9950-330

PHASE I OF THE NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM

FINAL REPORT

APPENDIX A : Mission Analysis and Performance Specification Studies

VOLUME I : Final Report

(NASA-CR-163220) PHASE 1 OF THE NEAR TERM HYBRID PASSENGER VEHICLES DEVELOPMENT PROGRAM. APPENDIX A: MISSION ANALYSIS AND PERFORMANCE SPECIFICATION STUDIES, VOLUME 1 Final Report (Fiat Research Center) 157 p HC A08/MF A01 N80-28246

Unclas

G3/85 22363

Prepared for

JET PROPULSION LABORATORY

by

CENTRO RICERCHE FIAT S.p.A.

Orbassano (Turin) – Italy

The research described in this publication represents the first of the several Tasks of the "Phase I of the Near Term Hybrid Passenger Vehicle Development Program" being carried-on by Centro Ricerche FIAT (CRF) on Contract No. 955187 from the Jet Propulsion Laboratory, California Institute of Technology.

Major part of this task has been carried on by the Illinois Institute of Technology - Research Institute (IITRI) on a subcontract from Centro Ricerche FIAT.

Turin, April 20, 1979

This Report, prepared by:

M. Traversi (CRF) and
L.A.C. Barbarek (IITRI)

has been issued in conformance to the following specifications:

JPL Contract No. 955187
Exhibit No. II, Dec. 1,77
Contract Documentation - Phase I
Data Requirement Description No.1

This Report on the "Mission Analysis and Performance Specification Studies" is the result of a joint effort between Illinois Institute of Technology Research Institute (IITRI) and Centro Ricerche Fiat (CRF) S.p.A. (FIAT Research Center).

Specifically the methodology for the calculation of all mission parameters but the annual vehicle distance and the Vehicle Characteristics and Performance Specifications described in this report have been defined by IITRI. The criteria for the distribution of Trip Purpose and Vehicle Classes among the Missions have been determined by CRF which, on the basis of the methodology developed by IITRI and the information provided by the 1969/70 Nationwide Personal Transportation Survey Reports, developed the methodology for the annual vehicle distance calculation and performed the conclusive Mission Analysis calculations accounting for the projected 1985 car ownership/household distribution.

The Authors wish to express their appreciation to Messrs. Viergutz of IITRI, Frondaroli of CRF and their staff who made the essential contribution to the study development as well as to Mrs. Floreani and Mr. Vercelli of CRF and their staff for their fine work in the final typing and editing effort of the Report preparation in compliance with JPL's Data Requirement Description.

FOREWORD AND ACKNOWLEDGEMENTS

LIST OF CONTENTS

LIST OF TABLES

Section 3 - METHODOLOGY DESCRIPTION

Section 5 - PRIMARY RESULTS

LIST OF FIGURES

Section 3 - METHODOLOGY DESCRIPTION

SECTION 1

BACKGROUND INFORMATION: SOURCES AND REFERENCES

1.1 DATA CATEGORIES

The kinds of information that were found to be particularly relevant in the performance of the mission-analysis task are organized according to the following subjects/cathegories.

Passenger-Car Usage

- Trip types, lengths, frequencies,
- Daily and annual vehicle distances,
- Number of occupants, amount of cargo,
- Driving speeds, accelerations, stops,

Road and Environmental Factors

- Road types and grades,
- Climate and weather: temperature, precipitations, etc.,
- Pollution levels

Demographics

- Population by age groups and urban vs. rural,
- Licensed drivers,

Vehicle Population

- Types, fleet penetration,

Driving Cycles

- SAE J227a(B), FUDC, FHDC

In some cases the current information can be assumed to apply to the near-term future (mid 1980's) without change. In other cases, e.g., annual vehicle distances, size of human and vehicle populations, trends exist which can be projected to the target time period. Geographic and short-range temporal variations are important aspects of some of the factors listed.

The aim in data acquisition and processing was a sufficiently accurate coverage of conditions affecting passenger-car missions in the United States as a whole without excessive disaggregation.

The information in some of the above categories is primarily relevant to Task 2 and is presented and discussed in later sections of the report, e.g., highway grades. Other kinds of information provided background for Task 1 but did not explicitly enter into the analysis, e.g., demographic data. (See Appendix A.1-3)

1.2 INFORMATION SOURCES

A concerted effort was made to identify and obtain the pertinent reference materi , needed for the study. Three basic modes of acquiring information were utilized:

1) Computer searches of selected reference files.
2) Library literature searches and document retrieval.
3) Personal contacts through local visits and long distance telephone calls.

1.2.1 Reference Files

The first search mode accessed the information system of Lockheed Retrieval Services, the System Development Corp., and Battelle. The following computer files were searched by the IITRI librarian:

1) Smithsonian Science Information Exchange
2) National Technical Information Service (NTIS)
3) SAE Abstracts
4) PTS U.S. Statistical Abstracts
5) PTS U.S. Annual Time Series
6) Magazine Index
7) EIS Industrial Plants
8) Transportation Research Information Services (TRIS).

1.2.2 Library Literature

Literature searches were made at:

1) IITRI Engineering Division Library
2) John Crerar Library on the IIT campus

3) Chicago Public Library
4) The Transportation Center Library at Northwestern University, Evanston, Illinois
5) Library of the Chicago Area Transportation Study.

The most relevant source documents were obtained, and selected data sets were prepared in tabular or computer-readable form for analysis and subsequent reporting.

Citations of the data sets and documents utilized are made in Sections 3 and 5 of this Report; these references (cited in the text by numbers in brackets) are listed in the following Subsection 1.3.

1.2.3 Personal Contacts

In addition to the computer and library searches, many people were contacted in the third search mode, i.e., phone calls and/or personal visits. The people and organizations contacted in this manner for technical information and/or further leads were:

1. Institute of Transportation Engineers, Arlington, VA
2. Mr. Roy Bell, Chicago Area Transportation Study, Chicago, IL
3. Mr. Don Berry, Norwestern University, Evanston, IL
4. U.S. Weather Service
5. U.S. Bureau of Census, Chicago, IL
6. Mr. John McCue, City of Chicago
8. Mr. Brian Johnson, Barton Aschman Assn., Evanston, IL
9. Mr. Dick Hankett, City of Chicago, Department of Public Works
10. Mr. John La Plant, City of Chicago

11. Mr. Marty Bernard, Argonne Laboratory, Lemont, IL
12. Mr. Donald Schwartz, State of Illinois, Department of Transportation
13. Mr. Richard Lill, American Trucking Assn., Washington, DC
14. Mr. Seppo Sillan, Federal Highway Administration, Washington, DC
15. Mr. Gary Maring, National Highway Traffic and Safety Administration, Office of Highway Planning, Washington, DC
16. Messrs. Anthony Kane, Dick Ledbetter and Dwight Briggs, Bureau of Motor Vehicle Safety, Washington, DC
17. Mr. Jim Rutherford, Environmental Protection Agency, Ann Arbor, MI
18. Mr. Roy Husted, Department of Transportation, Washington, DC
19. Mr. Weaver, Motor Vehicle Manufacturers Assn., Detroit, MI
20. Systems Technology Corporation, Hawthorne, CA
21. Mr. Paul Abbot, Federal Highway Administration, Washington, DC
22. Mr. Mort Oskard, Federal Highway Administration, Washington, DC
23. Mr. Tom Hollowel, National Highway Traffic & Safety Adm., Washington, DC

1.3 REFERENCES

Appropriate references for the material used to perform the Mission Analysis and Performance Specification Studies have been provided in the text. In order to explicitly comply with JPL data requirements, this subsection has been prepared and presented. The references used in the study activities are contained in the following bibliographic material.

1.3.2 Mission Analysis (Subsection 3.2.1)

[1] "Nationwide Personal Transportation Survey, 1969-70", No. 11 Reports, U.S. Department of Transportation/Federal Highway Administration (1972-74).

[2] "Near Term Hybrid Passenger Vehicle Development Program, Phase I, Assumptions and Guidelines," Jet Propulsion Laboratory (1978).

[3] Hastings, N. A. J., and Peacock, J. B., "Statistical Distributions", John Wiley & Sons (1975).

[4] Claffey, P.J. "Travel Estimates from Fuel Consumption Information", Final Report, Contract DOT-FH-11-7833 (1972).

[5] Joksch, H.C., and Reidy, J.C., "Categorization and Characterization of American Driving Conditions", Phase I, Final Report for U.S. Department of Transportation, Contract DOT-TSC-1419 (1978).

[6] Kruse, R.E., and Huls, T.A., "Development of the Federal Urban Driving Cycle", SAE Paper 730553 (1973).

[7] "SAE Handbook", Part 2 (1978).

1.3.2 Vehicle Characteristics (Subsection 3.2.2)

[1] "New Details On GM Compacts", Automobile News, Sept. 11, 1978, p 2.

[2] "'79 Brings Additional Downsizing", Automobile News, Nov. 6, 1978, p 11.

[3] "GM's X Bodies Blaze Front-Drive Design Tril", Automobile News, Nov. 11, 1978, p 3.

[4] "GM Maps Major Shift To Front Drive In '80s", Automobile News, Dec. 11, 1978, p 1.

[5] "LTD Tops Ford Changes For '79", Automobile News, Sept. 18, 1978, p 9.

[6] "Styling Facelifts Mark Chevy Lines", Automobile News, Aug. 28, 1978, p 22.

[7] "Rulemaking Support Paper, Concerning the 1981-1984 Passenger Auto Average Fuel Economy Standards", July 1977, p 5-48, Figure 5-1, p. 5-49 Figure 5-2.

[8] Chaffey, P. J. "Travel Estimates from Fuel Consumption Information", Final Report, Contract DOT-FH-11-7833, Sept. 1972.

[9] "Horsepower Considerations for Trucks and Truck Combinations", Western Highway Institute, 1969 TEA 505W4A35, Number 2C.2.

[10] "Survey of Grades in the U.S.", Bureau of Motor Carrier Safety.

[11] Solomon, D. "Accidents on Main Rural Highways Related to Speed Drivers, and Vehicles" U.S. Department of Commerce, Washington, D.C., July 1964.

[12] Mela, Donald F. "Review of Information on the Safety Effects of the 55 MPH Speed Limit in the U.S.", DOT-HS-802-383, National Highway Traffic Safety Administration, Washington, D.C.

[13] Heckard, R. F. et al. "Safety Aspects of the National 55 mph Speed Limit", DOT-FH-11-8597, Pennsylvania Transportation Institute, Final Report, University Park, Pa., Nov. 1976.

[14] Torres, M. "The Amount of Vehicle Operation Over 50 mph", Draft Tecnical Report LDTP 78-13, U.S. EPA, Washington, D.C., July 1978.

[15] "Climates of the U.S." - U.S. Dept. of Commerce, Washington, D.C., 1973.

[16] "Comparative Climatic Data" (through 1977), U.S. Department of Commerce, National Oceanic and Atmospheric Administration, May 1978.

[17] "Local Climatological Data" - 1976 (Annual Summary with Comparative Data) - Chicago, Illinois, National Ocean and Atmospheric Administration, 1976.

[18] Wells, E. N. et al. "Investigation of Used Car Safety Standards Volume II, Degradation, Failure, and Criticality of Motor Vehicles" Operations Research Inc., Silver Springs, Maryland, 12 Sept. 1969.

[19] "1979 General Motors Maintenance Schedule for Gasoline Fueled Passenger Cars", Part 472986 A.

[20] Automotive News, "1978 Market Data Book", pp 66-70,80-82,73, Automotive News, Nov. 11, 1978, p 38.
Road Test, Sept. 1978, p 81.
Car and Driver, Sept 1978, p 82.

[21] Liston, L. L. and Aiken, C. A. "Cost of Owning and Operating an Automobile", U.S. Department of Transportation, Federal Highway Administration, Office of Highway Planning, Highway Statistics Division, U.S. Government Printing Office, 1977, 731-786/128.

[22] U.S. NEWS and WORLD REPORT, OUTLOOK '79, Dec. 25,78 Jan 1,79.
"At Last, Signs That Inflation Will Slow", pp. 55,56,57, Jan. 1, 1979

1.3.3 Vehicle Performance Specifications (Subsection 5.3)

[1] Kelderman, J. "EPA Eyes More Controls", Automotive News, Oct. 2, 1978.

[2] Federal Register - "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines", Environmental Protection Agency, June 1977.

[3] Lapedes, D. E., et al. "Hybrid Vehicle Technology Constraints and Application Assessment Study", Vol. II, Final Report for the U.S. Dept of Transportation, Contract DOT-TSC-OST-77-23, June 1976.

1.4 LIST OF RELATED APPENDICES

The following Appendices have been included in Volume II of this Report to provide a handy reference for JPL Minimum Requirements and Guidelines as well as some side comments on the use of the fundamental Information Source represented by the Nationwide Personal Transportation Survey.

Other data on U.S. demographic statistics and Highway speeds are also included.

Appendix A.1-1 : JPL Minimum Requirements and Guidelines

Appendix A.1-2 : Comments on NPTS use for Mission Analysis

Appendix A.1-3 : Demographic Data

Appendix A.1-4 : Miscellaneous Highway Speeds Data

SECTION 2

SIGNIFICANT ASSUMPTIONS

2.1 GENERAL ASSUMPTIONS

The General Assumptions presented here are excerpts from the JPL Assumptions and Guidelines Package.

2.1.1 The 1985 Travel behaviour pattern is assumed to duplicate the travel pattern as described in the NPTS (Ref. [1] of Subsection 1.3.1)

2.1.2 From 1978 the driver licenses will reach a saturation point equal to 85% of 16 years and older.

2.1.3 From 1980 the passenger cars will reach a saturation point equal to 75% of driver licenses.

2.2 MISSION ANALYSIS ASSUMPTIONS

The Mission Analysis Assumptions presented here are the assumptions which the conclusive Mission quantification, as presented in the Report, was based upon. They represent CRF technical opinion and position on the subject as resulted from assessments and discussion of preliminary results obtained during the Task-1 work effort.

CRF has therefore based the final mission quantification on the following assumptions related to trip purpose/mission and vehicle class/mission combinations.

2.2.1 The Mission Analysis as performed was intended to identify expected actual trip patterns of the expected actual fleet mix of 1985 ICE conventional vehicles.

2.2.2 The reference ICE vehicles are intended as representative of the expected actual 1985 new car fleet.

2.2.3 The Mission Analysis as performed was not intended to identify possible trip patterns that the expected trend in the institutional and economic factors could make more appropriate to be performed exclusively with possibly more appropriate types of vehicles than those expected to be available and actually used in 1985 to perform the expected missions of 1985.

2.2.4 The differentiation in the U.S. fleet mix from 1960 (essentially a single vehicle class for an all-purpose single mission, that is "complete standardization") until approximately 1975 (multiple vehicle classes performing multiple missions, that is "differentiated standardization") was mainly the result of the foreign imports impact and subsequent domestic compacts promotional effort without significant effects on the vehicle selection in terms of expected vehicle usage (selection merely on the basis of personal taste and/or cash/credit availability).

2.2.5 As a result of the 1973 oil embargo, in 1975 a trend has begun to base the vehicle selection on the expected prevalent usage with more and more emphasis being attributed to the capability of optimizing fuel consumption to the actual vehicle usage requirements.

2.2.6 This trend is expected to progress naturally, that is it will represent a conditioning element of selection in car buying but it will not suddenly become the predominant reason determining the new or used car purchase selection.

All the pre-existing reasons are assumed to remain effective, said trend being already accounted for by the projected car fleet mix of 1985.

2.2.7 The actual progress in the specialization trend being conditioned by the actual unavailability of multiple cars for multiple specific missions, the general assumption 2.1.3 imposes an actual limit to the level of automobile usage specialization as it limits the average number of cars/household and therefore the percentage of households with more than one car.

Depending on the number and types of missions to be identified, there shall be different limits for 1, 2, 3 or more cars households in the percentage of cars that can be used for a specific purpose.

2.2.8 It is assumed that the percent of households versus car ownership distributions, represented as $y(x)$ on an x-y plot at two different times t_1 and t_2, that is:

$$t_1 : y_1(0), \quad y_1(1), \quad y_1(2), \quad y_1(3)....$$
$$t_2 : y_2(0), \quad y_2(1), \quad y_2(2), \quad y_2(3)...,$$

can be obtained as intersections with the $x = 0,1,2,3...$axes (number of cars/household) by means of the same continuous curve passing through the $[y_1(i),i]$ points and translated along the $y = 0$ axis by an amount corresponding to the difference at the times t_1 and t_2 of the average number of cars/all household.

That is the $y_2(i)$ distribution can be obtained as intersection with such a curve by means of the $x = 0,1,2,3,$ axes translated in the opposite direction by said amount.

2.2.9 To calculate the average annual vehicle miles for the various missions it is appropriate to exclude from the average itself the trips and miles traveled by members of no car households.

To simplify the mission quantification such trips and miles are assumed to be traveled using the rental car/taxi fleet only, while the households with cars are assumed to use only their own vehicles.

2.2.10 The basic Missions are characterized in terms of primary trip purposes and it is assumed that, evolving from a <u>fully standardized</u> usage to a <u>fully specialized</u> usage, the percent of use for secondary purposes will diminish and eventually almost completely disappear in the 3 or more car households leading to the following fully specialized ultimate missions

a) Mission No. 1 - Family Business/Civic, Educational, Religious

b) Mission No. 2 Earning a living

c) Mission No. 3 - Social and Recreational.

In the 2-car households only missions No. 1 and No. 2 will possibly reach full specialization while mission No. 3 will maintain significant secondary purposes and therefore its General Purpose label.

In the 1-car households it is assumed that specialization will be limited to Mission M_1 in those households where no driving for earning a living occurs and social and recreational travel will predominantly show group-organized characteristics (e.g. retired people).

2.2.11 The trend to use a small car for the earning a living trip-purpose could be partially compensated, at least for commuter travel, by the alternate answer to increased cost of gasoline represented by a significant increase of "pool driving". This could ultimately limit the specialization of Mission M_2 as Earning a living usage covering most commuter trips with small, low occupancy cars. It is assumed, for the year 1985, that this factor will be already accounted for by the intermediate stage of the specialization process set for such a timeframe.

2.3 VEHICLE CHARACTERISTICS ASSUMPTIONS

The Vehicle Characteristics assumptions presented here are grouped by subtask identification to establish more easily the assumption use, should it not be clear by its context.

a) Vehicle Fleet Characterization

2.3.1 Vehicles manufactured prior to 1977 can be classified as being in the same size category as their 1977 models.

2.3.2 The change in the MPG fuel economy from year to year is relatively uniform across all five vehicle classes.

2.3.3 The ratio of MPG city and MPG SAE to MPG EPA combined will remain constant for 1978 to 1985.

b) Reference Vehicle Characterization

2.3.4 Gradeability: 15 percent grade 1000 ft long assumed for parking garages.

2.3.5 Acceleration: Primary requirement is to establish safety and that reducing the potential for vehicle accident involvement will increase safety.

2.3.6 Speed (cruise/top): It is assumed that the vehicle speed distribution documented for current highways will be appropriate in 1985.

c) Life Cycle Costs

2.3.7 The mean useful life of a vehicle is 100,000 miles or 10 years, whichever comes first.

2.3.8 The repair, routine maintenance and tire operating costs are a fixed percent of the total vehicle acquisition cost.

2.3.9 The base vehicle cost increases from 1978 at a rate of 5 percent per year. This establishes the cost of the new 1985 average vehicle.

2.3.10 The high-technology optimum 1985 vehicle will cost more than the average new vehicle. The increment is based on a fixed percent of the 1978 vehicle cost. The increased cost of a diesel engine in a 1978 Oldsmobile was about 10 percent of the typical delivered 78 gasoline engine vehicle. This percentage of the 1985 average new car acquisition cost will be assumed for the incremental increase in cost of the optimum vehicle.

2.4 VEHICLE PERFORMANCE SPECIFICATIONS ASSUMPTIONS

The Vehicle Performance Specification Assumptions presented here are intended to outline the relevant aspects of Hybrid Vehicle design, operation as use. Since the 1985 H.V. must represent a viable alternative to 1985 conventional vehicles, it will obviously benefit from all the technological improvements (both in terms of production and performance capabilities) of the last one. The assessments on this technology evolution, as result from the Background Information presented in the previous Section 1, are not therefore considered pertinent to this specific subject, dealing with relevant Hybrid Vehicle Implications only.

2.4.1 The hybrid vehicle specifications should be derived from the mission requirements only, irrespective of projected hybrid vehicle capabilities.

2.4.2 The hybrid vehicle will be "accepted" into the market as a replacement for conventional automobile designs.

2.4.3 The hybrid vehicle will penetrate the fleet irrespective of any consumer acceptance or rejection.

2.4.4 While the hybrid vehicle is primarily intended to provide optimum fuel efficiency, the operator will be allowed to adjust the power train control efficiency as required from maximum efficiency (maximum battery discharge) to maximum performance (minimum battery discharge for extended range operation).

2.4.5 Battery operation at very low temperatures is extremely detrimental to most types of traction batteries available for near term applications. Therefore, pending the results of the Preliminary Design Task, it has been considered that such an operating condition would then be very inappropriate for the traction battery of Hybrid Vehicles if unused and unserviced for a long time in cold weather (i.e. not connected to an electricity plug to charge and/or warm/heat them up).

It has been therefore assumed that, after extended unserviced storage, the vehicle will be allowed to run, if necessary, on thermal power only, with accordingly reduced performance while warming/heating up the traction battery using the engine power, or to be connected to an electric power source to warm or heat-up the battery itself.

SECTION 3

METHODOLOGY DESCRIPTION

3.1 SUMMARY OF PRINCIPAL STUDY ACTIVITIES

The methodology used during the study can be best illustrated by the following list of activities that were conducted. A discussion of each activity is contained in the detailed description that follows on subsection 3.2.

A data flow diagram indicating the relationship between the various activities and the corresponding major outputs is show in Fig. 3.1-1.

3.1.1 Mission Analysis

a) Data base acquisition/quantification - compiling the data base for the mission analysis and processing appropriate data into the form that facilitates the analyses to be conducted.

b) Usage characterization - categorization and processing of applicable data according to vehicle usage including climate, environment, terrain, population, etc.

c) Mission trip analysis - analysis of trips (ranges, frequency, purpose, etc.) and trip elements (acceleration, cruise speed, grades, etc.) with consideration of payload (cargo, people, size) and including applicable driving cycles.

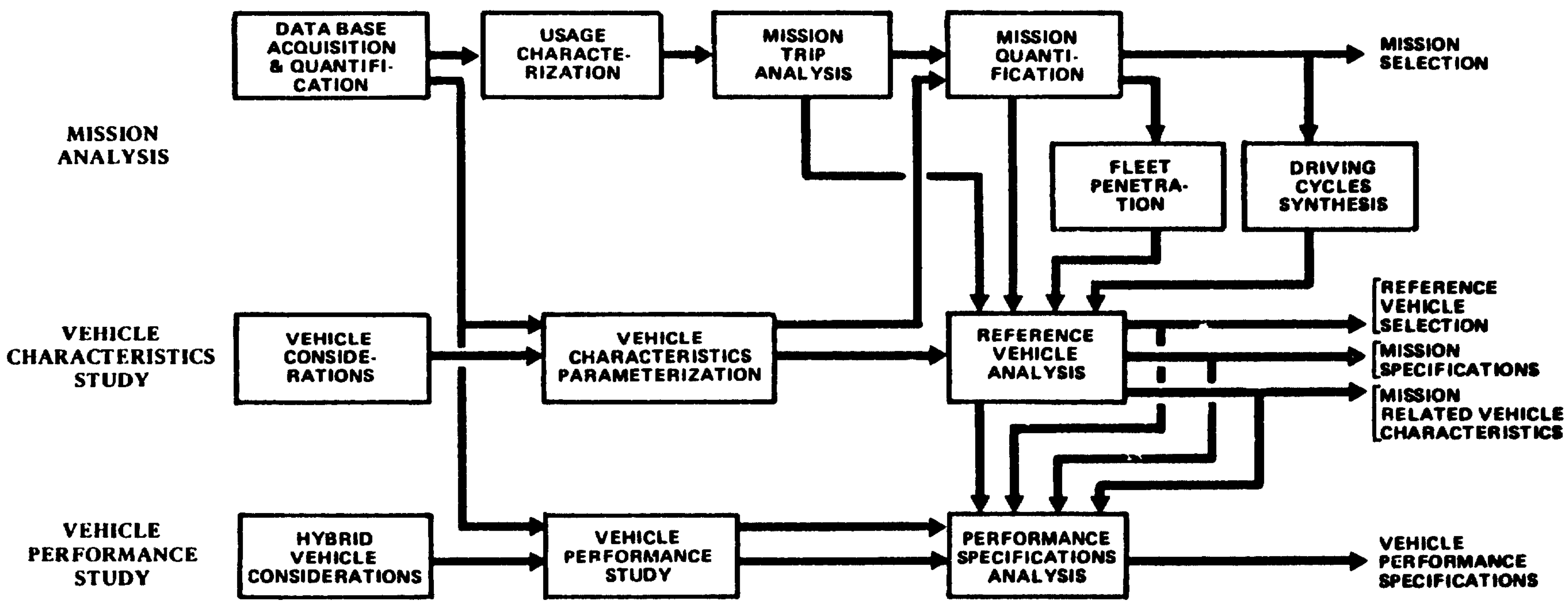
d) Mission quantification - development of a mission matrix that includes indices of measurement (range, time, cargo, etc.) parameter distributions, driving cycles, etc., in terms of vehicle usage that accounts for overlapping of missions.

e) Fleet penetration computations - estimation of size of fleet that has a potential of being captured by each of the quantified missions.

f) Driving cycle synthesis - formulation of the driving cycle combination that represent the quantified missions.

TABLE 3.1 – 1

FLOW CHART FOR PROGRAM ACTIVITIES



g) Mission selection - selection of mission or missions that maximize the potential of fuel savings for the total vehicle fleet.

