	11.22	9332	0.715
Massachusetts	23.0	2.78	8273	0.808
Wisconsin	22.6	2.13	10610	0.495
Iowa	15.5	1.54	10065	0.408
Illinois	48.1	5.35	8990	0.669
Indiana	29.5	2.57	11479	0.503
Maryland	19.9	2.07	9614	0.524
Rhode Island	4.5	0.50	9000	0.825
Virginia	27.3	2.71	10074	0.454
Michigan	45.9	4.63	9914	0.607
Minnesota	20.2	1.95	10358	0.553
All	1050.2	106.7	9843	0.548

In Section 5, where the rationale for the selection of the hybrid vehicle size and Reference ICE vehicle are discussed, it is recognized qualitatively that, in the future, some people will tend to buy a car in the next smaller category, but no attempt will be made to assess this effect quantitatively.

Table 4-6

NEW CAR SALES MIX STATISTICS, 1977, Ref. 9.

Region	Yr	% Sales - New Cars			
		Small	Compact	Mid	Full
US	1977	23.9	23.3	24.3	27.6
US	1976	22.1	22.4	29.5	24.7
New Jersey	1977	22.3	25.8	23.9	28.0
New York	1977	19.1	27.0	25.8	28.1
Rhode Island	1977	25.0	30.8	25.0	19.2
Connecticut	1977	30.4	28.9	21.7	18.9
North Carolina	1977	26.1	21.3	26.2	26.4
Georgia	1977	23.6	19.9	29.7	26.9
Nebraska	1977	20.8	18.6	27.5	33.2
Indiana	1977	18.4	20.3	29.0	32.3
Wisconsin	1977	16.7	23.5	26.4	33.3
California	1977	28.1	28.2	24.3	19.5
Ohio	1977	19.1	23.2	27.1	30.7
Massachusetts	1977	26.2	29.5	23.5	20.8
Urban	1977	27.0	29.5	23.5	20.0
Rural	1977	18.5	21.0	28.0	32.5
SMSAs*	1977	26.4	24.6	23.0	26.1
Outside SMSAs**	1977	18.5	21.0	28.0	32.5

* 70/30 split in new car sales between SMSAs and outside SMSAs

** Taken to be same as rural States

Table 4-7

1977 MODELS -- BY MARKET CLASS

Small*	Compact	Mid-Size	Full-Size
SUBCOMPACTS	COMPACTS	INTERMEDIATES	STANDARD SIZE
Astre	Aspen	Century	STANDARD
Bobcat	Camaro	Charger SE	Buick
Chevette	Comet	Chevelle	Chevrolet
Gremlin	Dart	Cordoba	Chrysler
Monza	Firebird	Coronet/Charger	Dodge
Mustang II	Granada	Cougar	Ford
Pinto	Hornet	Cutlass	Mercury
Skyhawk	Maverick	Diplomat	Oldsmobile
Starfire	Monarch	Elite	Plymouth
Sunbird	Nova	Fury	Pontiac
Vega	Omega	Grand Prix	Riviera
	Pacer	LeBaron	Thunderbird
	Skylark	LeMans	Toronado
	Valiant	LTD II	LUXURY STANDARD
	Ventura	Matador	Cadillac
	Volare	Monaco	Eldorado
		Montego	Lincoln
		Monte Carlo	Mark V
		Thunderbird	
		Torino	
		LUXURY INTERMEDIATE	
		Seville	
		Versailles	

*Imported cars were assigned to each class by manufacturer. For example, all Toyota, Datsun, and Honda sales were assigned to the small category. Other foreign manufacturers were assigned according to the size of their models with the highest sales. Information on foreign car sales is available from R.L. Polk by manufacturer only, not by model as for domestic cars.

4.2 MISSION SET DESCRIPTION

The use pattern of automobiles covers a wide range in terms of trip length, trip frequency, and trip purpose; certain combinations of which are suitable for hybrid vehicles, and others are not. Four general categories relating to trip purpose have been defined in the National Personal Transportation Study (NPTS):[10]

- Earning a living (work travel)
- Family business
- Civic, educational, and religious
- Social and recreational

In the present study the latter three categories have been consolidated and called personal travel. The relative contribution of each category in terms of annual mileage and annual trips is indicated in Table 4-8. This distribution is further modified depending upon whether incorporated or unincorporated areas are considered as indicated in Table 4-9. Thus, the specification of the place of residence becomes important in describing a vehicle mission profile. For purposes of the mission analysis presented in this report, the specification of the place of residence is divided into two general categories, i.e., inside and outside the Standard Metropolitan Statistical Areas (SMSAs).

The hybrid/electric vehicle is expected to have its most significant impact on petroleum consumption when operating under such conditions that its primary energy source is battery-stored energy. While an on-board heat engine can be used to recharge the battery, this mode of operation should be minimized in order to have maximum impact on petroleum savings. For this reason, the mission should focus on those applications where an all-electric mode of operation can be considered for the hybrid vehicle. This suggests that use patterns resulting in days of travel with daily mileage less than some prescribed value should be identified. The fact that a value of daily travel mileage is to be specified below which the hybrid will use electricity as the principal energy source does not suggest that the hybrid will be incapable of operating under conditions of daily travel beyond this value. Under such conditions, the hybrid vehicle will utilize the heat engine as its primary energy source and the battery system will function so as to load-level the heat engine. In this mode of operation, the hybrid vehicle range will be a function of the fuel storage capacity.

Daily travel less than the prescribed distance can be categorized in terms of random and non-random trips. Random trips are those which consist of varying length and frequency while non-random trips are those of known length and frequency (such as commuting to and from work). Trip length and frequency rather than whether a trip is random or non-random in nature are considerably more important in determining applicability of a

Table 4-8

DISTRIBUTION OF AUTOMOBILE TRIPS, VEHICLE MILES OF TRAVEL, AND TRIP LENGTH BY TRIP PURPOSE

Trip Purpose	Percent of Automobile		Average Trip Length (miles)
	Trips	Travel	
Earning a living			
Home-to-work	31.9	33.7	9.4
Related business	4.3	7.9	16.1
Subtotal	36.2	41.6	10.2
Family business			
Shopping	15.2	7.5	4.4
Medical and dental	1.8	1.6	8.4
Other	14.0	10.2	6.5
Subtotal	31.0	19.3	5.6
Civic, educational and religious	9.3	4.9	4.7
Social and recreational			
Visiting friends and relatives	8.9	12.1	12.0
Pleasure driving	1.4	3.1	20.0
Vacations	0.1	2.5	160.0
Other	12.0	15.3	11.4
Subtotal	22.4	33.0	13.1
Other and unknown	1.1	1.2	9.4
Total	100.0	100.0	8.9

Table 4-9

PERCENT OF AUTOMOBILE TRIPS AND VEHICLE MILES OF TRAVEL BY TRIP PURPOSE AND PLACE OF RESIDENCE -- IN ALL AREAS AND SELECTED PLACES

Trip Purpose	Place of Residence			All Areas and Places
	Unincorporated Areas	Incorporated Places		
		1,000,000 and Over	All	
	Automobile Trips (%)			
Earning a living	35.8	46.3	36.5	36.2
Family business	31.5	25.9	30.8	31.0
Civic, educat. and religious	10.0	8.8	8.9	9.3
Social and recreational	21.4	17.9	22.8	22.4
Other	1.3	1.1	1.0	1.1
Total	100.0	100.0	100.0	100.0
	Vehicle Miles of Travel (%)			
Earning a living	41.8	50.7	41.5	41.6
Family business	21.5	12.5	18.0	19.3
Civic, educat. and religious	6.0	4.9	4.3	4.9
Social and recreational	29.0	31.4	35.3	33.0
Other	1.7	0.5	0.9	1.2
Total	100.0	100.0	100.0	100.0

hybrid vehicle. However, whether a trip is random or non-random is crucial in performing a statistical analysis in order to predict trip behavior; therefore, the distinction must be recognized.

The methodology used for predicting daily and annual driving patterns (described in detail in Section 4.3) is basically that of Schwartz,[11] Surber and Deshpande[12] in which a Poisson distribution is used to generate the number of days per year in which a specified number of trips is taken, and a Monte Carlo simulation is used to generate the length of these trips. Schwartz, however, applied this technique to all travel regardless of whether the trips were random or not. Surber and Deshpande did account for the non-random nature of travel-to-work by excluding such trips from their random trip length generation.

For reasons discussed above it is preferable to describe a mission set in terms of random and non-random trips both inside and outside SMSAs rather than use the four categories outlined in the NPTS. Thus, a total of eight mission sets have been specified and analyzed as part of this task. One mission set includes only personal business travel inside the SMSAs consisting entirely of random trips in terms of both frequency and length. Another set includes the combination of the first set with trips to work inside the SMSAs which are non-random both in frequency and trip length. A third set includes all personal business travel, trips to work, and any other random trips resulting in a daily travel of less than 100 miles, again inside the SMSAs. Thus, this third set includes all travel with the exception of travel resulting in more than 100 miles in one day which may be construed to represent intercity travel. The fourth set includes all travel regardless of daily mileage. The other four sets of the eight are the same as the four sets described except that they occur outside of the SMSAs rather than inside. These eight-mission sets are summarized in Table 4-10.

Table 4-10

MISSION SETS TO BE ANALYZED

Inside SMSAs	Outside SMSAs
Personal business travel only	Personal business travel only
Personal business plus trips to work	Personal business plus trips to work
All-purpose (except trips of 100 or more miles per day)	All-purpose (except trips of 100 or more miles per day)
All purposes	All purposes

It should be mentioned again that the reason for excluding daily travel in excess of some value (100 miles per day) is to assess the impact of the hybrid vehicle in applications where battery-stored energy is the primary energy source. Daily travel in excess of this value will be accomplished with the heat engine as the primary energy source with the battery system serving only to load-level the heat engine.

4.3 TRAVEL CHARACTERISTICS

The travel characteristics of an automobile consist of three main factors:

- Annual mileage
- Daily travel in terms of number of trips and trip length
- The particular driving mode or cycles which characterize the method in which daily travel is accomplished

In many cases, the test or survey data which defines these three factors is limited or nonexistent. In such cases, estimates have been made, or interpolation/extrapolation has been used, to augment limited data. The methodology employed to analyze the above three factors in order to characterize the mission sets outlined in Section 4.2 are described below.

4.3.1 ANNUAL USE

Considerable data is available to evaluate average annual vehicle miles. Such a set of data is the Highway Statistics published annually by the Federal Highway Administration under the Department of Transportation. An example of such data is presented in Tables 4-11 and 4-12. The disadvantage of such data is that it permits determination of average annual vehicle mileage only and does not give a fractional distribution of vehicle annual mileage. The NPTS(13) includes data on annual mileage distribution; this data is presented in Table 4-13. This data is limited in that it is ten years old and gives no information regarding annual mileage distribution with regard to work trips, personal business, intercity travel, etc. In the absence of such data an estimate has been made for annual mileage versus percent of automobiles as indicated in Figure 4-1. Estimates are shown for personal business only both inside and outside SMSAs as well as for all-purpose trips both inside and outside SMSAs. The curve for all-purpose travel inside SMSAs is taken to be essentially parallel to the data in Table 4-13, but depressed for any given percentile because the data in Table 4-13 represents annual mileage for all vehicles; and vehicles inside SMSAs tend to have lower annual mileage than the national average. The curve for all-purpose travel outside SMSAs is: (1) elevated above that for inside SMSAs because of the higher annual mileage characteristic of vehicles outside SMSAs, and (2) somewhat flatter (less slope) than that for inside SMSAs because people living outside of SMSAs in geographically smaller communities tend to take more relatively short trips due to the limited size of the area. The curves for personal business are taken to have annual mileages of approximately 46% of the all-purpose figures at any given percentile since this is approximately the percentage of annual mileage accounted for by family business and civic, educational, religious, and social travel as indicated in the NPTS data.(10)

Table 4-11

ESTIMATED MOTOR VEHICLE TRAVEL IN THE UNITED STATES AND RELATED DATA - 1974 (1)

Source: Program Management Division
Office of Highway Planning, FHWA

TABLE VM-1
NOVEMBER 1975

ITEM	PASSENGER VEHICLES: PERSONAL PASSENGER VEHICLES: PASSENGER CARS 2/	PASSENGER VEHICLES: PERSONAL PASSENGER VEHICLES: MOTOR-CYCLES 2/	PASSENGER VEHICLES: PERSONAL PASSENGER VEHICLES: ALL PERSONAL PASSENGER VEHICLES	PASSENGER VEHICLES: BUSES: COMMERCIAL	PASSENGER VEHICLES: BUSES: SCHOOL	PASSENGER VEHICLES: BUSES: ALL BUSES	PASSENGER VEHICLES: ALL PASSENGER VEHICLES	CARGO VEHICLES 1/: SINGLE-UNIT TRUCKS	CARGO VEHICLES 1/: COMBI-NATIONS	CARGO VEHICLES 1/: ALL TRUCKS	ALL MOTOR VEHICLES
Motor-vehicle travel:											
(million vehicle-miles)											
Main rural roads			314,782	965	920	1,885	316,667	85,804	43,741	129,545	446,212
Local rural roads			113,352	90	1,010	1,100	114,452	21,336	1,474	22,810	137,262
All rural roads			428,134	1,055	1,930	2,985	431,119	107,140	45,215	152,355	583,474
Urban streets			589,757	1,555	520	2,075	591,832	104,229	10,110	114,339	706,171
Total travel	995,544	22,347	1,017,891	2,610	2,450	5,060	1,022,951	211,369	55,325	266,694	1,289,645
Number of vehicles registered (thousands)	104,857.4	4,966.4	109,823.8	90.1	356.8	446.9	110,270.7	23,524.4	1,064.6	24,589.0	134,859.7
Average miles traveled per vehicle	9,494	4,500	9,268	28,968	6,867	11,322	9,277	8,985	51,968	10,846	9,563
Fuel consumed (million gallons)	73,797	447	74,244	525	333	858	75,102	21,116	10,083	31,199	106,301
Average fuel consumption per vehicle (gallons)	704	90	676	5,827	933	1,920	681	898	9,471	1,269	788
Average miles traveled per gallon of fuel consumed	13.49	50.00	13.71	4.97	7.32	5.90	13.62	10.01	5.49	8.55	12.13

1/ For the 50 States and District of Columbia.
2/ Separate estimates of passenger car and motorcycle travel are not available by highway category.

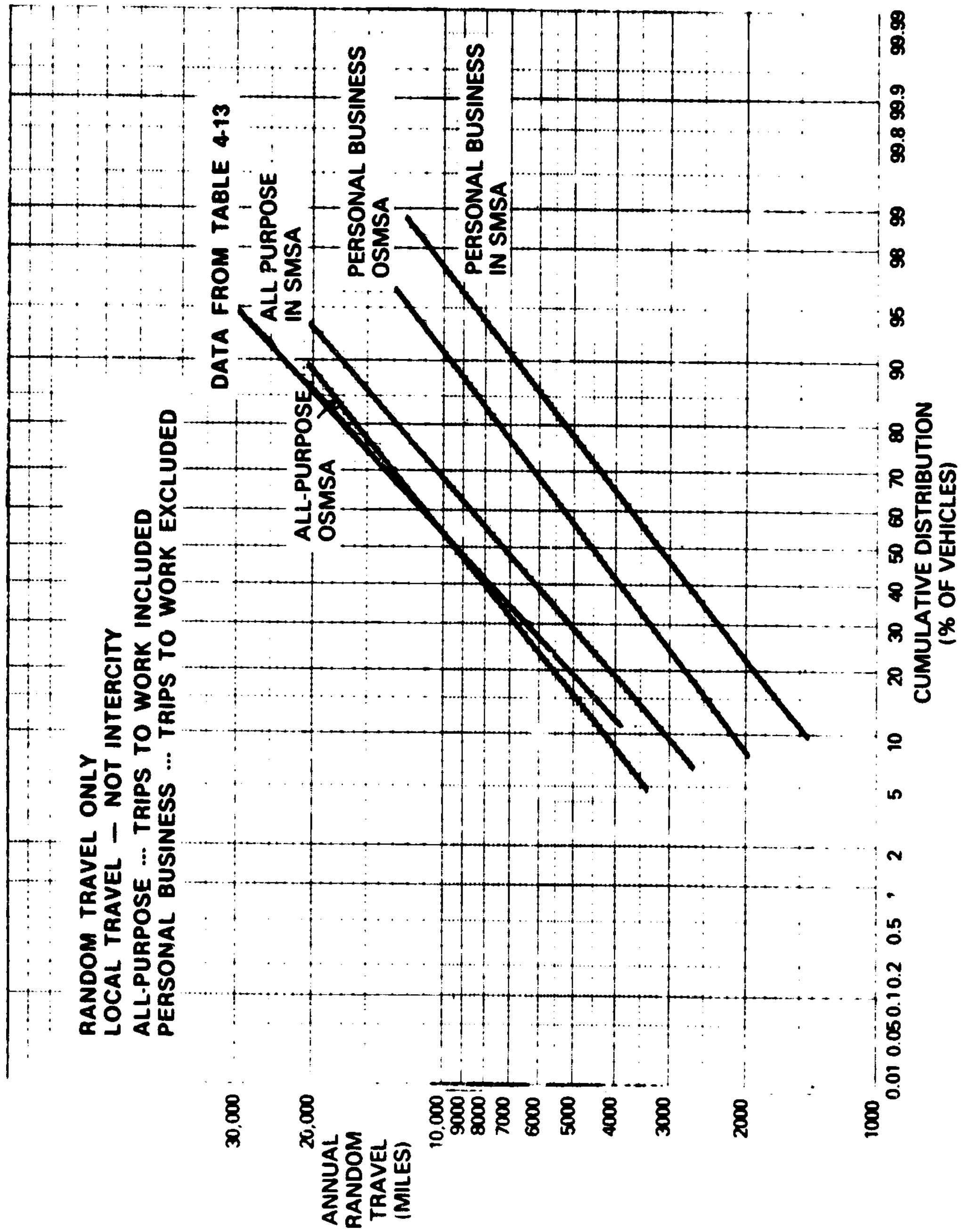


Figure 4-1. Annual Random Travel Mileage Characteristics

Table 4-12

VEHICLE MILES, BY STATE AND HIG

Source: Program Management Division
Office of Highway Planning, FHWA

(In millions of miles)

