23

BACKGROUND FACTS FOR ELECTRICALLY POWERED VEHICLES

Bureau of Public Roads
Office of Research and Development

March 8, 1967

23

Background Facts for Electrically Powered Vehicles

I. Introduction - Overall Transportation System Aspect

A. Support Systems
B. Commercial and Control Systems
C. Safety
D. Comfort and Convenience
E. Cost

II. Vehicle

A. Operating Performance Required for Electric Powered Vehicle
B. Automotive Air Pollution

III. Highway Plant

A. Inventory
B. Utilization

Appendix

I. Figures 1, 2, 3, 4, 5
II. Highway Utilization
III. Miscellaneous Highway Plant Data

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BACKGROUND FACTS FOR EPV

I. Introduction - The Overall Transportation System Aspect.

A basic assumption that must be made whenever one wants to evaluate a proposed system which would replace (in total or in part) the functions presently performed by an existing system or systems, is that the proposed system must perform the replaced functions as well as, or better than the existing system. One should not replace a system (or part of a system) in order to eliminate an existing problem by another system which may eliminate the original problem but possibly may create others whose sum total is equal or greater than the original existing problem. In order to avoid this dilemma, one should systematically look at the total overall systems in question to determine what effects the changes may have on the total transportation picture.

One can first begin by examining the various components of the existing highway plant and the present requirements for travel on it. (See Part III of this paper for selected data of this type). One can next look into and examine the existing and proposed vehicle systems performance characteristics. (See Part II of this paper for selected data on vehicle performance characteristics of both the internal combustion automobile and the electric powered automobile). The next step is to eliminate the large number of uncertainties about the proposed system by first fixing the problem in a given time reference, and with a given problem it must meet. For the purpose of this discussion we have therefore chosen to basically analyse what is presently (or within say the next five years) possible with respect to electric cars and to estimate what part of the existing automobile travel could be replaced.

The first part of this report (Part I) therefore attempts to discuss some of possible benefits and deficiencies which might accrue on the total highway transportation system if the electric powered vehicle were developed for use in the near future. The major parts of a transportation system which are discussed are: 1) the vehicle system, (see Part III), 2) the support system, and 3) the command and control system. In addition to these, a change in part of a system also may affect the total system safety, comfort and convenience, and cost.

Let us now examine the electric car on a total system basis and try to postulate how it may effect these various major and minor components systems of the total system.

A. The Support System (Includes Construction, Maintenance, and Operation of the Plant):

1. Construction:

a) Pavement Support - A wheeled vehicle requires support, usually in terms of a pavement or rail structure. The amount of support is dependent on

1) the vehicle weight distribution on the support

2) the number of repetitive loading on the support which induces fatigue and ultimately structural failure.

A small lightweight vehicle therefore need not imply less structural support if, for example, a greater number of repetitive loadings on the support were anticipated. A detailed analysis would have to be made with respect to weight of the vehicle and future travel predictions. (See Figure 1 & 2 Appendix I).

b) Parking - The amount of parking area that is needed is dependent on the vehicle sizes. If different sized vehicles are indiscriminately parked they may take up as much total room as if they were all of the larger size. However, if vehicles of different sizes have reserved parking spaces an increase in parking capacity is obtained. (The Pentagon parking lot is an example of a parking facility which uses this principle to increase its capacity.) If electric cars were as small as some proposals indicate they would require as little as one-fourth the parking space required by a standard size car today. This would help reduce our cities' parking problems at least temporarily. Small electric vehicles such as the Scottish Aviation Scamp which is less than 7 feet long would require one-fourth the amount of parking space needed by a standard size present day automobile. (See Figures 3 & 4 Appendix I).