3.1.2 Vehicle Characteristics Study

a) Vehicle considerations - identification and generation of those considerations based upon mission requirements that have a bearing on conventional and hybrid vehicle performance and characteristics.

b) Vehicle characteristic parameterization - analysis and tradeoff study of vehicle performance and characteristics in terms of mission requirements.

c) Reference vehicle analysis - analysis of performance and characteristics of candidate reference vehicles in terms of parameterization analysis and tradeoffs as well as annual fuel consumption in terms of the mission(s).

d) Reference vehicle selection - selection of reference conventional ICE vehicle that meets or exceeds all mission and minimum vehicle requirements and within applicable constraints.

3.1.3 Vehicle Performance Specifications

a) Hybrid vehicle considerations - identification and generation of updated considerations based upon the mission requirements and the impact of the selected reference vehicle performance and characteristics.

b) Vehicle performance study - analysis of candidate hybrid vehicle performance and characteristics in terms of mission requirements, mission related vehicle characteristics, fuel consumption, etc.

c) Specifications analysis - the generation of vehicle performance specifications for the hybrid vehicle to be designed during the following Tasks of the Near Term H.V. Development program.

3.2 DETAILED DESCRIPTION OF STUDY ACTIVITIES

3.2.1 Mission Analysis

3.2.1.1 Usage Characterization

Primary parameters of automobile usage from the viewpoint of required vehicle capabilities are: trip length and frequency, total distance covered per unit time period, and the number of passengers plus amount of cargo carried. The most basic information available concerning the human motivations that lead to automobile usage is expressed in terms of trip purposes. Nationwide data on these different aspects of automobile usage and their interrelationships are considered essential inputs to the task of defining a realistic set of missions for the evaluation of hybrid alternatives to conventional passenger cars.

The single most informative data base bearing on these key aspects of mission analysis for U.S. passenger cars was found to be the Nationwide Personal Transportation Survey [1].

A matrix of data on 1969 passenger-car usage by the average household, classified by trip purpose, is presented in Table 3.2-1, derived from the NPTS. The usage characteristics considered are: the relative frequency of trips, the relative vehicle miles of travel, the average annual vehicle miles per household, the average trip length, the average number of trips per day per household, and the average number of vehicle occupants. The numerical values of all these automobile usage characteristics vary significantly in relation to trip purpose.

Of particular relevance for defining different passenger-car missions is a pattern of increasing average trip length associated with trip purpose.

TABLE 3.2 – 1

DATA ON PASSENGER – CAR USAGE BY TRIP PURPOSE *

TRIP PURPOSE	PERCENT OF TRIPS	PERCENT OF VEHICLE MILES	AVERAGE ANNUAL VEHICLE MILES PER HOUSEHOLD	AVERAGE TRIP LENGTH, MILES	AVERAGE No. OF TRIPS PER DAY PER HOUSEHOLD	AVERAGE No. OF VEHICLE OCCUPANTS
P_1 EARNING A LIVING	36.2	41.6	5,166	10.2	1.39	1.4
a. WORK	31.9	33.7	4,183	9.4	1.22	1.4
b. RELATED BUSINESS	4.3	7.9	983	16.1	0.17	1.6
P_2 FAMILY BUSINESS	31.0	19.3	2.401	5.6	1.18	2.0
a. SHOPPING	15.2	7.5	929	4.4	0.58	2.0
b. MEDICAL, DENTAL	1.8	1.6	202	8.4	0.07	2.1
c. OTHER	14.0	10.2	1,270	6.5	0.53	1.9
P_3 EDUCATIONAL, CIVIL AND RELIGIOUS	9.3	4.9	612	4.7	0.36	2.5
P_4 SOCIAL & RECREATIONAL	22.4	33.0	4,094	13.1	0.85	2.5
a. VISITING	8.9	12.1	1,497	12.0	0.34	2.3
b. PLEASURE DRIVING	1.4	3.1	381	20.0	0.05	2.7
c. VACATIONS	0.1	2.5	320	160.0	0.01	3.3
d. OTHER	12.0	15.3	1,896	11.4	0.45	2.6
P_5 OTHER & UNKNOWN	1.1	1.2	150	9.4	0.04	(1.4)
ALL TRIPS	100.0	100.0	12,423	8.9	3.82	1.9

* FROM NATIONAL PERSONAL TRANSPORTATION STUDY (1969 – 1970) – AVERAGES FOR ALL 1969 HOUSEHOLDS

The shortest trips are those belonging to categories P_2 and P_3, i.e., for which the purpose is either family and personal business or educational, civic and religious activities. In 1969 the average lengths of P_2 and P_3 trips were 5.6 and 4.7 miles, respectively. Trips for the purpose of earning a living, category P_1, were characterized by a substantially greater average length, 10.2 miles. Social and recreational trips, category P_4, had a still greater average length, 13.1 miles. Considering the entire spectrum of trip purposes, vacation trips, category P_{4c}, were exceptional in having an extreme average length of 160 miles. The relatively few trips included in the survey that had other or unknown purposes, category P_5, were characterized by an average length of 9.4 miles, close to the P_1 value of 10.2 miles.

The average annual vehicle distance per household, that was accumulated in making trips for the major purposes distinguished, also varied greatly.

The greatest average annual distance, 5,166 miles, accrued from trips with purpose P_1 (earning a living), closely followed by the 4,094 miles that accrued from trips with purpose P_4 (social and recreational activities). The P_2 (personal and family business) and especially the P_3 (educational, civic and religious) trips accounted on the average for much less annual vehicle travel distance, the figures being 2,401 and 612 miles respectively. Thus, in relation to travel by privately owned passenger cars, purposes P_2 ana P_3 generate on the average both short trips and low accumulated distances as compared with purposes P_1 and P_4.

A different pattern of variation of car occupancy by trip purpose is exhibited in Table 3.2-1. The average number of occupants was lowest in the P_1 (work and work-related) trips, 1.4 persons. The P_2 trips (personal and family business) were intermediate, with 2.0 occupants on average. The P_3 and P_4 trips were highest in car occupancy, the average number of persons in the vehicle being 2.5 for both categories. Car occupancy was at a peak in vacation trips, which have an average of 3.3 persons on board.

3.2.1.2 Mission Definition by Trip Purpose Combination

The approach that was taken in Task 1 was to define a set of four passenger-car missions primarily by reference to the major categories of trip purpose that are distinguished in the NPTS [1]. The expected correspondence in 1985 between the four missions, designated M_1 through M_4, and the five trip-purpose categories, P_1 through P_5, is shown in Table 3.2-2. An indication of the usage patterns associated with the missions is provided by brief descriptive labels:

M_1. Intraurban/local

M_2. Urban/suburban commuting

M_3. General purpose

M_4. Taxi/police

Missions M_1, M_2, and M_3 are defined not as completely disjoint segments of the spectrum of trip purposes, but as successively more inclusive with respect to the purposes they encompass. The M_1 mission is devoted to tripmaking for the generic purposes of family and personal business (category P_2) and educational, civic, and religious activities (category P_3); M_1 trips are on the whole relatively short and the origins and destinations are usually in the same local area or city.

The M_2 mission incorporates work and work-related trips for the generic purpose of earning a living as the primary purpose (category P_1) but also includes the types of trips to which mission M_1 is restricted, i.e., categories P_2 and P_3, as secondary purposes. Work trips are typically longer than the M_1 trips and a great many involve commuting between urban and suburban communities, which fact is reflected in the label associated with the mission.

The third mission, M_3, has an expanded scope compared to M_2 since it includes social and recreational trips as the primary purpose (category P_4) in addition to trips for all other (secondary) purposes. The designation "general purpose" for mission M_3 is

TABLE 3.2 – 2

CORRESPONDENCE BETWEEN PASSENGER–CAR MISSIONS AND TRIP PURPOSES

PASSENGER–CAR MISSION	GENERIC TRIP PURPOSE				
	EARNING A LIVING P1	FAMILY BUSINESS P2	EDUCATIONAL CIVIC, AND RELIGIOUS P3	SOCIAL AND RECREATIONAL P4	OTHER AND UNKNOWN P5
M_1 INTRAURBAN/LOCAL		✓	✓		✓
M_2 URBAN/SUBURBAN COMMUTING	✓	✓	✓		✓
M_3 GENERAL PURPOSE	✓	✓	✓	✓	✓
M_4 TAXI / POLICE	✓	✓	✓		✓

therefore apt. Vacation trips (subcategory P_{4_C}), having an average length much greater than that of any other subcategory, are part of mission M_3.

A final mission, M_4, consists of taxicab and police operations, not directly covered in the NPTS. This mission is separate from the sequence of missions M_1 through M_3, which predominantly apply to individually owned passenger cars. The M_4 trip characteristics are treated as though identical in several respects to those of mission M_2, i.e., the generic trip purposes are considered to be P_2 and P_3 since trips by these types of vehicles are usually intraurban or local with some suburban traffic to account for trips to airport or highways patrolling around metropolitan areas, typical of P_1 trip purpose.

There are important quantitative differences and similarities among the four missions that have been defined; these are treated in detail in the next subsection.

Generally speaking, however and neglecting for the time being any specific consideration on the types of vehicle suited to the performance of the various missions, it can be stated that the first three missions, defined as trip patterns that can be associated to given fractions of the total vehicle fleet, represent an intermediate stage of the existing trend of changing the car usage from the single global mission of the single-size all-purpose standard cars of the 50's and early 60's to the multiple specific missions, associated with special purpose vehicles of appropriate characteristics, that can be expected in the 90's.

At that time it can be assumed the trip purpose/mission identification will probably be completed and, as mission M_1 should already be mainly characterized by trip purposes P_2 and P_3, mission M_2 should be mainly characterized by trip purpose P_1 and mission M_3 should split in mission M_{3_A} which, being performed by households with 1-2 car ownership, should mantain its general purpose characteristics and in mission M_{3_B} which, being performed by households with 3 or more car ownership should be mainly characterized by trip purpose P_4.

To illustrate the trend of changing from a standardization to a specialization of car usage, the matrix of Mission/Trip Purpose combination shown on table 3.2-2 can be substituted with a more general matrix indicating that all Trip Purposes are present in each mission, being the mission itself characterized by a given percent of the total number of trips or miles associated with each trip purpose (in the range 0 to 100%). This can be expressed more synthetically through the following general relationship indicating the mix of trip purposes on each mission:

$$M_k = M_k\,[x_k(P_1),\ x_k\ (P_2),\ x_k\ (P_3), x_k(P_4),\ x_k(P_5)] = M_k[x_k(P_i)]$$

associated to the conditions:

$$\sum_{k}^{1\rightarrow 3} x_k(P_i) = 100 \qquad i = 1 \text{ through } 5 \qquad (3\text{-}1)$$

Accordingly, the fully standardized missions (reduced to M_3) can be represented by:

$$M_1\ (0,0,0,0,0),\ M_2\ (0,0,0,0,0),\ M_3\ (100,\ 100,\ 100,\ 100,\ 100)$$

and the fully specialized missions by:

$$M_1[0,100,100,0,x_1(P_5)], M_2[100,0,0,0,x_2(P_5)], M_{3_B}[0,0,0,100,x_3(P_5)]$$

For the mission set to be representative of the situation expected in 1985 an intermediate condition would exist to be properly identified as described in the next subsections.

As a first step the control value of 11,850 miles for the mean annual distance of all U.S. passenger cars in 1985 provided by JPL [2] was readjusted to exclude travel performed in mission M_4.

From independent sources it was estimated that mission M_4 should be performed by 0.4% of the 1985 in-place fleet with an average annual distance of 20,000 miles; this leaves to the remaining 99.6% of the in place fleet an average annual distance of 11,770 miles/vehicle.

As a second step the mission M_1, M_2 and M_3 were associated, on a first try basis, with the in-place mix, by cargo size, projected to 1985 and associating minicompact cars with mission M_1, subcompact through mid size cars with mission M_2 and large-size cars with mission M_3. This assumption, in line with a reasonably appropriate usage of vehicle size according to trip purpose, provided a first set of mission characteristic parameters, through which to develop and verify the computational model required to assess the driving cycles combination to be used for fuel consumption calculations.

The assumption itself however did not satisfy the requirement of mantaining the trip purpose mix provided by the NPTS and expressed by equation (3-1). It was concluded that, by 1985, the car size mix, though modified according to JPL guidelines to account for the specialization trend, could not reflect in itself an appropriate car usage. That is, in 1985, cars should still be largely used beyond their strict purpose requirements due to the fact that the specialization trend can be mainly reflected by a progressively increasing fraction of the new car fleet, which is in turn just above 10% of the in-place fleet.

Assuming therefore that between 1960 and 1975 the evolution of the fleet mix was mainly due to a selection by acquisition and operating cost as well as occupancy capability and/or requirements, rather than by primary usage purpose, in 1975 the trip purpose distribution in the various missions, can be assumed to be uniform as well as the fleet size mix on each mission.

From 1975 it can be assumed that a specialization trend has begun of buying new cars also according to their expected usage pattern.

This trend could be accelerated assuming that used car buying also could add to the specialization results, particularly in the second and third car segments.

If it is assumed that, starting in 1976, every year a fraction of the purchased cars (both new and used), increased every year at a rate equivalent to 10% of the new car sales, has been and would be dedicated to specific usage purpose, in 10 years, that is by 1985, 55% of the in-place fleet should be mainly dedicated to special-purpose trips and, in the following years, all the new car sales should be special purpose oriented so that theoretically a 100% specialization (in-place fleet wide) should be reached by 1989.

Should the specialization increase rate be reduced by 50% to 5% of the new car sales per year, the special purpose segment of the 1985 fleet should be 27.5% and full in-place fleet specialization should be reached theoretically by 1995.

The above considerations will provide in section 3.2.1.5 a basis to determine the Trip Purpose percentages for the various missions, taking also into account that the specialization process is in reality limited by the fact that cars in households where 1 or 2 cars only are owned cannot perform 3 fully specialized missions.

3.2.1.3 Mission Quantification

Some of the factors that can be treated quantitatively vary relatively little by type of passenger-car mission, e.g., climate and terrain. Other factors do vary substantially in relation to mission type. Consideration will be given first to a group of important factors of the latter sort for which approximate probability distributions can be established by mission type through appropriate statistical model formulation and analysis of survey data reported in the NPTS [1]. These factors include trip length, number of trips per day, daily vehicle distance, annual vehicle distance, and number of vehicle occupants per trip.

a) Normal-Distribution Models and Maximum-Likelihood Parameters

A working assumption is that the actual distributions of certain continuous automobile-usage variables of importance in mission analysis can, after suitable transformations of the variables, be reasonably well approximated by normal distributions. Each normal distribution will have parameters μ (mean) and σ (standard deviation). It is further assumed that, for a given transformed variable (variate) having a distribution that is well approximated by the normal, σ can be treated as constant from mission to mission and over limited time periods, while μ can be allowed to vary and alter the locations of the distributions in accordance with the differing natures of the missions, near-term time trends, or both. For a given variable, the normal distributions generated by holding σ fixed and varying μ will constitute a family.

Each pair of values of μ and σ will then specify a normal distribution, of which any desired percentiles can readily be calculated, e.g., values of the variate corresponding to 90, 95, or 99 percent. Conversely, given any values of the variate, the corresponding percentage points can be calculated by the inverse relationship.

Three variables that are of particular interest, and for which there are tables of data in the NPTS reports, are: trip length, vehicle occupancy and annual vehicle distance.

For each of these variables, normalizing transformations were investigated, a suitable transformation was selected and maximum likelihood (ML) values of μ and σ applying to the transformed variable were obtained. Due to the highly aggregated form in which the data were published, a special method for parameter evaluation was employed. The method has general applicability to the frequently encountered problem of estimating the parameters of a normal distribution from highly aggregated (coarsely grouped) data. A computer program, HYBRID-1, implements the computational procedure.

The ML method of evaluating normal parameters from highly aggregated data and program HYBRID-1 are discussed in Appendix A.3-1.

The statistical distribution of the various travel parameters, such as trip length and occupancy, annual and daily distances obtained there can be thought as related to an average household global mission encompassing all trip purposes.

This global or combined mission has been disaggregated into three specialized mission to identify vehicle categories having different trip patterns in terms of usage. The quantification of the parameters of each mission must satisfy the condition that, recombining the travel characteristics of the three missions (in terms of trip purposes), the original percentages of travel variables for the various trip purposes must be mantained in the reaggregated combined mission.

Had the missions been identified each one by one or more exclusive trip purposes and no secondary trip purposes shared with other missions (i.e. 100% specialization), a single mission quantification would be possible.

In the intermediate case an infinite number of combinations would exist, each one resulting from a different split of trip purposes among missions to represent different stages in the standardization to specialization trend previously described. The methodology for travel parameters quantification is therefore described in general terms for the generic intermediate set of missions with the following constraints:

M_1: $x_1(P_1) = x_1(P_4) = 0$

M_2: $x_2(P_4) = 0$

M_3: $x_3(P_4) = 100$

The evaluation of the actual trip purpose percentages to be used for 1985 mission quantification will be described in the following Subsection 3.2.1.4 Trip Purpose/Mission Combinations.

b) Trip-Length Distributions

The first automobile usage variable of which the distribution will be modeled in the way described in the preceeding subsection is the trip length. The cumulative percent of one-way trips of passenger cars by trip length (all trip purposes combined) is given in Table 3.2-3 for a limited number of values of the variable applicable to 1969 and obtained from the NPTS. There are four finite values of the variable, at intervals of five miles, i.e., 5.5, 10.5, 15.5, and 20.5 miles. The corresponding cumulative percentages of trips are 62.4, 79.2, 87.4, and 91.7, respectively. In addition, it is known that as trip length increases without limit, the cumulative percent of trips will ultimately reach 100.

Denote one-way trip length in miles by X. The logarithmic transformation of the variable yields a variate, Y = Ln(X), that has an approximately normal distribution.

The data points are plotted in Fig. 3.2-1. The ordinate is cumulative percent of trips, P, on a normal-probability scale; the abscissa is trip length, X, on a log scale. The solid line is generated according to the parameters μ and σ of the fitted

TABLE 3.2 – 3
CUMULATIVE PERCENT OF AUTOMOBILE TRIPS BY TRIP LENGTH

TRIP LENGTH		CUMULATIVE PERCENT OF TRIP
MILES	KILOMETERS	
5.5	8.85	62.4
10.5	16.90	79.2
15.5	24.95	87.4
20.5	33.00	91.7
∞	∞	100.0

• FROM TABLE A–3, REPORT No. 10, "PURPOSES OF AUTOMOBILE TRIPS AND TRAVEL", NATIONWIDE PERSONAL TRANSPORTATION STUDY, U. S. DEPARTMENT OF TRANSPORTATION / FEDERAL HIGHWAY ADMINISTRATION (1974). (AVERAGE FOR ALL 1969 HOUSEHOLDS).

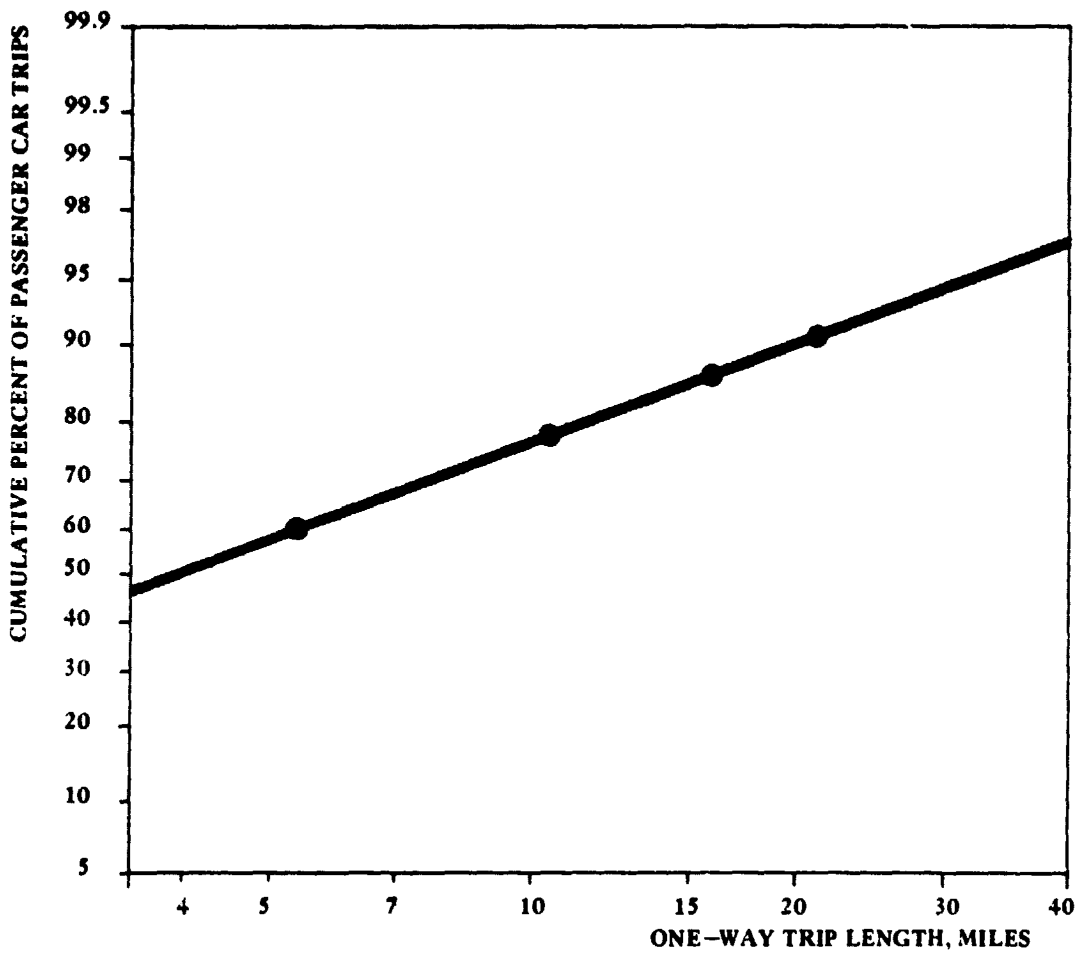


FIGURE 3.2 – 1
LOG NORMAL DISTRIBUTION OF TRIP LENGTHS, OF PASSENGER CARS, 1970 DATA POINTS WITH FITTED LINE (ALL TRIPS)

normal distribution with Y as the variate. The 1969 combined parameter values are $\mu = 1.3150$ and $\sigma = 1.2438$, computed by the ML method explained in Appendix A.3-1.

Each of the passenger-car missions that has been defined will have a characteristic mean trip length. This can be estimated from the NPTS data.

The computed arithmetic-mean trip lengths in miles for missions M_1 through M_4 can be derived from data analogous to those of Table 3.2-1 as weighted means of the average trip lengths associated with the component trip purposes. The weights are the percentages of trips having the specified purposes on each mission. For example, if mission M_1 includes $x_2\%$ of all P_2 trip purposes (family business) and $x_3\%$ of P_3 (educational, civic, and religious activities), being the average P_2 trip length ℓ_2 miles and the percent of trips $p_2 \cdot x_2$, being also the average P_3 trip lengths ℓ_3 miles and the percent of trips $p_3 \cdot x_3$, then the weighted mean trip length of mission M_1 is:

$$[(\ell_2)(p_2 \cdot x_2)+(\ell_2)(p_3 \cdot x_3)]/(p_2 \cdot x_2+p_3 \cdot x_3) = m_{M_1} \quad \text{(miles)}$$

The mean trip lengths of the other missions can be derived similarly. Missions M_2 and M_4 have the same estimated mean trip length because the trip purposes are assumed to be equivalent.

The values of the parameter μ are functions of the various mean trip lengths, m, and the single standard deviation, σ, of the log-normal distribution computed as explained above. Each value of m gives rise to a corresponding value μ by the relationship [3]

$$\mu = \text{Ln}\ (m) = \sigma^2/_2$$

A family of trip-length distribution functions can be generated for each mission using the corresponding values of μ and the common value $\sigma = 1.2438$.

c) Car Occupancy Distribution

A second important automobile-usage variable that can be analyzed by the method previously described is the number of vehicle occupants per trip, including the driver. Relevant 1969 data from the NPTS are presented in Table 3.2-4 in the form of cumulative percentages of trips by number of vehicle occupants, the latter ranging upward from 1 in increments of 1 passenger to a terminal class of 9 or more occupants. The empirical distributions are given for trip purposes P_1 through P_4, based on data from households in Stardard Metropolitan Statistical Areas (SMSA's) only.

The last column of the table contains the overall occupancy distribution used for quantification of the model finally chosen, i.e., all trips combined based on data from all the house-holds in the NPTS.

First, the applicability of a Poisson model of car occupancy was explored. Denote number of occupants per passenger car per trip by N, with possible values 1, 2, ... Then N_p = N-1 is the number of passengers (driver excluded), with possible values 0, 1, ...

An initial hypothesis was that N_p has approximately a Poisson distribution with parameter λ, the mean number of passengers per trip. The Poisson model would hold if, given λ , the actual number of passengers per trip is a random event. The theory was tested by applying the model to all five distributions of Table 3.2-4. The consistent finding was that there is an excess of trips with no passengers, and also an excess of trips with four or more passengers, compared with what would occur by chance. The compensating effect is a deficiency of trips in which the number of passengers is in the range from 1 to 2 or 3. Investigation of some further candidate models of car occupancy led to the final choice of the square-root-normal model as a reasonably good approximation to the actual distribution in the range of values of N that are of practical interest.