FEDERAL HIGHWAY ADMINIS-TRATION REGION	STATE	FEDERAL-AID HIGHWAY SYSTEM: INTERSTATE RURAL: FINAL 01	INTERSTATE RURAL: TRAVELED WAY 1/ 31	INTERSTATE RURAL: TOTAL RURAL	INTERSTATE URBAN: FINAL 02	INTERSTATE URBAN: TRAVELED WAY 1/ 32	INTERSTATE URBAN: TOTAL URBAN	TOTAL INTER-STATE	OTHER PRIMARY: RURAL 03	OTHER PRIMARY: URBAN 04	OTHER PRIMARY: TOTAL	SECONDARY: STATE RURAL 05	SECONDARY: STATE URBAN 06	SECONDARY: LOCAL RURAL 07
REGION 1	Connecticut	819	248	1,067	2,777	459	3,236	4,303	1,296	1,880	3,176	1,051	909	6
	Maine	600	151	751	108	16	124	875	1,542	528	2,070	1,023	214	-
	Massachusetts	1,795	123	1,918	3,401	1,391	4,792	6,710	2,165	9,055	11,220	491	1,102	816
	New Hampshire	585	27	612	200	59	259	871	1,441	341	1,782	824	114	4
	New Jersey	986	108	1,094	3,795	946	4,741	5,835	3,020	6,060	9,080	66	56	1,738
	New York	3,384	302	3,686	6,953	409	7,362	11,048	8,753	13,435	22,188	2,420	1,945	1,790
	Rhode Island	140	21	161	866	79	945	1,106	312	1,055	1,367	247	489	21
	Vermont	523	37	560	48	8	56	616	915	278	1,193	449	15	174
	Total	8,832	1,017	9,849	18,148	3,367	21,515	31,364	19,444	32,632	52,076	6,611	4,884	4,549
REGION 3	Delaware	144	(2/)	144	346	(2/)	346	490	981	583	1,564	417	238	-
	Dist. of Col.	-	-	-	288	158	446	446	-	1,065	1,065	-	-	-
	Maryland	1,482	-	1,482	3,332	430	3,762	5,244	3,563	3,671	7,234	1,826	1,600	505
	Pennsylvania	5,881	341	6,222	2,806	744	3,550	9,772	9,641	15,209	24,850	6,792	4,464	61
	Virginia	3,393	480	3,873	2,000	883	2,883	6,756	5,458	3,445	8,903	3,481	406	2,521
	West Virginia	1,028	371	1,399	257	125	382	1,781	2,222	1,098	3,320	1,572	270	1,197
	Total	11,928	1,192	13,120	9,029	2,340	11,369	24,489	21,865	25,071	46,936	14,488	7,578	4,284
REGION 4	Alabama	1,653	576	2,229	813	586	1,399	3,628	5,070	4,149	9,219	1,882	340	1,307
	Florida	3,710	1,275	4,985	2,742	1,186	3,928	8,913	6,872	3,282	10,154	4,956	2,230	1,928
	Georgia	4,186	683	4,869	3,427	112	3,539	8,408	6,909	2,325	9,234	3,473	413	1,979
	Kentucky	2,984	158	3,142	972	537	1,509	4,651	5,004	2,315	7,319	4,340	860	250
	Mississippi	1,451	120	1,571	443	353	796	2,367	4,697	1,061	5,758	1,107	107	1,446
	North Carolina	2,383	778	3,161	1,112	592	1,704	4,865	6,502	3,038	9,540	10,891	3,130	3
	South Carolina	2,356	260	2,616	709	30	739	3,355	6,132	3,123	9,255	3,426	1,332	173
	Tennessee	4,100	130	4,230	2,578	232	2,810	7,040	6,394	4,690	11,084	1,506	277	1,102
	Total	22,823	3,980	26,803	12,796	3,628	16,424	43,227	47,580	23,983	71,563	31,621	8,695	8,188
REGION 5	Illinois	4,277	768	5,045	6,667	495	7,162	12,207	8,464	10,091	18,555	844	1,141	1,932
	Indiana	4,125	122	4,247	2,701	273	2,974	7,221	6,794	2,714	9,508	3,881	1,098	1,977
	Michigan	3,306	117	3,423	5,023	1,076	6,099	9,522	6,891	7,398	14,289	1,756	301	6,623
	Minnesota	1,164	183	1,347	2,052	469	2,521	3,868	4,903	3,491	8,394	1,094	164	3,283
	Ohio	5,988	10	5,998	8,104	664	8,768	14,766	7,839	7,629	15,468	5,116	2,515	2,658
	Wisconsin	1,985	150	2,135	1,123	351	1,474	3,609	5,814	3,356	9,170	2,191	6	1,851
	Total	20,845	1,350	22,195	25,670	3,328	28,998	51,193	40,705	34,679	75,384	14,882	5,225	18,324
REGION 6	Arkansas	1,553	-	1,553	636	-	636	2,189	3,237	1,395	4,632	2,783	559	270
	Louisiana	1,404	489	1,893	1,269	99	1,368	3,261	2,948	1,994	4,942	4,281	1,065	3
	New Mexico	1,627	253	1,880	525	127	652	2,532	1,862	704	2,566	1,182	198	10
	Oklahoma	2,246	42	2,288	1,469	-	1,369	3,657	4,080	1,468	5,548	2,657	740	539
	Texas	6,915	1,114	8,029	9,788	467	10,255	18,284	12,259	9,427	21,686	8,845	3,140	-
	Total	13,745	1,898	15,643	13,587	693	14,280	29,923	24,386	14,988	39,374	19,728	5,702	822
REGION 7	Iowa	1,814	196	2,010	667	184	851	2,861	5,905	1,729	7,634	-	-	2,317
	Kansas	1,495	18	1,513	719	50	769	2,282	4,301	1,386	5,687	653	34	1,53[illegible]
	Missouri	3,071	410	3,481	3,409	189	3,598	7,079	5,969	1,963	7,932	4,447	1,036	10
	Nebraska	1,163	-	1,163	368	20	388	1,551	3,064	826	3,890	600	1[illegible]	842
	Total	7,543	624	8,167	5,163	443	5,606	13,773	19,239	5,904	25,143	5,700	1,0[illegible]	4,704
REGION 8	Colorado	1,709	194	1,903	1,400	-	1,400	3,303	2,858	2,162	5,020	1,403	333	-
	Montana	772	335	1,107	67	-	67	1,174	1,668	262	1,930	92	-	379
	North Dakota	564	33	597	44	3	47	644	1,304	296	1,600	286	2	523
	South Dakota	815	143	958	34	5	39	997	1,766	307	2,073	305	-	476
	Utah	758	693	1,451	1,026	52	1,078	2,529	1,061	766	1,827	604	677	149
	Wyoming	964	111	1,075	36	8	44	1,119	1,013	93	1,106	273	2	17
	Total	5,582	1,509	7,091	2,607	68	2,675	9,766	9,670	3,886	13,556	2,963	1,014	1,544
REGION 9	Arizona	1,724	708	2,432	595	79	674	3,106	1,777	699	2,476	504	63	1,037
	California	6,454	1,218	7,672	17,044	3,581	20,625	28,297	11,635	23,882	35,517	2,923	891	4,000
	Hawaii	64	120	184	403	189	592	776	850	626	1,476	216	24	57
	Nevada	745	114	859	152	10	162	1,021	782	455	1,237	343	44	117
	Total	8,987	2,160	11,147	18,194	3,859	22,053	33,200	15,044	25,662	40,706	3,986	1,032	5,211
REGION 10	Alaska 3/	-	-	-	-	-	-	-	691	448	1,139	253	33	-
	Idaho	925	169	1,094	131	10	141	1,235	1,422	360	1,782	444	68	198
	Oregon	1,923	24	1,947	1,189	88	1,277	3,224	2,659	1,525	4,184	1,148	48	1,006
	Washington	1,275	732	2,007	3,133	202	4,330	6,342	3,029	3,890	6,919	1,184	[illegible]	1,447
	Total	4,123	925	5,048	4,453	300	4,753	9,801	7,801	6,223	14,024	4,168	1,442	3,051
U. S. Total		104,408	14,655	119,063	109,647	18,028	127,673	246,7[illegible]	[illegible]	171,628	378,762	16[illegible]	[illegible]	50,677

1/ Traveled-way includes travel on highways in the Interstate System status of completion group 2. This group consists of mileage which is adequate for present traffic but will need further construction and improvement to bring it to full Interstate standards. In some instances these are divided highways with full control of access and in others they are two-, three-, or four-lane undivided highways with no access control.

Syst

Hig

FOLDOUT FRAME

Table 4-12

…HICLE MILES, BY STATE AND HIGHWAY SYSTEM - 1974

(In millions of miles)

…	TOTAL INTER-STATE	OTHER PRIMARY RURAL 03	OTHER PRIMARY URBAN 04	OTHER PRIMARY TOTAL	SECONDARY STATE RURAL 05	SECONDARY STATE URBAN 06	SECONDARY LOCAL RURAL 07	SECONDARY LOCAL URBAN 08	SECONDARY TOTAL	FEDERAL AID URBAN 14	TOTAL FEDERAL AID RURAL	TOTAL FEDERAL AID URBAN	TOTAL FEDERAL AID	NOT ON FEDERAL-AID SYSTEMS: OTHER STATE RURAL 09	OTHER STATE URBAN AND MUNICI-PAL 10	LOCAL RURAL 11	LOCAL URBAN AND MUNICI-PAL 12	TOTAL RURAL	TOTAL URBAN AND MUNICI-PAL	TOTAL
36	4,303	1,296	1,880	3,176	1,051	909	6	40	2,006	1,106	3,420	7,171	10,591	254	1,436	286	5,438	3,960	14,045	18,005
24	875	1,542	528	2,070	1,023	214	-	-	1,237	101	3,316	967	4,283	1,116	313	453	548	4,885	1,828	6,713
92	4,710	2,165	9,055	11,220	491	1,102	816	2,436	4,845	2,925	5,390	20,310	25,700	37	869	525	1,106	5,952	22,285	28,237
59	871	1,441	341	1,782	824	114	4	4	946	528	2,881	1,246	4,127	193	213	175	370	3,249	1,829	5,078
41	4,835	3,020	6,060	9,080	66	56	1,738	1,757	3,617	6,958	5,918	19,572	25,490	935	2,944	3,578	14,297	10,431	36,813	47,244
62	11,048	8,753	13,435	22,188	2,420	1,988	1,790	1,343	7,538	4,572	16,649	28,697	45,346	183	484	4,253	14,986	21,085	44,177	65,262
4	1,106	312	1,055	1,367	247	489	21	217	974	759	741	3,465	4,206	51	63	122	1,102	914	4,630	5,544
56	616	915	278	1,193	489	15	174	13	691	-	2,138	362	2,500	67	3	210	244	2,415	609	3,024
15	31,364	19,444	32,632	52,076	6,611	4,884	4,549	5,810	21,854	16,949	40,453	81,790	122,243	2,836	6,325	9,602	38,101	52,891	126,216	179,107
46	490	981	583	1,564	417	238	-	-	655	447	1,542	1,614	3,156	-	-	126	193	1,668	1,807	3,475
4	446	-	1,065	1,065	-	-	-	552	552	-	-	2,063	2,063	-	-	-	894	-	2,957	2,957
62	5,244	3,563	3,671	7,234	1,826	1,600	505	485	4,416	166	7,376	9,682	17,058	540	72	3,502	2,724	11,418	12,478	23,896
50	9,772	9,641	15,209	24,850	6,792	4,864	61	109	11,826	912	22,716	24,644	47,360	3,657	2,430	4,452	9,708	30,825	36,782	67,607
43	4,756	5,458	3,445	8,903	3,881	606	2,521	133	7,141	3,042	15,733	10,109	25,842	172	166	2,077	5,377	17,982	15,652	33,634
82	1,781	2,222	1,098	3,320	1,572	270	1,197	73	3,112	82	6,390	1,905	8,295	22	150	650	1,001	8,052	3,056	10,118
369	24,489	21,865	25,071	46,936	14,488	7,578	4,284	1,352	27,702	[illegible]	53,757	50,017	103,774	4,391	2,818	10,807	19,897	66,955	72,732	141,687
399	3,628	5,070	4,149	9,219	1,882	340	1,307	332	3,861	348	10,488	6,578	17,066	42	81	1,342	5,391	11,872	12,050	23,922
928	8,913	6,872	3,282	10,154	4,956	2,230	1,928	537	9,651	10,917	18,741	20,934	39,675	1,420	1,172	3,882	15,872	24,043	37,978	62,021
539	8,408	6,909	2,325	9,234	3,473	413	1,979	613	6,478	351	17,230	7,241	24,471	93	534	2,539	7,445	19,862	15,220	35,082
509	4,651	5,004	2,315	7,319	4,340	960	250	90	5,580	539	12,776	5,313	18,089	1,457	660	1,184	2,421	15,417	8,394	23,811
796	2,367	4,697	1,061	5,758	1,107	107	1,446	344	3,004	714	8,821	3,022	11,843	8	8	627	1,248	9,456	4,278	13,734
704	4,865	6,502	3,038	9,540	10,891	3,136	3	21	14,051	940	20,557	8,839	29,396	1,883	647	40	3,034	22,480	12,520	35,000
739	3,355	6,132	3,123	9,255	3,426	1,332	173	22	4,953	-	12,347	5,216	17,563	416	1,360	433	240	13,196	6,816	20,012
810	7,040	6,394	4,690	11,084	1,506	277	1,102	201	3,086	558	13,232	8,536	21,768	68	5	2,241	6,674	15,541	15,215	30,756
424	43,227	47,580	23,983	71,563	31,621	8,695	8,188	2,160	50,664	14,417	114,192	65,679	179,871	5,387	4,467	12,288	42,325	131,867	112,471	244,338
162	12,207	8,464	10,091	18,555	844	1,141	1,932	734	4,651	3,647	16,285	22,975	39,260	1,091	2,471	2,694	13,694	20,070	39,140	59,210
974	7,221	6,794	2,714	9,508	3,881	1,098	1,977	325	7,281	4,768	16,899	11,879	28,778	140	99	1,379	6,597	18,418	18,575	36,993
099	9,522	6,891	7,398	14,289	1,756	301	6,623	1,377	10,057	12,336	18,693	27,511	46,204	24	50	3,105	6,366	21,822	33,927	55,749
521	3,868	4,903	3,491	8,394	1,094	164	3,283	427	4,968	529	10,627	7,132	17,759	13	49	1,971	4,796	12,611	11,977	24,588
768	14,766	7,839	7,629	15,468	5,116	2,515	2,658	2,799	13,088	1,830	21,611	23,541	45,152	260	366	5,485	11,821	27,356	35,728	63,084
474	3,609	5,814	3,356	9,170	2,191	6	1,851	609	4,657	3,707	11,991	9,152	21,143	72	2	1,864	4,884	13,927	14,038	27,965
998	51,193	40,705	34,679	75,384	14,882	5,225	18,324	6,271	44,702	27,017	96,106	102,190	198,296	1,600	3,037	16,498	48,158	114,204	153,385	267,589
636	2,189	3,237	1,395	4,632	2,783	559	270	106	3,718	520	7,843	3,216	11,059	93	72	980	1,311	8,916	4,599	13,515
368	3,261	2,948	1,994	4,942	4,261	1,065	3	-	5,329	2,400	9,105	6,827	15,932	946	456	1,412	699	11,463	8,082	19,545
652	2,532	1,862	704	2,566	1,182	198	10	6	1,396	1,341	4,934	2,901	7,835	118	50	588	847	5,640	3,798	9,438
369	3,657	4,080	1,468	5,548	2,657	740	539	1,158	5,094	2,444	9,564	7,179	16,743	365	21	1,057	3,308	10,986	10,508	21,494
255	15,284	12,259	9,427	21,686	8,845	3,140	-	-	11,985	6,355	29,133	29,177	58,310	1,583	753	3,451	14,594	34,167	44,524	78,691
280	29,923	24,386	14,988	39,374	19,728	5,702	822	1,270	27,522	13,060	60,579	49,300	109,879	3,105	1,452	7,488	20,759	71,172	71,511	142,683
851	2,861	5,905	1,729	7,634	-	-	2,317	460	2,777	578	10,232	3,618	13,850	102	59	941	4,113	11,275	7,790	19,065
769	2,282	4,301	1,386	5,687	653	34	1,535	517	2,739	476	8,002	3,182	11,184	71	33	1,237	2,678	9,310	5,893	15,203
598	7,079	5,969	1,963	7,932	4,447	1,036	10	32	5,525	3,182	13,907	9,811	23,718	54	230	1,816	3,892	15,777	13,933	29,710
388	1,551	3,064	826	3,890	600	15	842	113	1,570	405	5,669	1,747	7,416	5	-	665	2,854	6,339	4,601	10,940
606	13,773	19,239	5,904	25,143	5,700	1,085	4,704	1,122	12,611	4,641	37,810	18,358	56,168	232	322	4,659	13,537	42,701	32,217	74,918
400	3,303	2,858	2,162	5,020	1,403	333	-	-	1,736	1,888	6,164	5,783	11,947	24	16	1,786	2,383	7,974	8,182	16,156
67	1,174	1,668	262	1,930	92	-	379	1	472	430	3,246	760	4,006	-	-	1,135	682	4,381	1,442	5,823
47	644	1,304	296	1,600	286	2	523	23	834	279	2,710	647	3,357	1	2	722	289	3,433	938	4,371
39	997	1,766	307	2,073	305	-	476	12	793	114	3,505	472	3,977	29	2	560	525	4,094	999	5,093
078	2,529	1,061	766	1,827	604	677	149	210	1,640	31	3,265	2,762	6,027	27	101	564	738	3,896	3,601	7,497
44	1,119	1,013	93	1,106	273	7	17	3	300	186	2,179	333	2,711	2	1	381	357	2,761	691	3,452
675	9,766	9,670	3,886	13,556	2,963	1,019	1,544	249	5,775	2,928	21,268	10,757	32,025	83	122	5,148	4,974	26,499	15,853	42,352
674	3,106	1,777	699	2,476	504	63	1,037	1,306	3,910	964	7,750	4,306	10,056	249	4	1,198	3,979	7,397	8,289	15,686
625	28,287	11,635	23,882	35,517	2,923	891	4,000	4,845	12,659	24,508	26,230	74,751	100,981	244	55	12,500	13,800	38,994	88,606	127,600
592	776	850	626	1,476	216	24	57	50	347	244	1,307	1,536	2,843	15	-	281	781	1,603	2,317	3,920
162	1,021	782	455	1,237	343	54	117	86	600	258	2,101	1,025	3,126	28	25	175	841	2,304	1,891	4,195
053	33,200	15,044	25,662	40,706	3,986	1,032	5,211	6,887	17,116	25,984	37,388	81,618	117,006	556	84	14,354	19,401	50,298	101,103	151,401
-	-	691	448	1,139	253	73	-	-	326	-	944	521	1,465	-	-	308	322	1,252	843	2,095
141	1,235	1,422	360	1,782	544	68	108	212	1,222	-	3,448	791	4,239	6	-	653	759	4,117	1,540	5,657
277	3,226	2,659	1,525	4,184	1,188	496	1,006	694	3,384	-	6,800	3,992	10,792	46	52	2,950	1,393	9,796	5,437	15,233
3,315	5,142	3,029	3,890	6,919	1,183	778	1,047	1,005	4,640	1,588	7,866	10,613	18,479	26	4	1,830	2,246	9,722	12,863	22,585
4,753	9,801	7,801	6,223	14,024	3,168	1,432	[illegible]	1,911	9,562	1,588	19,068	15,907	34,975	78	56	5,741	4,720	24,887	20,683	45,570
7,673	246,736	205,734	173,028	378,762	103,147	[illegible]	50,677	27,032	217,508	111,231	478,621	475,616	954,237	18,268	18,683	86,586	211,872	583,474	706,171	1,289,645

… completion group 2. This group consists of mileage …ment to bring it to full Interstate standards. In some … are two-, three-, or four-lane undivided highways

2/ Travel on Delaware's Interstate traveled-way, systems 31 and 32, is included in the figure for Interstate Final, Systems 01 and 02.

3/ Estimate of total travel provided by the State highway department. Distribution by highway system made by the Federal Highway Administration based on data for 1973.

FOLDOUT FRAME

Table 4-13

PERCENTAGE DISTRIBUTION OF AUTOMOBILES vs ANNUAL MILES TRAVELED

Annual Mileage	Percent of Automobile
<500	2.6
1,000- 3,000	8.4
3,000- 7,000	27.1
7,000-12,000	34.1
12,000-17,000	11.0
17,000-22,000	7.6
22,000-27,000	3.8
>27,000	5.4
	100.0

4.3.2 DAILY TRAVEL PATTERNS

The 1969 Nationwide Personal Transportation Study represents the most comprehensive study of personal driving habits published to date, and the data from this study has been issued in a series of reports. While this data is now ten years old, it is the only published data available and has been used for a number of analyses such as those by Schwartz,[11] Surber and Deshpande.[12]

The NPTS data is very comprehensive but covers trip purposes or missions other than the mission sets outlined in Section 4.2. Accordingly, only selected portions of the NPTS data have been used in defining daily travel patterns in this investigation. Specifically, the data used include the percent of annual trips and percent of annual vehicle miles versus trip length range as taken from Schwartz[11] and presented here in Table 4-14. Additional data used includes average trip length for different purposes both inside and outside of SMSAs. This latter data is included in Table 4-15.

The data included in these two tables has been used to predict daily travel patterns consistent with the mission sets outlined in Section 4.2. The specific methodology for accomplishing this prediction is the following. A computer program was written to simulate daily travel patterns by using a Poisson distribution and a Monte Carlo simulation in a manner similar to that of Schwartz[11] and Surber and Deshpande.[12] The Poisson distribution determines both the number of days per year in which a specified number of trips (i.e., 0, 1, 2, etc.) will be taken as well as the total number of trips per year. The Poisson distribution requires as known data the average number of trips per day, this being merely the annual mileage divided by the product of 365 days per year and the average trip length. A sample Poisson distribution is given in Table 4-16.

Table 4-14

ANNUAL TRAVEL CHARACTERISTICS BY TRIP LENGTH

Trip Length (miles one way)	Percent of Annual Trips	Percent of Annual Vehicle Miles
<5	54.1	11.1
5-10	19.6	13.8
10-15	13.8	18.7
15-20	4.3	9.1
20-30	4.0	11.8
30-40	1.6	6.6
40-50	0.8	4.3
50-100	1.0	7.6
>100	0.8	17.0

Source: Schwartz (11)

Table 4-15

AVERAGE TRIP LENGTH

Trip Purpose	Average Trip Length, Miles	
	Inside SMSAs	Outside SMSAs
All purposes	8.4	9.8
Family business	4.9	6.7
Social and recreational	13.0	13.3

Source: NPTS (10)

Table 4-16

POISSON DISTRIBUTION OF TRIPS PER DAY

Number of Trips Per Day, X	Calculated Annual Probability, P(X)	Number of Days Per Year with X Trips	Total Number of Trips
0	0.159	58	0
1	0.292	107	107
2	0.269	98	196
3	0.165	60	180
4	0.076	28	112
5	0.028	10	50
6	0.009	3	18
7	0.002	1	7
	0.999	365	670

Table 4-16 uses the Poisson distribution equation

$$P(X) = \frac{\lambda^X e^{-\lambda}}{\lambda!}$$

where

λ = average number of trips per day

X = number of trips per day (0,1,2,-----)

The numbers presented in Table 4-16 are based on an annual mileage of 4500 miles and an average trip length of 6.7 miles so that the average number of trips per day is

$$\lambda = \frac{(4500)}{(365)(6.7)} = 1.84$$

The Monte Carlo simulation then uses a random number generator to predict a trip length for each of the total annual trips to represent the annual driving pattern of one vehicle. The number of days in which daily travel is within a specified mileage range as well as the total annual mileage represented by these days is determined. This simulation is then repeated many times (approximately 300), and averages are taken to determine average annual mileage, average number of days per year with daily mileage within a given mileage range, and the annual mileage within the same mileage range.