c) Lane Widths - The width of a traffic lane effects the level of service that the vehicle driver may obtain. In general the wider the lane the greater level of service obtained. This implies greater driver comfort, safety, and flexibility. Todays wide vehicles require lane widths of up to 12 feet. Small vehicles (i.e. if part of the system were reserved for small vehicles) would accrue in smaller lane widths for the same level of service. Smaller lane widths would indicate: 1) less right-of-way needed to service the same traffic volumes, and 2) an increased traffic carrying capacity of existing roadways. For example: A 44 ft. wide street which presently has four 11 ft. lanes if converted for use by small vehicles alone whose width were 4 feet might be converted to 5 lanes of approximately 9 feet in width. If no parking had previously been allowed on this street there would now be ample room for 4 useable lanes and one parking lane. (See Figure 5, Appendix I).

d) Additional Support Hardware - 1) Every home or overnight parking space which had to handle a battery-type electric car would have to be equiped with an outlet to supply the vehicle with electricity.

2) AC to DC inverters would have to be provided either at the parking sights or on the vehicles.

3) Parking spaces at work sites would also have to provide the electric facilities and associated hardware so that batteries could be regenerated during work hours if necessary. (Parking meter type installations have been suggested.)

2. Operation of System

a) Separation of Traffic - During the transition period small underpowered vehicles would require separate right-of-way from larger high powered vehicles. This raises the following questions.

1) What streets or parts of streets should be assigned to small vehicles in a given city?

2) Should streets be reserved for small vehicles only during given time periods of the day?

3) How would the problem of small vehicle streets crossing regular vehicle streets be solved?

In general, this is a traffic assignment problem similar in ways to the separation of present pedestrian and vehicular traffic.

3. Maintenance of System

a) Snow Removal - Small vehicles might require more efficient and immediate snow removal than presently supplied in some parts of the country. The main reason for this is that a small vehicle would have less clearance.

B. Command and Control System

1. The electric car may more readily be converted to an eventual automated (or partially automated) system which may be electrically powered.

2. The electric car may be more readily and efficiently used in conjunction with electronic command and control equipment.

C. Safety

1) Fuel-cells of the hydrogen-oxygen type may be potential fire hazards.

2) Vehicle performance range should be in the same performance range as present gasoline cars so as not to increase potential mixed-system hazard (Note: deviations from mean speeds and horsepower are hazardous).

3) a) The electrical system has to be well insulated to prevent electric shock hazard from high voltages. b) If a collision occurred provisions should be made to guarantee that the electrical system could

not get shorted on the vehicle body and electricute the occupants.

4) Very small vehicles would be subject to higher property damage, and higher injury and fatality probabilities if they collided with bigger present-day type automobiles. Therefore very small vehicles whose performance did not equal that of present day cars should be provided with separate right-of-ways.

5) Vehicles could run out of power more often due to shorter driving ranges. An increase in disability of vehicles which have used up their power source could increase congestion tremendously especially during rush hour periods. Even today when a vehicle runs out of gas during the rush hour, tremendous congestion results until the vehicle is removed from the traffic stream or serviced.

6) Propane boosters could be hazardous.

D. Comfort and Convenience

1) A small electric vehicle would be compact and easily maneuverable.

2) Electric vehicles would be simple to operate.

3) Electric vehicles would be reasonably quiet (noise level varies according to the type of control gear used. The noise level on the British G & M electric van has been estimated to be below 65 decibels.

4) Electric vehicle could start instantly.

5) The short ranges presently possible would restrict its use for short range trips (or combination of trips) in one day.

6) Regeneration of the batteries would take at least 4-6 hrs. This would mean that during considerable portions of each day, the vehicle could not be used for a trẽp nearing the vehicle's total range.

7) Forgetting to "plug" it in to regenerate the batteries could cause the vehicle user to be unable to use it for a period of hours until it has then regenerated enough for him to make his desired trip. This could be very invonvenient especially in emergency situations.

8) The presently possible short range electric car would have to be regenerated almost on a daily basis in contrast to a gasoline car which may only require refueling on a weekly basis.

9) The electric car however could be more convenient than having to stop at a gasoline station since it could be regenerated at home or wherever parked overnight, or while at work.

10) Warm-up period - none required.

11) Carrying Capacity - Small cars would limit the quantity of people and goods one could carry in them. For example: a mother with 2 to 4 small children desiring to take them with her grocery shopping might be handicapped by a very small vehicle.