TABLE 3.2 – 4
CUMULATIVE PERCENT OF AUTOMOBILE TRIPS BY NUMBER OF OCCUPANTS

NUMBER OF OCCUPANTS	TRIP PURPOSE				
	EARNING A LIVING *	FAMILY BUSINESS*	EDUCATIONAL, CIVIC AND RELIGIOUS *	SOCIAL AND RECREATIONAL*	ALL TRIPS **
1	73.6	44.6	34.2	30.3	50.4
2	92.2	77.8	61.1	64.9	78.0
3	96.7	89.8	77.1	78.6	88.4
4	98.5	95.3	88.0	89.2	97.4
5	99.5	98.0	93.6	94.4	97.4
6	99.9	99.1	97.3	97.6	98.9
7	99.9	99.8	98.9	99.1	99.6
8	100.0	99.8	99.5	99.5	99.8
≥ 9	100.0	100.0	100.0	100.0	100.0

* FROM TABLE 3, REPORT No. 1, "AUTOMOBILE OCCUPANCY", NATIONWIDE PERSONAL TRANSPORTATION STUDY, U.S. DEPARTMENT OF TRANSPORTATION/FEDERAL HIGHWAY ADMINISTRATION (1972). DATA FROM HOUSEHOLDS IN SMSA's ONLY.

** FROM TABLE A–34, REPORT No. 8, "HOME–TO–WORK TRIPS AND TRAVEL", NATIONWIDE PERSONAL TRANSPORTATION STUDY, U.S. DEPARTMENT OF TRANSPORTATION/FEDERAL HIGHWAY ADMINISTRATION (1973). DATA FROM ALL HOUSEHOLDS.

The variate is $Y = N^{1/2}$.

The data points (last column of Table 3.2.4) are plotted in Fig. 3.2-2; the ordinate is the cumulative percent of trips, P, on a normal probability scale and the abscissa is the number of vehicle occupants, N, on a square-root scale. The ML values of the parameters of the distribution function for Y, assumed root normal, are $\mu = 0.9837$ and $\sigma = 0.6188$, computed by program HYBRID-1.

The solid line in Fig. 3.2-2 represents the combined distribution function. The deviations of the observed points from the fitted line are sufficiently small that no serious departure from normality is indicated.

The mean number of occupants in trips by vehicles performing missions M_1 through M_4 can be estimated from data Table 3.2-1 as follows.

The average number of occupants is given for trips in each purpose category. The mean number of occupants per trip is estimated for each mission type as the weighted mean of the average number of occupants in trips belonging to each component purpose category (similarly to the trip-length at 3.2.1.3.b).

For example, mission M_1 includes: family-business trips (purpose P_2) which constitute $p_2 \cdot x_2$ percent of all trips and have an average of n_2 occupants; and educational-civic-religious trips (purpose P_3) which constitute $p_3 \cdot x_3$ percent of all trips and have an average of n_3 occupants. The weighted mean number $n(M_k)$ of vehicle occupants in mission M_k trips is therefore

$$[(n_2)(p_2 \cdot x_2) + (n_3)(p_3\ x_3)]/(p_2 \cdot x_2 + p_3 \cdot x_3) = n(M_k)$$

The corresponding values of parameter μ, the mean of the square-root variate Y, were computed from the relationship

$$\mu_1 = \mu + m_1^{1/2} - m^{1/2}$$

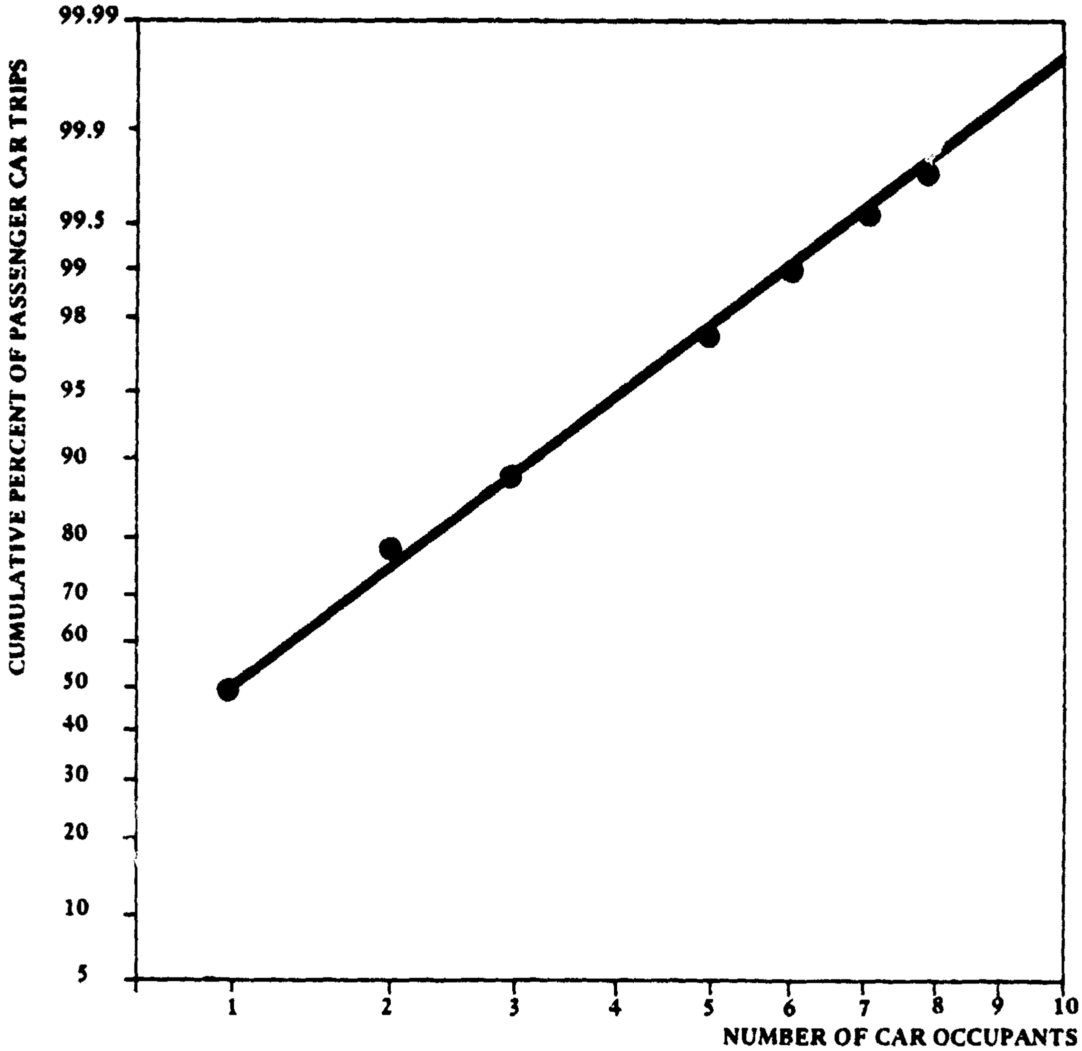


FIGURE 3.2 – 2
SQUARE–ROOT–NORMAL DISTRIBUTION OF CAR OCCUPANCY, 1970 DATA POINTS WITH FITTED LINE (ALL TRIPS)

where m_1 and μ_1 are, respectively, the mean number of occupants and the required mean of Y in mission M_1; m = 1.93 and μ = 0.9837 are, respectively, the mean number of occupants and the mean of Y in the reference data set (all NPTS trips) and σ = 0.6188, the standard deviation of Y in the reference data set, is held constant.

The distribution functions for number of vehicle occupants on each mission can be plotted as a family of parallel lines.

d) Annual Distance Distributions

The distances that passenger cars are driven per year have approximately a log-normal distribution. The method of data analysis employed to obtain annual-distance distributions by mission is similar to that described above for trip length.

The cumulative percent of passenger automobiles by annual distance driven in 1969 is given in Table 3.2-5 for seven particular distances. The figures are from the NPTS survey. Trial plotting of all the data showed that the distribution is roughly log-normal. However, the agreement between the log-normal model and the empirical data is considerably improved if the vehicles with extremely low reported distances, 500 miles per year or less, are excluded. The final column of Table 3.2-8 contains the adjusted cumulative percentages P after the exclusion of the 2.59 percent of vehicles having reported yearly distances no greater than 500 miles.

The adjusted data points related to 1969 travel are plotted in Fig. 3.2-3 (P on a normal probability scale vs. annual distance in miles, X, on a log scale). The variate for fitting the log-normal model to the data was Y = Ln(X). The ML values of the parameters are μ = 9.0508 and σ = 0.7838. The distribution function specified by these values is represented by the solid line in Fig. 3.2-3. There is more scatter of the data points around the ML line here than in Fig. 3.2-1 (trip length distribution); however, the fit is considered reasonably good,

TABLE 3.2 – 5
CUMULATIVE PERCENT OF AUTOMOBILES BY ANNUAL DISTANCE DRIVEN *

ANNUAL DISTANCE		CUMULATIVE PERCENT OF AUTOMOBILES	** CUMULATIVE PERCENT OF AUTOMOBILES
MILES	KILOMETERS		
500	805	2.59	—
2,500	4,025	11,01	8.64
7,500	12,070	38.08	36.43
12,500	20,120	72.23	71.49
17,500	28,160	83.21	82.76
22,500	36,210	90.80	90.55
27,500	44,260	94.61	94.46
—	—	100.00	100.00

* FROM TABLE 2, REPORT No. 2, "ANNUAL MILES OF AUTOMOBILE TRAVEL", NATION–WIDE PERSONAL TRANSPORTATION STUDY, U.S. DEPARTMENT OF TRANSPORTATION/FEDERAL HIGHWAY ADMINISTRATION (1972).
(AVERAGES FOR ALL 1969 HOUSEHOLDS)

** OMITTING AUTOMOBILES REPORTED AS BEING DRIVEN LESS THAN 500 MILES IN A YEAR.

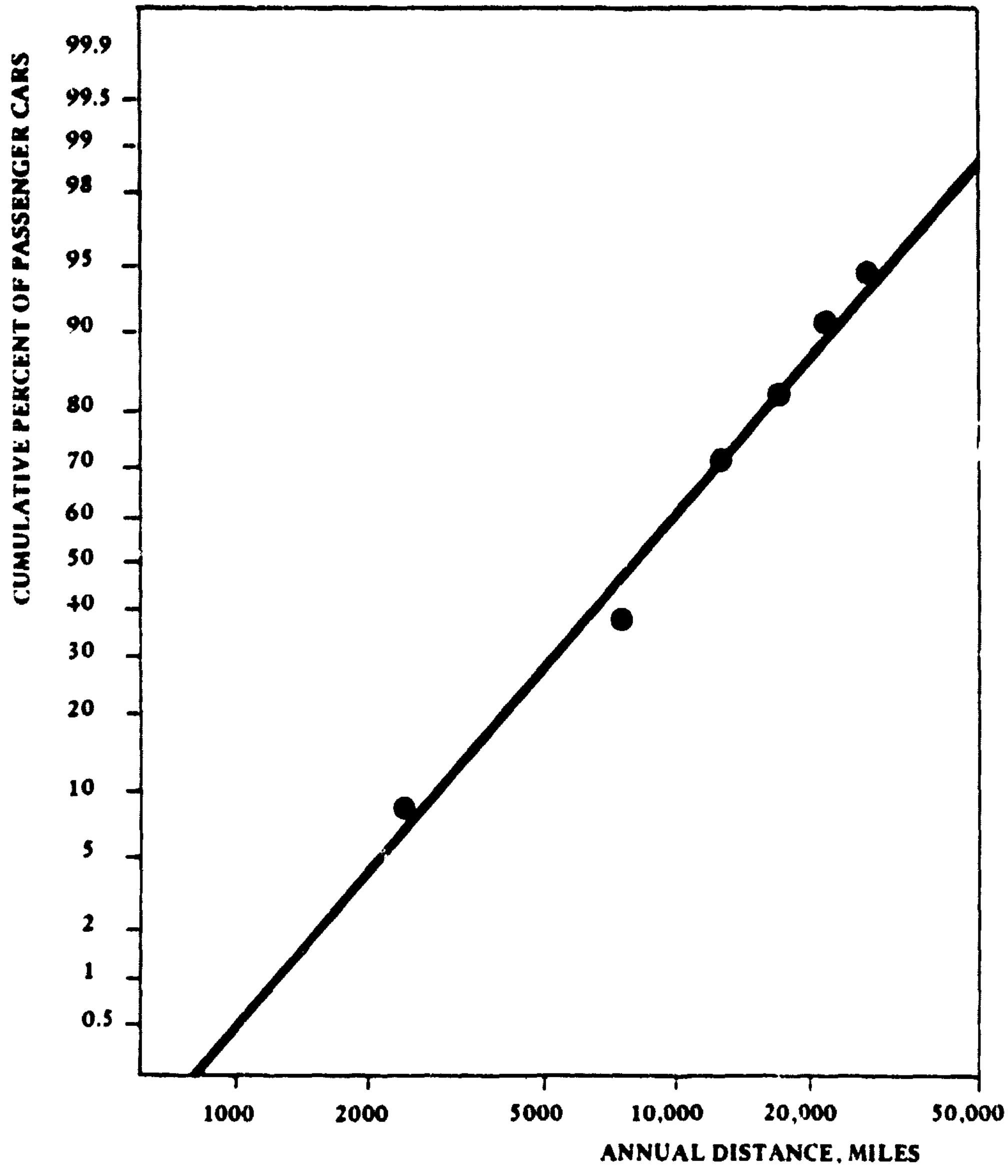


FIGURE 3.2 - 3
LOG--NORMAL DISTRIBUTION OF PASSENGER - CAR ANNUAL DISTANCES, 1970 DATA POINTS WITH FITTED LINE (ALL CARS)

particularly at the upper end of the distribution, which represents the higher-mileage vehicles.

The vehicles corresponding to the four missions can be expected to have different mean annual distances. For missions M_1, M_2, and M_3 the relative mean vehicle distances can be estimated on the basis of the 1969/70 NPTS data by the method to be described.

If $L_T(M_k)$ and $N_T(M_k)$ are respectively the average trip length and the average number of trips/vehicle for mission M_k, the average annual vehicle miles traveled VMT_k will be represented by

$$VMT_k = L_T(M_k) \cdot N_T(M_k)$$

While $L_T(M_k)$, as previously described, is a parameter characteristic of the various trips and is independent from the vehicles themselves, the number of trips/vehicle must be related to the number of vehicles performing a given mission. Missions having been defined as aggregations of trip purposes, no direct connection can be obtained from the NPTS data between mission trips (or mission annual miles) and vehicles, since annual miles/vehicle are only related to year-models, car ownership, income or driver occupation on Reports No. 2 and 11 and only annual miles/household or annual trips/household (not vehicle) are related to Trip Purposes on Reports No. 7 and 10.

Data on annual miles or trips/household must therefore be used first to obtain their fraction on a given mission. then the corresponding values/vehicle can be obtained through appropriate assessment of vehicle/household data information. Since for each trip purpose the data on trips/household had already been used, as previously described, to obtain by weighted means the average trip length and occupancy/mission, the same data were used, instead of the annual miles/household by trip purpose, to calculate the annual miles/household by mission.

Considering therefore a given group of households (e.g. 1-car owners), if mission M_1 includes x_2% of the p_2 fraction of all trip purposes and x_3% of the p_3 fraction of all trip purposes, the average number of trips on mission M_1 by all 1-car households is given by

$$N_T^{(1)}(M_1) = \left(\frac{x_2}{100} \cdot p_2 + \frac{x_3}{100} p_3\right) N_T^{(1)}$$

where $N_T^{(1)}$ is the average number of annual trips for all purposes by 1-car households.

After $N_T^{(i)}(M_k)$ has been similarly calculated for all missions and for all omogeneous groups of households, the average number of trips/mission and the average annual miles/mission and household, HMT_k, for all households having 1 or more car can be calculated as follows:

1) Weighted mean of trips/group of households for all households with cars:

$$N_T(M_k) = \sum_i^{1\to} [\, z_i \cdot N_T^{(i)}(M_k)] \qquad i = 1,2,3\ldots$$

2) Weighted mean of trip length/group of households for all households with cars,

$$L_T(M_k) = \sum_i^{1\to} [z_i \cdot N_T^{(i)}(M_k)] \,/N_T(M_k) \qquad i = 1,2,3..$$

and therefore:

$$HMT_k = L_T(M_k) \cdot N_T(M_k) = \sum_i^{1\to} [z_i \cdot N_T^{(i)}(M_k) \cdot L_T^{(i)}(M_k)]$$

$$i = 1,2,3...$$

where:

z_i is the fraction of i-car households with respect to all households with cars

$L_T^{(i)}(M_k)$ is the average trip length for mission M_k performed by i-car households.

For each group of households the number of cars per trip purpose and therefore per mission can also be assessed on the basis of assumptions similar to those made for the trip purpose distribution/mission so as to obtain the average number of vehicle/mission $N_V(M_k)$.

Since HMT_k represents the miles traveled on mission M_k averaged among all 1985 households with 1 or more cars, it must be multiplied by the total number of households with 1 or more cars

$$N_{Hc_{(85)}} = \sum_i^{1\to} N_{H\,(85)}^{(i)} \qquad i = 1,2,3...$$

and divided by $N_V(M_k)$ to obtain

$$VMT_k = \frac{HMT_k \cdot N_{Hc(85)}}{N_V(M_k)_{(85)}}$$

annual miles traveled/vehicle related to 1985 numbers of cars and households but to 1969 trips lengths and trip numbers per group of households.

The values so obtained (related to 1969 average miles/household) must then be factored up to account for the 1985 average miles/vehicle with the condition:

$$(VMT)_{(85)} = a \cdot \sum_{k}^{1 \to 3} [VMT_k \cdot \frac{N_V(M_k)_{(85)}}{N_{V\ (85)}}]$$

being $VMT_{(85)}$ = 11770 miles (excluding taxi/police travel)

$N_{V(85)}$ = 112,700,000 vehicles (excluding taxi/police vehicles)

The values of the parameter μ, mean of the logarithmic variate Y for the various mission were computed by the relationship

$$\mu_k = L_n(m_k) - \sigma^2/_2$$

where $m = VMT_k$ and $\sigma = 0.7838$ is the uniform standard deviation of Y derived as explained above.

e) Daily-Distance Distributions

Data on total distances that passenger cars are driven per day, including all trips, are not directly provided in the NPTS reports. Consequently, daily - distance distributions were synthesized from available NPTS and ancillary data by means of a model to be described. The distributions apply to passenger cars, segregated by mission, on a nationwide basis as of 1985. Daily-distance distributions are of particular importance in the assessment of concepts or designs for hybrid or pure electric cars in which there is overnight recharging of batteries, with subsequent utilization of the stored energy for motive power during part or all of the travel on the following day.

The model developed for the synthesis of daily distance distributions has as inputs four parameters characterizing the annual-vehicle-distance and trip-length distributions of the mission in question. Both distributions are assumed to be log-normal. The distribution of the variate $Y_1 = Ln(X_1)$, X_1 being vehicle annual distance in miles, has the two parameters

μ_1 Mean of Y_1

σ_1 Standard deviation of Y_1.

The normal distribution of the variate $Y_2 = Ln(X_2)$, X_2 being one-way trip length in miles, has the two parameters

μ_2 Mean of Y_2

σ_2 Standard deviation of Y_2.

The further variable, for which the distribution is desired, is X_3, daily vehicle distance in miles.
The outputs from the model include:

Percentage points and corresponding percentiles of the distribution of X_1, annual vehicle distance.

Percentage points and corresponding percentiles of the distribution of X_2, trip length.

Percentage points and corresponding percentiles of the derived distribution of X_3, daily vehicle distance.

The algorithm employed and the computer program HYBRID-2 that was written to perform the computations are described in Appendix A.3-2.

The values of the input parameters μ_1, σ_1, μ_2 and σ_2 used in synthesizing daily-distance distributions by means of program HYBRID-2 were derived as explained above at points b) and d) after processing the NPTS data as described in the following subsection 3.2.1.5.

f) Driving Speed

Over-the-road driving characteristics will be considered next, in particular average speed and frequency of stops.

Average speed is a travel parameter which has an important influence on fuel economy. Trips for the purpose of earning a living, category P_2, were the best documented in this respect. Several references were found that specifically addressed work trips; some listed average work trip speeds, while others presented travel distances and times from which average speeds could be computed. Table 3.2-6 summarizes the average work-trip speeds reported by the given sources.

The two Bureau of Census Special Reports categorize the Standard Metropolitan Statistical Areas (SMSA's) into four groupings:

Group A, largest metropolitan areas having major public transportation networks

Group B, very large public metropolitan areas with less developed public transportation system

Group C, other large and medium sized metropolitan areas with well-established public transportation systems

Group D, medium sized and smaller areas primarily limited to automobile travel.

TABLE 3.2 – 6
WORK TRIP AVERAGE SPEED SUMMARY

SOURCE	TRIP DESCRIPTION	SPEED
1 NATIONWIDE PERSONAL TRANSPORTATION STUDY, REPORT No. 8, HOME – TO WORK TRIPS AND TRAVEL, U.S. DEPARTMENT OF TRANSPORTATION, FHWA, AUGUST 1973.	WORK (NATIONAL AVERAGE)	25.6 mph
2. A SURVEY of AVERAGE DRIVING PATTERNS IN SIX URBAN AREAS OF THE UNITED STATES: SUMMARY REPORT, SYSTEM DEVELOPMENT CORPORATION, JANUARY 1971.	WEEKDAY (6–CITY AVERAGE)	24.7 mph
3. SELECTED CHARACTERISTICS OF TRAVEL TO WORK IN 21 METROPOLITAN AREA: 1975, U.S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS, FEBRUARY 1978.	WORK (21–CITY AVERAGE)	23.6 mph
4. SELECTED CHARACTERISTICS OF TRAVEL TO WORK IN 20 METROPOLITAN AREAS: 1976, U.S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS, SEPTEMBER 1978	WORK (20–CITY AVERAGE)	24.1 mph

The median work trip distance, time, and speed for these groups in 1975 and 1976 were as follows:

1975

GROUP		A	B	C (North)	C (South & West)	D
median distance	(mi.)	7.8	7.8	7.9	8.6	6.5
median time	(min.)	21.1	18.9	19.8	20.4	17.5
median speed	(mph)	22.2	24.8	23.9	25.3	21.9

1976

GROUP		A	B	C (North)	C (South & West)	D
median distance	(mi.)	8.6	9.0	6.5	8.7	6.7
median time	(min.)	22.0	21.6	18.3	20.5	17.2
median speed	(mph)	23.5	25.0	21.3	25.5	23.4

The data show that average travel speeds for work trips in both years are consistently in the low to mid twenties (mph) across the different metropolitan transportation groupings. It was therefore concluded on the basis of this evidence that the appropriate mission M_2 (urban/suburban commuting) average speed is approximately 23 mph since work and work-related trips are the dominant component of this mission.

Other average speed information which was collected is summarized in Table 3.2-7. No references giving directly the average speeds characterizing the other three missions --M_1 (intraurban/local), M_3 (general purpose), and M_4 (taxi/police) -- could be found. The best use was made of the available information along with the mission descriptions themselves to arrive at reasonable target estimates of average speed. The average work trip speed of about 24 mph was increased or decreased according to a comparison of the given mission with the commuter trip and an evaluation of their relative severity. The information presented in Table 3.2-7 also served as a guide and a check on the reasonableness of the estimates. Speed determination was closely associated with the specification of the stops-per-mile parameter in that they are inversely related, i.e., a higher average speed will result in fewer stops per mile and vice versa (see below).

g) Frequency of Stops

Another key travel descriptor that has a major effect on fuel consumption is the average number of stops per mile that a vehicle makes. Idling time, acceleration, and deceleration inefficiencies of conventional vehicles are also functions of the number of stops the vehicle makes. Slowdowns were not considered due to the scarcity of data on this subject and because full stops are a better indicator of the mission fuel economy. As previously mentioned, stopping frequency is inversely related to average speed. A 1976 EPA document illustrates this relationship, Figure 3.2-4.

Reference [4] contains a summary of stopping frequency for different types of areas, roads, and traffic conditions. The data are exhibited in Table 3.2-8.

TABLE 3.2 – 7
OTHER AVERAGE SPEEDS

SOURCE	TRIP TYPE	AVERAGE SPEED
1. TRAVEL CHARACTERISTICS, TRIP LENGTH CHICAGO AREA TRANSPORTATION STUDY NORTHWESTERN INDIANA COMMISSION, NOVEMBER 1975	WORK (CHICAGO AREA)	18 – 20 mph
2. CHICAGO LOOP SPEED & DELAY STUDY, 1974 and 1975, CENTRAL AREA, EPA, DECEMBER 1975.	CHICAGO CENTRAL BUSINESS DISTRICT	8.6 mph
3. CITY OF CHICAGO STUDY – PETERSON & ASHLAND AVENUES.	CHICAGO PEAK PERIOD	17 – 20 mph
4. CITY OF CHICAGO STUDY – ASHLAND AVENUE.	CHICAGO NORMAL PERIOD	28 mph
5. VEHICLE OPERATIONS SURVEY, VOL. I, SCOTT RESEARCH LABORATORIES, DECEMBER 1971.	5 CITY COMPOSITE (i) FREEWAY (ii) NONFREEWAY	 46.5 mph 21.3 mph

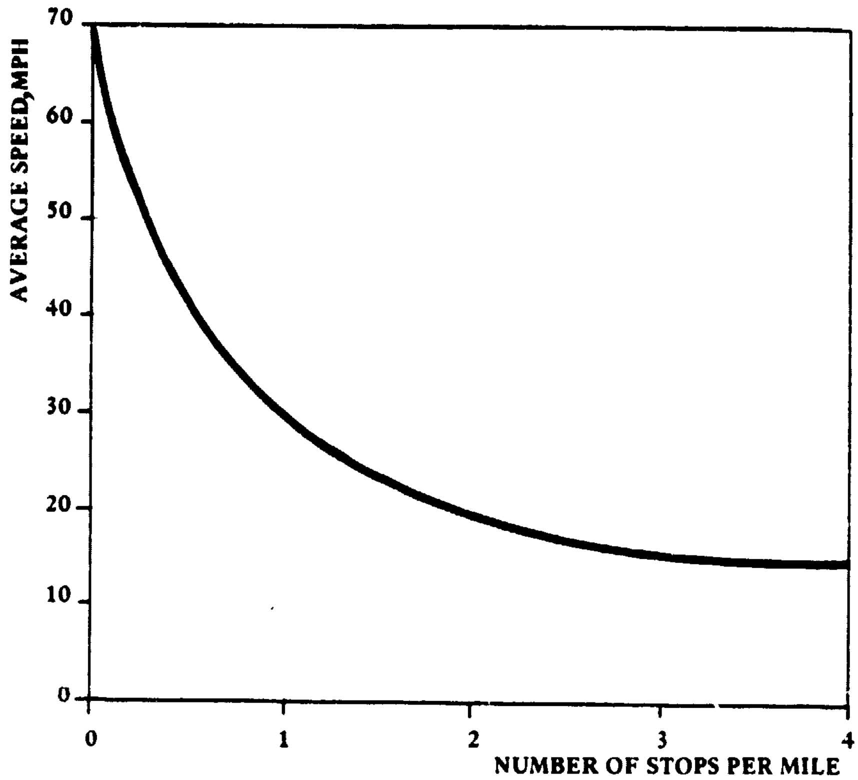


FIGURE 3.2 – 4
CURVE RELATING AVERAGE VEHICLE
SPEED AND AVERAGE FREQUENCY OF STOPS

TABLE 3.2 – 8
VEHICLE STOP SUMMARY (REF. 1)

CONDITIONS	NUMBER OF STOPS PER MILE
INTERSTATE, CONGESTED, URBAN	1
FEDERAL AID PRIMARY, SECONDARY AND NON–FEDERAL AID	
A. FREE–FLOWING RURAL	0
B. FREE–FLOWING URBAN	3
C. CONGESTED RURAL	1
D. CONGESTED URBAN	5

This information was used as a guide to approximate representative target stopping frequencies for the different missions. Similar to the speed estimation procedure, stopping frequency approximation involved a good deal of judgement and subjective evaluation of the available data base. The methodology used for synthesizing the most important trip elements of distance, speed, and stops into a composite characteristic driving cycle for each mission is described in the following Subsection 3.2.1.4.