The use of a Monte Carlo simulation requires the use of a distribution function for the variable being simulated which in this application is the trip length. The distribution function in this investigation was generated by using the data in Table 4-14 in conjunction with the average annual mileage and total annual trips as given in Table 4-16 to calculate an average trip length in a specified trip length range. The average trip length in a specified range was calculated using the following relation:

$$L_{AVG} = \frac{(AM)\cdot(P_{AM})}{(AT)\cdot(P_{AT})}$$

where

L_{AVG} = average trip length in a specified range

AM = annual mileage

AT = annual number of trips

P_{AM} = percentage of annual mileage in a specified range

P_{AT} = percentage of annual trips in a specified range

The annual number of trips is obtained by using the Poisson distribution as indicated in Table 4-16. The average trip length for various mileage ranges can thus be obtained by using the above equation and the data in Tables 4-14 and 4-16. The results for such calculations are presented in Table 4-17. The column labeled cumulative distribution is the summation of the percent of annual trips in a given mileage category, and this very column represents the distribution function for the average trip length. Thus, these last two columns are used to generate the probability function for use in the Monte Carlo simulation. The average trip length for each mileage range is assumed to occur at the middle of the distribution function range, and the distribution function is represented by a series of straight lines connecting such points.

Table 4-17

CUMULATIVE DISTRIBUTION OF TRIP LENGTH

Trip Length (miles one way)	Percent of Annual Trips, P_{AT}	Percent of Annual Vehicle Miles, P_{AM}	Average Trip Length, Miles, R_{AVG}	Cumulative Distribution
0-5	54.1	11.1	1.38	0.541
5-10	19.6	13.8	4.73	0.737
10-15	13.8	18.7	9.10	0.875
15-20	4.3	9.1	14.21	0.918
20-30	4.0	11.8	19.81	0.958
30-40	1.6	6.6	27.71	0.974
40-50	0.8	4.3	36.10	0.982
50-100	1.0	7.6	51.04	0.992
> 100	0.8	17.0	142.72	1.000

The trip length distribution function is dependent not only upon the annual mileage but also upon the percent of annual trips and the percent of annual vehicle miles within a given trip mileage range. In the present investigation, as in all previous studies (References 3 and 11), the percent of annual trips and percent of annual vehicle miles represented by a given trip mileage range were assumed to be independent of annual mileage, i.e., the data presented in Table 4-14 is assumed to be constant and independent of annual mileage. Such an assumption is questionable since it would seem likely that a change in annual mileage would cause a redistribution of percent trips and percent vehicle miles within given trip mileage ranges. However, since the only published data available is the NPTS data presented in Table 4-14, this data was used independently of the annual mileage.

In summary, the computer program described above requires the average annual mileage and average trip length as input parameters. Internally, the program computes a Poisson distribution similar to Table 4-16. The total annual number of trips from this computation is then used with the data given in Table 4-14 and the average annual mileage to generate a distribution function similar to the last two columns of Table 4-17. This distribution function is then used in a Monte Carlo simulation resulting in an output of average annual mileage, average number of days in which total travel is within a specified mileage range, and the total annual mileage driven within this specified mileage range.

This computer program was used to simulate annual driving characteristics for mission sets defined in Section 4.1. Inasmuch as the computer program by design simulates random travel, the program was used to augment non-random travel. For example, travel characteristics for work trips plus personal business were obtained by using the computer program to generate random trip data for the personal business portion only, and work trip data (which is predictable and non-random) was added to the personal business travel. As indicated above, the computer program requires average annual mileage and average trip length as input parameters. The average annual mileage for personal business and for all-purpose (excluding intercity travel) were taken from Figure 4-1 at the 30th, 50th, 75th, and 90th percentile. The average trip length was obtained by using the values from Table 4-15 designated therein as all purpose and family business to represent the all-purpose and personal business travel designation of this investigation. Inasmuch as average trip length is expected to vary with annual mileage, the following relationship was assumed to relate average trip length to annual mileage

$$L_{AVG(X)} = \sqrt{\frac{AM(X)}{AM(50)}}$$

where X denotes the Xth percentile, and AM annual mileage. The average trip lengths given in Table 4-15 are taken as the average trip lengths for the 50th percentile. The average annual mileage and average trip length for various purposes and percentiles were obtained by using the above relationship, the data from Table 4-15, and from Figure 4-1. These data, shown in Table 4-18, were used in the computer program to generate random trip data and annual driving characteristics. Annual mileage for days in which travel exceeded 100 miles was subtracted from the total mileage. This was done with the assumption that daily travel in excess of 100 miles would represent intercity travel. The results of these computations are presented in Figures 4-2 and 4-3. Inclusion of daily travel in excess of 100 miles corresponds to all purpose travel and is presented in Figures 4-4 and 4-5.

In order to augment personal business travel by work-related travel, it is necessary to use work trip length data. Such data has been collected by the Bureau of the Census and is presented in Figure 4-6. This data can be used to determine annual work-related travel to add to the data in Figure 4-1 to determine annual travel for work trips plus personal business. For example, at the 50th percentile, annual work travel inside SMSAs is 250 days/year x 14.5 miles/day = 3625 miles/year. When added to the annual mileage of 3000 miles/year from Figure 4-1, this gives a total of 6625 miles/year.

This work trip data can also be added to the data of Figures 4-2 and 4-3 to represent non-random behavior. In such calculations, only work travel for the 50th percentile worker is used. The relationship between the percentile of work travel and the percentile of personal travel is also statistical in nature. Using the 50th percentile work travel distance and the data of Figures 4-2 and 4-3, it is possible to generate annual mileage versus percent days and percent vehicle miles for different daily mileage ranges. For example, consider a daily range of 30 miles. For 50th percentile work travel of 14.5 miles per day (roundtrip) this leaves 15.5 miles per day of random travel. From Figure 4-2, for a random annual mileage of 9000 miles, these 15.5 miles per day account for 11.5% of the vehicle miles. The total annual mileage is 9000 + 250 x 14.5 = 12,625 miles, and a 30 mile range would then account for

$$(9000 \times 0.115 + 3625) / (9000 + 3625) = 0.37 \text{ or } 37\%$$

of the annual travel. Repetition of such calculations for various annual random travel mileage yields the results presented in Figures 4-7 through 4-10. Calculations for additional work travel distances will be made as part of the sensitivity studies.

Figures 4-7 through 4-10 can be used in conjunction with Figures 4-1 to generate daily travel requirements for various percentiles of random annual driving. For example, the 50th percentile personal business travel inside SMSAs represents 3000 miles per year random travel (Figure 4-1) plus 3625 miles of annual work travel for an annual mileage of 6625 miles. From Figure 4-7, this represents 81% of all days of driving with a vehicle range of 30 miles, 92.5% with a 40-mile range, 97% with a 50-mile range, and more than 99% with a 75-mile range. From Figure 4-8, 3000 miles per year random travel represents 76% of

Table 4-18

AVERAGE ANNUAL MILEAGE (AM) AND AVERAGE TRIP LENGTH (L_{AVG}) IN MILES

	Percentile 30		50		75		90	
Travel Pattern	AM	L_{AVG}	AM	L_{AVG}	AM	L_{AVG}	AM	L_{AVG}
All-Purpose Outside SMSAs	6,700	8.5	9,000	9.8	14,000	12.2	20,500	14.8
All-Purpose Inside SMSAs	4,900	7.0	7,000	8.4	11,000	10.5	17,000	13.1
Personal Business Outside SMSAs	3,300	5.7	4,500	6.7	6,600	8.1	9,300	9.6
Personal Business Inside SMSAs	2,200	4.2	3,000	4.9	4,500	6.0	6,500	7.2

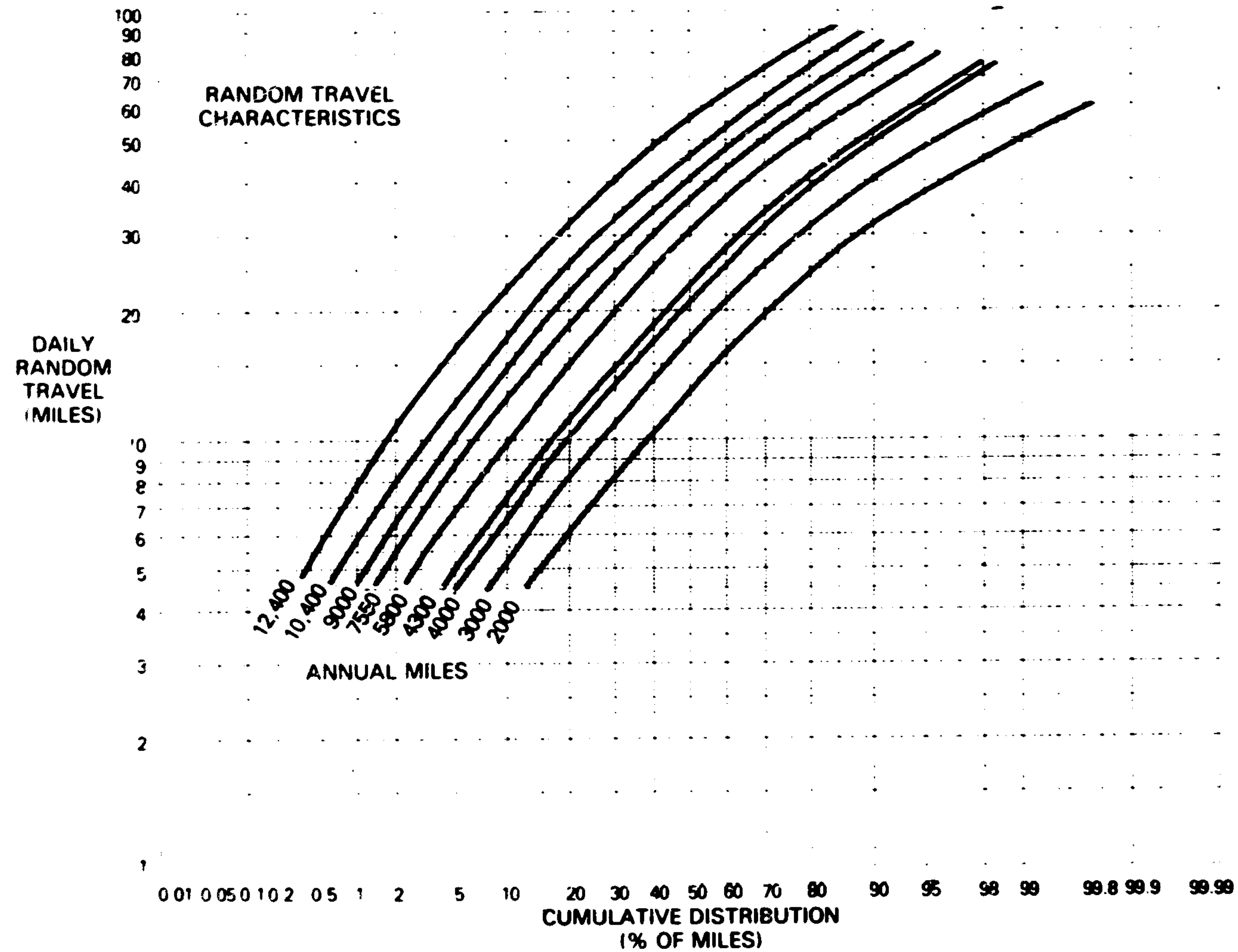


Figure 4-2. Daily Random Travel - Percent of Vehicle Miles - as a Function of Annual Miles

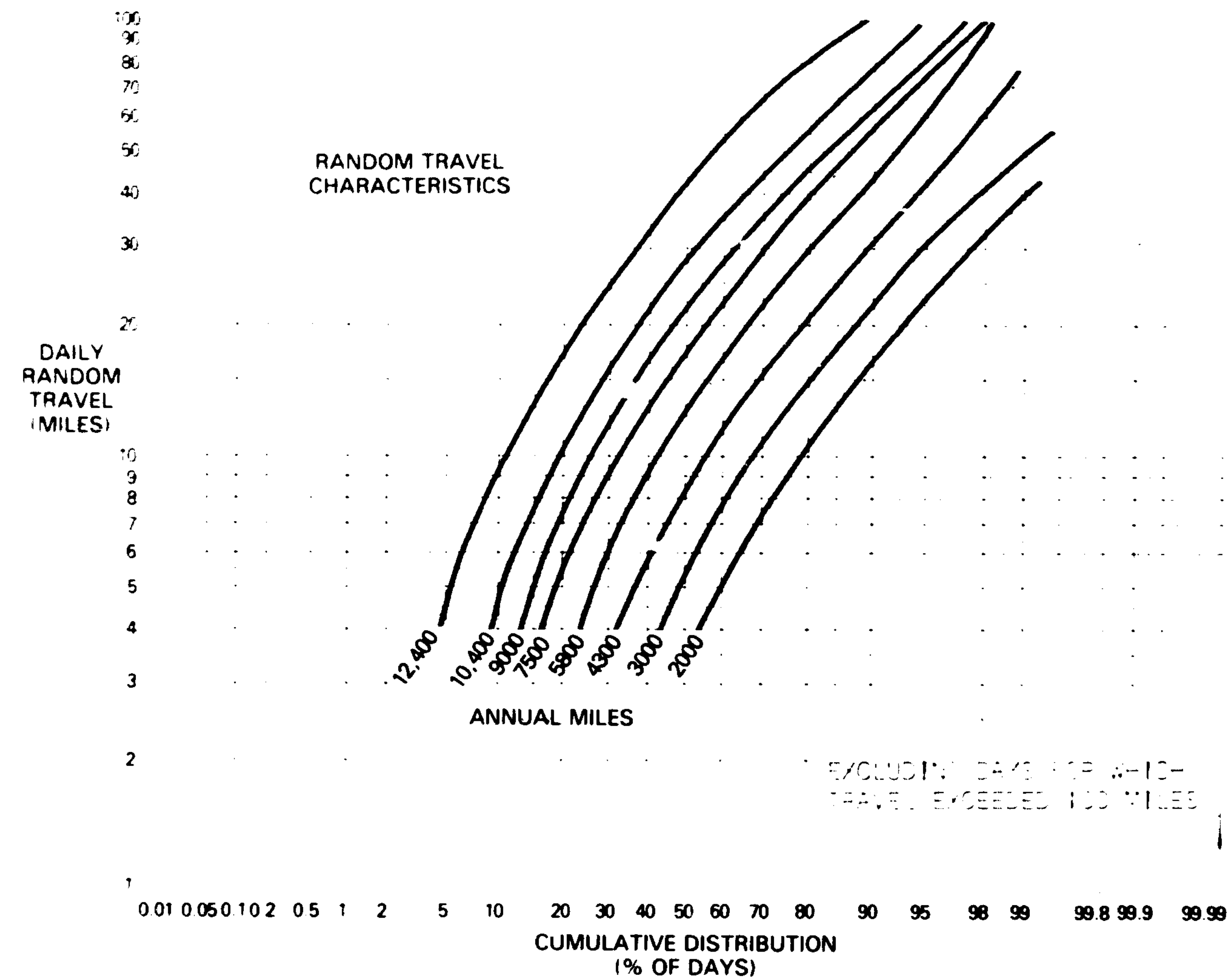


Figure 4-3. Daily Random Travel - Percent of Days - as a Function of Annual Miles

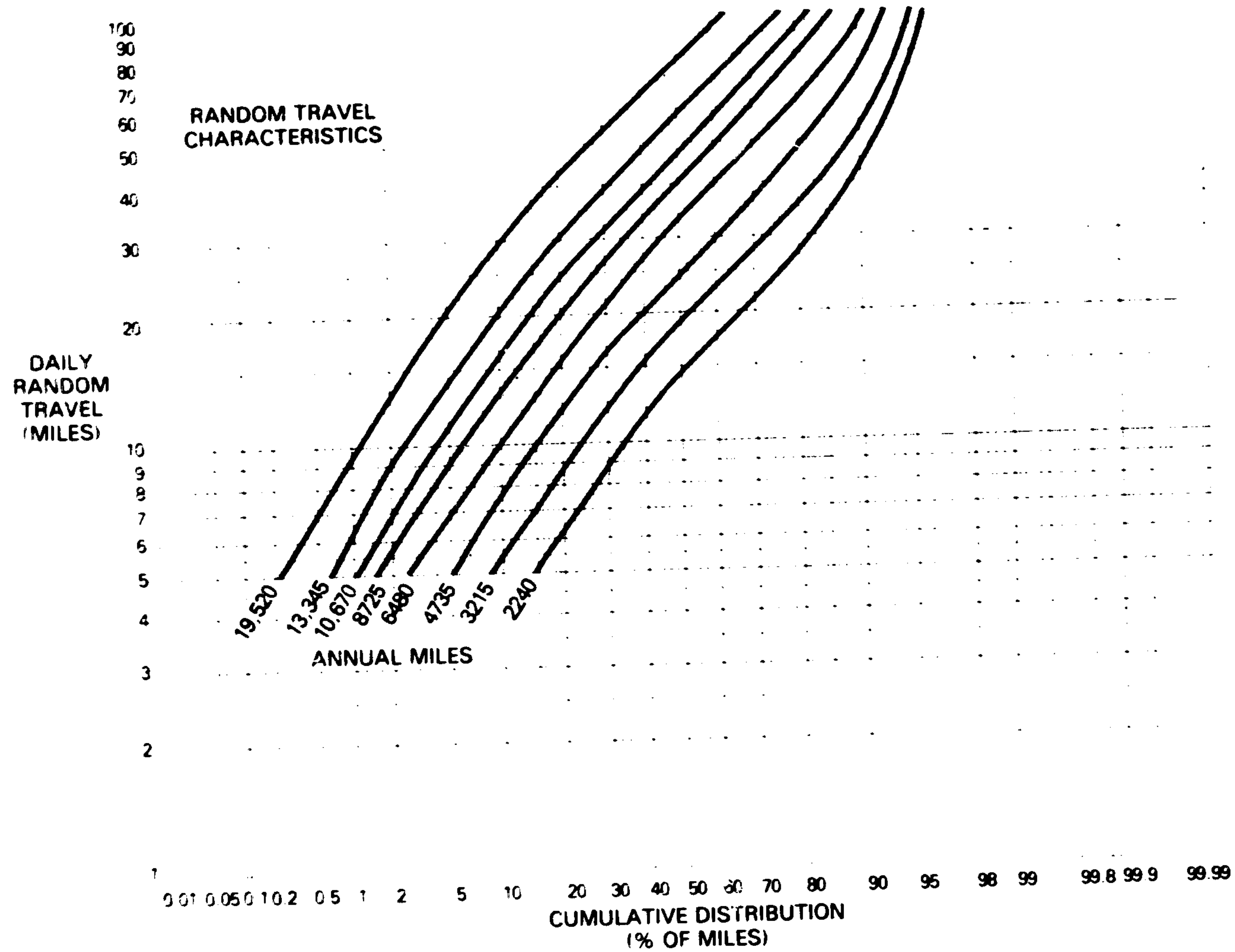


Figure 4-4. Daily Random Travel for All Travel - Percent of Vehicle Miles - as a Function of Annual Miles