12) No air polution or other undesirable odors.

E. Cost

1) Overall initial costs would include:

a) Equiping every overnight parking spaces with outlets from which the parked vehicles would recharge themselves. In conjunction with each outlet would be the need of an AC to DC inverter unit.

b) Also outlets and inverters should be available for the total expected all-day (or part-day) parkers at all on-street or off-street parking areas so that the vehicles could recharge while parked.

2) Operating costs would probably be less in terms of $/mi.

3) Overall maintenance costs would be lower because of fewer operating mechanical parts that could go bad.

4) Fuel cells would be costly until an inexpensive hydrogen source is discovered.

II - VEHICLES

A.- Operating Performance Required of Electric Powered Vehicles

One of the most important factors that influences the overall operation of our highway transportation systems is the capability of all vehicles to perform at a level of traffic operations commensurate with the type of highway system. Stated another way, it is important that the variation of speeds from the average speeds be as low as possible on any given type of highway in order that the accident involvement rate be at a minimum value. It has been shown that for daytime conditions the accident involvement rate on main rural highways is approximately twice as large when a driver's variation in speed is 10 m.p.h. below the average speed, but the involvement rate is nearly seven (7) times as large for a 20 m.p.h. variation in speed below the average operating speed.[1] However, accident involvement rate is only one consideration; the efficiency at which the highway systems operate is equally important. Everyone has experienced at one time or another the time consuming effect of underpowered or slow moving vehicles impeding uniform traffic flow. Thus when considering the use of electric propulsion as an alternative to the gasoline internal combustion engine it is mandatory that their operating performance capabilities be matched to the designed level of operations of the highway system. It then would be possible to reap the benefits of eliminating air polluting type propulsion systems from highway passenger cars without reducing the overall operating efficiency of our highway transportation system.

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1. "Accidents on Main Rural Highways," Bureau of Public Roads, U.S. Government Printing Office, Washington, D.C., July 1964.

The attached table permits the comparison of the weight and performance of passenger cars propelled with gasoline engines, batteries, gasoline turbines, and fuel cells. The weight and weight-horsepower values given for the foreign, compact and intermediate, and standard size cars are, in general, represenative of these categories of vehicles. The time values for 0-20 m.p.h., 20-40 m.p.h., and 0-60 m.p.h. are presented as represenative approximations of the level of acceleration required for city street, suburban, and freeway on-ramp merging operations, respectively. It should be noted that the range of the GM-Electrovair II is only about 1/6 of the present automobiles and the capital cost for silver-zinc batteries is prohibitive expensive as a competitor (in the order of 10-15 times as expensive as lead-acid batteries). Also, Mr. C. R. Erickson showed, in his American Public Power Association 1966 report entitled "Performance of Electric Passenger Cars," much poorer acceleration performance in his theoretical performance computations of electric powered cars by a factor of nearly four at the 20-40 m.p.h. level as compared to the Electrovair II.

Upon examination of the values given for the vehicles equipped with propulsion systems other than gasoline engines it is evident that these systems can not be successfully integrated into the operation of high speed highways, but their greatest potential for utility is in the area of low speed, short travel distance operations where slower acceleration capabilities may be permitted. For example, it has been shown that for passenger cars operating on main rural highways the accident involvement rate is greatest for the lowest horsepower cars having poor acceleration capabilities.[2]

Technology can develop electric powered vehicles as an alternative propulsion system to present gasoline internal combustion engines. But of all the constraints one of the most important is that of providing an electric powered vehicle with the performance capabilities required for integrating them successfully into the highway transportation system without detrimental effects to the efficiency of the entire system. Future highway transportation may also require better performance capabilities than those indicated in the table. In general, the levels of weight-horsepower ratios have continuously decreased since 1949, particularly for commercial vehicles.