3.2.1.4 Synthesis of Combinations of Driving Cycles

An important objective of Task 1 was to describe the selected passenger-car missions in terms of the three standard driving cycles for which computer models are available. Four missions, M_1 (intraurban/local), M_2 (urban/suburban commuting), M_3 (general purpose), and M_4 (taxi/police), were identified in Subsection 3.2.1.2 primarily on the basis of trip purposes. Detailed quantitative analyses of the missions were presented in Subsection 3.2.1.3. In this subsection the synthesis of combinations of driving cycles, i.e., "composite" driving cycles, to match as closely as possible the characteristics of the different missions will be described. The composite cycles can be used to compare fuel economy, emissions, and other properties of alternative vehicles under identical simulated operating conditions.

a) Mission Elements

The mission elements that were considered in detail during the course of the driving cycle synthesis were: daily travel distance, average speed and stopping frequency. These parameters provided the necessary information for the formulation of driving patterns for each selected mission in terms of the three standard driving cycles, i.e., FHDC, FUDC, and J227a(B). Reference [5] provided good background information for this part of the study. More detailed data on the other trip elements, such as acceleration and idle time, were not readily available and, furthermore, would likely not have contributed to a more accurate specification of mission driving cycles. This is due to the fact that only a limited number of target parameters can be satisfactorily matched by combining the standard cycles; the trip distance, speed, and stops were judged to be the most important for this purpose.

b) Standard Driving Cycles

The three standard driving cycles which served as the building blocks of the derived composite cycles for the four missions are:

1. FHDC: Federal Highway Driving Cycle, EPA Federal Test Procedure
2. FUDC: Federal Urban Driving Cycle, 1975, EPA Federal Test Procedure [6]
3. J227a(B): SAE Standard Procedure J227a, Cycle B [7]

The relevant descriptive characteristics of the three standard driving cycles are given in Table 3.2-9.

In reviewing these standard cycles, it is interesting to note the markedly different driving patterns that they represent. The FHDC is a free flowing expressway cycle which closely resembles the 46.5-mph-speed and no-stops-per-mile observations listed in Tables 3.2-7 and 3.2-8, for a rural freeway. The FUDC is a bit more severe driving cycle that appears to depict a mildly congested urban-suburban environment. The SAE cycle represents driving under extremely congested traffic conditions. These types of adverse conditions frequently arise in the central business districts of the larger metropolitan areas. Once again, the data shown in Tables 3.2-7 and 3.2-8 of 8.6 mph average speed in the Chicago central business district and five stops per

TABLE 3.2 – 9
PROPERTIES OF STANDARD DRIVING CYCLES

PROPERTY	DRIVING CYCLE		
	J227 a (B)	FUDC	FHDC
TOTAL DISTANCE			
MILES	0.182	11.09	10.25
km	0.293	17.85	16.50
TOTAL TIME			
s	72	1,877	765
hr	0.020	0.521	0.212
AVERAGE SPEED	9.1	21.3	48.2
Mph	9.1	21.3	48.2
km/hr	14.6	34.3	77.6
NUMBER OF STOPS	1	22	1
FREQUENCY OF STOPS			
NUMBER PER MILE	5.5	2.0	0.1
NUMBER PER km	3.41	1.23	0.06
NUMBER PER hr	50.0	42.2	4.7

mile for a congested urban area match rather well with the J227a(B) cycle characteristics.

Beyond these standard driving cycles, the literature review revealed that little in-depth research has been conducted on the real driving patterns of America's motorists. The references cited earlier on average speed and stopping frequency were the best available.

c) The Composite Driving Cycles

A good deal of care and judgment was exercised in using the documented information to describe typical mission driving conditions. Because daily travel distance was obtained from the rather thorough Nationwide Personal Transportation Survey, it can be treated as the most reliable driving cycle parameter. The target values of the three key cycle parameters were the following:

MISSION	AVERAGE SPEED(mph)	STOPPING FREQUENCY (per mile)	95th PERCENTILE DAILY TRAVEL DISTANCE (miles)
M_1 intraurban/Local	16-17	3-4	76
M_2 urban/suburban commuting	24-25	2-4	122
M_3 general purpose/ vacation	35	1-2	142
M_4 taxi/police	15-16	4	129

The initial target estimates of the speed and stop elements were at a lower confidence level than the daily travel distance. The formulation of the composite driving cycle became a trial and error process to achieve the best match between combinations of the three standard cycles and the three target parameters. The procedure that was used is outlined in the following steps:

Step 1. Select how many, if not all, of the three standard cycles should be included in the composite cycle based on a given mission description. This is the heuristic starting point of the iteration.

Step 2. Attempt to match the target average speed, $\bar{V}$, with the combination of standard cycles selected in step 1. Repeat until a satisfactory match with the target average speed is achieved. It should be noted that the combination of cycles at this point should be reduced to a form with no common multiple besides 1, e.g., a 6-4-2 combination should be reduced to 3-2-1. The applicable formula for the average speed computation is

$$\bar{V} = \frac{.182S + 11.1U + 10.25H}{.02S + .521U + .212H}$$

where H = number of FHDC in composite cycle
U = number of FUDC in composite cycle
S = number of J227a(B) in composite cycle
$\bar{V}$ = average velocity

Step 3. With the combination that satisfactorily matches the target average speed in 2, calculate the average stops per mile according to

$$\bar{SM} = \frac{1S + 22U + 1H}{.182S + 11.1U + 10.25H}$$

where H, U, S are as defined previously and $\bar{SM}$ = average stops per mile.

Iterate over steps 2 and 3 until a satisfactory match is reached for both $\bar{V}$ and $\bar{SM}$.

Step 4. Using the reduced form of the composite cycle described in step 2, scale the composite cycle up, if possible, so as to match the target daily travel distance. For example, if the target distance is 22.6 mi and a composite cycle of 1S and 1U (distance of 11.28 mi) meets the average speed and stopping frequency targets, the final composite cycle should be specified as 2S and 2U. Multiplying the reduced form of the composite cycle by a common factor will not, of course, change $\bar{V}$ or $\bar{SM}$ but will merely increase the travel distance. If the target daily travel distance cannot be rather closely matched in this manner, one must return to step 2 and begin over with another cycle combination. The intent was to match travel distance to its corresponding target estimate more closely than the more uncertain speed and stopping frequency parameters.

After the combination of standard driving cycles was completed, it was necessary to specify a cycle sequence for each mission. The ordering of the standard driving cycles was considered to be important because of its effect on hybrid vehicle fuel consumption and performance. The rationale for this task was to provide convenient checkpoints for vehicle performance evaluation at approximately the 50th, 80th, and 95th percentile daily travel distances within the composite cycle.

Interpretation of the mission trip environment played a major role in the sequencing. This was a rational attempt at putting the composite mission driving cycle into a realistic ordered form to provide a more credible estimate of the vehicle performance than a simple listing of the number of component standard cycles. Several general comments should be made on the aforementioned driving cycle synthesis. First of all, the composite cycle was limited to an integral multiple of its component standard cycles. Secondly, even with the three target parameters of distance, speed and stops, a unique solution usually did not exist for a given mission. At times, more than one cycle combination could satisfactorily depict the mission characteristics while in other instances no solution would exist. These multiple solution cases arose because of the opposite problem - underconstraint. The nosolution cases resulted from a set of target estimates that were incompatible with the inverse speed and stopping frequency relation exhibited by the standard cycles. This realization led to the conclusion that the initial target parameters were unreasonable and to their subsequent revision. Thus, both types of problems were encountered and had to be resolved through some rational judgment and/or modification of target parameters.

3.2.1.5 Trip Purpose/Mission Combination

The two most delicate assessments that had to be made in the accomplishment of the mission analysis were those related to the distribution of the trip purpose and fleet mixes among the identified missions.

The assumptions outlined in Subsection 2.2 provided general guidelines to identify the direction and, to some extent, the rate of the specialization trend being experienced in car usage, but the main problem of identifying, within such a trend, what the situation is expected to be in 1985 was still unresolved.

The "mission" concept as "representative trip pattern of typical vehicle usage", being a recently introduced tool for trip analysis, had no statistical data background for the past nor any data were available on vehicle class distribution as related to trip purposes . In fact, even in the late '60s, at the time the NPTS was conceived, the predominant car distribution of the in-place fleet was largely between large and mid sizes, with no real technical meaning as the difference in available engine power between the largest large-size and the largest mid-size car was much greater than the corresponding difference between the smallest large-size and the smallest mid-size car.

With reference to trip purpose distributions only and on the basis of the usage characterization assessments previously illustrated in subsection 3.2.1.1, using common sense and a rational evaluation of the past and present situation, it was assumed that:

1) in 1960 all trip purposes were concentrated in the fully standardized mission M_3 (1, 1, 1, 1, 1);

2) in 1975 the trip-purpose/mission distributions expected for 1985 would already qualitatively apply (work and social/recreational trips excluded from Mission M_1, social and recreational trips excluded from mission M_2 too) but the applicable trip purposes were evenly distributed among the mission M_1, M_2 and M_3;

3) in 1985 the trip-purpose/mission distribution should be within an expected range with nominal (i.e. to be used for mission specifications) values corresponding to mid range;

4) the theoretical complete specialization that should be reached in the time frame between the years 1990 and 2000 appears to be an unreacheable limit because of the saturation in the specialization trend resulting from the projected limited car availability per household.

The relevant mission parameters, calculated according to the methodology presented in Subsection 3.2.1.3 and corresponding to the expected 1985 conditions, are presented in the following tables.

This final missions quantification (1) based upon appropriate trip purpose distribution per mission was performed as follows:

---

(1) For preliminary mission quantifications refer to Section 4. Interim Results.

Step 1. According to projected values of the 1985 U.S. population and passenger vehicle fleet, the average number of car/household and the corresponding distribution of car ownership per household were calculated (2) with the following results:

a) Average number of car per household 1.58

b) households with

0	1	2	3 or more	cars/household
12.6	32.6	41.3	13.4	% of all households

Step 2. For each group of households and mission, assessments were made on the projected trips/mission distributions (according to the trip purpose/mission combination concepts described on subsection 3.2.1.2) and vehicle/mission distributions.

Step 3. The NPTS data on 1969 trip purpose distribution related to car ownership [1] were used to obtain, from the STEP 2 assessments, combined trip purpose parameters (number of trips and trip length) for each mission referred to all households with cars.

Step 4. The resulting annual vehicle miles/vehicle on each mission, obtained as product of the weighted annual mean number of trips/mission times the weighted mean trip length/mission divided by the average number of vehicles/mission, was adjusted to match the projected value of the 1985 average annual vehicle miles/vehicle according to JPL guidelines. As overall effect the increased number of vehicle/households alone would result in a lower annual mileage/vehicle, on the basis of 1969 number of trips and trip lengths per household group, since the NPTS data show, as reasonable, lower values of annual miles/vehicle in multiple car households than in single car households.

---

(2) Based upon the assumption described above on Section 2.

The performed adjustement accounts for the expected increase in the number of trips and trip length per household groups. The 15% increase in the average annual miles/vehicle was evenly distributed among these two parameters.

On Table 3.2-10 the data shown in the upper-left section, identified within the double line boundaries, are referred to 1969 number of trips and trip length/ household group. The data shown in the lower row and right end column (annual trips and trip length) are referred to fully adjusted 1985 conditions (increased mileage/vehicle included).

On the basis of the obtained average annual trips and trip length/mission values the corresponding annual trips and trip lengths/mission percentile distributions were obtained according to the methodology previously described.

The daily distance distribution was accordingly calculated using the methodology described on Subsection 3.2.1.3.e). The corresponding driving cycles were determined using the methodology described on Subsection 3.2.1.4.

The resulting data for the trip parameters related to the various missions quantification are outlined in Section 4 Interim Results. To complement the data shown on Table 3.2-10 a summary of data on daily distance and driving cycles are presented in Table 3.2-11.

3.2.1.6 Vehicle fleet/mission distributions and fuel consumptions

Upon completing the various mission quantification, the mission analysis required a final assessment on the vehicle fleet distribution among the missions themselves.

Starting from the assumption that for the original general purpose mission the in-place fleet mix evolved as a result of the performance, comfort, room availability requirements coupled to the

TABLE 3.2 – 10
SUMMARY OF MISSION QUANTIFICATION DATA PER HOUSEHOLD / VEHICLE

CAR OWNERSHIP		1 CAR HOUSEHOLDS				2 CAR HOUSEHOLDS				3 OR MORE HOUSEHOLDS				ALL HOUSEH. WITH CARS				COMBINED (ALL MISSIONS)		
PARAMETER		M_1	M_2	M_3	ALL MISS.	M_1	M_2	M_3	ALL MISS.	M_1	M_2	M_3	ALL MISS.	M_1	M_2	M_3	ALL MISS.	CAR OWN. HOUSE-HOLDS (1)	NO-CAR HOUSE-HOLDS (2)	ALL HOUSE-HOLDS
TRIP. PURP.	CAR/MISS DIST.	0.05	—	0.95	1.0	0.2	0.8	1.0	2.0	1.0	1.0	1.2	3.2				1.58			
	% of HOUSEHOLD	32.6 (37.3)				41.3 (47.4)				13.4 (15.3)				87.4 (100)				87.4	12.6	100
P_1	No. of TRIPS/HH % P1 TRIPS % ALL TRIPS	— — —	— — —	423 100 7.8	423 100 7.8	— — —	436 50 10.2	436 50 10.2	872 100 20.4	— — —	1049 90 7.9	117 10 0.9	1166 100 8.8	— — —	367 49 18.1	382 51 18.9	749 100 37.0	804 98.4 36.3	92 1.6 0.6	713 100 36.9
	TRIP LENGTH	—	—	9.5	9.5	—	10.7	10.7	10.7	—	11.4	11.4	11.4	—	10.7	9.91	10.3	11.4	7.6	11.3
P_2	No. of TRIPS/HH % P2 TRIPS % ALL TRIPS	40 10 0.7	— — —	357 90 6.6	397 100 7.3	214 30 6.0	286 40 6.7	214 30 6.0	714 100 16.7	715 85 5.2	84 10 0.6	42 5 0.3	841 100 6.3	226 36.7 11.1	148 24.1 7.3	241 39.2 11.9	615 100 30.3	660 98.5 29.8	71 1.5 0.5	585 100 30.3
	TRIP LENGTH	5.6	—	5.6	5.6	5.6	5.6	5.6	5.6	5.3	5.3	5.3	5.3	5.45	5.68	5.59	5.54	5.9	5.4	5.9
P_3	No. of TRIPS/HH % P3 TRIPS % ALL TRIPS	10 10 0.2	— — —	91 90 1.7	101 100 1.9	68 30 1.6	91 40 2.1	68 30 1.6	227 100 6.3	284 85 2.2	35 10 0.3	17 5 0.1	346 100 2.6	81 40.9 4.0	48 24.2 2.4	69 34.9 3.4	198 100 9.8	212 98.3 9.6	26 1.7 0.2	189 100 9.8
	TRIP LENGTH	4.1	—	4.1	4.1	5.4	5.4	5.4	5.4	4.3	4.3	4.3	4.3	4.75	5.28	4.72	4.87	5.2	3.9	5.1
P_4	No. of TRIPS/HH % P4 TRIPS % ALL TRIPS	— — —	— — —	285 100 5.2	285 100 5.2	— — —	— — —	477 100 11.2	477 100 11.2	— — —	— — —	718 100 5.4	718 100 5.4	— — —	— — —	442 100 21.8	442 100 21.8	475 97.8 21.4	71 2.2 0.5	42 100 21.9
	TRIP LENGTH	—	—	12.6	12.6	—	—	13.6	13.6	—	—	14.3	14.3	—	—	13.53	13.53	14.5	11.6	14.4
P_5	No. of TRIPS/HH % P5 TRIPS % ALL TRIPS	1.3 10 —	— — —	11.7 90 0.2	13 100 0.2	8 30 0.1	11 40 0.2	8 30 0.1	27 100 0.4	1.5 5 —	3 10 —	26.5 85 0.5	31 100 0.5	4.4 20.1 0.2	5.6 25.4 0.3	12.0 54.5 0.6	22.0 100 1.1	24 98.9 1.1	2 1.1 —	21 100 1.1
	TRIP LENGTH	9.4	—	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	10.1	10.1	10.1
ALL. PURP.	No. of TRIPS/HH % ALL TRIPS	55 0.9	— —	1252 21.5	1307 22.4	311 6.8	884 19.3	1290 28.1	2485 54.2	1083 7.6	1257 8.8	987 7.0	3327 23.4	334 15.3	611 28.1	1230 56.6	2175 100	2175 98.2	262 1.8	1944 100
	TRIP LENGTH	5.75	—	9.15	9.0	6.07	8.92	11.4	9.86	5.37	10.87	14.92	10.52	5.70	9.74	10.97	9.82	9.8	7.7	9.8
ALL PURP.	ANNUAL MILES/CAR $\times 10^3$	6.3	—	12.1	11.75	9.43	9.87	14.67	12.25	5.82	14.46	12.25	10.93	7.18	11.2	13.3	11.77	11.77	20.0	11.85
	% OF CAR	1.0	—	19.6	20.6	5.83	20.92	24.15	52.3	8.47	8.47	10.2	27.14	14.7	29.4	55.9	100	99.6	0.4	100

A) CONDITIONS:
- No of TRIPS AND TRIP LENGTH PER GROUP OF HOUSEHOLDS FROM 1969 NPTS DATA. COMBINED DATA ARE RELATED TO 1985 CAR/HOUSEHOLD
- No of CARS/HOUSEHOLD AND ANNUAL MILES/CAR ADJUSTED IN LINE WITH 1985 JPL FORECASTS.

B) SIMPLIFYING ASSUMPTIONS:
- TAXI CAB AND RENTAL CAR TRIPS EXCLUDED FROM HOUSEHOLDS WITH CARS (1)
- NO-CAR HOUSEHOLD TRIP INCLUDED IN MISSION M4 – TAXI/POLICE (2)

TABLE 3.2 – 11
SUMMARY OF DAILY DISTANCE AND DRIVING CYCLES

MISSION	DAILY DISTANCE (MILES)			DRIVING CYCLES					
	PERCENTILE			COMPOSITION	SEQUENCE	DAILY DISTANCE		AVER. SPEED (MPH)	STOPS PER MILE
	50	80	95			(PERCENTILE)	(MILES)		
M1	11	52	76	44S, 4 U	(18 S U, 4S, U, U, 4S, U, 18S)	90.0	52.4	17.7	2.5
M2	17	84	122	4S, 6U, 2H	(U, H, 2U, 2S, 2S, 2U, H, U)	91.0	88	24.2	1.6
M3	20	100	142	4U, 10H	(H, U, 4H, U, U, 4H, U, H)	95.5	147	34.9	0.67
M4	35	103	129	400S, 2U, 4H	(90S, H, 70S, U, 40S, H, 40S, H, 40S, U, 70S, H, 80S)	96	136	13.7	3.3

prospective buyers' purchasing capability, it was assumed that the specialization trend in car usage was and would be associated to a similar trend in car size class to mission association.

In Subsection 3.2.2.2 the vehicle classes are defined in detail by cargo size as follows:

K_1	minicompact
K_2	subcompact
K_3	compact
K_4	midsize
K_5 & K_6	large

From a uniform distribution of all vehicle classes among all mission, it was assumed that, by 1985 a maximum vehicle class specialization would have been reached for the two extremes K_1, and K_5 , that is a (85, 10,5 %) distribution of K_1 vehicles and a (5, 10, 85 %) distribution of K_5 vehicles among mission M_1, M_2 and M_3 were tentatively assumed with intermediate distributions for K_2, K_3 and K_4 vehicles. Such tentative distributions, shown on the upper row of each mission on Table 3.2-12, while obviously satisfying the assigned totals/column did not match the prescribed mix per mission.

Using an available iterative computer method of successive approximations, the initial distributions were corrected until the assigned column and row totals were verified within acceptable limits.

The final results are presented in the lower row of each mission on Table 3.2-12.

The corresponding fuel consumptions for the various missions and 1985 reference new vehicles representative of each class, calculated according to the previously defined driving cycles and to the fuel economies calculated as described on Subsection 3.2.2.2 below are shown in Table 3.2-13 for the 1985 reference new vehicles.

TABLE 3.2 – 12

VEHICLE / MISSION DISTRIBUTIONS

MISSION	DISTRIBUTION	K1 % K1	K1 % FLT.	K2 % K2	K2 % FLT.	K3 % K3	K3 % FLT.	K4 % K4	K4 % FLT.	K5 % K5	K5 % FLT.	TOTAL	TOTAL % FLT.
M1	TENTATIVE	85	8.67	50	10.95	30	6.12	20	5.02	5	1.10		31.86
	FINAL	60.8	6.2	21.0	4.6	10.2	2.1	5.6	1.4	1.4	0.3		14.6
M2	TENTATIVE	10	1.02	30	6.58	40	8.16	30	7.53	10	2.20		25.49
	FINAL	23.5	2.4	41.1	9.0	44.2	9.0	28.7	7.2	7.6	1.7		29.3
M3	TENTATIVE	5	0.51	20	4.37	30	6.12	50	12.55	85	18.70		42.25
	FINAL	15.7	1.6	37.9	8.3	45.6	9.3	65.7	16.5	91.0	20.0		55.7
ALL MISSIONS		100	10.2	100	21.9	100	20.4	100	25.1	100	22.0		99.6

Note : MISSION M4 (TAXI / POLICE – 0,4% OF FLEET) NOT INCLUDED – VEHICLED CLASS EQUIVALENT TO K5

TABLE 3.2 – 13
MISSION AND VEHICLE CLASS FUEL CONSUMPTIONS, BILLIONS OF GALLONS
(% OF VEHICLE CLASS, MISSION, FLEET CONSUMPTIONS)

MISSION	VEHICLE CLASS						
	K1 % % FLT.	K2 % % FLT.	K3 % % FLT.	K4 % % FLT.	K5 % % FLT.	K6 % % FLT.	ALL CLASSES % FLT.
M1 % FLT.	1.63 (51.1) (36.9) (3.5)	1.35 (16.0) (30.6) (2.9)	0.74 (7.6) (16.8) (1.6)	0.58 (4.4) (13.2) (1.2)	0.11 (0.9) (2.5) (0.2)		4.41 (100) (9.4)
M2 % % FLT.	0.88 (28.3) (6.4) (1.9)	3.67 (43.5) (26.8) (7.8)	4.42 (45.3) (32.2) (9.4)	3.80 (28.9) (27.8) (8.1)	0.93 (7.8) (6.8) (2.0)		13.70 (100) (29.2)
M3 % FLT.	0.61 (19.6) (2.2) (1.3)	3.40 (40.4) (12.0) (7.3)	4.59 (47.1) (16.3) (9.8)	8.77 (66.7) (31.0) (18.7)	10.94 (91.3) (38.5) (23.3)		28.31 (100) (60.4)
M4 % % FLT.						0.45 (100) (100) (1.0)	0.45 (100) (1.0)
ALL MISSIONS % FLT.	3.12 (100) (6.7)	8.42 (100) (18.0)	9.75 (100) (20.8)	13.15 (100) (28.0)	11.98 (100) (25.5)	0.45 (100) (1.0)	46.87 (100)

As a result the single vehicle/mission combination which offers the largest fuel consumption and therefore the maximum potential for fuel saving by a single hybrid design is the K_5, M_3.

If however a missions set is considered, said maximum potential must be attributed to the K_4, (M_1, M_2, M_3) combination. The final selection of the reference ICE Vehicle to be considered for mission specifications was based upon the following considerations:

1) Criteria of vehicle selection should be largely influenced by usage requirements (as a result of the projected specialization trend); it can be therefore expected that, by 1985, a prospective ICE K_4 buyer should more easily be convinced by the fuel economy impact on vehicle operating costs to purchase a hybrid K_5 vehicle (offering larger than required cargo space availability) than a prospective ICE K_5 vehicle buyer could be induced to purchase a hybrid K_4 vehicle (with more limited than required cargo space availability).