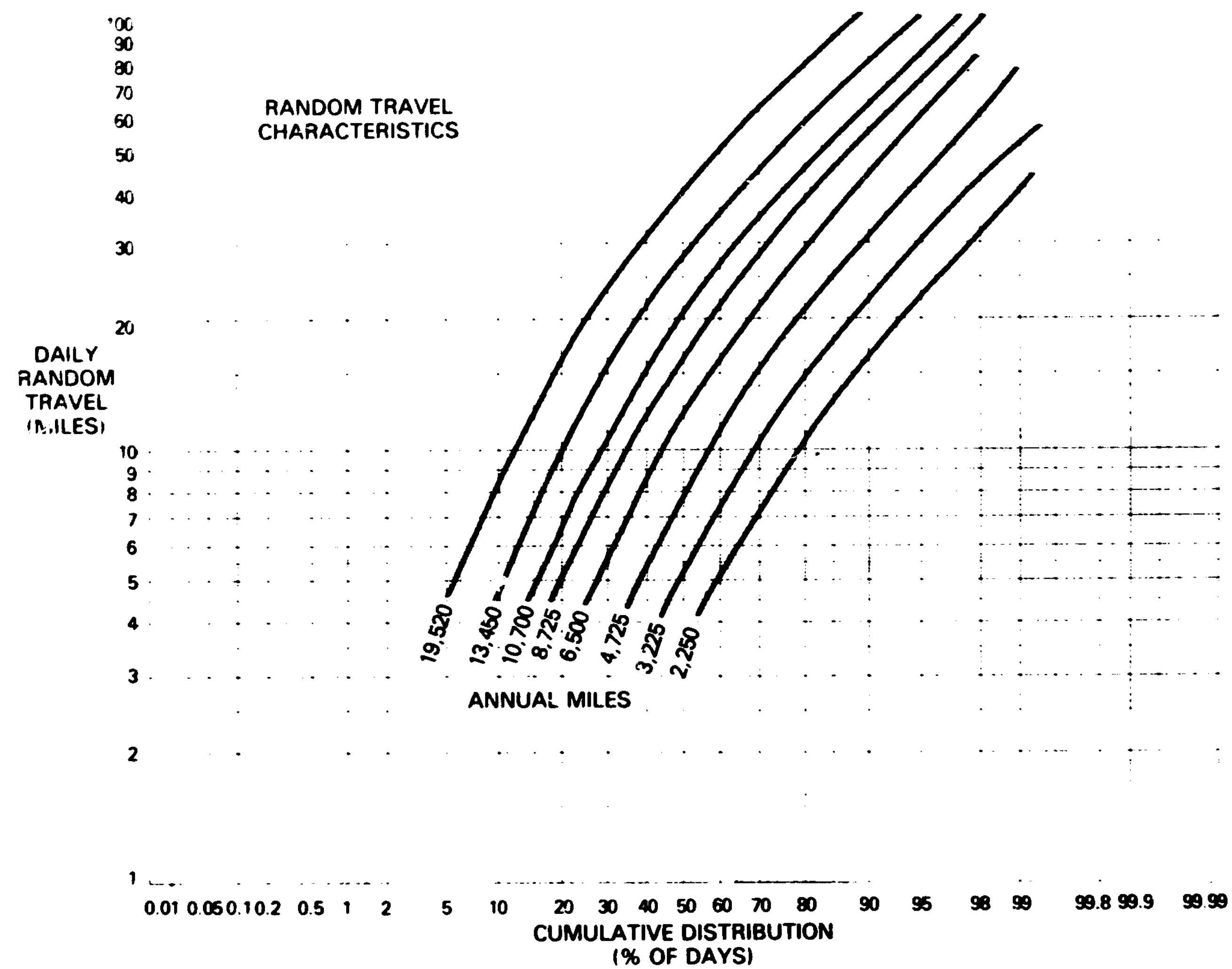


Figure 4-5. Daily Random Travel for All Travel - Percent of Days - as a Function of Annual Miles

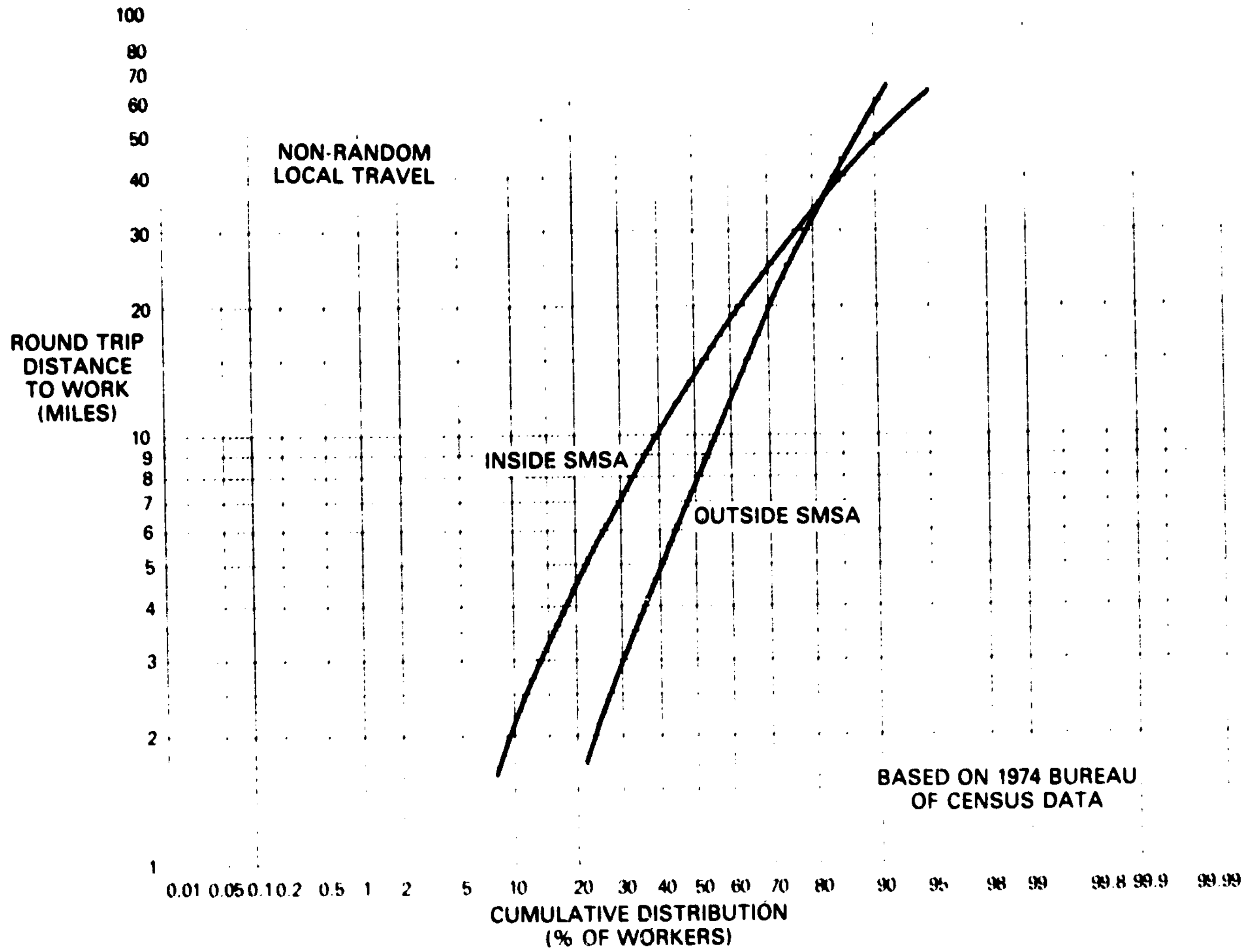


Figure 4-6. Travel to Place of Work

annual vehicle miles with a 30-mile range, 87% with a 40-mile range, 94% with a 50-mile range, and almost 99% with a 75-mile range. Repetition of these calculations for various percentiles of annual random travel for personal business both inside and outside SMSAs produces the data presented in Figures 4-11 thru 4-14. In a similar manner, Figure 4-1 can be used with Figures 4-2 and 4-3 to generate Figures 4-15 through 4-18. Also, use of Figures 4-1, 4-2, and 4-3 will produce Figures 4-19 through 4-22. Finally, Figures 4-1, 4-4, and 4-5 can be used to generate Figures 4-23 through 4-26. Figures 4-19 through 4-22 represent similar vehicle use patterns represented by Figures 4-23 through 4-26, but the first set of figures does not include any daily mileage figures in excess of 100 miles.

Figures 4-11 through 4-26 are used in Section 6.2 to define annual travel and daily mileage for the various mission sets under consideration.

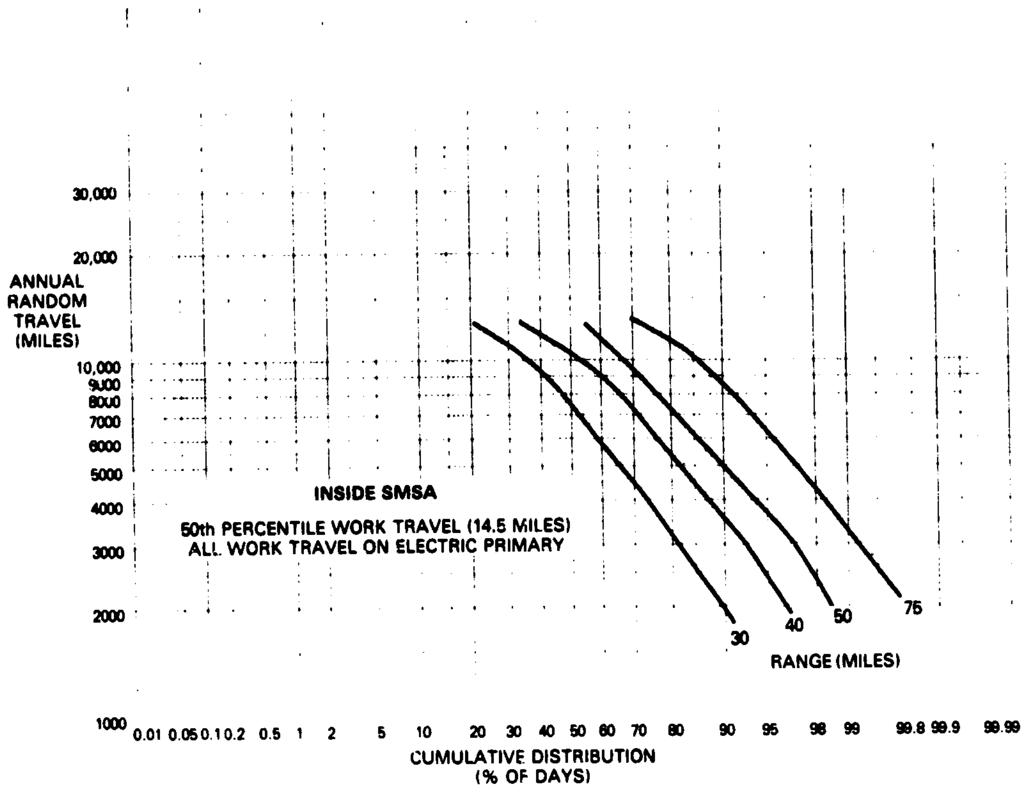


Figure 4-7. Effect of Electric Vehicle Range on All-Electric Vehicle Travel Inside SMSA - Percent of Days

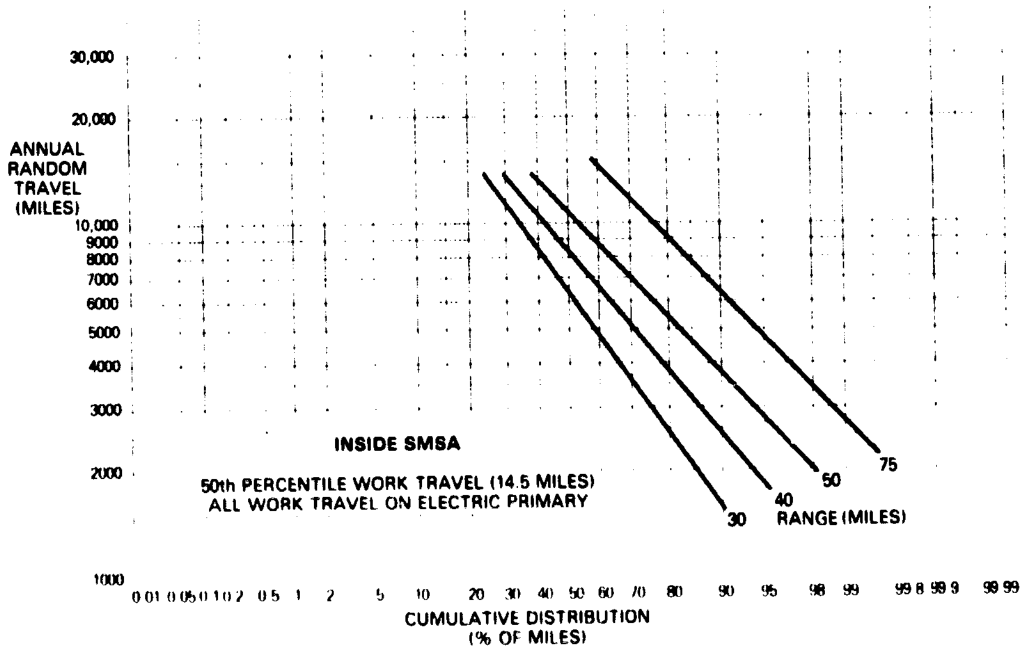


Figure 4-8. Effect of Electric Vehicle Range on All-Electric Vehicle Travel Inside SMSA - Percent of Vehicle Miles

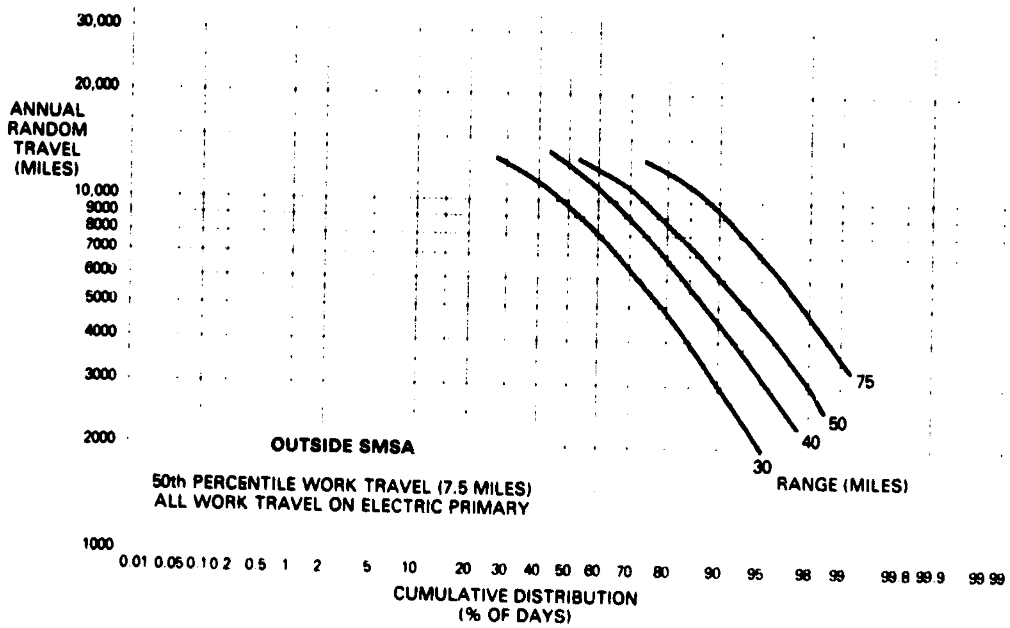


Figure 4-9. Effect of Electric Vehicle Range on All-Electric Vehicle Travel Outside SMSA - Percent of Days

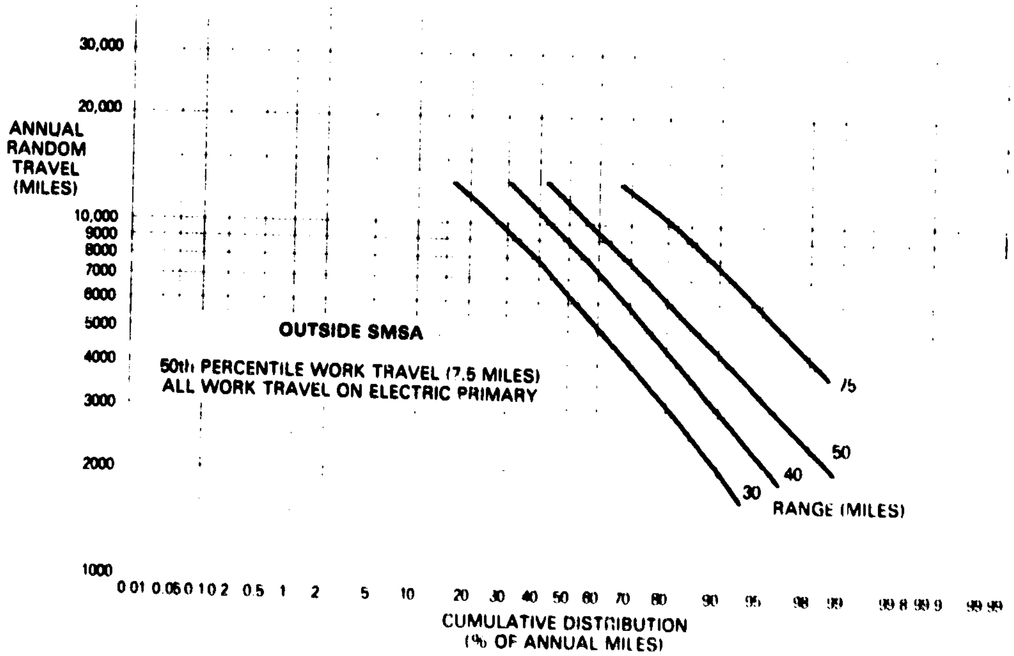


Figure 4-10. Effect of Electric Vehicle Range on All-Electric Vehicle Travel Outside SMSA - Percent of Vehicle Miles

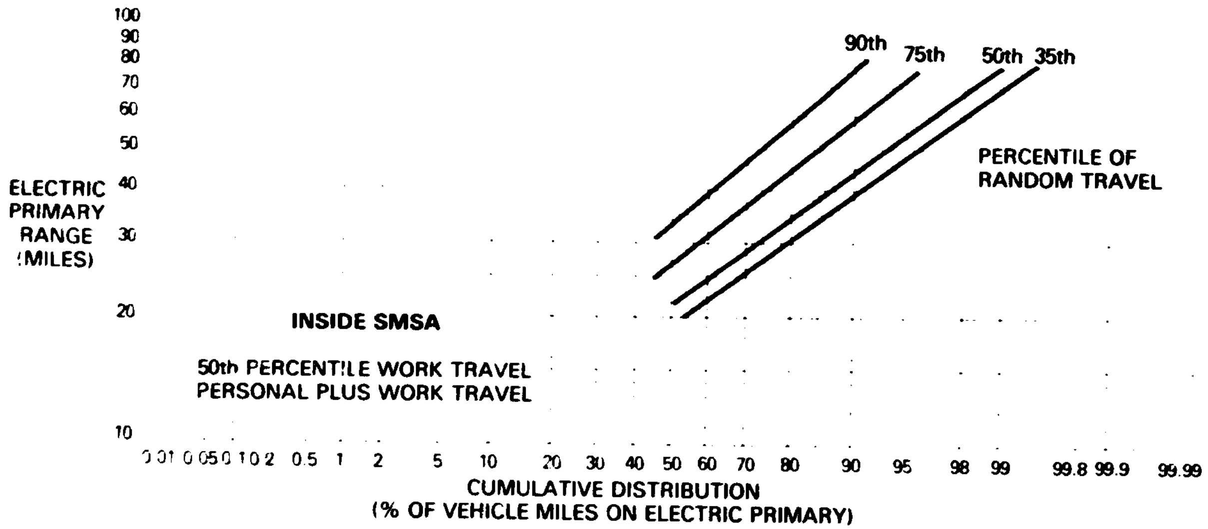


Figure 4-11. Effect of Vehicle Range on Vehicle Use - % of Vehicle Miles, Inside SMSA, Personal Plus Work Travel

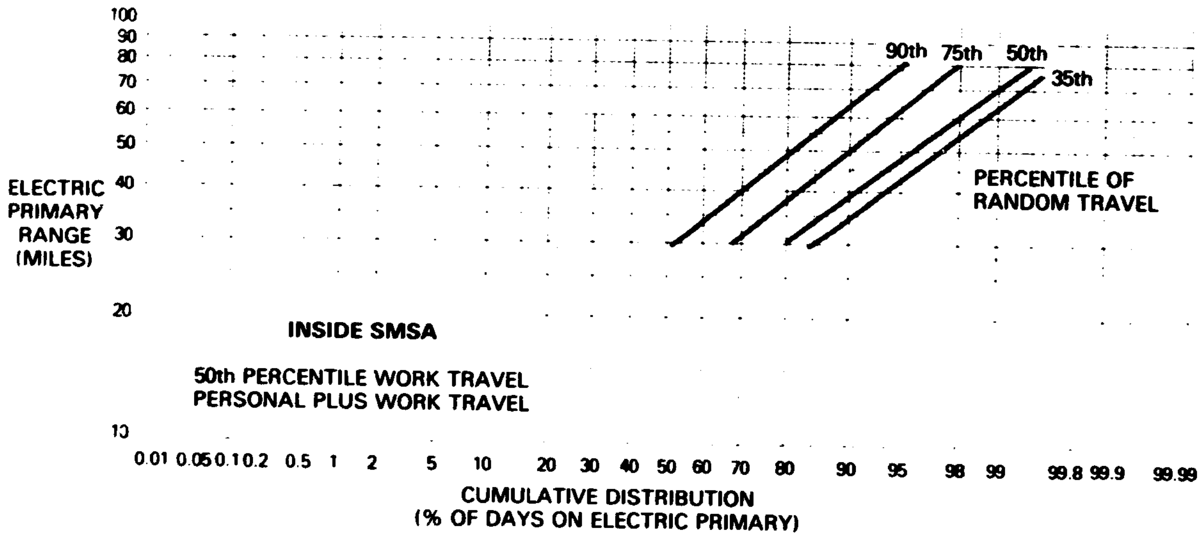


Figure 4-12. Effect of Vehicle Range on Vehicle Use - % of Days, Inside SMSA, Personal Plus Work Travel