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2. "Accidents on Main Rural Highways," Bureau of Public Roads, U.S. Government Printing Office, Washington, D.C., July 1964

	Weight, Pounds	Wt/HP Pounds/HP	Maximum Capability on Level Grades 0-20mph	20-40mph	0-60mph Time in Seconds	Range, Miles
Gasoline Engines:						
Foreign	2000	30 & above	4-5	4-6	18-20	300
Compact and Intermediate	3000	20-30	3-4	4-6	14-16	300
Standard Size	4000	10-20	2-3	3-5	8-10	300
Electric Cars						
Silver-Zinc (Electrovair II)*	3400	23	6	4	17	50
Fuel Cell						
GM Electrovair**	7100	57	6	N.A.	30	125
Turbine-Chrysler	4100	31	N.A.	N.A.	12	N.A.

N.A. -- Not Avaialble
* -- "Electrovair - A Battery Electric Car" SAE Preprint 670175, January 1967.
** -- "Electrovan - A Fuel Cel Powered Vehicle," SAE Preprint 670176, January 1967.
*** -- "History of Chrysler Corporation Gas Turbine Vehicles," Chrysler Corporation Engineering Office, August 1966.

B.- Automotive Air-Pollution

The rapid and enormous increase in the number of motor vehicles used in the United States has presented a very serious problem, a problem of the effects of vehicle emissions upon the population. The 86th Congress recognized the possible consequences of harmful air pollutants and on June 8, 1960 in Public Law 86-493 directed the Surgeon General of the Public Health Service to study the problem and report to the Congress from the standpoint of public health considerations.

Interest in the control of motor vehicle engine emissions has continued due to a large part because of the establishment of the Motor Vehicle Pollution Control Board by the California Legislature. California subsequently developed motor vehicle air pollution standards which have also served as the guide and frame for the Federal Standards on the control of air pollution from new motor vehicles. These Federal Standards are applicable to all passenger cars and light trucks (1/2 ton), both foreign and domestic with engines larger than 50 cubic inches, effective with the 1968 models. The standards apply to the exhaust emissions of hydrocarbons and carbon monoxide as shown in the following table:

Federal Exhaust Emission Standards

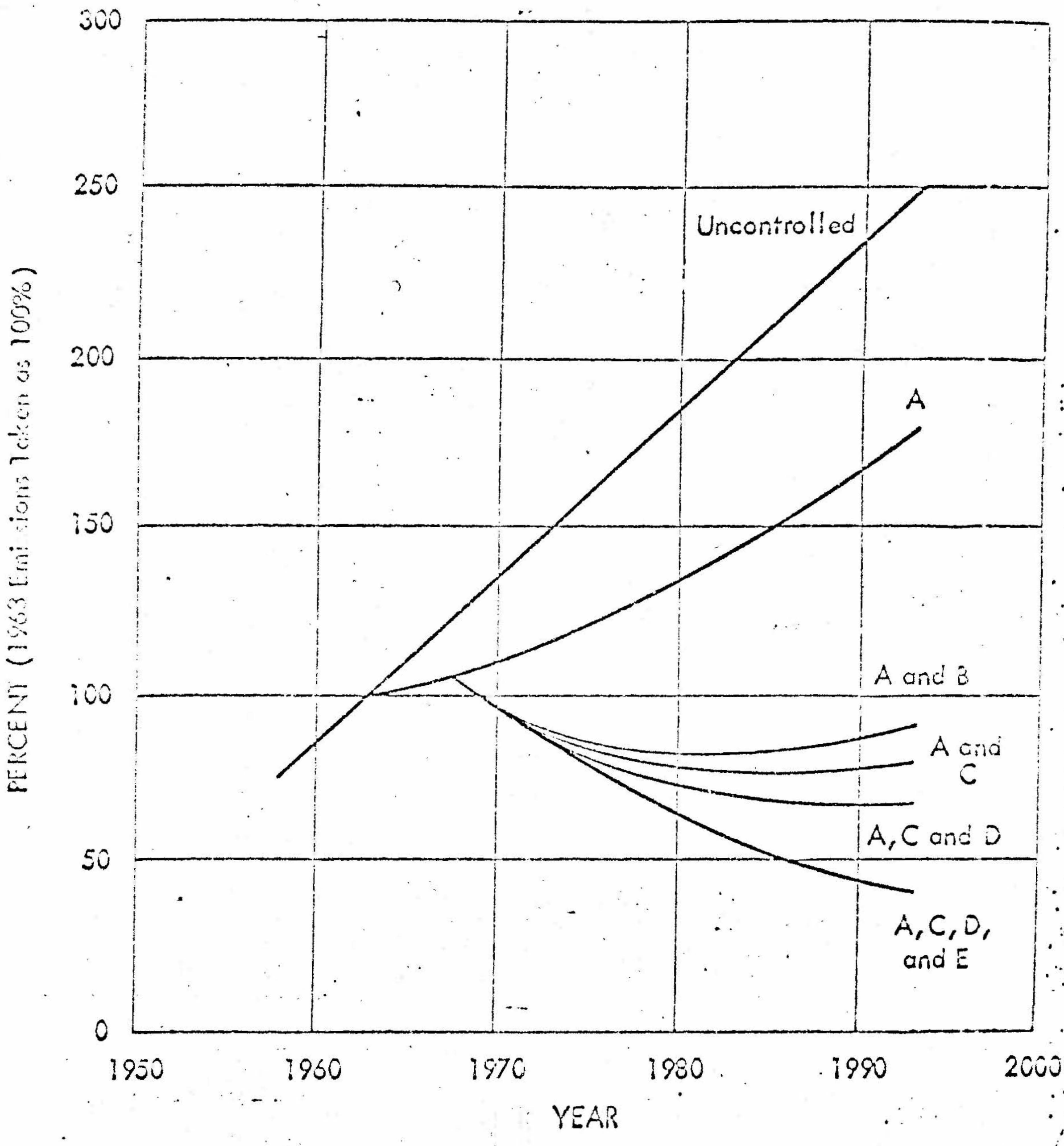
Engine Displacement cubic inches	Hydrocarbons p.p.m.	Carbon Monoxide percent
Over 140	275	1.5
100-140	350	2.0
50-100	410	2.3