2) Should an advanced type of battery be selected, to minimize near term production costs, a single battery size should be selected which could reach the widest possible market. Since battery cost increase is not expected to be simply proportional to size, it appears more appropriate to select a battery size adequate for a K_5 vehicle which could provide better fuel economy on a K_4 vehicle, than a battery size adequate for a K_4 vehicle which could not be used for a K_5 vehicle.

3) Due to the existing trend of vehicle "down-sizing" it is reasonable to expect that the actual difference between intermediate and large size vehicles should diminish and possibly disappear, because of the difficulty in technically distinguishing between vehicles very close to each other, that will possibly use the same basic set of power train configurations and will be almost exclusively differentiated by the number of passengers (5 or 6) and, for most vehicles, by a less than 10% difference in cargo space.

Considering also the opposite European trend to make larger small cars, by 1985 it could be more reasonable to divide the vehicle fleet into three rather than into five classes: small, medium (or compact) and large (or full size). This last class (the sole satisfying the 5/6 passenger requirement) is expected to be the most widely used to perform mission M_3 which, due to its general purpose usage characterization, represents on the one hand the largest overall fuel consumption and, on the other hand, being unspecialized, the least efficient car usage and therefore the most worth an efficiency improvement effort such as the "hybridization".

In conclusion, the single hybrid design which shall maximize the potential of fuel savings should be applied to the K_5 ICE reference vhicle.

For the reasons mentioned above, the hybrid vehicle sizing should be selected close to the low-boundary of the K_5 class. By 1985 it can be expected that this size should not be just the "average" size of the higher vehicle class but the most popular and best selling size of its class as well. That is, where usage specialization cannot win because of the actual spread of usage requirements it should end-up in a specialized and therefore wholly optimized general purpose vehicle in which the cost of introducing the most advanced technological improvements, besides the performance and efficiency results, could be compensated by the attainable mass production savings.

3.2.2 Vehicle Characteristics

Upon completion of the specific Mission Analysis methodology description (i.e. mission quantification and mission/vehicle combination) the description of the methodology used to define the remaining parameters of the Mission Specifications, were not included in Section 3.2.1 since it was felt more appropriate to associate Reference ICE Vehicle characterization to this section dealing with the vehicle characteristics study; it focused upon accomplishing three tasks:

- Definition of candidate reference vehicles characteristics
- Selection of a reference ICE vehicle
- Generation of mission related vehicle characteristics.

In doing so, three areas of investigation were pursued: vehicle considerations, vehicle characteristic parameterization and reference vehicle analysis. The major area of study was the parameterization effort. The 1985 candidate reference vehicles were characterized and described by size fraction and fuel economy, as well as by the mission related vehicle characteristics, e.g., speed and acceleration.

In performing the vehicle characterization effort, the primary initial characterization was the selection of the fleet stratification criterion. This criterion had to be and was consistent with the JPL guidelines. Three criteria were given serious consideration weight, volume and performance. Vehicle weight is quite important from a fuel economy standpoint, but relatively few uses dictate the vehicle weight. Similarily, vehicle performance is seldom the primary requirement for fulfilling a mission. Minimum performance standards must be met, but do not provide a real utilitarian basis for segregation of the fleet.

The vehicle internal volume seems to provide the best compromise as to the criterion for use in fleet stratification. This criterion is quite utilitarian and tends to present itself when use surveys are reviewed. These surveys relate to the number of trips made with various numbers of passengers making up the vehicle payload.

Stratification of the in-place 1985 fleet according to EPA internal volume criteria has been performed in such a manner as to preserve adherence to the JPL guidelines. Available data on 1977 new car fleet were compared with the corresponding JPL data on the 1976 new car fleet mix by weight and extrapolated to 1985.

In addition to the above JPL guidelines and fleet stratification by EPA volume/size, the fuel economy was defined for each vehicle class into which the fleet was stratified.

The number of driving cycles for the EPA city and highway and SAE(b) and the total annual miles driven for the relevant vehicle classes/missions were already defined, consistent to JPL guidelines, as a result of the Mission Analysis.

3.2.2.1 Vehicle Considerations

In accomplishing the characterization, both conventional and hybrid vehicle performance and characteristics were considered, although the emphasis has been upon conventional vehicles. Of primary interest were those factors that defined the extent of parameterization of vehicle characteristics as influenced by the mission requirements, and impacted upon the reference vehicle selection. The primary considerations were those relating to the output of the task: capacity (passenger and cargo); range, speed acceleration and gradeability; cost constraints (initial and operating) and finally ambient conditions, availability and amenities. Added to these characteristics were parameters required for calculation of fuel economy.

In the first place representative vehicles of model year 1978 were identified and their characteristics analyzed in detail. The height and width dimensions were used to determine the frontal areas in computing aerodynamic drag. The frontal area has been defined as 90 percent of the product of the vehicle outer cross-sectional dimensions. In many cases the weight distribution was not available. It has been taken to be 55 percent of the curb weight on the front axle with the balance on the rear axle. The EPA fuel consumption was used as a reference characteristic to aid in vehicle selection. The vehicular sales were utilized to assure that the final class stratification as identified included at least 90 to 95 percent of the fleet.

This set of considerations was largely based on "name plates", however there was insufficient input for the computer model when undertaking the effort to characterize optimum 1985 vehicles. Thus, the characterization of the 1985 fleet was pursued using data available in the trade publications (primarily Automobile News)(1) and "Rulemaking Support Paper Concerning the 1981-1984 Passenger Auto Average Fuel Economy Standard" [7]. These documents provided a basis for predicting the weights of the various vehicle classes in 1985 and for verifying the reasonableness of the fuel economy predicted.

Explicit consideration of diesel engine power for vehicles has not been made. The fuel economy which may be obtained through the use of diesel engines is considered part of the technology which may be applied to achieve optimum fuel economy. Also not explicitly addressed is the use of turbocharged engines. For this technology the potential for achieving fuel economy is recognized but not explicitly defined yet.

3.2.2.2 Fleet Characterization

a) Fleet Size: The total number of passenger automobiles on the road in 1985 was projected on the basis of the historical relationships between the U.S. population of people 16 years of

(1) Ref. [1] through [6].

age and older, the number of operator licenses in force each year, and the actual number of passenger vehicles in operation. The data in Tables A-1 and A-2 of JPL Guidelines, indicate that in 1978 approximately 85 percent of the people of age 16 years or older have driver licenses and that the number of vehicles registered represents slightly less than 75 percent of that figure.

Using the projections of the U.S. population for 1985 and by assuming that the above percentages remain fixed at 85 and 75 percent in future years, the JPL guidelines provide for 1985 a vehicle population of 113,200,000. The fleet size for the remaining years can be obtained by interpolation from the plot of vehicle population versus years shown in Figure 3.2-5

The total number of cars in operation for each year until 1985 was determined by discounting the original production figures for each model year according to the vehicle age in 1985. The schedule appearing in Table 3.2-14 contains the percent makeup of the total fleet as a function of vehicle age.

The number of units produced each model year for sale in the U.S., by both domestic and foreign car manufacturers, was calculated by assuming that yearly production was equal to slightly more than 11 percent of the total number of vehicles in operation in that given year. This value was derived by averaging the ratios of the number of vehicles produced to the fleet size for the years 1972 through 1977. Combining these figures with the age discounting schedule in Table 3.2-14, the 1985 fleet makeup contained in Table 3.2-15 results. It should be noted that the number of new 1985 cars present in the fleet is considerably less than that produced. The reason for this is that the number of 1985 model year vehicles represents a yearly average for the purpose of calculating the annual mileage and fuel consumption.

b) Vehicle distribution by Class: In order to determine the percent of penetration each vehicle class represents in the 1985 fleet,

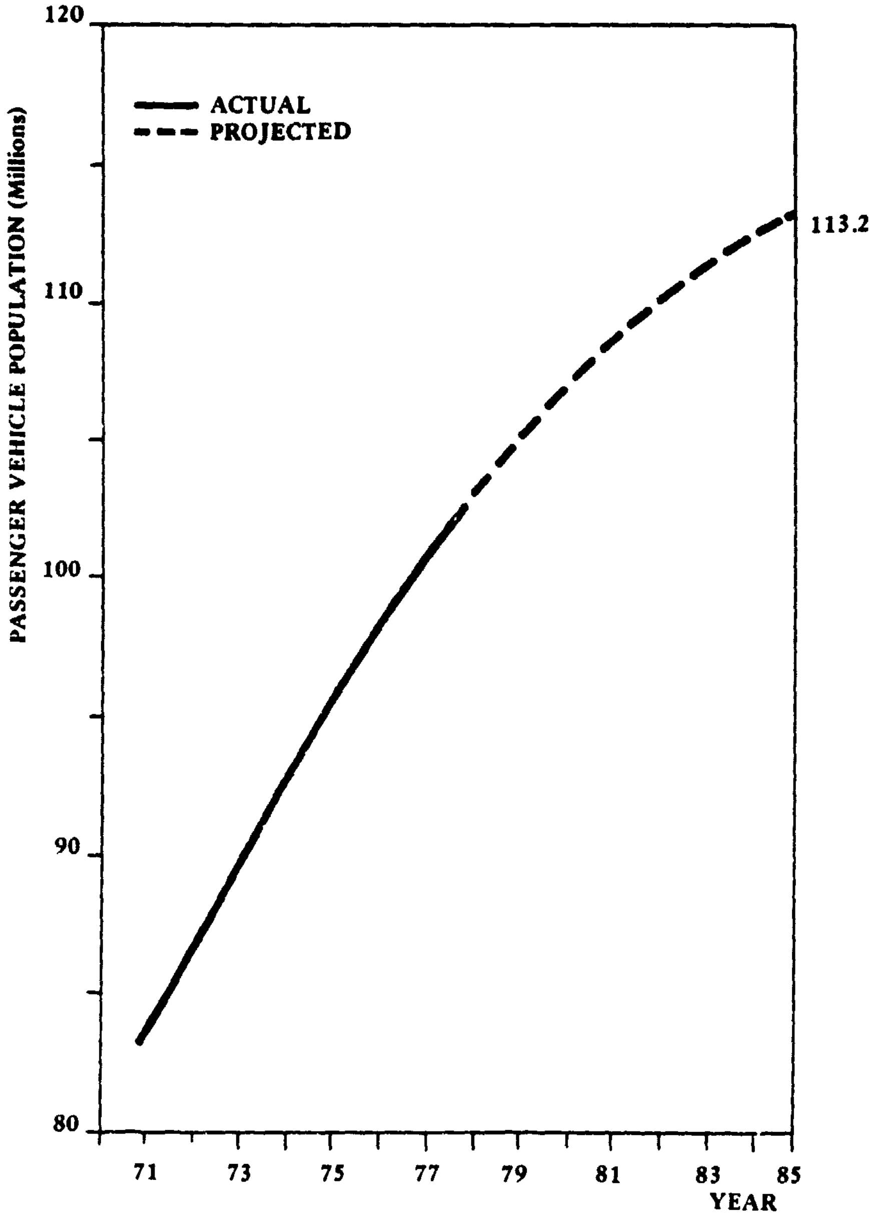


FIGURE 3.2 – 5
U.S. PASSENGER VEHICLE POPULATION

TABLE 3.2 – 14

PERCENT OF VEHICLE FLEET AS A FUNCTION OF VEHICLE AGE

MODEL YEAR	VEHICLE AGE (YEARS)	% OF 1985 VEHICLE FLEET
1985	< 1	8.0
1984	1–2	11.0
1983	2–3	10.5
1982	3–4	10.1
1981	4–5	9.7
1980	5–6	9.3
1979	6–7	8.9
1978	7–8	7.9
1977	8–9	6.0
1976	9–10	5.0
1975	10–11	4.0
1974	11–12	3.0
1973	12–13	2.0
1972	13–14	1.2
1971	14–15	1.0
1970	15–16	.8
1969 and before	> 16	2.0

TABLE 3.2 – 15

1985 FLEET MAKEUP AS A FUNCTION OF VEHICLE MODEL YEAR AND MODEL YEAR PRODUCTION FIGURES

MODEL YEAR	TOTAL FLEET SIZE (THOUSANDS)	UNITS PRODUCED IN GIVEN MODEL YEAR (THOUSANDS)	UNITS SURVIVING IN 1985 (THOUSANDS)
1985	113,200	12,680	9,060
1984	112,500	12,580	12,450
1983	111,500	12,480	11,890
1982	110,300	12,350	11,440
1981	108,900	12,200	10,980
1980	107,300	12,010	10,530
1979	105,200	11,790	10,080
1978	102,860	11,520	8,490
1977	99,900	11,546	6,790
1976	97,820	9,888	5,660
1975	95,240	8,361	4,530
1974	92,610	9,848	3,400
1973	89,800	11,708	2,270
1972	86,440	10,157	1,360
1971	83,140	8,687	1,130
1970	80,450	8,388	910
1969 and before	––	––	2,230

U.S. production and foreign car sales data for model years 1971 through 1977 were analyzed according to EPA size classification versus interior volume (Table 3.2-16 below).

The new car fleets for those model years were characterized by individual name plate (make and model) association with the internal volumes listed in the 1977 EPA gas mileage guide. Since

Table 3.2-16 - EPA Size Classification Versus Interior Volume

EPA Class	Vehicle Size Class	(Cargo + Passenger) Volume, V (ft^3)
Minicompact	K_1	$V \le V < 100$
Subcompact	K_2	$85 \le V < 100$
Compact	K_3	$100 \le V < 110$
Midsize	K_4	$110 \le V < 120$
Large	K_5 and K_6	$120 \le V$

model year 1977 was the first year in which the EPA classified vehicles according to volume, it was assumed that vehicles manufactured prior to 1977 remained in the same basic size category. Two-seater vehicles such as sport cars were distributed uniformly between classes K_1 through K_5; no two-seaters were included as K_6 fleet vehicles.

After all the 1971 through 1977 vehicles were categorized into their appropriate size classes and the production and sales figures tabulated, the sales mix for each class was calculated on a percentage basis using the total new car fleet figures from Table 3.2-15. The resultant mix percentages were projected forward to 1985 by assuming a slight increase in market share for the minicompact, subcompact, and compact classes and a decrease in market share for the midsize and large car classes in conformance with JPL guidelines. The sales mix for 1970 and 1969 or older vehicles was set equal to that of the 1971 fleet. The projections of the new car market share by class for each model year are listed in Table 3.2-17.

Table 3.2-18 contains the percentages of the 1985 in-place fleet represented by each class as a function of vehicle model year.

c) Fuel Economy: The sales weighted EPA combined fuel economy for the new car fleets were calculated in a manner similar to the sales mix percentages. The production figures by vehicle nameplate for model years 1974 through 1977 were used to tabulate individual fuel economy values taken from the EPA gas mileage guides for those years. The fuel economies were then sales weighted and harmonically averaged to obtain the new car fuel economy for each of the six vehicle classes. The composite fuel economies for the remaining years were calculated by uniformly incrementing the baseline figures for each class to match the miles per gallon (mpg) change in the total fleet as provided by Table C-3 of the JPL Guidelines. The calculated EPA combined fuel economy values for each vehicle class and model year along with the total nex fleet economies are listed in Table 3.2-19.

In calculating the city/highway fuel economies from the projected combined figures, a fixed ratio for mpg "city" to MPG "composite" equal to 0.87 was used. For the highway fuel economies, a ratio of mpg "highway" to mpg "combined" equal to 1.23 was utilized.

The fuel economies for the SAE(b) driving cycle were obtained from the EPA city cycle corresponding to each vehicles class. Fuel economies for both cycle types and for typical vehicles were calculated using an existing computer programmed performance model. Ratios were formed from these values and used for the vehicles which were not simulated by the computer model. The

TABLE 3.2 – 17
1969 to 1985 NEW CAR FLEET MIX AS A FUNCTION OF VEHICLE SIZE CLASS

MODEL YEAR	% OF NEW CAR FLEET				
	MINICOMPACT	SUBCOMPACT	COMPACT	MIDSIZE	LARGE
1985	11.4	23.2	26.2	21.3	17.9
1984	11.1	22.6	25.2	22.3	18.8
1983	10.8	22.1	24.2	23.2	19.7
1982	10.6	21.6	23.0	24.2	20.6
1981	10.3	21.1	21.8	25.2	21.6
1980	10.0	20.5	20.8	26.1	22.6
1979	9.7	19.9	19.8	27.1	23.5
1978	9.5	19.4	18.6	28.1	24.4
1977	9.2	18.8	17.6	29.1	25.3
1976	9.6	21.5	20.7	27.0	21.2
1975	10.7	26.9	14.4	25.1	22.9
1974	12.2	29.2	8.3	26.9	23.4
1973	7.8	24.1	6.9	26.6	34.6
1972	7.9	24.0	8.0	23.9	36.2
1971	8.3	25.8	6.9	24.6	34.4
1970	8.3	25.8	6.9	24.6	34.4
1969 and before	8.3	25.8	6.9	24.6	34.4

TABLE 3.2 – 18
1985 IN–PLACE FLEET MIX BY VEHICLE CLASS AND MODEL YEAR

MODEL YEAR	MINICOMPACT K1	SUBCOMPACT K2	COMPACT K3	MIDSIZE K4	LARGE K6	LARGE K5
1985	0.91	1.86	2.10	1.70	0.03	1.40
1984	1.22	2.49	2.76	2.45	0.04	2.03
1983	1.14	2.33	2.52	2.44	0.04	2.03
1982	1.07	2.18	2.32	2.45	0.04	2.05
1981	1.00	2.04	2.12	2.44	0.04	2.06
1980	0.93	1.91	1.13	2.44	0.04	2.06
1979	0.87	1.77	1.76	2.42	0.04	2.05
1978	0.71	1.46	1.40	2.11	0.04	1.80
1977	0.55	1.13	1.05	1.74	0.03	1.49
1976	0.48	1.07	1.03	1.35	0.02	1.04
1975	0.43	1.08	0.58	1.00	0.02	0.90
1974	0.37	0.88	0.25	0.81	0.01	0.69
1973	0.16	0.48	0.14	0.54	0.01	0.68
1972	0.09	0.29	0.10	0.29	0.01	0.43
1971	0.08	0.26	0.07	0.25	0.01	0.34
1970	0.07	0.21	0.06	0.20	0.01	0.27
1969 and before	0.16	0.51	0.14	0.48	0.01	0.66

TABLE 3.2 – 19
EPA COMPOSITE FUEL ECONOMY FOR NEW CAR FLEETS

MODEL YEAR	EPA COMBINED FUEL ECONOMY (MPG)						
	MINICOMPACT K1	SUBCOMPACT K2	COMPACT K3	MIDSIZE K4	LARGE K6	LARGE K5	FLEET
1985	36.7	33.5	27.8	25.9	27.0	25.2	28.7
1984	35.8	33.1	27.4	25.5	26.5	24.8	28.2
1983	35.0	32.3	26.6	24.8	25.7	24.0	27.3
1982	33.2	30.5	24.8	23.0	24.9	22.3	25.4
1981	31.5	28.8	23.1	21.2	22.0	20.5	23.5
1980	29.7	27.0	21.3	19.4	20.0	18.7	21.6
1979	28.9	26.2	20.5	18.5	19.1	17.9	20.6
1978	28.0	25.3	19.6	17.6	18.3	17.0	19.6
1977	27.4	24.7	19.0	17.0	17.6	16.4	18.9
1976	25.6	22.4	18.0	15.7	14.9	14.0	17.5
1975	21.9	19.5	16.1	13.6	13.7	12.7	15.6
1974	20.7	18.3	14.9	12.4	12.3	11.5	14.4
1973	21.5	19.1	15.7	13.2	13.2	12.3	14.5
1972	22.0	19.6	16.2	13.7	13.7	12.8	15.0
1971	22.0	19.6	16.2	13.7	13.7	12.8	15.1
1970	22.4	20.0	16.6	14.1	14.1	13.2	15.5
1969 and before	22.4	20.0	16.5	14.0	14.0	13.1	15.4

ratios used in the fuel economy and consumption calculations are summarized below:

Vehicle Type	mpg ratio: SAE(b)/EPA city
Minicompact	0.86
Subcompact	0.79
Compact	0.73
Midsize	0.67
Large (taxi/police)	0.76
Large (general use)	0.69

A listing of the number of vehicles in the 1985 fleet and the individual SAE city, EPA highway, and SAE(b) fuel economies for each vehicle class and model year is outlined in Section 4 - Interim Results.

3.2.2.3. Candidate Reference Vehicle Characterization

It was considered appropriate to define vehicle characterization in terms of "average new" and "optimum new" 1985 cars. The new 1985 vehicles, of both types, are considered candidate reference vehicles. The candidate reference vehicles were defined for vehicle class (interior volume) with fuel efficiencies projected for new average 1985 and optimum 1985 vehicles. In addition, selected performance characteristics were established.

Candidate reference vehicles are described by the entries shown in Table 3.2-20. The weight reductions and improvements in the other characteristics from those of 1978 vehicles were obtained from predictions cited in Automotive News (1) and "Rulemaking Support Paper Concerning the 1981 to 1984 Passenger Auto Average Fuel Economy Standards" [7]. These documents provided the basis

(i) Ref. [1] through [6]

TABLE 3.2 – 20
AVERAGE 1985 NEW ICE VEHICLES

ITEM	CLASS					
	K 1	K 2	K 3	K 4	K 6	K 5
EPA CLASS	MINICOMP.	SUBCOMP.	COMPACT	MIDSIZE	LARGE	LARGE
PRIMARY USE	INTRAURBAN	URBAN/SUB & GEN. PURP.	GEN. PURP. & URBAN/SUB	GEN. PURP.	TAXI/POLICE	GEN. PURP.
WEIGHTS, lb :						
CURB (CuW)	1600	1750	2375	2800	3200	3200
AVERAGE PAYLOAD	350	325	325	450	485	550
TOTAL	1950	2075	2700	3250	3685	3750
DIMENSIONS :						
WIDTH (W), in.	60	62	68	69	72	72
HEIGHT (H), in.	52	52	55	53	58	58
WHEELBASE	90	94	104	104	112	112
FRONTAL AREA (0.9 WH), sq.ft.	19.5	20.2	23.4	22.9	26.1	26.1
DRAG COEFFICIENT (CD)	.384	.394	.394	.384	[illegible]	.403
CAPACITIES, cu ft. :						
PASSENGER	76	85	90	102	111	111
CARGO	4	11	13	17	20	20
TOTAL	80	96	103	119	131	131
TIRES :						
ROLLING RADIUS, in.	10.8	11.2	12.7	12.7	13.3	13.3
PRESSURE, psi	40	40	40	40	40	40

for making predictions concerning the 1985 model year vehicles and for verifying the reasonableness of fuel economy predictions.

The curb weights presented in Table 3.2-20 were obtained directly from the cited references. In some cases the weight reductions estimated in the Rulemaking Paper were used to reduce the 1978 values. The class payload weights were maintained for the 1985 fleet, as were the volumes for the cargo volumes for all the vehicle classes. The passenger volumes for class K1, K2, and K6 vehicles were unchanged. The volume of the K5 vehicle was made identical to the K6 as these would be the same car, but with different engines. The vehicle dimensions were taken from the references. The frontal area was calculated as indicated in the table (0.9 times the product of height and width). The drag coefficient was reduced according to the prediction presented in Table 3.2-21.

In addition to the above predictions, five specific improvement areas were condidered. These are constituted by the following vehicle characteristics, which were addressed in terms of mission requirements:

- fuel efficiency
- gradeabilities
- acceleration
- cruise and top speed
- availability

In addition to these considerations, the concept of an optimized new 1985 candidate reference vehicle was delineated.

a) Optimum New 1985 Vehicle: The primary concept embodied in this version of the candidate reference vehicles is fuel economy. The Rulemaking Paper on 1981 to 1984 fuel economies presents technology factors (Table 3.2-21) which indicate potential for achieving significantly greater fuel economy than indicated by the analysis described under "Fuel Economy" in Subsection

TABLE 3.2 – 21
ECONOMY TECHNOLOGY FACTORS [a]

TECHNOLOGY ITEM	PERCE·· IMPROVEMENT
AUTOMATIC TRANSMISSION [a]	10
MANUAL TRANSMISSION [b]	5
LUBRICANTS	2
ACCESSORIES	2
AERODYNAMIC DRAG	4
ROLLING RESISTANCE	3
DIESEL (OR EQUIVALENT)	25
WEIGHT REDUCTION	1 per 40 POUNDS

---

a – RULEMAKING SUPPORT PAPER CONCERNING THE 1981 – 1984 PASSENGER AUTO AVERAGE FUEL ECONOMY STANDARDS, JULY 1977, U.S. DEPARTMENT OF TRANSPORTATION NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION.

b – USE ONE OR THE OTHER TRANSMISSION – NOT BOTH.

3.2.2.1.c). The harmonic mean fuel economy for the new 1985 model year vehicles is provided by the JPL guidelines as 28.7 mpg (EPA combined). The segregation by vehicle size sales weighting is used with this combined fuel economy to establish for each vehicle size class appropriate values which appear to be conservative.

As described in the following subsection, more optimistic fuel economies were predicted for the candidate reference vehicles termed "optimum". However, the fuel economies for even these vehicles is conservative according to the factors shown in Table 3.2-21. The primary factor, among the eight shown in Table 3.2-21 is the application of diesel power or equivalent technology.

The optimum candidate vehicles may require more application of this particular technology than that required for the average new 1985 vehicles. Note that there is no specific technology being specified for achieving the higher fuel economy being predicted. It is just specified that MORE advanced technology is required.

It is, however, assumed that a "penalty" must be paid for achieving this higher fuel economy. First there will be a cost penalty -- the higher fuel economy car will cost more. Possibly more important, the vehicle may not be capable of meeting some minimum JPL requirement. For example, the engine might be turbocharged and this could result result in some loss of high or low speed acceleration which could impact minimum requirements. Another type of penalty could be reliability loss, if a high speed engine were used. The vehicle availability could suffer as a result of more frequent breakdowns with reduced mean usage between failures (MUBF) or increased maintenance requirements. These negative aspects of the optimistic vehicle should not be too pronounced as the level of fuel economy improvement has been conservative.