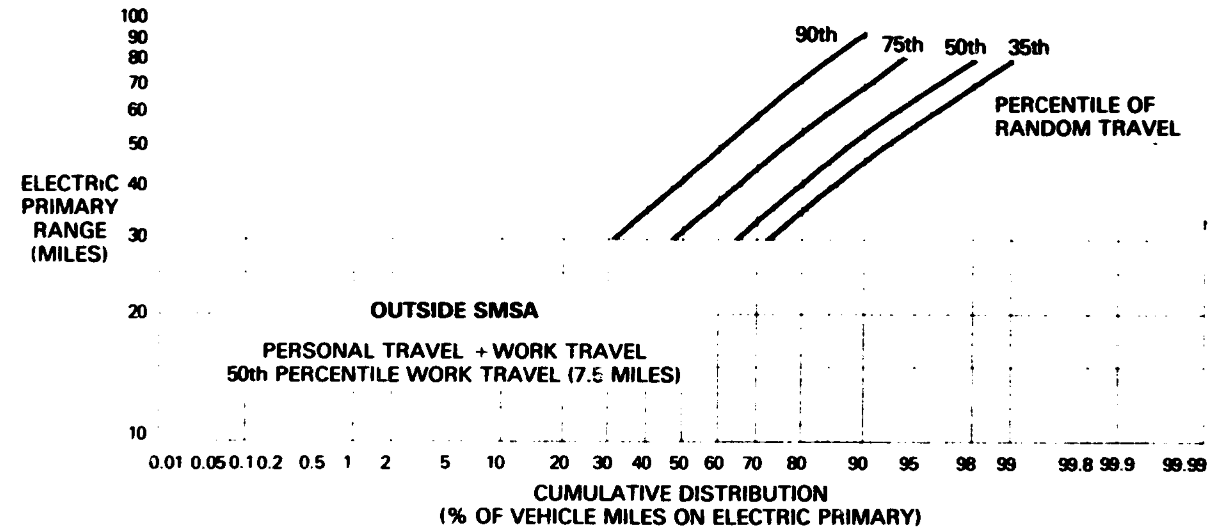


Figure 4-13. Effect of Vehicle Range on Vehicle Use - % of Vehicle Miles, Outside SMSA, Personal Plus Work Travel

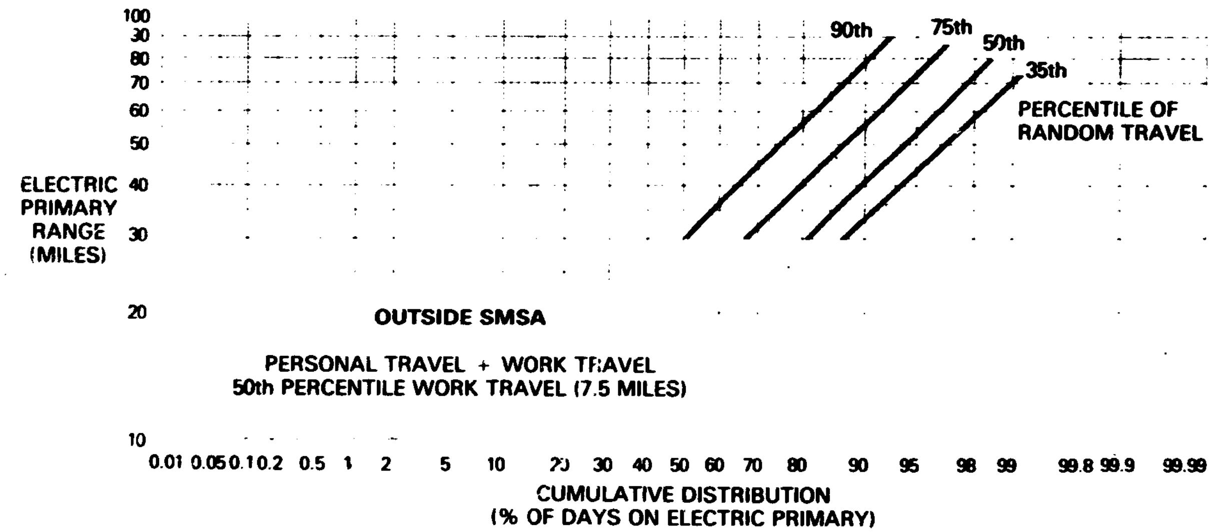


Figure 4-14. Effect of Vehicle Range on Vehicle Use - % of Days, Outside SMSA, Personal Plus Work Travel

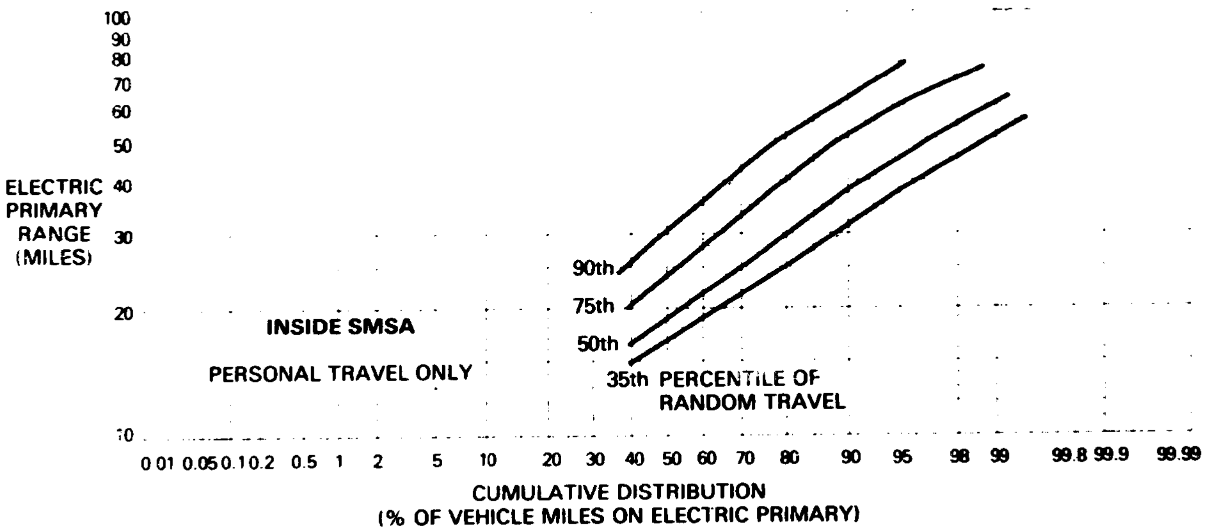


Figure 4-15. Effect of Vehicle Range on Vehicle Use - % of Vehicle Miles, Inside SMSA, Personal Travel Only

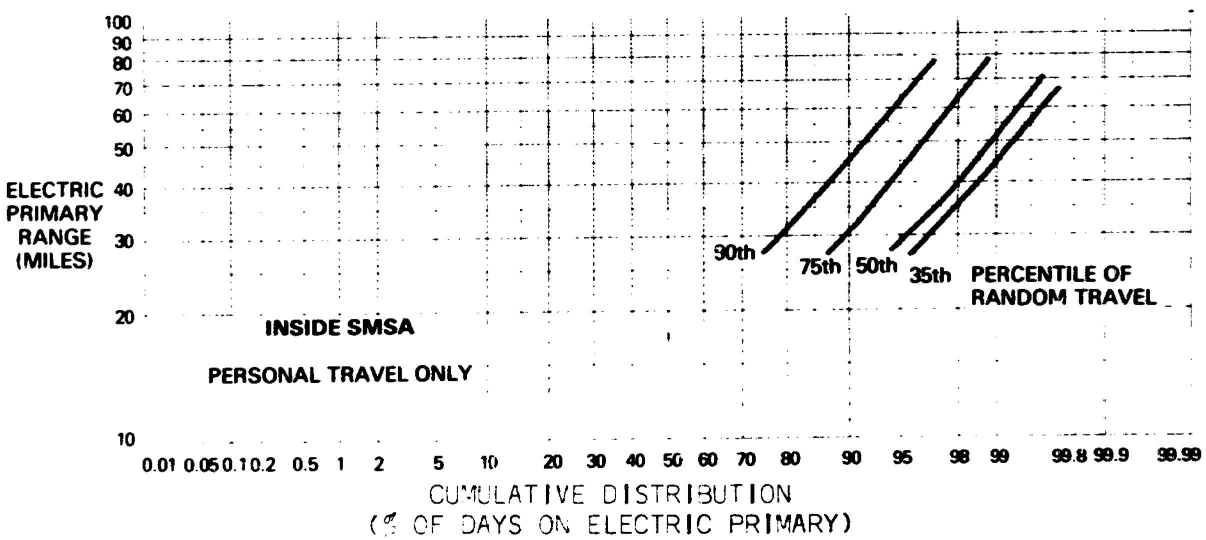


Figure 4-16. Effect of Vehicle Range on Vehicle Use - % of Days, Inside SMSA, Personal Travel Only

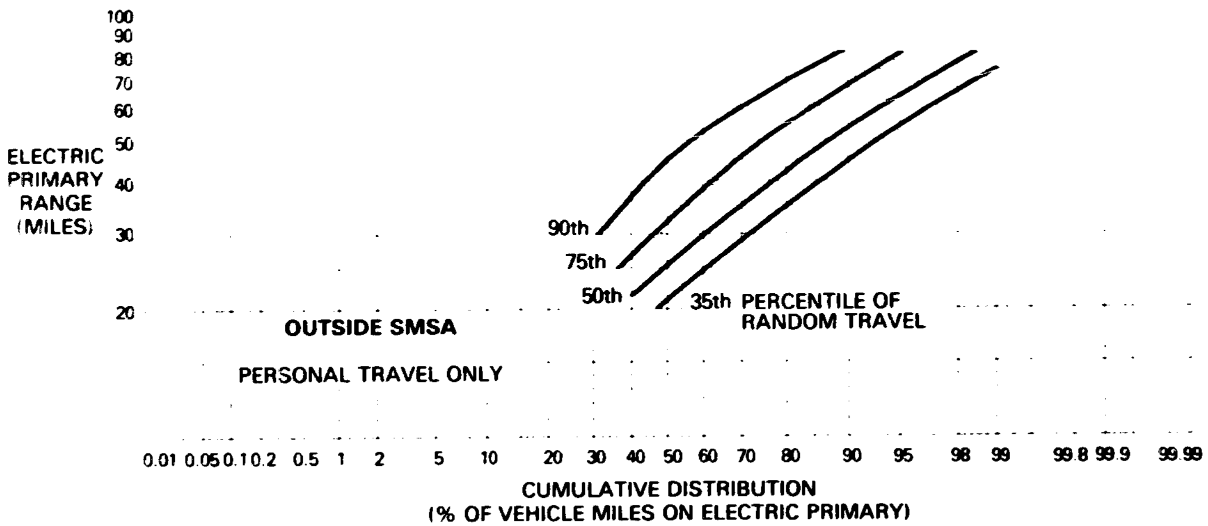


Figure 4-17. Effect of Vehicle Range on Vehicle Use - % of Vehicle Miles, Outside SMSA, Personal Travel Only

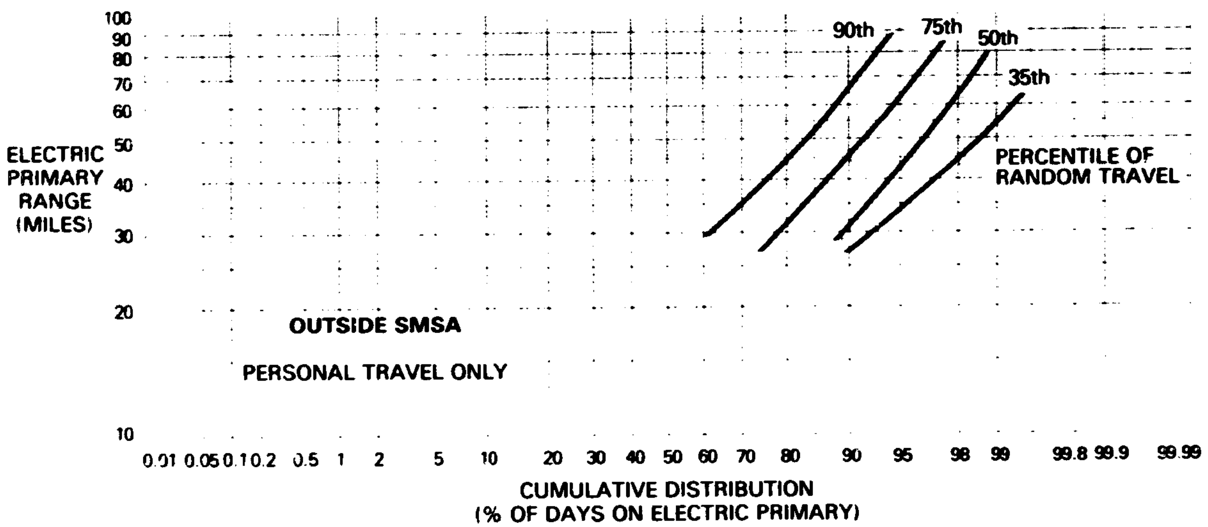


Figure 4-18. Effect of Vehicle Range on Vehicle Use - % of Days, Outside SMSA, Personal Travel Only

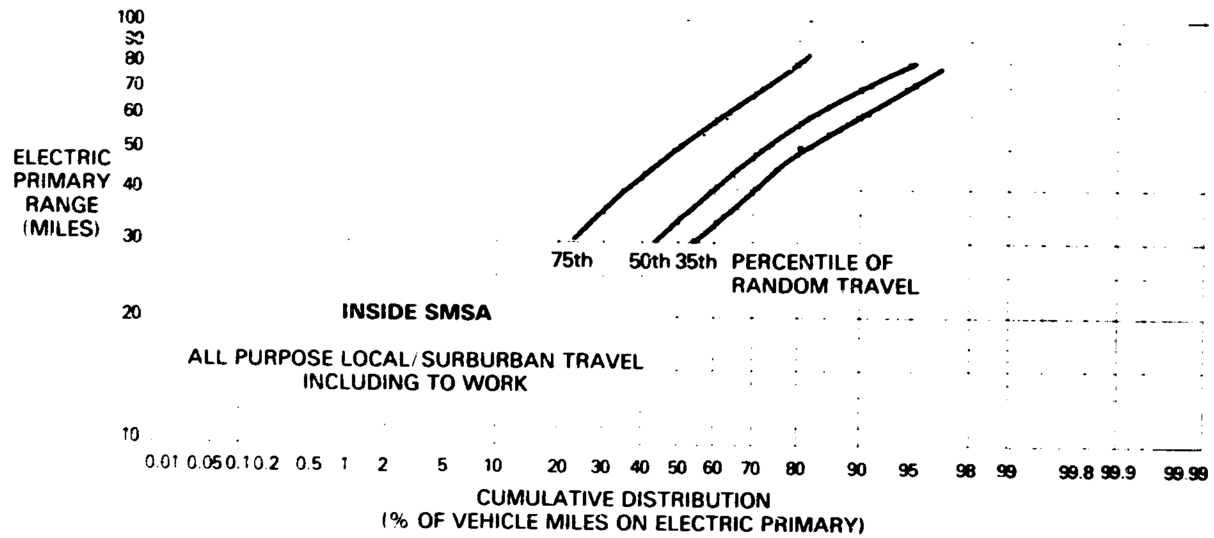


Figure 4-19. Effect of Vehicle Range on Vehicle Use - % of Vehicle Miles, Inside SMSA, All-Purpose Local/Suburban Travel, Including Work Travel

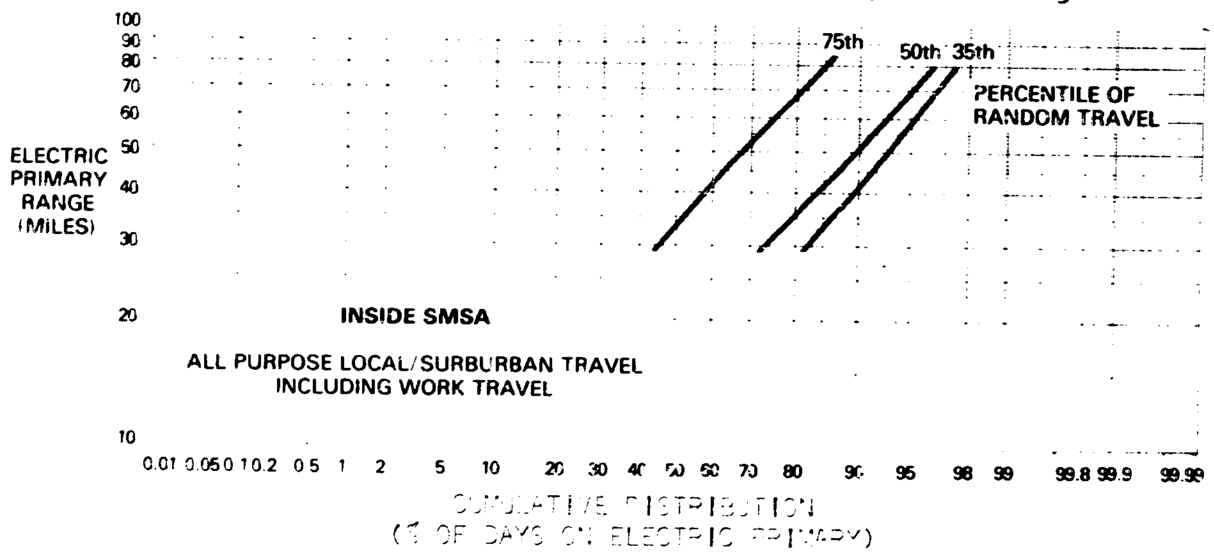


Figure 4-20. Effect of Vehicle Range on Vehicle Use - % of Days, Inside SMSA, All-Purpose Local/Suburban Travel, Including Work Travel

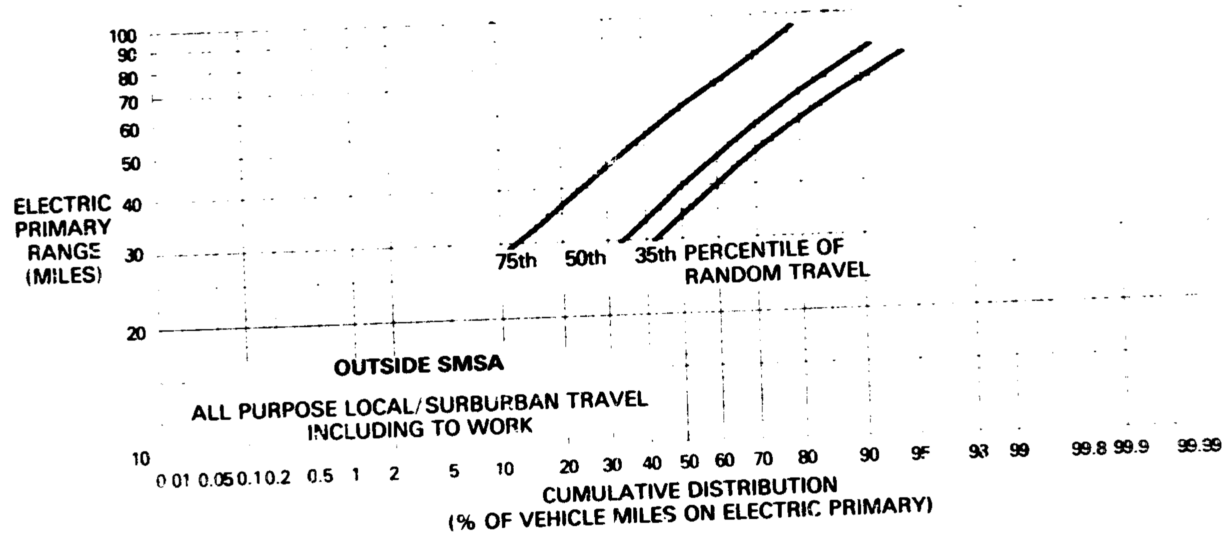


Figure 4-21. Effect of Vehicle Range on Vehicle Use - % of Vehicle Miles, Outside SMSA, All-Purpose Local/Suburban Travel, Including Work Travel

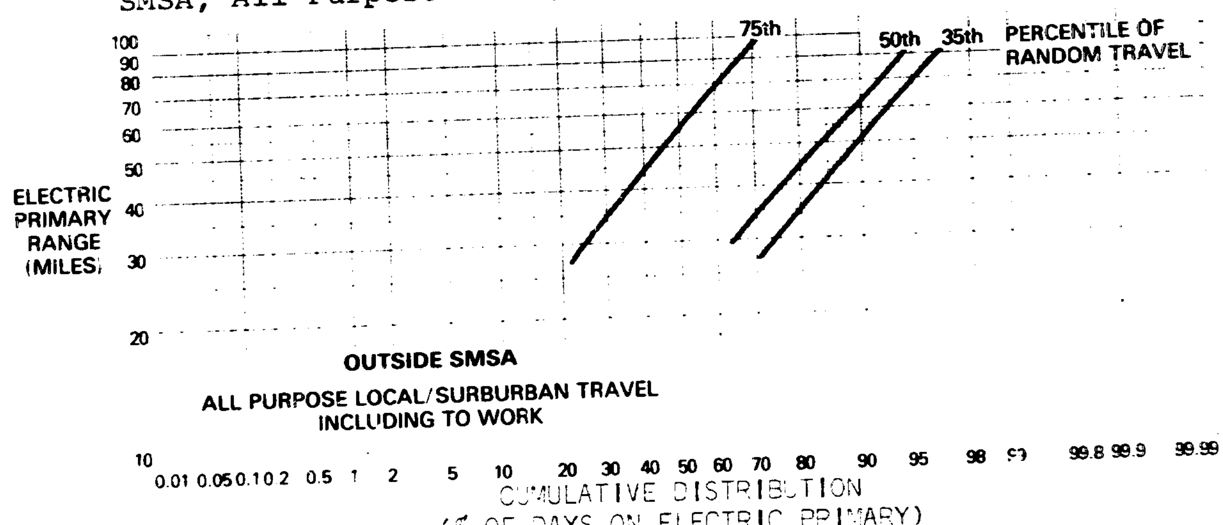


Figure 4-22. Effect of Vehicle Range on Vehicle Use - % of Days, Outside SMSA, All-Purpose Local/Suburban Travel, Including Work Travel