Since the 1963 model year, crankcase ventilation devices have been used for the reduction of blowby gases which account for approximately 1/3 of the pollutants escaping from an automobile. Blowby gases are those gases containing hydrocarbons blown past the engine pistons into the crankcase. The other 2/3 of the pollutants escape to the atmosphere through the exhaust emissions as well as from carburetor and fuel tank evaporations.

Various methods have been developed and are in use for controlling the exhaust emissions to meet the present California standards of 275 ppm of hydrocarbons and 1.5 percent carbon monoxide. General Motors and Ford Motor Company mix air with the hot exhaust gasses in the manifold to further oxidize the hydrocarbon and carbon monoxide into carbon dioxide and water vapor. Chrysler uses a lean carburetor and an altered ignition advance curve to control vehicle exhaust emissions. These systems are not as efficient as the crankcase ventilation systems which control nearly all of the emissions from that source, however the exhaust emission problem is a more difficult problem. It is expected that the automotive manufacturers will use essentially the same systems for meeting the Federal Standards for the 1968 model vehicles.

It has been suggested, as shown in the attached figure, what the levels of automotive emissions might be in future years if the indicated types of controls are used.

PROJECTED HYDROCARBON EMISSIONS FROM GASOLINE POWERED MOTOR VEHICLES



LEGEND

(Assumed control modes (new automobiles only)

A – blowby device
B – exhaust control (275 ppm)
C – exhaust control (180 ppm)
D – evaporation control – fuel tank
E – evaporation control – carburetor

III. Highway Plant

A. Inventory

Statistics are readily available to describe the highway plant itself. The annual BPR publication, "Highway Statistics," contains many of these, but they have been supplemented in the tables that follow.