C-2

b) Fuel Efficiency: The technological factors which may be employed in predicting improved fuel economy are summarized in Table 3.2-21. The fuel economy for the in-place 1985 fleet, the new car 1985 fleet and the optimized 1985 vehicles is summarized in Table 3.2-22. The SAE fuel economy has been included in the table.

The optimized 1985 fuel economy was obtained by extrapolation from 1979 fuel economy data. The arithmetic average fuel economy for each vehicle class was established (from published data) with a standard deviation. An estimate of the same average for the 1985 new car fleet was obtained by proportioning it to the harmonic means for the 2 years. These data, arithmetic means and standard deviations, were smoothed and then three standard deviations from the 1979 fleet were added to each of the new 1985 fleet classes to establish the optimized fuel economies. The values were compared to values which could be derived by use of the factors presented in Table 3.2-21 and were found to be lower and therefore the optimum values projected were considered conservative.

c) Grade Requirements: The gradeability (percent grade, speed and distance) is an important consideration in the design of a vehicle for general usage on the nation's roads. If a vehicle does not meet the predominant grade requirements of national roads, it will not satisfy the normal travel demands of the motoring public and thus will not be widely accepted. In addition, substandard grade capability can result in unsafe vehicle operation within a fleet that includes older vehicles with superior gradeability. The literature search revealed three sources of highway grade data. These are summarized in Table 3.2-23 [8], [9], [10]. The conclusion that may be reached from these references is that a large portion of the nation's roads are at 3 percent average grade or less. Therefore, it would seem reasonable that vehicles

TABLE 3.2 – 22
ICE FUEL ECONOMY

		1985 VEHICLES					
CLASS		MINICOMPACT 1	SUBCOMPACT 2	COMPACT 3	MID SIZE 4	LARGE 6 TAXI & POLICE	LARGE 5
1985 IN–PLACE	EPA						
	COMBINED	30.0	26.8	22.7	19.3	19.4	18.2
	CITY	26.0	23.2	19.7	16.7	16.6	15.7
	HIGHWAY	37.0	33.1	27.9	23.8	24.5	22.5
	SAE	22.4	18.3	14.4	11.2	11.5	11.9
1985 NEW	EPA						
	COMBINED	36.7	33.5	27.8	25.9	27.0	25.2
	CITY	31.8	29.1	24.1	22.5	23.2	21.9
	HIGWAY	45.1	41.2	34.2	31.8	33.4	31.0
	SAE	27.3	23.0	17.6	15.1	16.1	16.6
1985 OPTIMUM							
	COMBINED	44.0	38.0	34.0	32.0	31.1	29.0
	CITY	38.2	33.0	29.5	27.8	26.7	25.2
	HIGHWAY	54.1	46.7	41.8	39.3	38.9	35.6
	SAE	32.9	26.1	21.5	18.6	18.4	19.2

TABLE 3.2 – 23
SURVEY OF HIGHWAY GRADES

SOURCE	REMARKS
1. CLAFFEY, P.J. "TRAVEL ESTIMATES FROM FUEL CONSUMPTION INFORMATION", FINAL REPORT, CONTRACT DOT–FH–7833, SEPTEMBER 1972 (11).	A. 90 % OF INTERSTATE SYSTEM for ROLLING TERRAIN HAS MAXIMUM OF 3% AVERAGE GRADE. B. 82 % OF FEDERAL AID PRIMARY SYSTEM FOR ROLLING TERRAIN HAS MAXIMUM 3% AVERAGE GRADE. C. 85% OF FEDERAL AID SECONDARY SYSTEM FOR ROLLING TERRAIN HAS MAXIMUM 3% AVERAGE GRADE.
2. HORSEPOWER CONSIDERATIONS FOR TRUCKS & TRUCK COMBINATIONS, WESTERN HIGHWAY INSTITUTE, TEA505W4A35 NUMBER 2C.2, 1969 (12).	MAXIMUM GRADES ON MAIN HIGHWAYS USED BY INTERSTATE TRUCKS IN 11 WESTERN STATES IS ROUGHLY 6 %.
3. SURVEY OF GRADES IN U.S. BUREAU OF MOTOR CARRIER SAFETY (13).	GRADES EXIST WHICH ARE: A. 3% OR MORE AND 10 MILES OR MORE IN LENGTH. B. 6% OR MORE AND 1 MILE OR MORE IN LENGTH. C. 10% OR MORE AND 1000 FT OR MORE IN LENGTH.

should be capable of traversing these grades at speeds ranging from 45 to 55 mph for grade lengths up to 10 miles. This range of speeds was based on the minimum and maximum speed limits on U.S. interstate highways. The fact that grades more severe than 3 percent do exist and should be within the vehicle capability, leads to the moderate gradeability requirement at 8 percent for a 2 mile length. The 15 percent grade requirement was found to be necessary for parking garage ramps. The maximum grade on parking garage ramps specified by the City of Chicago is 13 percent. The 0.2 mile length was specified under the assumption that a maximum of 10 parking garage stories will need to be traversed. The grade requirements arising from these observations and judgements are summarized in Table 3.2-24 below.

Table 3.2-24 - Grade Requirements

55	mph	at	3	percent	grade	for	5	miles
45	mph	at	3	percent	grade	for	10	miles
35	mph	at	8	percent	grade	for	2	miles
15	mph	at	15	percent	grade	for	0.2	miles

d) Acceleration: The vehicle acceleration requirements were evaluated in terms of safety. Vehicular accident involvemnts may be correlated to differences in average speeds of two vehicles. Data prepared by David Solomon, "Accidents on Main Rural Highways Related to Speed, Driver and Vehicle" [11], has been used for this purpose. These data relate the rate of accident involments to the number of miles a vehicle has traveled. A range of constant vehicle accelerations was assumed for the various acceleration requirements (0/31, 0/56 and 25/56 mph) and the number of accident involvments which would be accrued, during the time that two vehicles were moving at some speed differential, calculated. The speed difference was used with the referenced data to calculate the increase in the number of accident involvements over that which would have taken place had there been no speed differential. This analysis did not establish a basis for changing the minimum specifications set by JPL. The accident involvment increase resulting from the JPL minimum specifications and those which could be expected from 1979 Cutlass and 1979 Covettes are shown in Table 3.2-25. The Cutlass is rather typical of the low end of acceleration, while the Corvette represents the high end. As it may be seen, the minimum JPL requirements for acceleration are quite similar to the acceleration provided by the Oldsmobile in that the times and increase in accident involments are similar. The gratest increase in the number of accidents will be experienced by the taxi/police vehicle, class K_6. However, this increase amounts to a little over one accident involvement per K_6 vehicle per year for performance just meeting the minimum JPL requirements. The significance of the minimum acceleration requirements are examined further in relation to the cruise and top speed characteristics.

e) Speed Requirements: A literature search was performed for the purpose of determining the cruising and top speeds for the reference vehicles.(1) These speeds were to be based on current and past driving trends on interstate highways and it was believed that they should not be wholly determined by the 55 mph national speed limit, because it may be changed in the future. Based primarily on data regarding the amount of vehicle operation above 55, 60, 65 mph etc, cruise speed capability for vehicles K_2, K_3, K_4, and K_5 was set at 65 mph. This speed reflects the 90 percent percentile speed on rural interstate highways.

(1) Ref. [12], [13], [14].

TABLE 3.2 – 25

INCREASE IN ACCIDENT INVOLVEMENTS RELATED TO ACCELERATION

SPEED RANGE FOR ACCELERATION	1979 OLDSMOBILE CUTLASS		1979 CORVETTE		JPL MINIMUM REQUIREMENTS	
	ACCELERATION TIME, SECONDS	INCREASE IN NUMBER OF ACCIDENT INVOLVEMENTS*	ACCELERATION TIME, SECONDS	INCREASE IN NUMBER OF ACCIDENT INVOLVEMENTS*	ACCELERATION TIME, SECONDS	INCREASE IN NUMBER OF ACCIDENT INVOLVEMENTS*
0 to 31 mph	5.8	12	2.6	7	6	11
0 to 56 mph	14.1	4000	5.8	1600	15	5230
25 to 56 mph	9.8	110	3.2	35	12	140

* THE ACCIDENT INVOLVEMENTS ARE STATED "PER 100,000,000 MILES".

Vehicles K_1 and K_6 are intended to be mainly urban vehicles whose high speed travel can be characterized by speeds on urban interstate highways. Speeds on urban interstates are, on the average, lower than on rural interstates, and the amount of vehicle operation on these road for K_1 and K_6 is less than the other classes. Therefore, the cruise speed was set at 55 mph, or roughly the 50 percent percentile speed.

Top speed was calculated such that the vehicle would have enough acceleration to pass a vehicle traveling at a constant 65 mph for vehicles K_2, K_3, K_4, K_5 and 55 mph for vehicles K_1 and K_6. This passing must be accomplished in the minimum allowable distance for the particular speed (1100 ft at 65 mph and 900 ft at 55 mph) (1). Using the equations of motion, and the given passing distance, a calculated acceleration of less than 1 mph/s was needed throughout the passing interval. Relating this to an acceleration versus velocity curve (for an Oldsmobile Cutlass), it was found that this minimum acceleration could be achieved up to within 3 mph of the top speed. Therefore, the design top speed is the speed at the end of the minimum passing interval plus 3 mph. For vehicles K_2, K_3, K_4, K_5 this top speed is 75 mph, and for vehicles K_1 and K_6, top speed is 68 mph. Figure 3.2-6 shows a typical performance curve which is illustrated by the acceleration versus speed for the 1979 Oldsmobile Cutlass. Its data are differentiated from trade magazine test data, relating times to various speeds as the calculated points were smoothed in preparing the plot. The lower horizontal line segment labeled "Class K_2-K_4 and K_5 Cars" represents the assumed constant acceleration required to pass within 1100 ft a vehicle traveling at constant 65 mph speed by another vehicle initially traveling at 65 mph. The other line segment, above and slightly to the right of the first one,

---

(1) The minimum passing distance is based upon FHWA Safe Passing Standards

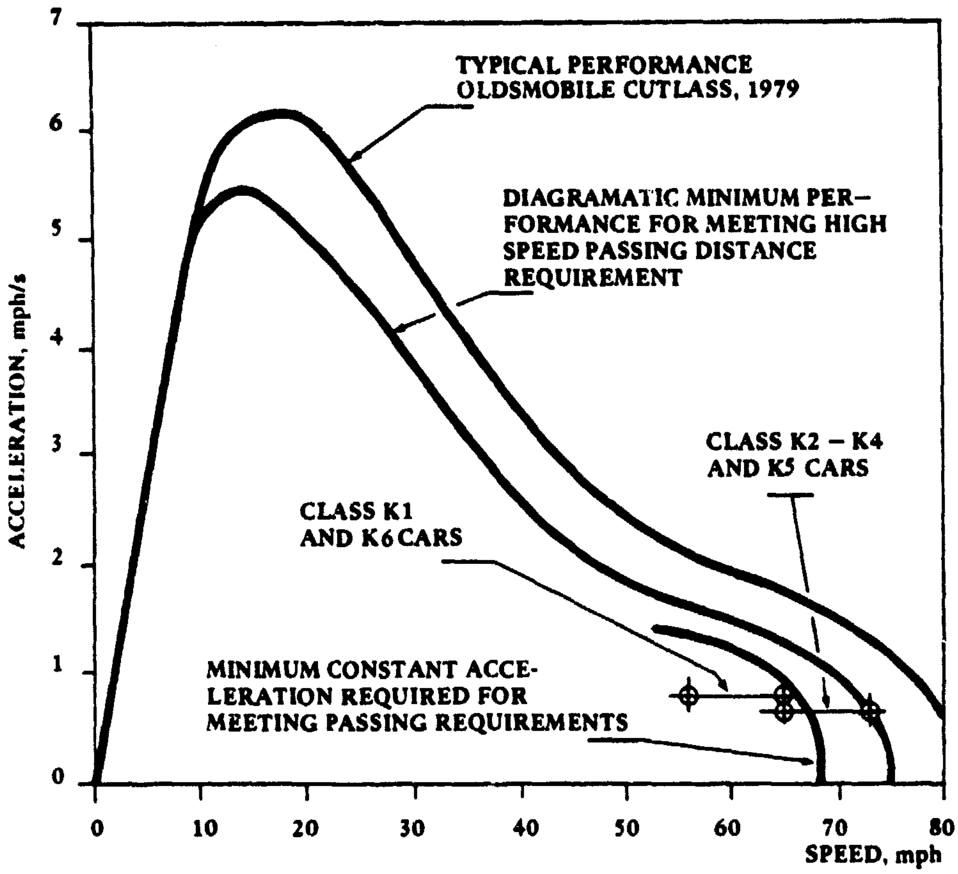


FIGURE 3.2 – 6
ACCELERATION VERSUS SPEED PERFORMANCE CHARACTERISTICS

represents the same data as for the first one. Only in this case it is the required acceleration for passing from 55 mph within 900 ft. The curve labeled "Diagramatic......Requirement" was constructed to be "parellel" to the Cutlass performace curve speed resulting from the acceleration during the high speed pass. It was assumed that the initial portions of the two performance curves would be the same. A similar curve could be developed for the K_1 and K_6 class vehicles, as the partial curve indicates.

The diagramatic performance curve was integrated to establish the speed versus time performance. These data were used to compare the requirements for the high speed pass to the minimum JPL requirements; if the high speed pass requirements are less stringent than the JPL's, then the minimum JPL requirements are satisfactory. Figure 3.2-7 presents the desired speed versus time history for the hypothetical performance data describing a vehicle which will meet the minimun high speed passing requirements. As indicated in Figure 3.2-7, the performance of a vehicle which meets the high speed passing requirements will accelerate to 31 mph in 7.2 s and to 56 mph in 19 s. This curve also indicates that the acceleration time between 25 mph and 56 mph is 12.6 s. In all cases, the acceleration profile which meets the high speed pass criteria is less "demanding" in performance than the minimum JPL requirements. Therefore there is no incentive to change the minimum requirements and they are specified accordingly to JPL.

f) Climatological Considerations: The contiguous United States are in a temperate climatic zone. The 48 states can be divided into seven physical regions [15]

1. Pacific Coast
2. Cascadesierra Nevada Mountains
3. Intermountain Plateau

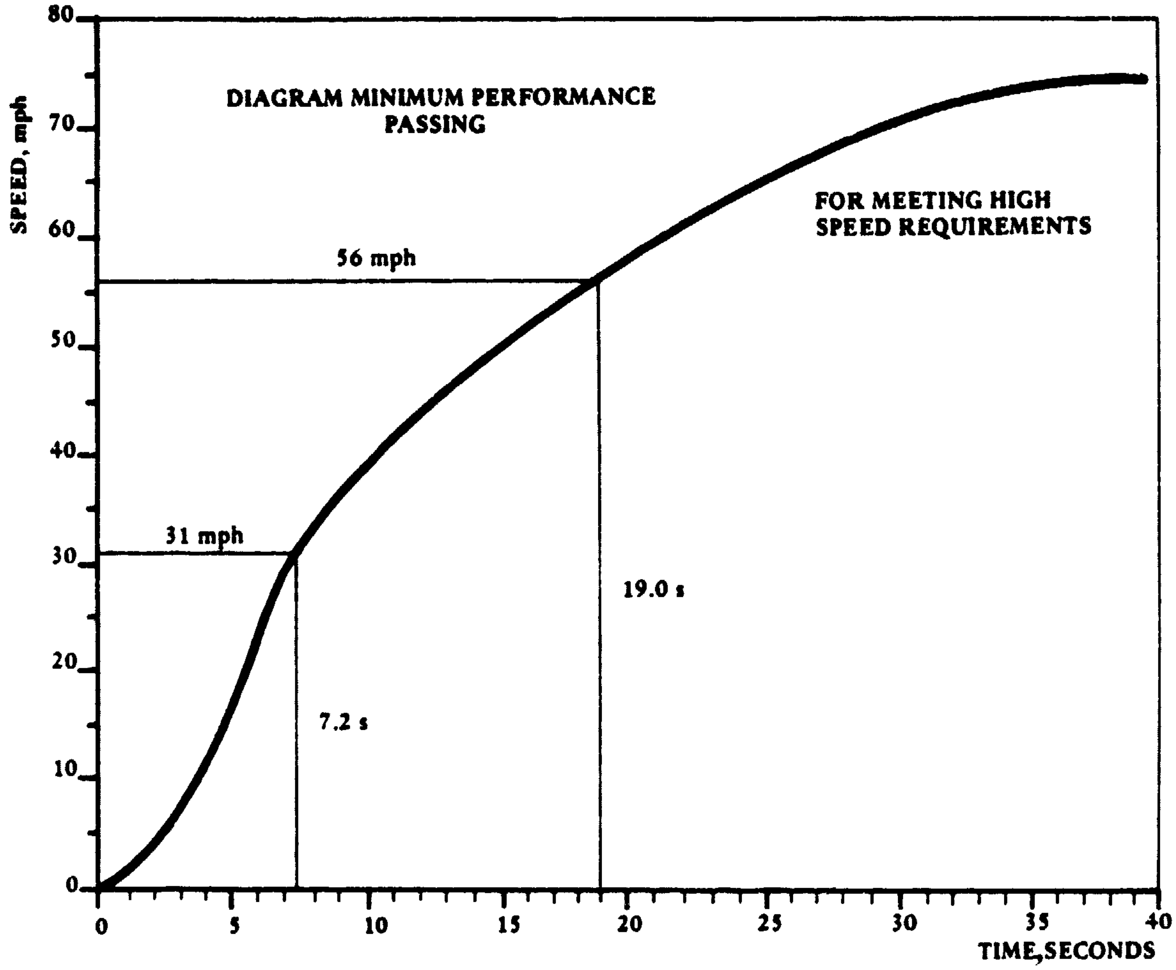


FIGURE 3.2 – 7
SPEED VERSUS TIME PERFORMANCE CHARACTERISTICS

4. Rocky Mountains
5. Great Interior, Southern Plains and Lowlands
6. Appalachian Mountains
7. Middle and North Atlantic Lowlands

The coldest temperatures are found in the extreme northern interior and in the higher mountain elevations, while the extreme southern areas are the warmest. The mean annual temperature of the contiguous United States is 53.2°F. In the summer, the warmest regions are the interior valleys and desert areas of the far Southwest, the southern great plains and the deep south, while the coolest areas are the extreme northern districts and the mountains. The temperature ranges form average summer highs of 100 to 110°F in Arizona and California to average winter highs of 10 to 15°F in Minnesota. Thus, the contiguous states represent a rather wide variation in temperatures as the overall average of 53.2°F would indicate.

Climatological considerations are relevant to the hybrid vehicle mission study due to their impact on the automobile passenger compartment heating and cooling requirements. The southern portions of the country will need more vehicle cooling than heating and the opposite will hold for the northern regions. The initial design should be based on a representative average value. The criterion for the necessity of cooling (air conditioning) was chosen as a daily maximum temperature above 90°F. The criterion for necessity of heating was chosen as a daily minimum temperature of 32°F and below. These values seemed to be reasonable and, furthemore, information was readily available in the national weather documents on these temperature limits. Based on these selected temperature limits, the average number of days and energy requirements for vehicle heating and cooling can be estimated. Climatological maps [16] indicate the averages summarized in Table 3.2-26. Other data [17] showed that Chicago had 125 days below 32°F and 20 days above 90°F. Therefore a reasonable requirement for the near-term hybrid vehicle design would be the capability to provide the heating and cooling requirements listed in Table 3.2-26 for a minimum period of 2 to 3 hours (for each condition listed).

Table 3.2-26 - U.S. Average Heating and Cooling Days

Mean Annual Number of Days at the Minimum Temperature 32°F and Lower	90-150 days
Mean Annual Number of Days at the Maximum Temperature 90°F and Above	30-60 days

g) Availability: The availability of the reference vehicles must be equal or better than the vehicles in the in-place fleet. Table 3.2-27 provides data on "critical" vehicle components/subsystems which were used to estimate the average (MMBF) of the in-place fleet [18]. The exponential failure law was used to calculate an MMBF of 1335 miles. Then the probability (P_s) that no failure will occur during a given driving cycle of "m" miles is given by

$$P_s = e^{-m/MMBF} = e^{-m/1335} \qquad (3-2)$$

From equation (3-2) it may be seen that the greater the trip miles, the lower the probability of having no breakdowns. The police/taxi mission (K_6) which has a yearly travel of 20,000 miles will surely have a breakdown without performing routine preventive maintenance. The probability of survival for a

TABLE 3.2 – 27
COMPONENT MEAN MILES BETWEEN FAILURE (MMBF) **

MMBF THOUSANDS OF MILES	COMPONENT DESCRIPTION
90	IGNITION COIL
72	ENGINE ASSEMBLY
65	POWER STEERING PUMP
62	BRAKE MASTER CYLINDER
60	WHEEL BEARINGS
59	FUEL PUMP
55	GEAR BOX, STEERING
55	BRAKE DRUMS
55	STARTER MOTOR
54	GENERATOR / ALTERNATOR **
54	VOLTAGE REGULATOR
54	TRANSMISSION GEARS
50	SPRINGS AND SHAKLES **
45	BRAKE PEDAL
45	BRAKE LINKAGE
45	DISC BRAKE CALIPERS
45	BRAKE POWER ASSIST SEALS
45	POWER TRANSMISSION CLUTCH
45	UNIVERSAL JOINTS
45	DIFFERENTIAL SEALS
42	DRUM BRAKE LININGS
40	SUSPENSION LINKAGE
40	SHOCK ABSORBERS
38	CLUTCH THROW OUT BEARING
36	STEERING BUSHINGS FOR: LINKAGES
36	: KNUCKLES
36	WATER PUMP BEARINGS
36	BALL JOINTS AND KING PINS **
35	WATER PUMP HOSES
32	TIRES
28	POWER STEERING DRIVE BELT
15	ACCELERATOR PEDAL / LINKAGE **

* SOURCE: E.N. WELLS, ET AL., "INVESTIGATION OF USED CAR SAFETY STANDARDS", VOLUME II, DEGRADATION, FAILURE, AND CRITICALITY OF MOTOR VEHICLE SYSTEMS AND COMPONENTS, OPERATIONS RESEARCH INC., SILVER SPRINGS, MARYLAND, 12 SEPTEMBER 1969.

** TWO COMPONENTS

minicompact traveling only around 4,000 miles annually is predicted to be about 4.6 percent.

The large vehicles have miniscule survival, without breakdown, probabilities. The police/taxi mission has only a 0.0003 percent probability for having no breakdowns during its annual travel. Note that the failure rate is based on limited data pertaining to the "used car" fleet. Thus the interpretation which is placed on the MMBF is that this is a mean value which describes the mean availability of the vehicles during their approximate useful lifetime. The service life of vehicles decreases rapidly after the seventh to eighth year of service so that the MMBF may be thought of as describing a vehicle in about its fourth year of service. It is furtner noted that the variance of an exponential failure distribution is the square of the MMBF or just under 1.8 million miles.

Monthly routine maintenance requirements should not exceed those of the ICE vehicles in the fleet. The current routine maintenance [19] is required periodically every 7,500 miles (approximately) or 12 months. Under some conditions the requirement is stated in terms of calendar time rather than miles driven. This is particularly true in special areas of the country, e.g., localities where there is excessive dust. It would appear that during the timeframe to 1985, the calendar periodic maintenance requirements would be extended so that they should be no more frequent than quarterly.

Under these assumptions, the number of routine maintenances required by vehicle class due to driving may be estimated. The typical annual mileage for minicompacts is expected to be small enough that service should be required annually. The typical subcompact, compact and midsize vehicles should require only 1 to 2 routine maintenances per year. The typical larger vehicles with higher yearly mileage should also be maintained satisfactorily with two annual maintenance services. The taxi/police large vehicles should be maintained satisfactorily with three routine service yearly.

The mean miles (driven) between failures indicated by equation (3-2) show that the number of breakdowns will be a function of the vehicle usage. MUBF is equivalent to MMBF.

The power train and brake subsystems represent an aggregation of component failures and therefore the MUBF is less than any one item listed in Table 3.2-28

Table 3.2-28 - Summary of Mean Usage Between Failures

Item	MUBF
Powertrain	14,480 km (9000 miles)
Brakes	8,410 km (5230 miles)
Vehicle	2,150 km (1335 miles)

The MUBF for a system composed of separate components with individual MUBF is found by adding the reciprocals of the individual MUBF and than taking the reciprocal. This also holds for the entire vehicle.

Repair time for the vehicle, for routine maintenance of breakdowns, has been defined as the time the car is not available for its intended use. The minimum time for any maintenance or repair has been set as 8 hours and the daily use time has been taken as 8 hours also. Routine maintenance is defined as taking 8 hours; customarily this is the usual time lost for this type of service. Time lost for repair of breakdowns is also 8 hours in most cases. Referring to Table 3.2-28, only the engine and transmission (gears) are assumed to require longer service times. That for the engine is taken as 24 hours and for the transmission gears, 16 hours. On this basis, the mean repair time is 8.67 hours (1.083 days) with a standard deviation of about 3 hours (the square of the standard deviation).

Just as in the case of the MUBF, time for each vehicle class being dependent on its usage, so is the maintenance and/or repair time. The availability of a vehicle is defined as

$$A = 100\% \times (1-T_o/T_a)$$

where

A is the availability, %

T_o is the total time the vehicle is out of service (hr)

T_a is the total time the vehicle could be in service (hr)

Since the routine maintenance and repair of breakdowns depend upon mission usage, the availability of each class vehicle will be different. The routine maintenance time lost for the missions varies from 8 to 24 hours. The usage rates for the various vehicles and varying numbers of failures lead to varying repair periods. The number of breakdowns is from 3 to 15, annually. This frequency is sufficient to preclude losing time for routine maintenance alone. In other words, the routine maintenance will be performed at the same time a repair (of a breakdown) is made.

h) Vehicle Characteristics Summary

The parameter study has established the mission related vehicle characteristics required as output for the vehicle characteristics study.