ORIGINAL PAGE IS OF POOR QUALITY

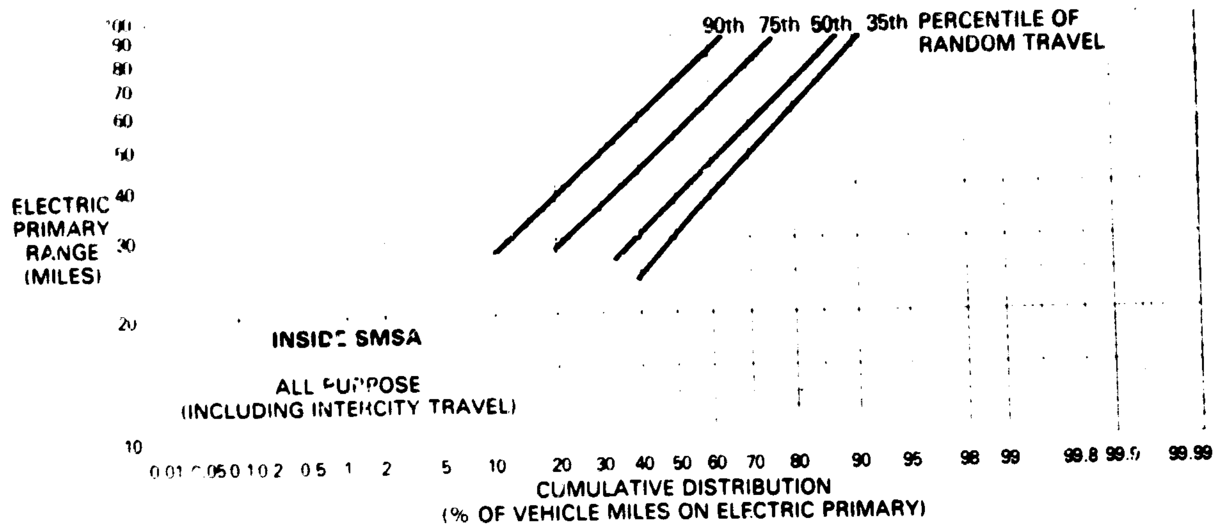


Figure 4-23. Effect of Vehicle Range on Vehicle Use - % of Vehicle Miles, SMSA, All-Purpose, Including Intercity Travel

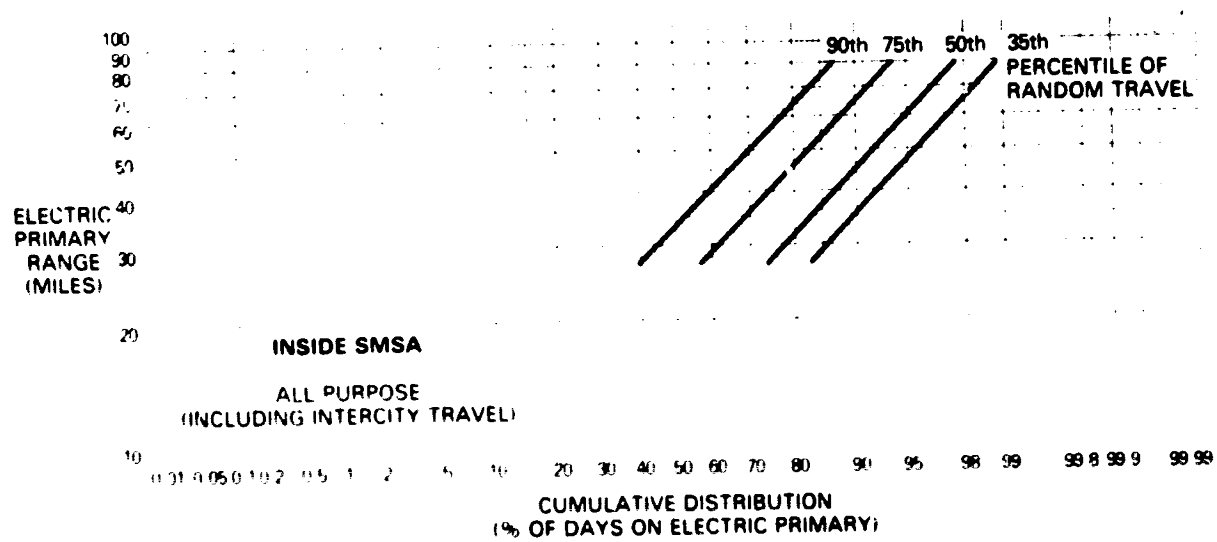


Figure 4-24. Effect of Vehicle Range on Vehicle Use - % of Days, Inside SMSA, All-Purpose, Including Intercity Travel

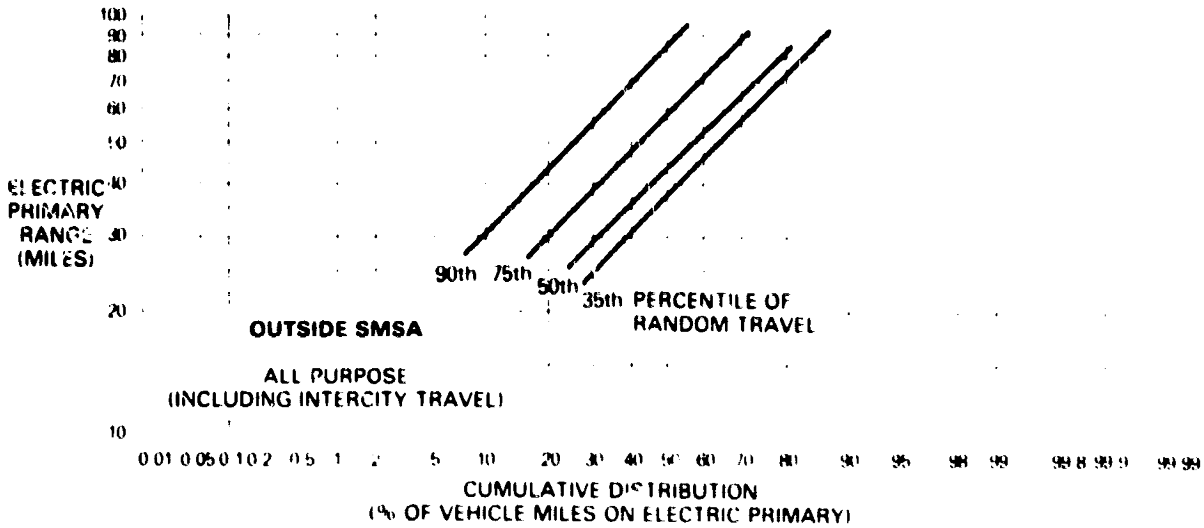


Figure 4-25. Effect of Vehicle Range on Vehicle Use - % of Vehicle Miles, Outside SMSA, All-Purpose, Including Intercity Travel

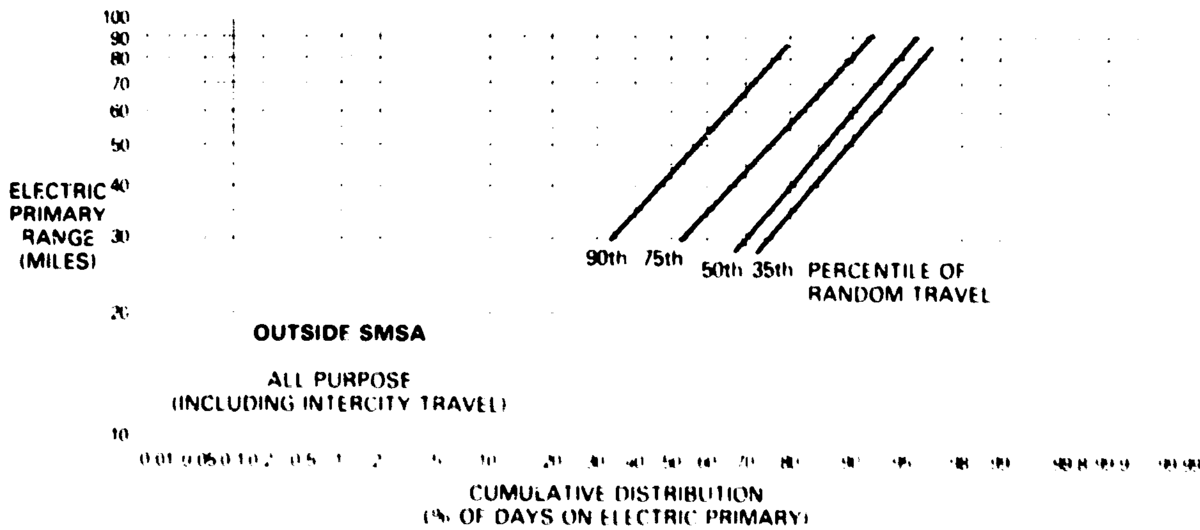


Figure 4-26. Effect of Vehicle Range on Vehicle Use - % of Days, Outside SMSA, Including Intercity Travel

4.3.3 DRIVING CYCLES

A number of driving cycles can be utilized as a means of representing vehicle operation in city and highway driving. A summary of selected characteristics of the following driving cycles are given in Table 4-19:

(a) EPA urban (FUDC)

(b) EPA highway (FHDC)

(c) SAE J227a B, C, D.

The first two driving cycles are used by the Environmental Protection Agency (EPA) to certify that passenger cars meet Federal Exhaust Emission Standards and to estimate fuel economy for the various car models. The EPA cycles were developed from actual pursuit data taken in traffic and are intended to simulate realistically the manner in which cars are actually driven (e.g., acceleration and braking rates, speeds and speed modulation, idle times, etc.). The SAE J227a cycles were developed purely as a means of comparing all-electric vehicles of differing design and capability on a common cycle. It has never been claimed that vehicles were driven in actual traffic conditions in modes like the SAE B, C, D cycles. For this reason, the plan is to adapt the EPA urban and highway cycles rather than the SAE cycles for use on the hybrid/electric design Tasks 2 and 3. The vehicle power-to-weight ratios needed to follow the SAE cycles are significantly less than the power-to-weight specified from other considerations (e.g., 0-60 mph acceleration, high-speed passing, etc.), so exclusion of the SAE cycles has no impact on vehicle design from the power requirement point of view. The hybrid/electric vehicle non-refueled SAE J227a Schedule B operation will be calculated, however, for comparison purposes as required.

A closer look at the EPA urban cycle, which consists of two parts (Figures 4-27 and 4-28), is recommended. The first portion of the cycle (505 s) is termed the (cold) transient, the second part is called the (hot) stabilized. As indicated in Figures 4-27 and 4-28, the characters of the two parts are surprisingly different as far as average speed and stops/mile are concerned. The "transient" part has nearly two minutes of high-speed driving (55 mph) and only 1.4 stops/mile. The peak power demand for the EPA urban cycle occurs in the "transient" part of the cycle. The second part of the EPA urban cycle is relatively low speed (maximum speed of only 34 mph) and has 3.4 stops/mile. It appears that the "stabilized" part of the urban cycle is a better representation of neighborhood and business district driving than either the SAE B or C cycles. Likewise, the "transient" part seems to be a reasonable representation of suburban or boulevard/expressway driving in which traffic often permits reasonable speeds and less stops/mile than in more congested neighborhood business district driving.

The EPA highway cycle was developed to obtain fuel economy data for highway driving. It is really typical of driving on the open highway at near constant speed (55 mph) with a stop every 10 to 20 miles. The EPA highway cycle is characteristic of freeway/expressway travel only during off-peak hours.

Table 4-19

SUMMARY OF DRIVING CYCLE CHARACTERISTICS

Driving Cycle	Cruising Speed (mph)	Length (miles)	Time (seconds)	Accel. mph/sec	Decel. mph/sec	Cruise Distance (miles)	Stops/ Mile	Idle Time (seconds)	Idle Time %
SAE J227a									
B	20	0.193	72	[illegible]	3.25	0.106	5.46	25	35
C	30	0.31	80	[illegible]	2.59	0.167	3.2	25	31
D	45	0.917	121	[illegible]	3.47	0.625	1.09	25	21
EPA									
City *	55 +	7.4	1372	[illegible] +	2.90 +		2.4	246	18
Highway	55	10.3	765	[illegible]	1.30		0.1	5	<1

* EPA City -

Cold start, 505 seconds, 3.6 miles, 5 stops, 1.4 stops/mile, max. speed 55 mph.
Hot transient, 867 seconds, 3.86 miles, 13 stops, 3.4 stops/mile, max. speed 34 mph.

\+ Cruising speed and acceleration/deceleration. Values shown for the EPA cycles are maximum values.

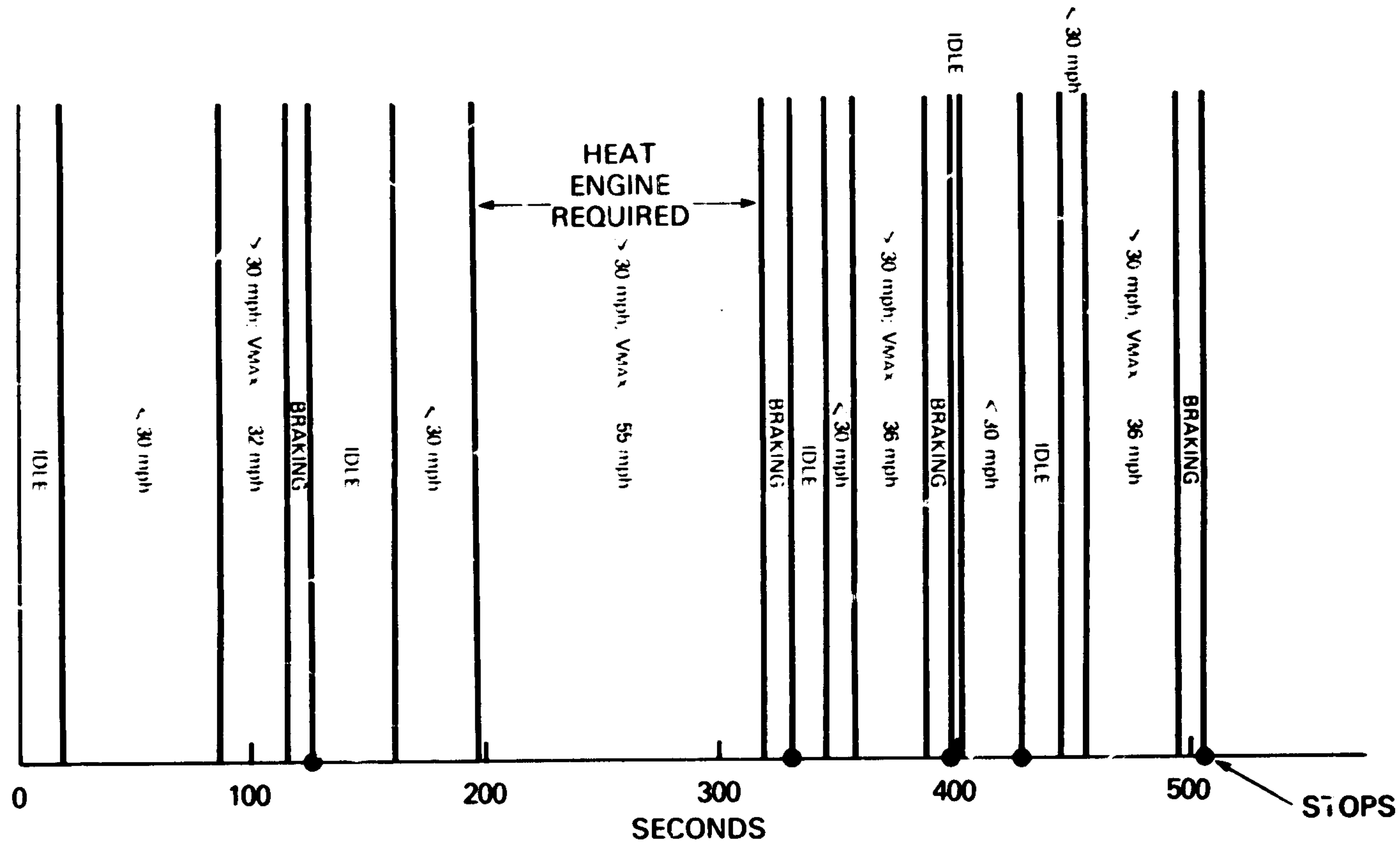


Figure 4-27. EPA Urban Cycle (Transient)

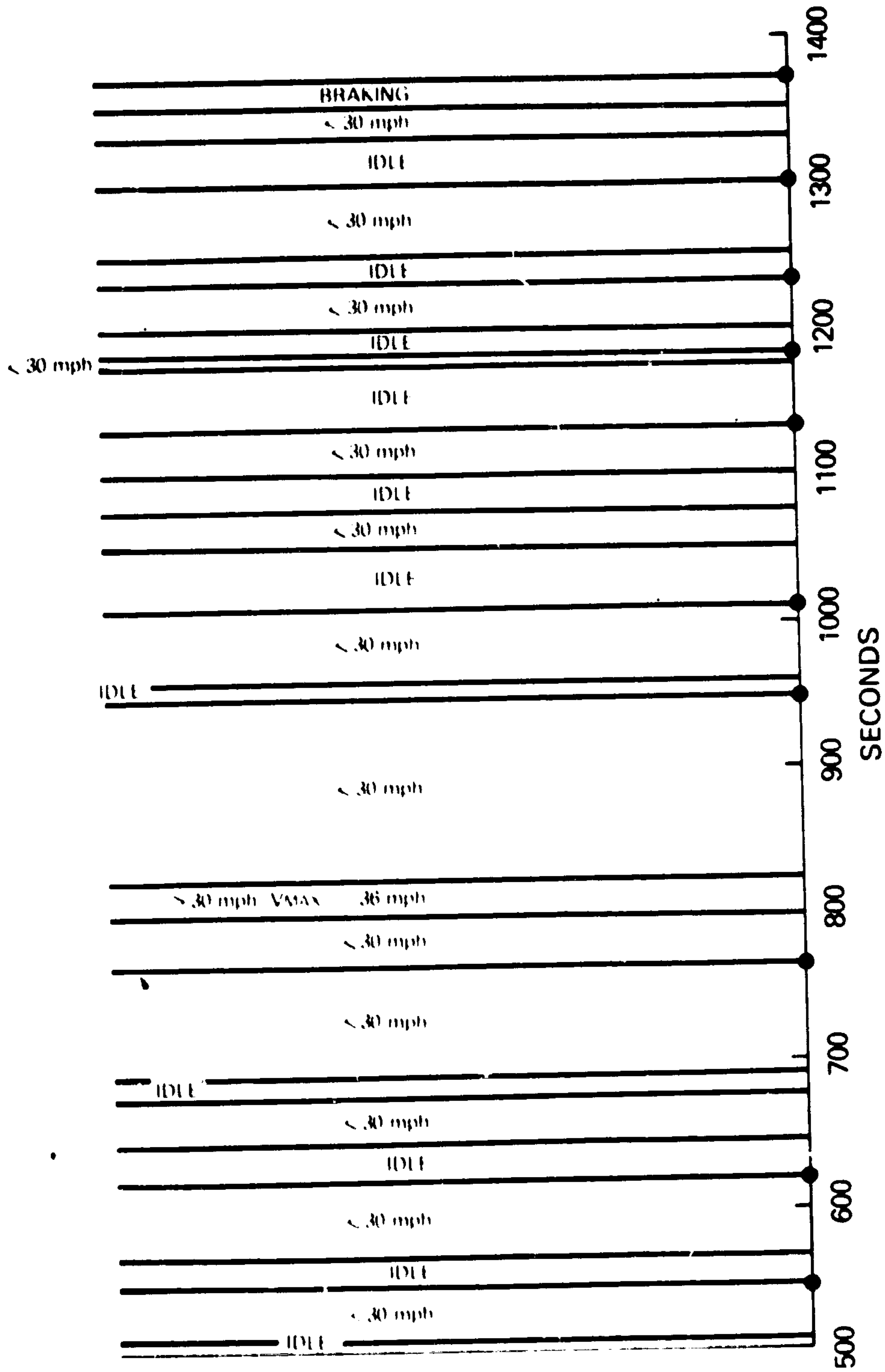


Figure 4-28. EPA Urban Cycle (Stabilized)

Based on the discussions in the foregoing paragraphs, it seems appropriate to use the EPA urban cycle in its entirety, or the "transient" and "stabilized" parts individually, to represent urban driving (to/from work and random personal travel) and to use the EPA highway cycle to represent only intercity travel (trips usually greater than 100 miles). Undoubtedly, there are some random trips of less than 100 miles on high mileage days, especially in the all-purpose mission set, which would logically qualify as highway driving. Such trips can be accounted for by adjustments in the annual random urban mileage.