The United States highway system is basically constituted as follows:

U. S. Highway Mileage

Source: Highway Statistics, 1964 - BPR

Rural:		
Federal-aid Primary (Includes Interstate, 34,339 mi)		222,509 mi
Federal-aid Secondary		607,127 mi
County and Other		2,322,941 mi
	Total Rural	3,152,577 mi
Urban:		
Federal-aid Primary (Includes Interstate, 6,806 mi)		25,785 mi
Federal-aid Secondary		19,217 mi
Local		446,490 mi
	Total Urban	491,492 mi
	Grand Total:	3,644,969 mi

Table 1 describes this highway network in somewhat greater detail.

Table 1

Approximate Mileage of U.S. Highway System, by Classification and Geographical Region

Highway Classification \ Region	Eastern	Central	Western	Total
Federal-Aid System	(miles)	(miles)	(miles)	(miles)
Interstate	19,700	10,400	11,000	41,100
Rural	15,700	8,800	9,800	34,300
Urban	4,000	1,600	1,200	6,800
Beltways only	300	400	-	700
Urban "Through" Sections only	3,800	1,400	1,200	6,400
Primary (other than Interstate)	101,100	69,900	36,200	207,200
Rural	88,500	65,700	34,000	188,200
Urban Arterials	12,600	4,200	2,200	19,000
Secondary	331,400	226,100	68,800	626,300
Rural	317,900	223,200	66,000	607,100
Urban Connectors	13,500	2,900	2,800	19,200
Total Federal-Aid System	452,200	306,400	116,000	874,600
Rural	422,100	297,700	109,800	829,600
Urban	30,100	8,700	6,200	45,000
Non-Federal-Aid Systems				
Local	1,166,600	949,200	653,700	2,769,500
Rural	915,400	826,400	581,200	2,323,000
Urban	251,200	122,800	72,500	446,500
Total U.S. Highway System	1,618,800	1,255,600	769,700	3,644,100
Rural	1,337,500	1,124,100	691,000	3,152,600
Urban	281,300	131,500	78,700	491,500

B. Utilization

Motor Vehicles Registered

Almost 92,000,000 motor vehicles currently make use of our highway system, and by 1975, it is estimated that 116,000,000 vehicles will be in operation (Source: BPR)

Passenger Cars Registered

56,950 households own 58,800,000 cars. This is, on the average, there is about 1 car/household. Total registration of cars is higher, though, 76,000 due to commercially-owned passenger cars, etc. In addition, 15,000,000 trucks and buses exist.

In 1960, one automobile existed for every 3.2 persons, and by 1980, there will be one for every 2.5 persons.

Source: "Automobile Facts and Figures" Automobile Mfgrs. Assoc., 1966.

Average Daily Traffic

Table 2 presents average daily traffic figures for various representative elements of the highway system.

Table 2

Average Daily Traffic (ADT) on U.S. Highways by Classification and Geographical Region

Highway Classification \ Region	Eastern	Central	Western	Overall
	(veh/day)	(veh/day)	(veh/day)	(veh/day)
Interstate				
Rural	8,500	5,600	4,400	6,700
Urban	26,000	18,000	52,000	30,000
Beltways only	45,000	40,000	------	43,000
Primary	4,000	2,100	2,600	3,100
Rural	2,900	1,600	1,700	2,200
Urban Arterial	11,500	8,800	16,600	11,500
Secondary	800	300	900	600
Rural	600	300	600	500
Urban Connection	6,200	3,700	6,400	4,400
Local	400	130	250	270
Rural	160	40	100	100
Urban	1,270	720	1,420	1,140

Annual Travel

Average annual mileage data are readily available. Table 3 presents consolidated data for the years 1963, 1964, and 1965, together with related fuel consumption data.

It will be noted from this table that average passenger car usage has remained quite constant at about 9,300 miles per year.

The basic criteria used by Mr. G. E. Brokke, Research Assistant in the Urban Planning Division, Office of Planning, to develop travel patterns of urban dwellers fit this measure quite well. These are as follows:

Average Motor Vehicle Travel, per Person:

8 miles/day (going up to 10 in foreseeable future)
2 trips/day

Average dwelling unit contains 3.3 occupants

8 (3.3) = 26 miles/day, travel per dwelling
2 (3.3) = 7 trips/day, per dwelling

Mileage/Year

26 (365) = 9490 miles (in close agreement with other figures of average mileage per year).