In some instances there has been no basis established to deviate from the minimum values established by JPL. These instances were cost constraints and acceleration. Life cycle costs were calculated for the large vehicle only, class K_5, and are therefore not included in the vehicle characteristics summary as explicit numerical values.

The final values are provided in Section 5. Primary Results.

i) Life Cycle Costs

Costs were estimated for the K_5, large, general purpose vehicle. Two sets of these costs were prepared for the vehicle representing the average new 1985 vehicle, and the optimum new 1985 vehicle. JPL guidelines were followed in preparing these costs.

The acquisition cost analysis was initiated by establishing a purchase price for a 1978 Impala with a V-8 305 CID engine which had all the popular amenities included (those specified for the reference vehicle) [20]. The purchase price of $ 6,116 was increased to be applicable to the mean vehicle in the K_5 class by the use of a technology cost increase factor of 5 percent per annum. The base cost of the 1985 car was calculated to be $ 9,036 (purchase price in 1978 dollars).

The sales tax was computed according to the JPL guidelines of 5 percent ($ 452) and the total of the purchase price and sales tax were used to calculate the 4 year interest charge at 12 percent annual rate. The $ 850 interest per year discounted 2 percent/year results in a total interest charge of $ 4,337. The useful life of the vehicle has been assumed to be 100,000 miles or 10 years, whichever comes first with 13,300 average annual traveled miles. In this case, the useful life is 7,5 years and the salvage value has been taken as zero. The sum of these figures determine the acquisition cost as $ 13,825. Routine maintenace, repair and tire cost were determined from: Liston and Aiken, Cost of Owning and Operating an Automobile, DOT, 1977. [21] The cost presented in this reference are in terms of 1976 dollars. Using a U.S. News and World Report, [22], the inflationary effect for cars was determined to be 18.2 percent over the years form 1976 to 1978. The costs in the Liston report were escalated to take this inflation into account. The maintenance costs were reported over a 10 years period and covered 100,000 mile. These costs were redistributed over the 7.5 year life for the average new K_5 wehicle on the basis of annual mileage accumulation. These annual costs were used to calculate fractions of the vehicle acquisition cost so that they could be applied to the acquisition costs of the 1985 vehicles in estimating the operating costs for them. The maintenance costs were also discounted 2 percent per year and the total cost was $ 6,471.

The yearly cost for the annual taxes, license and registration was set at $ 33 (as stated in the JPL guidelines). These costs were discounted at the standard rate (2%) and came to $ 240. The insurance costs were also calulated as per JPL recommedations: $ 175 + 0.01% of the purchase price for each of the first 5 years ad at $ 75 + 0.006% of the purchase price for the sixth year. The yearly cost for the initial period was $ 215 and for the remaining years, $ 129. The total, 2 percent discounted cost, came to $ 1,343. The average on-the-road fuel economy used was 27.7 mpg and with the 13,300 average annual mileage driven, amounted to an annual fuel consumption of 480 gallons. This corresponds to a life time total of 3610 gallons. The cost of the gasoline was calculated according to the JPL established procedure. The yearly cost used are:

Year	¢/gal	Year	¢/gal
1985	95.5	1989	108.0
1986	99.5	1990	110.0
1987	103.0	1991	111.7
1988	105.7	1992	113.0

The total discounted fuel cost for the 7,5 years was $ 3,519 making the total operating life cycle cost $ 11,573.

The total life cycle cost of the average new 1985 vehicle, purchase plus operating, is $ 25,398. On a yearly basis this amounts to $ 3,372 and on distance traveled basis: 25.4¢/mile or 15.8¢/km. The life cycle costs for the optimum new 1985 vehicle were calculated in the same manner as described for the average new vehicle. The purchase price of the vehicle was increased to $ 9,940 by the method described. The percentage maintenance cost were applied to the total acquisition cost of $ 15,206. The on-the-road fuel economy is 31.8 mpg so that a total of 3150 gallons of gasoline would be used in the useful life. The total operational cost is $ 11,783, making the total life cycle cost $ 26,989. The key cost figures for the two 1985 vehicles are presented in Table 3.2-29.

3.2.3 Vehicle Performance Specifications

The preceeding Subsections have described the efforts undertaken in the two initial subtasks in the mission analysis methodology. These subtasks have defined mission requirements for a proposed hybrid vehicle as user identified. Additionally, procedures have been established and measures identified for characterizing the fuel consumption for various classes of vehicles. Within each class of vehicle performance, user perceived requirements were maintained at the level of conventional passenger automobile technology. These input data were used to characterize appropriate levels of fuel consumption and acceptability into the automobile fleet. It should be noted that acceptability was defined as the capability to be inserted into that market segment without any evaluation of the consumers acceptance of the vehicle.

This final task is directed at generating a data package containing all of the functional requirements used to design the

TABLE 3.2 – 29
LIFE CYCLE COSTS: LARGE GENERAL PURPOSE VEHICLE (K5) *

ITEMS VEHICLES	NEW 1985	OPTIMUM 1985
PURCHASE PRICE, $	9036	9940
SALES TAX, $	452	497
INTEREST, $	4337	4769
SALVAGE VALUE, $	0	0
A - ACQUISITION COST, $	13,825	15,206
TIRES, REPAIRS AND ROUTINE MAINTENANCE, $	6471	7123
ANNUAL TAXES, LICENSE AND REGISTRATION, $	240	240
INSURANCE, $	1343	1401
FUEL, $	3519	3019
B - OPERATING COSTS, $	11,573	11,783
C - LIFE CYCLE COST, $ (A+B)	25,398	26,989
D - LIFE—7.5 YEARS AND 100,000 MILES		
COST / YEAR, $	3378	3589
COST / MILE, ¢	25.4	27.0
COST / KILOMETER, ¢	15,8	16,8
E - ON–THE ROAD FUEL ECONOMY, mpg	27.7	31.8

* ALL COSTS DISCOUNTED AT 2% PER YEAR AND IN 1978 DOLLARS

hybrid vehicle candidate. As directed, these specifications have been developed from the reference vehicle ICE technology.

This procedure eliminated the need for detailed data pertaining to hybrid vehicle performance which would not be available until later phases of this program. Instead, reliance was placed upon evaluating the hybrid vehicle considerations subjectively in relationship with the selected reference vehicle.

3.2.3.1 Hybrid Vehicle Considerations

This Subsection provides a first-order summary of the effects of required minimum performance and vehicle characteristics on the HV system configuration and its related costs.

a) Performance Effects - The K_5 vehicle determined to be most appropriate H.V. candidate by this study should provide an acceptable equivalent to current "full size" automobiles being produced by Ford, General Motors, etc. That is, a surrogate downsized LTD or Impala capable of performing missions now commonly undertaken with such vehicles.

   This capability requires that equivalent vehicles be able to perform the average mission associated with full size and lesser vehicle classes, without being necessarily precluded from common extreme missions such as vacation trips. In order to perform a vacation type mission, these vehicles must be capable of cruising long distances at safe highway speeds carrying a full load of passengers and cargo without discharging the batteries to a level that would reduce passing and hill climbing ability below the minimum requirements.

   The engine should therefore be tentatively sized to provide full cruising speed or to maintain minimum speed on the shallower grades, whichever is greater, on engine power alone without relying on power drawn from the batteries. The selection of motor power and to a large extent the peak short-term amperage requirement for the batteries will be determined by the acceleration and steeper grade requirements, again whichever is greater.

The sizing of both the engine and the motor are, of course, functions of vehicle size, weight and configuration (streamlining) as well as transmission and drive line efficiencies, tire rolling resistance, and power required for amenities. Although analysis has shown that some fuel savings can be achieved by operating the vehicle on motor power alone for some portion of a typical mission, the necessity of providing continuous power to the amenities, particularly heating and air conditioning, will probably preclude this type of operation during temperature extremes since it appears more fuel-effective to provide interior heat extracted from the engine cooling or exhaust system rather than to provide an auxiliary fuel fired heater. Air conditioning, power steering and power brakes also could be more efficiently supplied from the engine rather than from the drive motor and/or auxiliary battery powered motors. These assumptions are to some extent drive-and-control strategy dependent and must be considered in the tradeoff analysis to be performed during succeeding tasks.

Battery storage capacity should be generally determined by the requirements of a typical maximum range mission. Assuming that the engine is providing the majority of the vehicle power, assisted by the battery-powered motor during high demand periods, the battery should be capable of providing power for sufficient acceleration and hill climbing for a highway mission and also for a large percentage of other missions.

Battery capacity is also generally greatly reduced by low temperatures and must be sufficient for operation in cold climates and/or battery heaters must be provided. These requirements will of course be determined accurately during the trade-off studies.

b) Cost Effects - The intent of a hybrid vehicle is to conserve petro fuels while providing a vehicle with acceptable room and performance capabilities at a reasonable cost. However many of the techniques that can be applied to conserve fuel in a hybrid vehicle can also have an adverse effect on the vehicle initial and life cycle cost (LCC).

The hybrid vehicle is inherently more complex than a current automobile because of the addition of a motor, controller, and batteries to a vehicle that retains most of the powertrain components of a standard ICE vehicle. Although some savings in initial cost can be realized (depending on the hybrid configuration selected) by the possible elimination of a transmission, the reduction in engine size or a reduction in engine and emissions control equipment, the probability of reducing the initial cost below that of an equivalent ICE vehicle seems small.

Saving therefore must be incurred through a reduction in LCC. Major factors in LCC that can be influenced by the design of the vehicle include initial vehicle cost, maintenance and repair and fuel/power costs.

Some maintenance and repair costs may be reduced because of the use of smaller less complex engines with fewer emissions controls or the possible elimination of the transmission. This is made possible by relieving the engine from peak load responsibility. The additional complexity of the total system should have and adverse effect.

The objective of the design program must therefore be to maximize fuel/power efficiency while minimizing any adverse effects in initial and maintenance/repair costs.

This is a very complex issue which will be addressed during the tradeoff studies.

3.2.3.2 Vehicle Performance Study

As discussed previously, the mission related vehicle performance characteristics were identified for each class of vehicle in the U.S. fleet. A minimum set of performance specifications were derived for each class of vehicles. Therefore it has been necessary to provide an additional performance study related to the specific hybrid vehicle at this point of the analysis. A set of performance specifications was developed consistent with the selected mission usage which would allow substitution of the hybrid vehicle for the reference vehicle as specified. The list of performance specifications is presented in the following Section 5, "Primary Results", with a brief discussion of the rationale behind the establishment of each of the performance specifications which in all cases meet or exceed the JPL minimum requirements.

3.3 LIST OF RELATED APPENDICES

The following Appendices have been included in Volume II of this Report, in compliance with JPL Data Description Requirement, to provide Flow-diagrams and Description of Computer Models developed in defining the Methodology used for the Mission Analysis.

Appendices related to parameters and/or interim results of the Mission Quantification are attributed to Section 4 of Volume I (Interim Results) and are therefore included in the following Section A.4, while the method used to implement assumption 2.2.8 on Section 2 of Volume I has been considered related to the methodology development and therefore included in this Section.

Appendix A.3-1 : Maximum-Likelihood method for Normal Parameters evaluation

Appendix A.3-2 : Model for the synthesis of daily distance distributions

Appendix A.3-3 : Projection of car ownership distributions

SECTION 4

INTERIM RESULTS

4.1 SUMMARY OF INTERIM RESULTS

This section deals with preliminary/tentative assessments or calculations leading to "interim" primary results as well as with the interim results obtained in the process of defining the primary results presented in the following Section 5.

It was felt appropriate to include information of the first type to provide complete description of the Mission Analysis as performed in accordance to the monthly reporting JPL was provided with and to show the impact on the primary results of different assessments and or calculation procedures. This summary contains therefore a brief description of the various items while detailed quantitative results are provided within the related appendices.

The interim results, on the other hand, consist of specific numerical values related to the various trip parameters distributions, calculated according to the methodology described in the previous Section 3. It was therefore felt appropriate to collect all such data in the appendices, were all reference values could be found and compared, rather than disperse them at the end of the corresponding subsections along the methodology description.

4.1.1 Tentative Mission quantification

As previously outlined in Subsection 3.2.1 upon defining a trip purpose to mission correspondence, it was considered the possibility of a "natural" mission characterization, in terms of fleet penetration, that is of identifying the number of vehicles which should perform a given mission with the projected mix in terms of vehicle size classes which could more appropriately perform such a mission.

As a result Mission M_1 (intraurban-local) was identified with minicompact K_1 vehicles (10,2% of the 1985 in-place fleet) Mission M_2 (urban-suburban) was identified with the intermediate classes from subcompact K_2 to midsize K_4 vehicles (67,4%) and Mission M_3 with large size K_5 vehicles (22%).

The total trips for the various purposes were assumed to be uniformely distributed among the various missions and the results presented in Appendix A.4-1 were obtained.

The analysis of these results had shown that a uniform trip purpose distribution per mission combined with an independently obtained fleet mix distribution could not mantain the original trip distribution among the various purposes. Mission M_1 would therefore show a much smaller than average annual mileage due to the fact that its trip purposes P_2 and P_3 are excessively diluted among the other missions even though the correspondent percent of vehicles is also rather small.

Mission M_3 on the other hand, while showing an annual mileage much larger than the total average due to the limited size of its fleet, would be characterized by an insufficient percentage of total annual miles to account for all travel due to P_4 trip purpose and for a certain amount of the remaining trip purposes.

Finally mission M_2, showing an annual mileage close to the total average, appeared to correspond to a fleet size much larger than appropriate, to only account for a fraction of work related trips P_1 in addition to the rest of P_2 and P_3 trips.

In conclusion it appeared that mission quantification in terms of the number of vehicles performing a given mission must be the result of a trip purpose distribution alone and cannot be associated with independently projected vehicle class mix.

On the other hand it can be noted that daily distance distributions at the higher percentiles used to characterize the mission capabilities rather than the average mission characteristics, are much closer to the final data presented in Section 5-Primary Results.

Considering that the daily distance distributions are not obtained from observed data as the other parameters distribution but only as a combination, by means of a computer model, of the trip length and annual distance observed distributions, it could be concluded that the model itself and its basic assumptions provide some form of compensation of the different assumptions that must be made on trip purpose/mission combination and, as a result, on the missions annual distance distributions.

4.1.2 Intermediate Mission quantification

As a result of the tentative mission quantification previously described it was considered necessary to perform a mission quantification based upon trip purpose and vehicle distributions among the various mission resulting from an assessment of the existing "changing" trend from a standardized to a specialized use of personal vehicles.

Various trip purpose/mission distributions have been evaluated covering the whole range from full standardization to theoretical full specialization. Resulting percentages of vehicle fleet and corresponding average annual miles/vehicle were obtained for mission M_1, M_2 and M_3, as presented in Appendix A.4-2, assuming that, on the average, vehicles would perform the same number of trips in the various missions. This assumption was consistent with the reasonable implication that vehicle used on a more limited number of trip purposes than in the average household will perform more trips of these specific purposes than in the average household itself.

The expected 1985 distribution was assumed to fall within a given range, the high and low-boundaries of which were fully quantified in terms of mission parameters.

The most relevant results, presented in Appendix A.4-2 are more in line with the Primary Results presented in the following

Section 5, the main difference in methodology being that trip purposes are not analyzed for households with different car ownership and vehicles per mission are not accordingly specifically assigned as described in Section 3.

Vehicle Class/Mission distributions were not evaluated since the mission quantification was not completed when a decision was made to proceed with the final Mission Quantification itself.

The value of average annual miles/vehicle in Mission M_3 higher than in the final Mission Quantification can be explained considering the smaller quota of vehicle fleet attributed to this mission (implying lesser usage of general purpose vehicles).

It should be noted that, besides the qualitative aspect of using the most appropriate methodology to obtain a given result, the main quantitative difference in methodology used in the intermediate and final mission quantifications is related to the better knowledge of actual vehicle availability, resulting from actual car ownership per household, which provides a better ground to assess the trip purpose/mission distribution.

As far as the overall "combined" Trip purpose quantification a comparison between Tables 3.2-1 (valid for the intermediate Mission Quantification) and 3.2-10 show that:

a) Trip purposes P_1 increase from 36.2% (1969) to 36.9% (1985)
b) Trip purposes P_2 decrease from 31.0% (1969) to 30.3% (1985)
c) Trip purposes P_3 increase from 9.3% (1969) to 9.8% (1985)
d) Trip purposes P_4 decrease from 22.4% (1969) to 21.9% (1985).

Since trip length (referred to 1969 annual miles/vehicle) increases from 10.2 (1969) to 10.6 miles (1985) for P_1 and from 13.1 (1969) to 13.5 miles (1985) for P_4 and varies by .1 miles for P_2 and P_3, the two approaches to mission quantification provide a difference of slightly above a percent in the average annual miles/vehicle for P_1 (Earning a living) and less than half a percent for the other trip purposes.

The expected accuracy of the assessment made on trip purpose/mission and vehicle class/mission distribution should obviously be much worse and this should confirm that the only significant impact of the final mission quantification should be the better "visibility" of vehicle availability in assigning their usage to special or standard purposes.

4.2 LIS'.' OF RELATED APPENDICES

The following Appendices have been included in Volume II of this Report to provide detailed information on the subjects ontlined in this Section.

Appendix A.4-1 : Synthesis of Tentative Mission Quantification Results

Appendix A.4-2 : Synthesis of Intermediate Mission Quantification Results

Appendix A.4-3 : Synthesis of Mission Quantification Parameters

Appendix A.4-4 : 1985 In-place Fleet Fuel Economy Data.

SECTION 5

PRIMARY RESULTS

This section provides the quantitative results, in terms of mission specifications and vehicle characteristic and specifications, of the first task of the Near Term Hybrid Passenger Vehicle Development Program Phase I, the "Mission Analysis and Performance Specification Studies".

While Background Information, Significant Assumptions and Methodology as well as Interim Results, which led to the following results, are presented in the preceeding Sections, a detailed description of each Mission is provided here to expressely comply with the JPL Data Requirement Description. It is quite appropriate on the other hand to associate to the missions specifications, as handy reference, a synthesis of the specific background, assumptions and rationale that have contributed to such missions definitions. Taking also into account that the most appropriate passenger hybrid vehicle, identified by this study as the general purpose type, can perform any of the other missions, especially in the near term, such a requirement should help the reader in comparing the missions that could be performed by the hybrid vehicle to be defined in the following trade-off and preliminary design studies.

5.1 MISSION ANALYSIS

5.1.1 Missions Description

As illustrated in detail in the description of the methodology used to quantitatively define the missions' characteristics, mission characterization was accomplished primarily by reference to the major categories of trip purpose that are distinguished in the NPTS on the basis of a projected intermediate situation assumed to exist in 1985 as a result of the trend of changing automobile usage from the standard all-purpose cars of the 50's to the fully dedicated special-purpose cars expected for the 90's.

An indication of the usage patterns associated with the missions in terms of prevaling driving environment and trip purpose is provided by brief descriptive labels:

1) Mission M_1 Intraurban/local - Family business traveling

2) Mission M_2 Urban/suburban - Work commuting/traveling

3) Mission M_3 General purpose - Recreational traveling

4) Mission M_4 Urban/suburban - Taxi, police.

Only the first three missions were characterized on the basis of NPTS data; they do not represent disjoint segments of the spectrum of trip purposes but rather successively more inclusive aggregations of the trip purposes they encompass, as explained in detail in the following Subsections.

5.1.1.1 Mission M_1 - Family business traveling

This trip pattern is intended to be representative of vehicles which are used as primary purpose on personal and family business trips. These trips are on the whole relatively short and the origins and destinations are usually in the same local area, city or township. According to the NPT Survey they can of course be broken down into the subcategories of shopping, medical and dental care and other trips of similar nature.

The secondary purpose of this mission is identified with trips related to educational civic and religious activities, which are also similarly short and connected to local and intraurban traffic.

Mission M_1 is therefore typically performed using the second family car which at the present time can be often represented either by an older model large or mid size car or by a newer model of smaller size.

It must however be recognized that this mission can also be typical of elder retired people who typically drive relatively new and large cars for such specific trip purposes but tend not to use their own car for recreational or vacation trips.

Tentatively projecting this trip pattern to the mid 80's, one can expect to see increased buying, for this specific usage, in the range of minicompacts through compacts (both new and used cars) as second family car, decreasing usage of older family cars (as it would be worth to trade them in for smaller used cars, due to the increased costs of gasoline as well as of maintenance/spare parts/replacements) and steady usage of rather new cars of the larger sizes by retired people.

In conclusion this mission appears to be rather inappropriate for penetration by a hybrid vehicle as defined in the Near Term Development Program, because the smaller new cars would not comply with the 5/6 passenger requirements and the larger new cars must reach a customer category possibly not so appealed by outstanding fuel economy and advanced car design features.

5.1.1.2 Mission M_2 - Work commuting/traveling

This trip pattern is intended to be representative of vehicles which are used as primary purpose on work and work related trips for the generic purpose of earning a living. Work trips are typically longer than the family business trips and a great many involve commuting between urban and suburban communities.

In addition to such repetitive travel from the place of residence to the place of work in the form of daily round trips, 5 days a week, work trips cover occasional commuting to and from the airports, related to most of the business air travel, occasional business trips to business facilities within 1 to 2 hours driving as well as systematic over-the-weekend commuting by people who work and live during the working days close to business facilities 2 or more driving hours away from their family residence.

Finally mission M_2 includes extensive business travel by traveling salesmen and other people with similar work related needs to drive extensively all day long.

The secondary purpose of this mission is identified with trips related to occasional personal business and/or educational, civic, etc. activities typical of Mission M_1.

Mission M_2 is therefore typically performed, nowadays, using the first family or personal car, at least for commuting trips performed on limited access highways and beyond the range of local traffic, due to the need to avoid chances of breakdowns away from service stations in heavily congested traffic (commuting peak hours).

The NPTS data show that the primary trip purpose of this mission is characterized by the lowest car occupancy of all trip purposes. In fact work travel has been typically and will probably still be in the future a "driver-only" type of travel. However, since the time of the NPT Survey, 1970, as far as commuting trips are concerned, the "pool driving" has become more and more popular every year as a result of the increased price of gasoline as well as of the increased frequency, lenght and therefore duration of traffic jams during peak hours due to the automobile fleet expansion and to the extensive road constructions around the larger cities.

While therefore, in projecting to the mid 80's the present use of vehicles to perform work related travel, we can expect on the one side a significant enhancement of the trend to use smaller cars as specific vehicles for commuting trips associated with a more and more extensive use of large and comfortable cars in pool commuting trips. However the optimum 2-passenger car for this purpose has to be conceived yet, since it should be rather different than the existing 2-seater sports car.

The pool driving for commuting purposes should actually be heavily favored by the Government, the local Administrations and the private business since it represents by far the best solution to unnecessary fuel consumption, traffic congestion on highways and lack of parking space around the business facilities. While in fact the optimum small car in terms of fuel economy is no more than two times better than the largest car, no more than 40% shorter but occupies its same nominal parking space, a single 5-passenger loaded large commuter car would be 2.5 times more fuel efficient, and respectively 3 and 5 times "smaller" on road traffic and parking area than 5 "driver-only" minicompact cars.

On the other hand it must be pointed out that this mission is intended to be representative of vehicles which are effectively used for work related travel as their primary trip purpose and for personal business travel, thought as mainly originated from the working location rather than from the residential location (i.e. occasional personal business/civic, educational trips during the working days), as their secondary trip purpose; use of such vehicles for recreational purposes, as projected to the mid 80's, has not been included in mission M_2 since it was specifically attributed to Mission M_3 as representative of the remaining general-purpose car usage.

The large-size cars driven once-a-week for pool-commuter trips cannot in fact be considered as used there in their primary trip purpose, but rather in one of their multiple functions and must be therefore assigned, as appropriate, to Mission M_3.

The overall analysis of the present and projected vehicle usage for earning a living purpose has been thoroughly performed here, even in those aspects which are not relevant in the definition of what Mission M_2 should be, for sake of evaluation completeness of such a trip purpose; on the other hand it has appeared appropriate to include in Mission M_2 description a clear definition of what Mission M_2 should not be, as well. Such "negative" description will apply, of course, in a reversed "positive" assessment to the following definition of Mission M_3.

Tentatively projecting this trip pattern to the mid 80's, one can expect to see, similarly to Mission M_1, increased buying in the range of minicompacts through compacts (both new and top-condition used cars) for the specific work related purposes, decreasing use of larger cars at a higher rate than for Mission M_1, due to the more significant impact of the higher gasoline (or even diesel fuel) price as well as of the increased maintenance/spare parts/replacement costs as a result of the heavier and more demanding type of driving that is involved.

In conclusion this mission too appears to be rather inappropriate for penetration by a hybrid vehicle as defined in the Near Term Development Program because the smaller new cars would not comply with the 5/6 passenger requirement.

5.1.1.3 Mission M_3 - General Purpose

This trip pattern is intended to be representative of vehicles which will be used more or less on all the trip purposes identified by the NPTS to account for the intermediate stage of the changing trend from the standardized to specialized vehicle use that is expected for 1985, as previously discussed.

Due to the expected saturation in the number of cars/licensed driver and therefore in number of cars/household, this mission will mantain indefinitely its representativeness as such, to account for the predominant general purpose usage of most cars in 1 car households and for about half of the cars in 2 car households.

According to the general purpose definition of the mission, the association with a primary trip purpose could appear inappropriate. However, having assumed in the definition of missions M_1 and M_2 that their specialization is characterized by the exclusion of social and recreational trips, the general purpose mission must be considered characteristic of vehicles to be used for such trips. In fact this mission could ultimately, at the end of the specialization process, be representative of social and recreational trips (as primary trip purpose) and of "pool commuting" trips as secondary trip purpose, plus occasional family business trips for most 3 or more car households.