The split between urban and intercity (highway) travel used by EPA and DOT to determine the composite fuel economy for passenger cars is 55% urban/45% highway. The urban/rural mileage data given in Table 4-4 for various states shows rather clearly that the urban/rural mileage split in most states departs markedly from the national average 55/45 split. Relatively few states have ratios close to 55/45. Many states, especially in the more populous areas including California and New York, have urban mileage fractions between 65% and 75%. Hence, although more study of this point is needed, it is being assumed at the present time for the design trade-off studies (Task 2) that inside SMSAs, 70% of the total annual mileage is driven on the EPA urban cycle, and 30% on the highway cycle. The primary use of the 70/30 split is in the determination of operating cost and break-even gasoline price.

Various combinations of the urban "transient" and "stabilized" cycles and the intercity highway cycle can be used to determine energy usage (electricity and gasoline) for specified daily travel and mission sets. The effect of these cycle mixes on vehicle "electric" range requirements and associated operating costs can only be determined by detailed vehicle simulations. This will be done as part of Task 2 and 3. A detailed determination of the urban cycle mixes appropriate for the to/from work and personal travel missions must await the simulation study results. Every attempt will be made to keep the driving cycle descriptions as simple as possible and consistent with realistic vehicle energy usage, both for electricity, and gasoline.

The effect of the driving cycle on the heat engine warmup time is also important and should be considered. This is especially true for the Reference ICE Vehicle. A recent study of the effect of trip length on fuel economy for conventional vehicles is reported in Ref. (5). Figure 4-29, taken from that reference, shows that the EPA urban and highway fuel economy values are at best applicable only under very special conditions (trip length, ambient temperature, etc.). It is not surprising that most car owners have found that the fuel economy they experience differs significantly from the EPA mpg values. Usually, owners find on-road fuel economy considerably lower than the EPA values. As indicated in Table 4-14, trips less than 7.5 miles length (EPA urban cycle) account for 66% of the trips

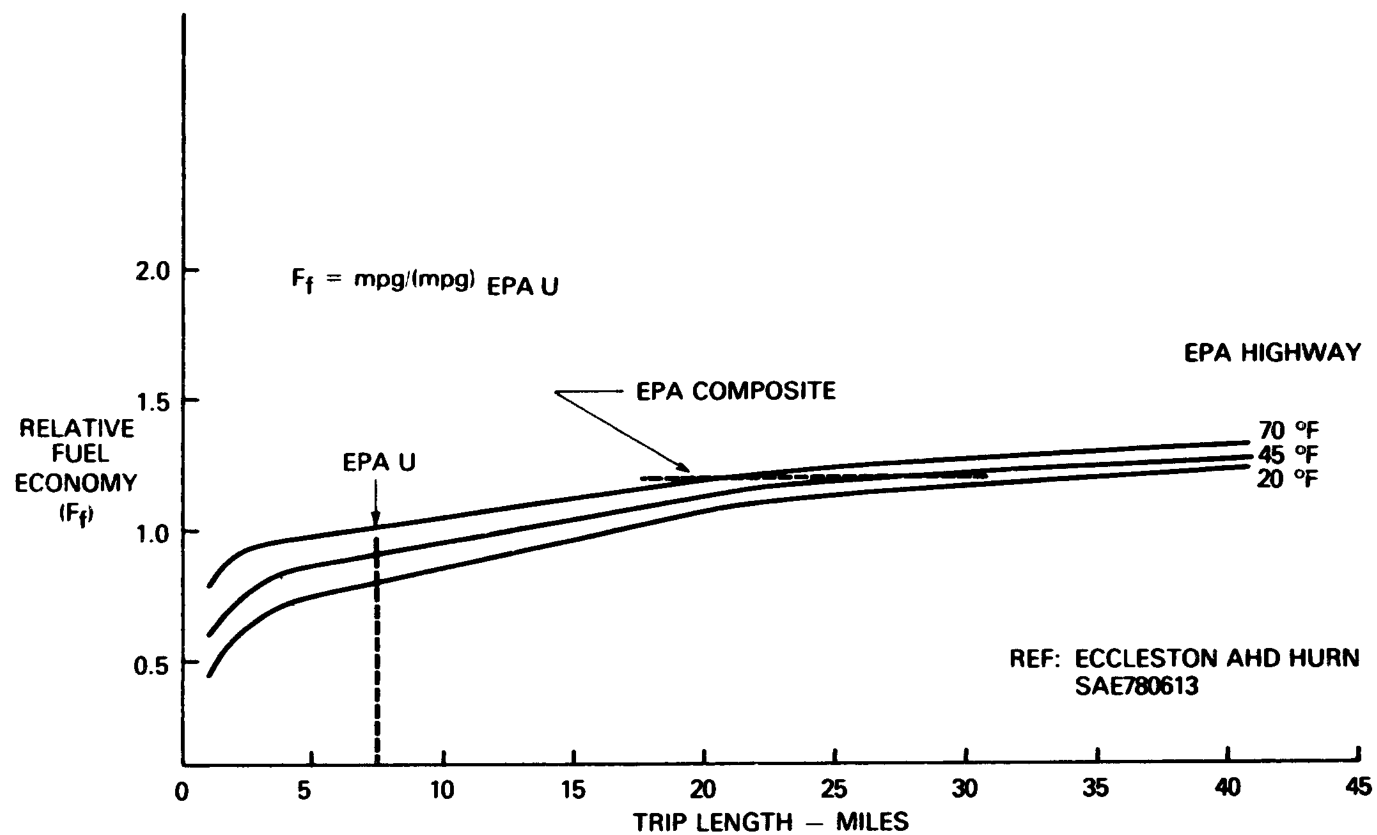


Figure 4-29. The Effect of Trip Length and Ambient Temperature on Fuel Economy for an ICE Vehicle

and 18% of the miles. Figure 4-29 shows that a trip length of at least 20 miles is needed before the EPA composite fuel economy value can be expected. Trips of less than 20 miles account for 92% of all trips and 53% of total vehicle miles. Therefore, it is clear that in estimating the fuel economy of the reference ICE vehicle on the various mission sets and percentile daily travel days the effect of engine warmup should be included. Likewise, the effect should also be included in the hybrid/electric calculations. This means that average trip length as well as daily travel (miles) must be considered in determining daily fuel usage. Fortunately, such travel statistics are available from the mission analysis. They will be incorporated into the work on energy consumption in Task 2.

Section 5

RATIONALE FOR THE SELECTION OF THE ICE REFERENCE VEHICLE

5.1 HYBRID VEHICLE SIZE CLASS

For purposes of this study it is necessary to identify a conventional internal combustion engine (ICE) passenger vehicle for comparison with the electric/hybrid car to be designed according to the present contract. The contract specifies that the hybrid vehicle should have a passenger capacity of at least five adults. This means that the hybrid vehicle must be either a mid-size (5-passenger) or a full-size (6-passenger) car. As indicated in Table 3-9, cars in these two classes use approximately 64% of the fuel consumed for personal transportation. The development of a hybrid/electric car in either class thus has the potential for saving a large quantity of petroleum if the market penetration of the hybrid design is significant. Hence, the key factor in deciding whether the hybrid vehicle should be mid- or full-size is the effect of size on market penetration.

It seems probable that the sales mix will increasingly favor the mid-size car during the next 5-10 years, especially in urban areas. In addition, the use pattern of the mid-size car is expected to be more consistent with the hybrid/electric concept which assures that much of the driving can be done using primarily battery-stored energy. Full-size cars probably will be purchased by people willing to pay for comfort on long trips and those seeking status. The present study will be directed toward the design of a hybrid/electric mid-size car which will be attractive to people who do most of their driving in urban/suburban areas with only occasional long intercity trips. This section is concerned with the selection of a conventional ICE passenger car for comparison with such a mid-size hybrid/electric car.

5.2 CRITERIA FOR SELECTION OF ICE REFERENCE VEHICLE

The criteria for the selection of the ICE reference vehicle are the following:

- 5-passenger capacity (mid-size)
- high sales volume
- acceleration performance of 0-96.54 km/h (0-60 mph) in 15-17 seconds

The high sales volume criterion is used as an indication of good consumer acceptance. It would also be highly desirable if the Reference ICE Vehicle represented a recent downsized design in the mid-size class since this would facilitate extrapolation of 1978/79 characteristics to those pertinent to 1985. In this respect, the Chevrolet Malibu/Olds Cutlass, Ford Fairmont, and Audi 5000 are of particular interest. The exterior and interior dimensions of those models and other selected 1978 passenger cars are

Table 5-1

INTERIOR AND EXTERIOR DIMENSIONS OF SELECTED 1978 PASSENGER CARS

Vehicle	Curb Wv lb	Exterior Dimensions (inches)		Eng/HP	Interior Dimensions (inches)		
		L	W		Front Shoulder	Rear Shoulder	Fore-Aft Rear
Audi 5000	2825	190	70	L5/103	56.0	55.5	27.0
Fairmont	2890	194	71	L6/88	57.0	57.0	28.5
Malibu	3155	193	72	V6/95	57.5	57.0	28.5
Cutlass	3275	197	72	V6/105	56.0	56.5	29.0
Saab 99	2670	178	66	L4/115	53.0	53.0	27.5
Impala	3890	212	76	V8/145	61.0	61.5	29.0
LTD (1979)	3650	209	78	V8/145	61.7	61.7	29.0
LTD II	4145	220	80	V8/134	58.5	56.0	29.5
Delta 88	3655	218	78	V6/105	61.0	61.5	29.0
Pontiac Catalina	3900	214	78	V8/140	61.5	61.0	29.0
Cadillac Seville	4290	204	72	V8/170	55.5	55.5	30.0
Mercedes 300 SD	3890	191	70	L5/110 (TC)	56.0	55.5	28.0

Source: Consumers Union, April 1978 issue, and 1979 Sales Brochures given in Table 5-1. By definition, a 5-passenger car carries two people in the front and three people in the rear seat. Using the criteria stated by Consumers Union in the April 1978 issue, this requires a rear shoulder width of at least 57 in., and a rear fore-aft dimension of at least 27 in. On this basis, the Chevrolet Malibu and the Ford Fairmont are 5-passenger cars, but the Audi 5000 is a little too narrow to fall into this category. The differences in weight and size between the 5- and 6-passenger cars are readily apparent from Table 3-7 and Table 5-1.

As indicated in Table 5-2, the new downsized mid-size car models have been well received by the public. Both the Malibu/Cutlass/Regal and Fairmont/Zephyr experienced impressive sales in 1978. Hence, both the Malibu and Fairmont meet the criteria of high volume sales.

Table 5-2

SALES OF MID-SIZE PASSENGER CAR MODELS IN 1978

General Motors

Division	Model	Sales (10^3)
Chevrolet	Malibu	374
Chevrolet	Monte Carlo	355
Oldsmobine	Cutlass	520
Buick	Century	75
Buick	Regal	248
Pontiac	Le Mans	125
	Total	1700

Ford Motor Company

Division	Model	Sales (10^3)
Ford	Fairmont	406
Mercury	Zephyr	121

Ref: Automotive News, January 15, 1979

Engine characteristics and related vehicle fuel economy for 1978 mid-size cars are given in Table 5-3. Data is given for both the General Motors Corporation and Ford Motor Company mid-size models. At the present time, mid-size cars are marketed using 4-, 6-, and 8-cylinder engines. Except for the Fairmont equipped with an L4 engine and manual 4-speed transmission, most mid-size cars are bought with 6-cylinder or small V-8 engines and automatic (A3) transmissions.

Acceleration characteristics of the Malibu, Cutlass, and Fairmont are summarized in Table 5-4. The information shown indicates that meeting the acceleration criteria of 0-60 mph in 15 to 17 seconds using a 6-cylinder engine (100-110 HP) and an automatic transmission presents no problems.

Either the General Motors (Malibu/Cutlass) or Ford Motor Company (Fairmont/Zephyr) mid-size cars could be used as the Reference ICE Vehicle. Both the Malibu and Fairmont meet all the criteria. The Malibu/Cutlass has been selected as the Reference ICE Vehicle primarily because General Electric, through its subcontractors, has access to more detailed information on the General Motors cars than on the Ford Motor Company cars. For example, arrangements have been made with General Motors to obtain data from their computer program (GPSIM) runs for the Malibu using several drivelines (V-6, V-8 engines and automatic and manual transmissions). Unfortunately, the results of the GPSIM computer runs have not been received for inclusion in this report, but assurances have been obtained from General Motors that they will be provided in the near future.* It is evident (Table 5-1) that the Fairmont is slightly lighter than the Malibu. Expectations are that, in the coming years, GM will reduce the weight of their mid-size cars and by 1985 will eventually utilize front-wheel drive in that size class. A summary of General Motors' plans regarding the use of front-wheel drive is given in Automotive News, 11 December 1978, indicating that the mid-size cars are likely to be the last to be redesigned in this way. Nevertheless, the General Electric projections of the weight and fuel economy of the ICE reference vehicle will assume the utilization of front-wheel drive by 1985.

5.3 SELECTED ICE REFERENCE VEHICLE

The ICE reference vehicle is taken to be the Chevrolet Malibu using a V-6, 231 CID engine. Currently, this engine is manufactured by the Oldsmobile and Buick Divisions of General Motors and is marketed by the Chevrolet Division only in California. A 1978 Malibu with the V-6, 231 CID engine is estimated to have 0 to 60 mph acceleration of less than 15 seconds and an EPA fuel economy of at least 19 mpg urban and 28 mpg highway. The cited acceleration time and fuel economies are those of the heavier Cutlass, as predicted by the GM GPSIM computer program. Therefore, they should be met or exceeded by the slightly lighter Malibu. GPSIM calculations of the performance and fuel economy of the Malibu with the V-6 engine and various transmissions and axle ratios are expected to be available to General Electric in the near future. A further discussion of the ICE reference vehicle and its characteristics is given in Section 6.4.

*GPSIM computer runs for the 1979 Malibu were not received from General Motors as had been expected.

Table 5-3

ENGINE CHARACTERISTICS AND RELATED VEHICLE FUEL ECONOMY FOR 1978 MID-SIZE CARS

General Motors Corporation				
Engine Type	Displacement (in^3)	HP/rpm	Axle Ratio	1978 Fuel Economy* Urban/Highway
V-6	200	95/3800	2.73	19/26
V-6	231	105/3400	2.41	19/28
V-8	260	110/3400	2.29	19/27
V-8	305	145/3800	2.29	17/25
Ford Motor Company				
Engine Type	Displacement (in^3)	HP/rpm	Axle Ratio	1978 Fuel Economy* Urban/Highway
L-4	140	88/4800	3.08	22/33 (I_W = 3000)
L-6	200	85/3600	3.08	19/25
V-8	302	139/3600	2.47	16/23

*EPA Buyer's Guide Data, Sept. 14, 1977.

C-2

Table 5-4

ACCELERATION CHARACTERISTICS OF 1978 INTERMEDIATE PASSENGER CARS

Eng/Trm/HP	Curb Weight kg (lb)	Acceleration in Seconds 0-48.27 kmh (0-30 mph)	Acceleration in Seconds 0-96.54 kmh (0-60 mph)	Source
Malibu				
V6/A3/95	1431.1 (3155)	6.6	18.2	Consumers Union
V8/M4/145	1597.1 (3521)	3.4	10.8	Car and Driver
V8/A3/145	1576.3 (3475)	3.6	11.4	Road and Track
Cutlass				
V8/A3/110	1526.4 (3365)	5.6	15.5	Consumers Union
		N.A.	15.2	General Motors
		N.A.	15.8	GM GPSIM Calculation
Fairmont				
L6/A3/85	1310.9 (2890)	5.4	15.8	Consumers Union
L4/M4/88	1299.6 (2865)	5.6	15.4	Consumers Union
L4/A3/88	1299.6 (2865)	N.A.	16.4	Ford Motor Co.
V8/A3/140	1359.9 (2998)	N.A.	11.1	Ford Motor Co.

N.A. - Not Available

Section 6

PRIMARY RESULTS OF MISSION ANALYSIS AND PERFORMANCE SPECIFICATIONS STUDY

Deliverable Item Number 1, "Mission Analysis and Performance Specification Studies Report" of Contract No. 955190 includes a number of items specified in the Data Requirements Description. Among these items are the primary results of the study. The primary results of the study are reported in the following subsections.

6.1 Vehicle Performance Specifications

6.2 Mission Description and Daily Travel

6.3 Mission Specifications

6.4 ICE Reference Vehicle and Its Characteristics

Subsections 6.1 and 6.3 are patterned after Exhibit I of Contract No. 955190 and use the same identification code as the contract.

The primary results are presented in a condensed form below and in an expanded form in the pages which follow.

CONDENSED RESULTS

Vehicle Performance Specifications		
P1,	Minimum Non-refuelable Range	
	Urban/Suburban	-- 56 to 64 km (35-40 miles) on battery
	Highway	-- 402 km (250 miles) with 37.85 liter (10 gallon) fuel tank
P2,	Cruise Speed	
	Electric Drive only	-- 88 km/h (55 mph)
	ICE Engine only	-- 105 km/h (65 mph)
P3,	Maximum Speed	-- 121 km/h (65 mph)
P4,	Acceleration	-- 0-96 km/h (0-60 mph) in 16 seconds
P5,	Gradability (minimum continuous	
	5%	- 88 km/h (55 mph)
	15%	-- 32 km/h (20 mph)
P6,	Passenger Capacity	-- 5 adults
P7,	Cargo Capacity	-- 0.5 m³ (17.7 ft³); 100 kg (220 lb)
Mission Specifications		
M1,	Daily Travel	-- See Tables 6-1 and 6-2
M2,	Payload	- passenger and cargo loads not assigned to specific type trips
M3,	Trip Length, Frequency and Purpose	- see Section 4.3
M4,	Driving Cycles	-- EPA Urban (FUDC) and EPA Highway (FHDC)
M5,	Annual Vehicle Miles	-- see Figures 4-1 through 4-10 for annual mileage statistics
M6,	Potential Number of Hybrid/Electric Vehicles in Use	-- will be analyzed in later task
M7,	ICE Reference Vehicle	-- Chevrolet Malibu with V-6, 231 CID engine
M8,	Reference ICE Vehicle Annual Fuel Consumption	in 1985 all mid-size passenger cars estimated to use 27% of fuel used for personal transportation

6.1 VEHICLE PERFORMANCE SPECIFICATIONS

P1 Minimum Nonrefuelable Range -

P1.1 Highway Driving (FHDC)

(a) 402 km (250 miles) between gasoline refueling stops [i.e., about 37.85 liter (10 gallons) fuel tank capacity]
(b) battery-stored electricity sufficient to load-level the heat engine for 804 km (500 miles) highway driving without recharge from the heat engine

P1.2 Urban/Suburban Driving (FUDC)

(a) 56-64 km (35-40 miles) using electric drive as primary system
(b) 112-128 km (70-80 miles) using heat engine as primary system, but no battery recharging with heat engine

P1.3 SAE J227a(B)

To be calculated during Task 2 and Task 3 for comparison purposes.

P2 Cruise Speed -

(a) electric drive only - 88 km/h (55 mph)
(b) heat engine drive only - 105 km/h (65 mph)

P3 Maximum Speed -

(a) 121 km/h (75 mph) continuous as long as battery charge level permits - combined efforts of electric and heat engine drives

P4 Acceleration (minimum values) -

0-48 km/h (0-30 mph) 6 seconds
0-96 km/h (0-60 mph) 16 seconds
Safe passing on a two-lane road

P5 Gradability (minimum values) -

Grade	Speed		Distance*
3%	88 km/h	(55 mph)	Unlimited
5%	88 km/h	(55 mph)	Unlimited
8%	64 km/h	(40 mph)	Unlimited
15%	32 km/h	(20 mph)	Unlimited

Maximum Grade: 25%

P6 Passenger Capacity -

5 passengers (350 kg)

*On heat engine alone, distance determined by fuel available.

P7 Cargo Capacity -

$0.5\ m^3$ ($17.7\ ft^3$)
100 kg (220 lb)

P8 Consumer Costs -

Consumer Purchase Price (1978, $)

List price of 4-door Malibu sedan with automatic transmission, power steering, power brakes, radio, and air conditioning was $5725. (Reference: Automotive News, 1978 Market Data Book Issue.)

Consumer Life Cycle Cost (1978, $)

12¢/km (19¢/mile) based on 10,000 miles/year. (Reference: Automotive News, 1978 Market Data Book Issue.)