The average trip lengths making up this travel are reported as follows, by the Automobile Manufacturers Association, quoting BPR figures which appear in Appendix II:

Average Trip Lengths (One-way):

Earning a living	
To & from work	6.4 mi.
Related business	10.2 mi.
Family business	
Medical and dental	9.7 mi.
Shopping	3.8 mi.
Other	6.8 mi.
Education, civic, & religion	4.1 mi.
Social and recreational	
Vacation	296.0 mi.
Pleasure rides	14.2 mi.
Other	12.3 mi.
All purposes	8.0

Appendix II contains several tables which further describe average vehicle utilization.

Figure III - 1 shows the distribution of one-way travel by length of trip.

Figure III-1

Distribution of Passenger Car Travel

(Combined - All Purposes)

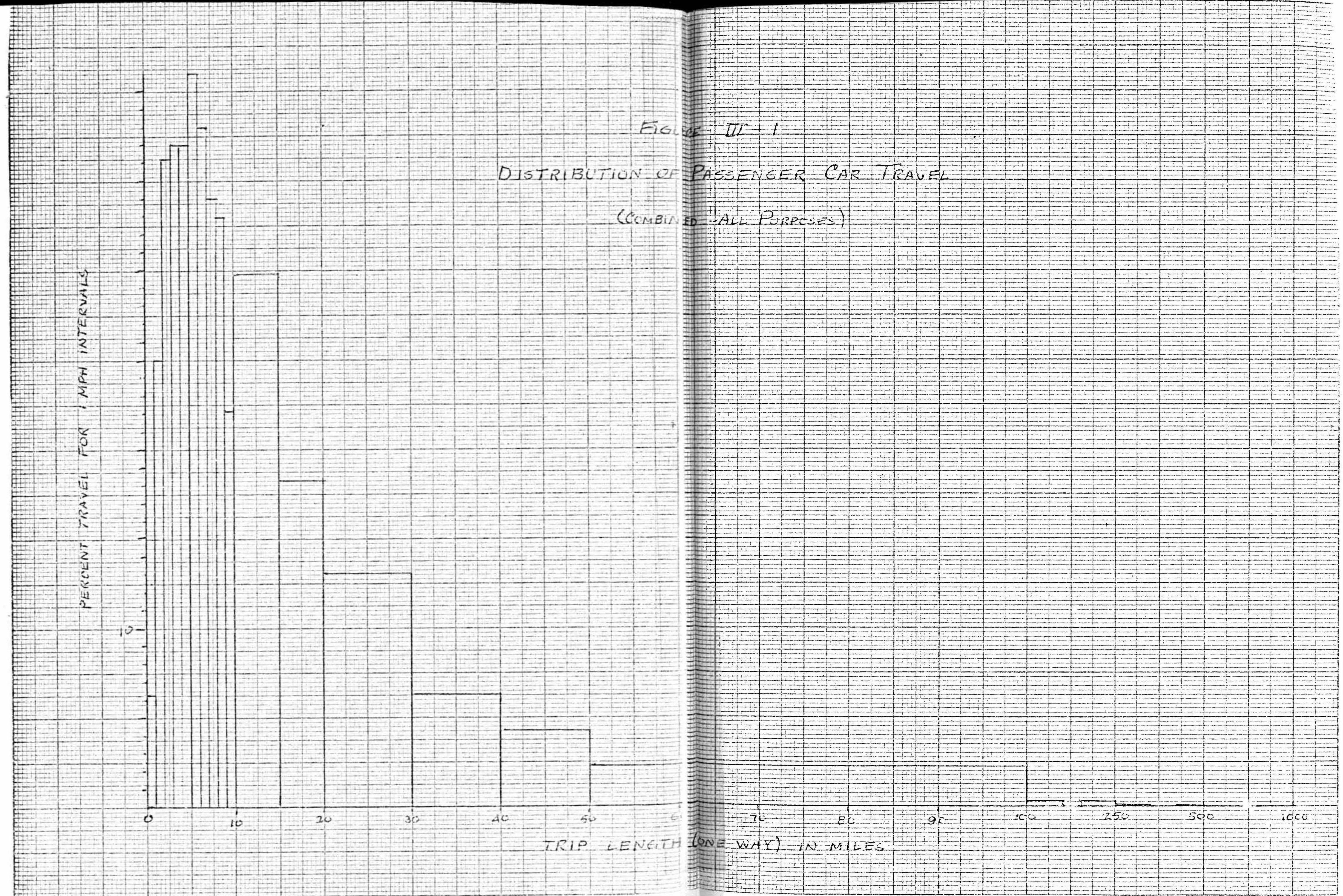


Table 3.—Estimated motor-vehicle travel in the United States and related data for calendar year 1965 and revised data for 1963 and 1964 [1]

Vehicle type	Motor-vehicle travel: Main rural roads	Motor-vehicle travel: Local rural roads	Motor-vehicle travel: Total rural	Motor-vehicle travel: Urban	Motor-vehicle travel: Total	Number of vehicles registered	Average travel per vehicle	Motor-fuel consumption: Total	Motor-fuel consumption: Average per vehicle	Average travel per gallon of fuel consumed
1965										
	Million vehicle-miles	*Million vehicle-miles*	*Million vehicle-miles*	*Million vehicle-miles*	*Million vehicle-miles*	*Thousands*	*Miles*	*Million gallons*	*Gallons*	*Miles/gallon*
Passenger cars [2]	254,975	97,662	352,637	356,663	709,300	76,643	9,255	49,723	649	14.27
Buses:										
Commercial	922	184	1,106	1,815	2,921	85.0	34,365	628	7,388	4.65