It is unlikely on the other hand that complete and rigid specialization could be attained even in the long term, because, in addition to the single-car households necessarily using general purpose cars for multiple purposes, there will be as well multiple drivers in multiple-car households who cannot easily complement each other in the use of the household fleet for the individual and often overlapping trip purposes. Since, in fact, according to the JPL guidelines, it is not expected to go beyond 3 cars every 4 licensed drivers (including company and rental cars) the situation will always be quite far away from the hypothetical condition of unlimited availability of the most appropriate car for each trip pattern (3 cars per driver).

Of course the situation itself should improve as a result of the availability of special purpose rental cars as well. This category however should mainly address two special subcategories of trip purposes, that are vacation trips and family business trips, as sufficiently spread over the significant usage intervals (day, week, month, year). Special rental cars for commuter trips, as an example, appear rather inappropriate, business-wise not being adequately used beyond the rush hours.

With reference to mission M_3, being delt in this subsection, it should not be forgotten that personal car ownership will never be disjointed from the fulfilment of people social and, particulary in the U.S., recreational needs. Commuter and family business trips with their implications of congested traffic, lack of parking space, considerable time and energy wastes could be in principle more appropriately taken care of by efficient and advanced urban/suburban transportation systems which, expecially in the largest metropolitan areas, could even substitute part or, maybe, most of the special purpose cars considered for mission M_1 and M_2. But even in this energy concerned society, nothing could provide a substitute to the personal car to fulfill the people's need for social and recreational freedom of movement but the loss of freedom itself.

Therefore, projecting to the mid 80's the present use of vehicles for general purpose and, in particular, for social and recreational travel, we can expect, associated with the downsizing of the american-made cars, a significant enhancement of the trend to use smaller (as referred to engine power and outside dimensions) but not necessarily less comfortable cars for such trip purposes which would include considerable "pool-commuter" usage. The existing trend to use rented car for vacation trips (both long-distance or local area in connection with air travel) should not be limited to large size cars since the higher cost of gasoline should force parties of 2-3 people to select smaller but similarly comfortable cars. Due to this specific long-travel type of usage with night stops in often continuously varying places, the vacation-type rental cars are definitely not appropriate for hybrid vehicle implementation because of the prevalent highway travel and the possible uncertainties about recharging outlets availability.

Tentatively projecting this trip pattern to the mid 80's one can expect increased buying in the range of subcompacts through mid-size cars. Due to the technological trend to associate the same power train to car bodies appropriate for both mid and large cargo size, this mission is the only one, but the taxi mission to be considered next, which:

1) includes car sizes used appropriately to perform the mission itself,

2) satisfies the 5/6 passenger requirement and

3) is appropriate for being performed using a single hybrid design.

The actual fuel consumption for each of the two classes of vehicles (mid and large) will depend on the appropriateness of the assessment made on the fleet mix penetration; it can be already pointed out that an obvious choice for the initial hybrid vehicle scheme should be a vehicle size close to the low end of the higher class which could be easily downsized to more deeply penetrate the lower class.

5.1.1.4 Mission M_4 - Taxi/police

This trip pattern is intended to be representative of vehicles used for the specific taxicab and police operations. It is quite different from the previous trip patterns which predominantly apply to individually owned passenger cars.

Many of the characteristis fo M_4 trips are similar to those of mission M_2 (family business and, partially, airport/hotel commuting by people on business missions) for taxicab operations; to those of all missions for police operations (city, suburb, highway patrolling).

What mainly differentiate mission M_4 from other missions are the much higher daily and annual travel distances.

A similar consideration would have applied to rental-cars if analyzed by themselves. However, while rental-cars were considered not appropriate for hybrid implementation, because of the extensive highway driving (and the same would apply to police cars, because of the most demanding performance capabilities requested) the taxicabs with their extensive local/urban/suburban driving are ideally suited for hybrid implementation. The basic power train appropriate for mission M_3 mid/large size vehicles could be used for a taxi version characterized by somewhat extended cargo capabilities.

5.1.2 Mission Specifications

The Mission Specifications are summarized as required in the following Table 5-1.

They are referred to an average new K_5 large ICE conventional vehicle performing the M_3 Mission. While M_3 Missions have been identified and characterized in Section 3 for households with different car ownership, Mission Specifications are referred to the "composite" M_3 Mission resulting from the weighted average of all M_3 Missions performed by members of all households with cars.

TABLE 5 – 1
M3, K5 MISSION SPECIFICATIONS

No.	PARAMETER	VALUE	COMMENTS
M1	DAILY TRAVEL, MILES (km) MILES (km)	20 (32) 142 (227)	50 TH PERCENTILE (1) 95 TH PERCENTILE (1)
M2	PAYLOAD, kg (PASSENGERS + CARGO)	350 + 50 400 (TOTAL)	95 TH PERCENTILE 4,15 PASSENGER OCCUPANCY (2)
M3	TRIP LENGTH, MILES (km) TRIP FREQUENCY, TRIPS PER DAY TRIP PURPOSE, MISSION	11.0 (17.6) 3.4 M3	MEAN (ONE WAY) MEAN (PER VEHICLE) GENERAL PURPOSE (URBAN/SUBURBAN/INTRAURBAN)
M4	DRIVING CYCLES, (REFERRED TO DAILY TRAVEL)	S U H – 4 10	SEQUENCE: U, 5H, 2U, 5H, U (3) 95.5 PERCENTILE (149 MILES)
M5	ANNUAL TRAVEL, MILES (km) MILES (km)	13,300 (21,300) 35,500 (56,700)	MEAN (PER VEHICLE) 95 TH PERCENTILE (4)
M6	VEHICLES IN USE, MILLIONS OF VEHICLES (%OF FLEET) (%OF K5 CLASS)	22.6 (20.0) (91.0)	TOTAL FLEET: 113,2 MILLIONS VEHICLES TOTAL K5 CLASS: 24,9 MILLIONS VEHICLES
M7	REFERENCE CONVENTIONAL ICE VEHICLE	K5	AVERAGE NEW 1985 LARGE AUTOMOBILE
M8	FUEL CONSUMPTION, GALLONS BILLIONS OF GALLONS (%OF TOTAL) BILLIONS OF GALLONS (%OF TOTAL) BILLIONS OF GALLONS (%OF TOTAL)	480 46.4 (100) 10.9 (23.5) 28.2 (60.7)	K5 REFERENCE ICE VEHICLE (SINGLE M3 MISSION) ALL REF. ICE VEHICLES (ALL MISSIONS) K5 REF. ICE VEHICLES (K5 FRACTION OF ALL M3 MISSION) ALL REF. ICE VEHICLES (ALL M3 MISSIONS)

(1) CUMULATIVE PERCENT OF DAYS
(2) CUMULATIVE PERCENT OF TRIPS (2 MALES 95 TH PERC. + 2.15 MALES 50 TH PERC.)
(3) S – SAE, U – FUDC, H – FHDC
(4) CUMULATIVE PERCENT OF K5 VEHICLES IN M3 MISSION

5.2 MISSION RELATED VEHICLE CHARACTERISTICS

The Mission Related Vehicle Characteristics are summarized as required in the following Table 5-2.

The vehicle characteristic range was assumed to correspond to the 95th percentile of the daily travel as indicated at M1 of the Mission Specifications (Table 5-1).

Cost Constraints have been expressed in 1978 U.S. $, according to JPL Guidelines, although the original list of Mission Related Vehicle Characteristics, included in Exhibit I of the executed contract, called for 1977 U.S. $.

All the most common and relevant optionals have been included in the Amenities as characteristics of the reference 1985 conventional vehicle. Although the radio can be considered an amenity more popular than, for istance, the Air Conditioner it has not been deliberately indicated as relevant characteristic of the conventional vehicle to have it included in the "additional" accessories and amenities listed in the Hybrid Vehicle Performance Specifications so that emphasis could be placed on the EMI compatibility with the electric motor operation.

TABLE 5 – 2

M3 MISSION RELATED K5 VEHICLE CHARACTERISTICS

	PARAMETER	VALUE	COMMENTS
V1	CAPACITY, PASSENGER, No.	6	111 CUFT (3.17 m^3)
	CARGO,CUFT (m^3)	20 (0,57)	
V2	RANGE, MILES (km)	142 (227)	DAILY (95 TH PERCENTILE)
	SPEED CRUISE, MPH (km/h)	65 (104)	
	MAXIMUM,MPH (km/h)	75 (120)	
	ACCELERATION TIME, s	6	0 – 31 MPH (0 – 50 km/h)
		15	0 – 56 MPH (0 – 90 km/h)
		12	25 – 56 MPH (40 – 90 km/h)
	GRADEABILITY		
	GRADE AT GIVEN SPEED, MPH (km/h)	3% AT 56 (90)	FOR 5 MILES (8 km)
		8% AT 31 (50)	FOR 2 MILES (3.2 km)
		15% AT 16 (25)	FOR 0.2 MILES (0.32 km/h)
		20% MAXIMUM	
V3	COST CONSTRAINTS, INITIAL (1978 $)	9,488	PURCHASE PRICE + SALES TAX
	OPERATING (1978 $)	11,573	(TOTAL ACQUISITION COST $ 13,825)
V4	AMBIENT CONDITIONS	– 30 TO + 50°C	
	AVAILABILITY	97.2	10 BREAK DOWNS (DAYS OF UNAVAILABILITY) / YEAR
	AMENITIES	––	POWER STEERING & BRAKES – HEATER & A/C

5.3 VEHICLE PERFORMANCE SPECIFICATIONS

This subsection provides a brief discussion of the rationale behind the establishment of each of the performance specification presented on Table 5-3.

a) Range: The minimum nonrefueled range for the HV was based upon the daily fuel consumption for the selected reference vehicle. This fuel usage was then applied to a single test cycle and the total range calculated. The daily requirement of 142 miles resulted in approximately 5.4 gallons of petroleum consumed per day for the candidate reference vehicle. The following ranges were established on the Federal Highway Driving Cycle, 168 miles; the Federal Urban Driving Cycle, 118 miles; and on a repetitive SAE J227A(B), 90 miles. These values represent equivalent ranges for each of the selected test cycles.

b) Speed: The cruise speed and maximum speed for the candidate hybrid vehicle were selected at 65 and 75 mph respectively. These values were established based upon the mission related vehicle characteristics. The vehicle must be able to maintain this maximum speed for 2 minutes. This length of time is equal to 2-1/2 miles of travel at this velocity. This distance should cover all of the passing requirements for the candidate hybrid.

c) Acceleration: The acceleration levels that were identified in the mission related characteristic study were less than the required JPL minimum, therefore we concur with the selected JPL minimums as the specifications for the candidate hybrid. These accelerations do not present an unreasonable accident potential nor unduly tax the energy reserves of the hybrid vehicle.

d) Gradeability: The gradeability requirements for the hybrid vehicle were determined from the requirements as specified for the selected reference vehicle. In order to ensure a safe level of performance in potentially hazardous or mission restricting

TABLE 5 – 3 a
VEHICLE PERFORMANCE SPECIFICATIONS

P 1 MINIMUM NONREFUELED RANGE				
P 1.1 FHDC				270 km
P 1.2 FUDC				190 km
P 1.3 J227 a (B)				145 km
P 2 CRUISE SPEED				105 km/h
P 3 MAXIMUM SPEED				
P 3.1 MAXIMUM SPEED				120 km/h
P 3.2 LENGHT OF TIME MAXIMUM SPEED CAN BE MAINTAINED ON LEVEL ROAD				2 min
P 4 ACCELERATION				
P 4.1 0 – 50 km/h (0 – 30 mph)				6 s
P 4.2 0 – 90 km/h (0 – 56 mph)				15 s
P 4.3 40 – 90 km/h (25 – 56 mph)				12 s
P 5 GRADEABILITY	GRADE	SPEED km/h	DISTANCE	
P 5.1	3 %	89	8.0	
P 5.2	5 %	72	16.0	
P 5.3	8 %	56	3.2	
P 5.4	15 %	24	0.8	
P 5.5 MAXIMUM GRADE	20 %			
P 6 PAYLOAD CAPACITY				545 kg
P 7 CARGO CAPACITY				0.57 m^3
P 8 CONSUMER COSTS				
P 8.1 CONSUMER PURCHASE PRICE (1978 $)				$ 9,500
P 8.2 CONSUMER LIFE CYCLE COST (1978 $)				$/km 0,158
P 9 EMISSIONS – FEDERAL TEST PROCEDURE				
P 9.1 HYDROCARBONS (HC)				0.236 gm/km
P 9.2 CARBON MONOXIDE (CO)				2.240 gm/km
P 9.3 NITROGEN OXIDES (NO_x)				0.634 gm/km
P 10 AMBIENT TEMPERATURE CAPABILITY				
TEMPERATURE RANGE OVER WHICH MINIMUM PERFORMANCE REQUIREMENTS CAN BE MET				– 30°C to 50°C
P 11 RECHARGEABILITY				
MAXIMUM TIME TO RECHARGE FROM 80 DEPTH–OF–DISCHARGE				4 hr

TABLE 5 – 3b
VEHICLE PERFORMANCE SPECIFICATIONS (CONCL.)

P 12 REQUIRED MAINTENANCE	
ROUTINE MAINTENANCE REQUIRED PER MONTH	1hr
P 13 UNSERVICED STOREABILITY	
UNSERVICED STORAGE OVER AMBIENT TEMPERATURE RANGE OF – 30°C to + 50°C (– 22°F to + 122°F)	
P 13.1 DURATION	14 DAYS
P 13.2 WARM–UP TIME REQUIRED	5 min
P 14 RELIABILITY	
P 14.1 MEAN USAGE BETWEEN FAILURES – POWERTRAIN	14,480 km
P 14.2 MEAN USAGE BETWEEN FAILURES – BRAKES	8,410 km
P 14.3 MEAN USAGE BETWEEN FAILURES – VEHICLE	2,150 km
P 15 MAINTAINABILITY	
P 15.1 TIME TO REPAIR – MEAN	8 hr
P 15.2 TIME TO REPAIR – VARIANCE	3 hr
P 16 AVAILABILITY	
MINIMUM EXPECTED UTILIZATION RATE	96 %
i.e., 100 x TIME IN SERVICE ÷ (TIME IN SERVICE + TIME UNDER REPAIR)	
P 17 ADDITIONAL ACCESSORIES AND AMENITIES	RADIO STATE – OF – CHARGE METER

situations, it was determined that two grade requirements be increased over those for the reference vehicle. Specifically, the requirement for the 15 percent grade at 15 mph was extended to a length of 1 mile to ensure a safe operation within the confined limits of a highrise garage structure. Additionally, the maximum grade requirement for the hybrid vehicle was increased to a 20 percent grade, encompasing all grade limitations normally encountered either in rural or urban operation.

e) Payload and Cargo Capacity: The selected hybrid vehicle specifications were derived from the K_5 reference vehicle. Therefore, the maximum passenger capacity should be consistent with the K_5 classification, that is six passengers. The payload capacity is specified as 1200 lbs which consists of the maximum passenger load and an appropriate amount of cargo. The cargo capacity is retained from the reference vehicle specification.

f) Consumer Costs: The cost to the consumer must be compatible with the reference vehicle if it is to have any possibility of penetrating the market. The acquisition cost of the vehicle should be established on the basis of the new K_5 vehicle level, i.e., between $ 9,000 and 9,500. The total costs for the vehicle should not exceed the value of 15.8 cents per kilometer traveled. These costs will support the basic assumption that the hybrid vehicle may be placed into the fleet without regard for consumer preference or consumer resistance.

g) Emissions: The vehicle performance emission specifications for the 1985 fleet were obtained from the proposed EPA guidelines for light duty vehicles.[1] These emission guidelines were proposed for 1980, 1981 and later model years. The 1978 vehicle

---

[1] Kelderman, Jake, "EPA Eyes More Controls", Automotive News, October 2, 1978.

emission guidelines as listed [2] were 0.255 gm/km, 2.12 gm/km and 0.249 gm/km for HC, CO, and NO_X, respectively. When compared to the 1981 and later specifications, it is seen that the HC and CO emission standards are made more stringent while the NO_X standard is relaxed.

h) <u>Ambient Temperature Capability</u>: A review of the U.S. climate revealed a wide temperature range between the extreme northern and southern portions of the country. Temperatures can easily approach O°F in the winter and 100°F in the summer even in the more moderate climate regions, such as Chicago. An additional temperature margin is recommended to account for the more extreme regions. A rather generous ambient temperature capability should be specified for satisfactory vehicle operation within the whole United States. The 30 to 50°C (-22 to 122°F) range appears to be proper for this purpose. This requirement does not appear to be unfeasible because the TRW hybrid motor system [3] listed an ambient operating temperature range of -30 to 50°C.

i) <u>Rechargeability</u>:

Maximum time to recharge from 80 percent depth-of-discharge:

Mission	Time
M_1 - intraurban	4 hr
M_2 - urban-suburban commuter	4 hr
M_3 - general purpose	4 hr
M_4 - commercial	1 hr

---

[2] Federal Register - "Control of Air Pollution From New Motor Vehicles and New Motor Vehicle Engines", Environmental Protection Agency, June 1977.

[3] Lapedes, D.E., et al, Hybrid Vehicle Technology Constraints and Application Assessment Study, Vol. II, Final Report for the U.S. Dept. of Transportation, Contract DOT-TSC-OST--77-23, June 1976.

The rechargeability recommendations were based on an evaluation of the required vehicle mission. For a mission wherein the auto should be ready for use at almost any time, a shorter rechargeability time was specified than for a mission wherein the auto was likely to be used less frequently.

l) Required Maintenance: The required routine maintenance includes checking oil, battery levels, tire pressures, etc, and monthly distribution of one or two tune-ups per year and three or four oil changes per year. This should not exceed 1 hour per month, consistent with the conventional vehicle.

m) Unserviced Storability: The rationale for these unserviced storability specifications is essentially the reasonable expectation of an average motorist. Since vacations are usually 1 to 2 weeks long, this imposes the upper bound on duration for auto nonuse. Business trips with a personal car parked at the airport are usually less than 7 days and thus, do not offer a major problem. The only other consideration could be given to the very infrequent users of personal vehicular transportation, such as the elderly, retired, or the sick. However, these people are probably a rather small percentage of the total motoring public and their possibly prolonged nonuse of the auto should not be taken into account for the setting of this specification.
The current recommended engine warm-up time is at least 30 at 60s during colder weather. The impatience of the average motorist is such that even this minimum recommendation is often not adhered to. Thus, a 5 min maximum warm-up time might even seem excessive to many. However, it probably is not unreasonable.

n) Additional Accessories and Amenities: the optionals listed in the Mission Related Vehicle Characteristics have been considered standard accessories for the Hybrid Vehicle so that only "additional" items have been listed here.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

In the previous Sections of this Report, Information Sources and Methodology used, As:umptions made in performing the Mission Analysis and Performance Specification Studies have been addressed and obtained Results have been presented.

This conclusive Section aims at presenting a synthesis of the opinion of the CRF technical Staff resulting from a final review and discussion of the whole matter with particular emphasis on its possible limitations in accuracy and/or completeness as well as on the expected impact on the other tasks of the Phase I - H.V. Development Program.

a) Sensitivity to our-own assumptions. The most relevant assumptions made in performing the Mission Analysis were those used to attribute trip purposes, vehicles and vehicle classes to the various missions.

We think that differences in opinion on such matters could be more significant than for the qualitative definition of the missions themselves, as the caracterization by means of statistically defined trip purposes of the specialization trend imposed by fuel economy pressure, should not lead to a wide spread of choices.

The assumptions mentioned above are supposed, on the other hand to define quantitatively at a given time (1985) and for a number of parameters related to each other a set of independent patterns which could all be true but at different times.

The accuracy of such projections, not being based on actual data, as they are not available, could be therefore rather questionable.

The best approach should be the one presented for the Intermediate Mission Quantification in Section 4 - Interim Results; the limits of a range of possible solutions were selected in the 0 through 100% total range and the mean values were considered the most probable.

Unfortunately such a solution could not be used as the final one since the sensitivity of the trip purpose distribution to the average number of cars/ household had not been accounted for in the Intermediate Quantification and, being at that time the Task-1 Report long overdue, the same approach could not be used for the final Mission Quantification leading to the Primary Results presented in Section 5; only a reasonable estimate of a "mean" configuration was therefore made.

It has already been mentioned in Section 4 that average results (such as annual miles and therefore fuel consumption) appear to be much more sensitive to these subjective quantifications than the extreme range values (such as the 95th percentile daily range). While this could make more difficult to compare results obtained from different approaches, the effect on the fuel and energy savings obtainable by means of the hybrid vehicle use should be negligible, at least for a given approach, as long as expressed as percentages. The less the traction battery performance of the hybrid vehicle will be state-of-charge dependent, the more this will hold true.

During the Sensitivity analysis we will consider the possibility of defining also low and high-boundary specifications related to this type of assessments.

b) Adequacy of Analysis Depth. The selected M_3 mission has been quantified in the Mission Specifications as "average" of the average M_3 missions performed by households with 1, 2, 3 or more cars. The K_5 large vehicles were distributed among the available missions and the M_3 general purpose mission was distributed among the available classes according to the assumptions and procedure described in Section 3.

As a result different numbers of K_5, K_4 , ... vehicles were attributed to such an "average" M_3 mission.

Our analysis did not go any deeper because of time unavailability, although we felt that, if the analysis depth could reach the specific M_3 missions of the 1, 2, 3 or more cars households, the vehicle/mission combinations would have been made on more realistic grounds or, at least, the uncertainties about a larger number of assessments made on such grounds could lead statistically to more accurate results, so that a (K_5, M_3) mission could end up differently quantified than a (K_3, M_3) mission for istance. Since we had however no evidence that this would hold true in any event, we elected to use a simpler and more straightforward approach.

c) Adequacy of Specification Parameters. The most relevant mission parameter can be considered the fuel consumption for a given vehicle/mission combination as it is the result of a product of various other significant and independent parameters such as vehicle fuel economy and annual miles, percent of vehicles and vehicle classes. This specification parameter is requested to be represented as total fuel consumption of missions entirely performed by reference vehicles.

Since vehicle quotas/mission and average annual miles/mission are referred to the in-place fleet, the above defined fuel consumption provides a lower value than the actual fuel consumption of the actual quota of the in-place fleet performing such an "average" mission (because of the different fuel economy), but much higher than the actual fuel consumption of the actual reference vehicles, that are the new 1985 vehicles only. While the value itself provides a maximum potential reference term (in-place fleet completely substituted with new vehicles) which could be scaled down to account for the actual fraction of new vehicles in the fleet, it is not so obvious that in so doing one should also account for the following considerations: 1) The Hybrid vehicles should in fact physically substitute only a quota of the conventional new vehicles, since one should not assume that a larger number of new vehicles (conventional + hybrid) could be absorbed by the market, unless specific and exceptional promotional conditions are proposed; 2) because of the higher annual mileage typical of new vehicles, the average missions performed by the new vehicles should be differently characterized than the average missions performed by the average in-place fleet. Since the fuel consumption is already expressed in terms of reference vehicle fuel economy, the higher new vehicle mileage should therefore result in a lesser reduction of the actual new vehicle fuel consumption than imposed by their limited quota of the in-place fleet.

d) Rules for Extrapolation of Results. Some of the primary results are referred to specific operating conditions. It is expected that, to evaluate vehicle performance under different operating conditions during the following Tasks of the Phase I Hybrid Vehicle Development Program, it could be necessary to extrapolate the corresponding values of such parameters.

To judge on the "extrapolability" of a given parameter, attention must be paid to the rules used for its computations as described in Section 3-Methodology.

The Driving Cycle Combination can be considered as an example. It was assumed that for each mission, independently from the actually driven distance, the average trip on a given mission would be performed at the average speed and with the average number of stop/miles characteristic of such a mission.

The actual standard driving cycles combination was calculated for a distance close to the mission range percentile (95th), to perform the computation with a higher number of discrete terms and obtain therefore more accurate results. As long as the assumption of constant operating conditions (speed and stop/mile) holds true, the fuel consumption for a different distance can be scaled down according to the simple ratio between the reference and the actual distance.

In conclusion it can be stated that a fully quantified Mission Analysis (in terms of number and types of vehicle) should be more properly performed through a selective iterative approach.

This is ment to refer to an iterative approach where more emphasis of in-depth analysis is placed upon those parameters which would appear more relevant to the hybrid vehicle optimization to be performed in the following tasks.

As an example, while it is stated that the hybrid vehicle cost must be competitive in terms of purchase price and equivalent in terms of life cycle cost, it should be noted that, with the nominal gasoline price, the life time fuel operating cost of a conventional vehicle is less than 15% of the total life cycle cost.

The optimum conventional new vehicle which has better fuel economy than the average conventional new vehicle, under the assumption made, should have a higher life cycle cost. Being the only difference a better fuel economy, the use of an "optimum" vehicle should not provide therefore <u>any</u> significant advantage to the owner; as such it <u>should not</u> be a "sellable" car.

As a result, the hybrid vehicle should be priced lower than the "optimum" vehicle and have better performance in terms of fuel economy, at least to match the average vehicle figure.

Considering that, as an absolute limit, the extreme hybrid vehicle (i.e. an electric vehicle using free electric power) would only save less than 15% of the life cycle cost of a conventional average vehicle, under the projected conditions, there is not <u>much</u> room for significant production cost increase to provide improved fuel economy performance assuming that all other non technical factors (taxes, financing interest, insurance) will mantain the same rates for all vehicles.

On the other hand, since few cars only reach actual end-of-life because of age rather than accumulated mileage, it could be worth to more deeply analyze the projected missions to more accurately define the quota of <u>new</u> vehicle fleets which would accumulate more than

100,000 miles in a lesser length of time so that the economical feasibility could also be assessed of higher quality high performance hybrid vehicles more apt to reliably afford extensive travel and result therefore more competive in terms of operating costs.

The overall picture of course, could drastically change, should the impact of gasoline price increase be much larger than projected.