P9 Emissions - Federal Test Procedure -

Standards have been set for conventional ICE passenger cars; applicability of those standards to an electric/hybrid whose emissions will depend on battery state-of-charge has not yet been established.

The passenger car emission standards for 1978, 1981, and 1985 are as follows:

	Standards (gram/mile)		
Year	HC	CO	NO_x
1978	1.5	15	2
1981	0.4	7	1
1985	0.4	3.4	1

The electric/hybrid will meet the above standards for all operating modes except possibly when the battery is being recharged by the heat engine. Meeting the NO_x standard during battery charging may prove to be difficult. This will be investigated during other tasks of the program.

P10 through P17 -

Will be treated during the design trade-off and preliminary design tasks of the program.

6.2 MISSION DESCRIPTION AND DAILY TRAVEL

Figures 4-11 thru 4-26 have been used to generate daily range capabilities for the eight mission sets defined in Section 4.2. This data is presented in Table 6-1 for the four mission sets inside the SMSAs and in Table 6-2 for the four mission sets outside the SMSAs. The percentiles listed under daily distance in these tables are for percent vehicle miles, not for percent days.

The assumption that daily travel in excess of 100 miles means intercity travel is reasonable in most instances but there are certainly exceptions where there are many short trips in one day all within a city and totaling 100 miles or more. On the other hand, daily travel of considerably less than 100 miles could be intercity travel. The larger the metropolitan area in which a vehicle is based, the greater the daily travel distance that would constitute intercity travel. Since data is not available to define the distribution of intercity travel, the criterion specified herein has been selected. Future sensitivity studies of the mission analysis will examine the significance of this assumption.

Comparisons between Tables 6-1 and 6-2 indicate that any vehicle capable of meeting annual and daily travel requirements for outside SMSAs would also meet requirements inside SMSAs. Thus, it would seem reasonable to let Table 6-2 represent the mission data for all vehicles. However, inasmuch as the purpose of the hybrid vehicle study is to assess impact on total fuel consumption, it is also necessary to factor in the relative sales and potential market penetration both inside and outside SMSAs. For this reason, a distinction between vehicle missions inside and outside of SMSAs will be retained. It is highly unlikely that a different design for inside and outside SMSAs is reasonable. A final decision on whether vehicle use patterns inside or outside SMSAs dictate the final design will be made when the fuel consumption impact study is completed (Task 2).

Table 6-1

DAILY AND ANNUAL TRAVEL DISTANCES INSIDE SMSAs FOR VARIOUS MISSIONS

Mission	Annual Distance (miles)	Daily Distance (miles) Percentile *		
		50	75	90
Personal business only				
50th percentile	3,000	20	29	39
75th percentile	4,500	25	38	49
90th percentile	6,500	32	49	66
Personal business plus work trips				
50th percentile	6,625	21	32	43
75th percentile	8,125	26	39	57
90th percentile	10,125	32	51	76
All-purpose (excluding intercity travel)				
50th percentile	6,400	34	52	69
75th percentile	9,200	52	74	99
90th percentile	11,600	>100	>100	>100
All-purpose (including intercity travel)				
50th percentile	7,000	36	61	>100
75th percentile	11,300	50	84	>100
90th percentile	17,000	70	>100	>100

*Percentiles are for vehicle miles

Table 6-2

DAILY AND ANNUAL TRAVEL DISTANCES OUTSIDE SMSAs FOR VARIOUS MISSIONS

Mission	Annual Distance (miles)	Daily Distance (miles) Percentile*		
		50	75	90
Personal business only				
50th percentile	4,400	25	38	52
75th percentile	6,500	31	49	67
90th percentile	9,300	43	64	82
Personal business plus work trips				
50th percentile	6,275	23	36	54
75th percentile	8,375	31	49	68
90th percentile	11,175	42	64	90
All-purpose (excluding intercity travel)				
50th percentile	7,800	40	62	83
75th percentile	10,600	61	90	>100
90th percentile	12,700	>100	>100	>100
All-purpose (including intercity travel)				
50th percentile	9,000	43	72	>100
75th percentile	13,700	58	>100	>100
90th percentile	20,500	84	>100	>100

*Percentiles are for vehicle miles

6.3 MISSION SPECIFICATIONS

M1 Daily Travel -

Daily travel requirements are summarized in Tables 6-1 and 6-2.

M2 Payload (in terms of cargo and passengers) -

No attempt was made to assign passenger and cargo loads to specific type trips because such information was not needed to proceed with the design of the hybrid 5-passenger, mid-size passenger car.

M3 Trip Lengths, Trip Frequency, and Trip Purpose -

Trip purposes were subdivided only as needed to obtain design constraints for the hybrid vehicle. In this regard, only to/from work travel, local random personal travel, all-purpose travel, and intercity travel were considered separately. Work travel and intercity travel were not considered random travel and hence were not included in the random trip calculations. Trip frequency (trips per day) and trip length were calculated as indicated in Section 4.3. Results are summarized in Table 4-18.

M4 Driving Cycles -

It was concluded that all travel could be described in terms of the EPA urban (FUDC) and highway (FHDC) cycles. Travel in congested city areas is better simulated by the "stabilized" portion (Figure 4-28) of the EPA urban cycle than the J227a(B) cycle. The EPA highway cycle applies only to intercity travel. The "transient" portion of the EPA urban cycle applies to relatively uncongested expressway travel (Figure 4-27). An important factor as far as driving cycles are concerned is the assumed split between the mileage on the FUDC AND FHDC cycles. The customary split of 55/45 is the national average, but does not apply to those living in urban areas, especially in the Northeast. A more appropriate split would seem to be 70/30 (Table 4-4) for those living in the near metropolitan areas. The assumed split between urban and highway mileage is an important input for the economic calculations.

M5 Annual Vehicle Miles Traveled Per Vehicle -

This is an important factor in determining mission specifications and vehicle range requirements. Unfortunately, very little data is available in this area. Annual vehicle-miles-traveled distributions (that is fraction of vehicles traveling a specified mileage or less - see Figure 4-1) are required to interpret and apply the random trip computer results to the various mission sets. It was necessary to make a "best judgement" estimate of the annual miles traveled distributions for personal and all-purpose travel. Estimates were made for inside SMSAs and outside SMSAs for both types of travel. Data/information on intercity travel is also needed, but such is not critical in determining the required "electric" range of the hybrid vehicle. Additional data on annual vehicle miles traveled per vehicle will be sought during the other tasks of the program.

M6 Potential Number of Vehicles in Use as a Percentage of Total Vehicle Fleet -

It is not possible as yet to estimate the function of mid-size vehicle sales in 1985 which could be hybrid/electric. If possible, this will be attempted in a later task after the economics of hybrid vehicle use has been assessed. It is estimated that in 1985 about 24% of the vehicles in the passenger car fleet will be mid-size vehicles.

M7 Reference Conventional ICE Vehicle -

The Reference ICE Vehicle selected for comparison with the mid-size hybrid vehicle is the Chevrolet Malibu with a V-6, 231 CID engine and a three-speed automatic transmission. This vehicle is a popular (high sales volume) 5-passenger car meeting the performance requirements determined for the hybrid electric design. A brochure describing the Chevy Malibu is included in the Appendix.

M8 Estimated Annual Fuel Consumption of the Reference ICE Vehicle -

It was estimated that in 1985 mid-size passenger cars will use about 27% of the gasoline consumed for personal transportation (Table 3-9). This estimate will be refined as part of later tasks of the program.

MISSION RELATED VEHICLE CHARACTERISTICS

V1 Capacity (Passengers and Cargo) -

5 passengers
17.7 ft^3 or 200 lb of cargo

V2 Range, Speed, Acceleration, and Gradability -

(a) Range

Range, primarily on stored electrical energy utilized through the electric drive system is a key design parameter for the hybrid/electric vehicle. The range requirement depends on a number of factors including the mission set, travel distance to/from work, and annual vehicle miles in random personal travel. The latter mileage varies considerably from owner to owner (Figure 4-1). The viability of the hybrid/electric vehicle for a particular car owner depends to a large extent on whether the "electric" range provided permits him to operate the vehicle most days and for a significant fraction of his total urban miles on stored electricity rather than gasoline. If that is not the case, the owner would not realize the cost advantage of electrical energy. Range requirement results from the mission and trip analysis studies (see Section 4 for the detailed approach) are given in Figures 4-11 through 4-23 for various percentiles of car users. From the range studies it was concluded that between 35 and 40 miles were required so that at least 50% of the mid-size car users could operate on stored electrical energy for between 50 and 75% of their annual vehicle miles in urban driving. The results given in Figures 4-11 through 4-23 will be utilized on a continuing basis in the design trade-off studies (Task 2) to further refine the "electric" range of the hybrid vehicle.

(b) Speed

There is little uncertainty regarding speed requirements as they are set by the 55-mph speed limit and the desire of most car owners to travel slightly in excess of the speed limit when traffic conditions permit and to attain speeds well in excess of the speed limit for passing. Therefore, a cruise speed of 60 to 65 mph and a maximum passing speed of 65 to 70 mph will be specified. These speeds will make the hybrid/electric vehicle competitive with the conventional ICE vehicles.

(c) Acceleration and Gradability

Performance of a passenger car is often stated in terms of its 0-60 mph acceleration time. Acceleration performance is important to the car owner both for safety reasons and for the "good feeling" he gets from driving a responsive vehicle. The analysis discussed in Section 3 indicates that safe operation of the vehicle on 2-lane suburban and rural roads and on some limited-access expressways requires a power-to-weight ratio (HP/lb) consistent with a 0-60 mph acceleration time of 15-16 seconds. The associated gradability would depend somewhat on the vehicle gearing and shift logic, but should permit maintenance of 55 mph on grades up to 5%, and 40 mph on grades up to 8%. A maximum gradability of 25% will be used as a design target.

V3 Cost Constraints

Cost constraints are not set by the mission analysis, but certainly will greatly influence the marketability of a hybrid mid-size vehicle. The purchase price of mid-size cars (high sales volume, popular models) in 1978 ranged from $4500 to $6000 depending on installed equipment (e.g., air conditioning, radio, etc.). The price of a well equipped Malibu was about $5700 in 1978. Data for 1978 (Automotive News, Market Book Issue) indicates an operating cost of about 19.5¢/mi for a mid-size passenger car. Every attempt will be made to design the hybrid/electric mid-size car so that it is cost-competitive with the Reference ICE Vehicle in terms of both initial and operating costs. These considerations will be central to the work in Tasks 2 and 3.

V4 Ambient Conditions, Availability and Amenities

The hybrid/electric vehicle will be designed to be equivalent in all respects as far as these factors are concerned. These factors were not felt to be effected significantly by mission set, thus, they were not considered in Task 1. They will be considered in Tasks 2 and 3.

6.4 ICE REFERENCE VEHICLE AND ITS CHARACTERISTICS

A 5-passenger mid-size car, the Chevrolet Malibu, has been selected as the ICE reference vehicle for comparison with the hybrid vehicle designs to be developed in Tasks 2 and 3. The characteristics of the Reference Vehicle in 1978, and those projected for a mid-size car in 1985, are summarized in Table 6-3. The acceleration performance indicated for the reference vehicle is consistent with that required of the hybrid vehicle designs. The 1978 fuel economies are those measured by EPA and corrected to account for actual on-the-road experience. The 1985 fuel economies reflect improvements due to reduced curb weight for mid-size cars, lower aerodynamic drag, wider range, and more efficient automatic transmissions, etc. It has been assumed that the fuel economy improvement indicated can be achieved along with meeting the 1985 emission standards of 0.4 gram/mile HC, 3.4 gram/mile CO, and 1.0 gram/mile NO_x.

Table 6-3

SUMMARY OF THE CHARACTERISTICS OF THE ICE REFERENCE VEHICLE IN 1978 AND 1985

	1978	1985 (estimate)
Model	Chevrolet Malibu, 4-door, 5-passenger	GM Mid-Size
Engine (gasoline)	V-6, 231 CID, 105HP	L4 or V-6, 85HP
Transmission	3-speed, automatic	4-speed, automatic with lock-up
Curb Weight kg (lb)	1451.5 (3200)	1179.4 (2600)
Length, cm (in.)	490.2 (193)	469.9 (185)
Width, cm (in.)	182.9 (72)	185.4 (73)
Height, cm (in.)	137.2 (54)	137.2 (54)
Fuel Economy, km/l (mpg)		
urban-corrected	7.226 (17)	9.648 (22.7)
-uncorrected	8.075 (19)	11.900 (28)
highway-corrected	9.648 (22.7)	13.898 (32.7)
-uncorrected	11.900 (28)	17.850 (42)
Emissions gram/km (gram/mile)		
HC	0.932 (1.5)	0.249 (0.4)
CO	9.32 (15.0)	2.113 (3.4)
NO_x	1.24 (2.0)	0.622 (1.0)
Performance (seconds)		
0-48.3 km/hr (0-30 mph)	6	6
0-96.5 km/hr (0-60 mph)	16	16
72.4-104.6 km/hr (45-65 mph)	11	11
Range on 56.8 liters (15 gallons)		
urban, km (miles)	410.3 (255)	547.1 (340)
highway, km (miles)	547.1 (340)	788.4 (490)

Section 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

7.1.1 GENERAL CONCLUSIONS AND OBSERVATIONS

The following general conclusions were formulated based on the work done on mission analysis:

(1) The statistical character of automobile use is important in determining the "electric" range of the hybrid/electric car and the fraction of potential car buyers whose transportation needs would adequately be met by a specific hybrid/electric car design.

(2) Statistical data on annual mileage including the relationships between annual mileage and trip length frequency along with fraction of vehicle miles in trips of specified length are important in calculating auto use statistics, but the available key input data is very limited.

(3) The auto use patterns in terms of daily travel and annual mileage are significantly different inside and outside of SMSAs, and these differences can significantly effect the selection of design range for hybrid/electric cars.

(4) The fraction of vehicle miles rather than the fraction of days on which the car can be operated primarily on the battery is the critical factor in selecting "electric" range.

(5) The EPA urban and highway cycles can be used to describe vehicle use, and the "stabilized" portion of the EPA urban cycle is a better representation of central city driving than the SAE J227a (B) cycle.

(6) The urban/highway mileage split of 70/30* is more realistic for metropolitan areas in which hybrid/electric vehicles will be most attractive than the more customary 55/45 split.

7.1.2 SPECIFIC CONCLUSIONS

(1) The Chevrolet Malibu with a V-6, 231 CID engine, a 5-passenger mid-size car made by General Motors, was selected as the ICE reference vehicle.

---

*An urban/highway mileage split of 65/35 was used as nominal in the Design Trade-off and Sensitivities Studies (see Appendices B and D).

(2) An "electric" range of 35 to 40 miles for the hybrid/electric vehicle is needed so that at least 50% of the potential mid-size car buyers would drive at least 75% of annual urban vehicle miles using the electric drive as their primary propulsion means.

(3) A 0-96.5 km/h (0-60 mph) acceleration time of 16 seconds was selected for the acceleration performance specification. The critical factor in this selection was safe, high-speed passing on two-lane roads. This level of performance resulted in more than adequate gradability, freeway merging capability, and top speed.

7.2 RECOMMENDATIONS FOR CONTINUING MISSION ANALYSIS ACTIVITIES

Continuing activity on mission analysis is required as it relates to the design of the hybrid/electric vehicle, its potential sales, and thus its gasoline saving potential. Areas needing additional work were cited in previous sections of this report. Those areas are summarized below:

(1) A sensitivity analysis should be made of the calculated travel characteristics to statistical trip frequency/length and annual mileage data which were used as input to the Monte Carlo travel simulation program.

(2) The impact of statistical travel characteristics on hybrid/electric sales potential and energy usage should be examined.

(3) A study should be made on the detail needed in describing the driving cycle mixes (EPA urban, both transient and stabilized; and highway cycle) to calculate properly the operating costs and energy usage for the various mission sets.

(4) Further detailed evaluations should be made with regards to high-speed passing on a 2-lane road as the critical factor in setting power requirements using specific power train configurations.

(5) Interpretation of the GPSIM computer results for the ICE reference vehicle (Chevrolet Malibu with V-6, 231 CID engine) will be needed after the computer results have been received from General Motors.

Section 8

REFERENCES

1. General Motors' Response to the 81-84 Fuel Economy Proposal and Special Order, 1977.
2. A Policy on Geometric Design of Rural Highways - 1965, American Association of State Highway Officials.
3. F.T. Surber and G.K. Deshpande, "Hybrid Vehicle Missions," paper presented at the 5th International Electric Vehicle Symposium, Philadelphia, Pa., Oct. 1978.
4. A.F. Burke, "The Moving Baseline of Conventional Engine-Powered Passenger Cars (1975-1985)," SAE Paper No. 780347, Detroit, Mich., 1978.
5. B.D. McNutt, et al., "A Comparison of Fuel Economy Results from EPA Tests and Actual In-Use Experience, 1974-1977 Model Year Cars," HCP/M8435-01, Feb. 1978.
6. "Near-Term Hybrid Passenger Vehicle Development Program - Phase I, Guidelines and Assumptions," Jet Propulsion Laboratory, received 27 Sept. 1978.
7. Statistical Abstract of the US, 1977, 98th Annual Edition, published by the US Department of Commerce, Bureau of Census.
8. Motor Vehicle Facts and Figures '77, published by the Motor Vehicle Manufacturers Association, Washington, DC.
9. 1977 Year End Service D (New Passenger Cars), by State and US; 1977 Year End Service K (Imported Cars), by State and US, purchased from R.L. Polk Company, Detroit, Michigan.
10. US Department of Transportation/Federal Highway Administration, Nationwide Personal Transportation Study - Report No. 10, "Purposes of Automobile Trips and Travel," May 1974.
11. H.J. Schwartz, "The Computer Simulation of Automobile Use Patterns for Defining Battery Requirements for Electric Cars," Fourth International Electric Vehicle Symposium; Düsseldorf, West Germany (1976).
12. F.T. Surber and G.K. Deshpande, "Hybrid Vehicle Missions," Fifth International Electric Vehicle Symposium, Philadelphia, Pa. (1978).
13. US Department of Transportation/Federal Highway Administration, Nationwide Personal Transportation Study - Report No. 2, "Annual Miles of Automobile Travel," April 1972.

APPENDIX

Note: The Chevrolet Malibu Brochure number 3804, dated July 1978, was included only in those copies of this report which were delivered to the Government.

APPENDIX

CHEVROLET MALIBU TECHNICAL SPECIFICATIONS

Model	5-passenger, 4-door sedan
Engine (gasoline)	V-6, 231 CID, 105 HP
Transmission	3 speed, automatic
Curb Weight, kg (lb)	1451.5 (3200)
Exterior Dimensions, cm (in.)	
Length	490.2 (193)
Width	182.9 (72)
Height	137.2 (54)
Fuel Economy 1978, km/liter (mpg)	
EPA-Urban	8.08 (19)
-Highway	11.90 (28)
EPA Corrected	
-Urban	7.22 (17)
-Highway	9.65 (22.7)
Emissions, g/km (g/mi)	
HC	0.93 (1.5)
CO	9.32 (15.0)
NO_x	1.24 (2.0)
Acceleration, seconds	
0-48.27 km/h (0-30 mph)	6
0-96.54 km/h (0-60 mph)	16
72.40-104.58 km/h (45-65 mph)	11
Range, 56.78 liters (15 gallons)	
Urban, km (miles)	410.3 (255)
Highway, km (miles)	547.1 (340)

BASIC INTERIOR DIMENSIONS - REFERENCE VEHICLE

According to the basic plan outlined in the original proposal, the interior dimensions as relating to the occupant seating package would be utilized in the hybrid vehicle. Listed below are the interior dimensions of the reference ICE vehicle (1979 Malibu 4-door sedan) which will be used in the preliminary packaging exercises.

		Degrees	Inches	Millimeters
Front Compartment				
W20	Centerline Occupant to Centerline Car		14.48	368
H61	Effective Headroom		38.70	983
L64	Maximum Effective Leg Room		42.75	1086
H30	H Point to Heel Hard (chair height)		8.97	228
L40	Back Angle	26.5		
L42	Hip Angle	99.5		
L44	Knee Angle	131.0		
L46	Foot Angle	87.0		
L53	H Point to Heel Point		35.07	891
L17	H Point Travel		6.73	171
H58	H Point Rise		.98	25
W3	Shoulder Room		57.32	1456
W5	Hip Room		52.20	1326
W16	Seat Width		49.49	1257
Rear Compartment				
L50	H Point Couple		32.56	827
W25	Centerline Occupant to Centerline Car		13.27	337
H63	Effective Head Room		37.68	957
L51	Maximum Effective Leg Room		38.00	965
H31	H Point to Heel Point (chair height)		11.73	298
L41	Back Angle	27		
L43	Hip Angle	92		
L45	Knee Angle	102		
L47	Foot Angle	118.5		
W4	Shoulder Room		57.08	1450
W5	Hip Room		55.59	1412
Control Location				
H18	Steering Wheel Angle	19.5		
L7	Steering Wheel Torso Clearance		13.38	340
L13	Brake Pedal Knee Clear		24.42	595
L52	Brake Pedal to Accelerator		4.48	114