School and nonrevenue	687	758	1,445	318	1,763	229.3	7,689	247	1,077	7.14
ALL BUSES	1,609	942	2,551	2,133	4,684	314.3	14,903	875	2,784	5.35
All passenger vehicles	256,584	98,604	355,188	358,796	713,984	76,957	9,278	50,598	657	14.11
Cargo vehicles:										
Single-unit trucks	56,832	28,378	85,210	55,949	141,159	14,008	10,077	13,848	989	10.19
Trailer combinations	21,994	1,395	23,389	9,108	32,497	787	41,292	6,658	8,460	4.88
TOTAL	78,826	29,773	108,599	65,057	173,656	14,795	11,737	20,506	1,386	8.47
ALL MOTOR VEHICLES	335,410	128,377	463,787	423,853	887,640	91,752	9,674	71,104	775	12.48
1964 Revised										
Passenger cars [2]	243,429	93,539	336,968	340,645	677,613	72,969	9,286	47,567	652	14.25
Buses:										
Commercial	908	181	1,089	1,803	2,892	82.3	35,140	622	7,558	4.65
School and nonrevenue	674	743	1,417	307	1,724	223.1	7,727	242	1,085	7.12
ALL BUSES	1,582	924	2,506	2,110	4,616	305.4	15,115	864	2,829	5.34
All passenger vehicles	245,011	94,463	339,474	342,755	682,229	73,274	9,311	48,431	661	14.09
Cargo vehicles:										
Single-unit trucks	52,929	27,112	80,041	53,670	133,711	13,275	10,072	13,199	994	10.13
Trailer combinations	20,592	1,307	21,899	8,661	30,560	738	41,409	6,271	8,497	4.87
TOTAL	73,521	28,419	101,940	62,331	164,271	14,013	11,723	19,470	1,389	8.43
ALL MOTOR VEHICLES	318,532	122,882	441,414	405,086	846,500	87,287	9,698	67,901	778	12.47
1963 Revised										
Passenger cars [2]	231,298	89,080	320,378	324,993	645,371	69,842	9,240	45,246	648	14.26
Buses:										
Commercial	877	170	1,047	1,794	2,841	82.2	34,562	606	7,372	4.69
School and nonrevenue	642	708	1,350	292	1,642	215.7	7,612	232	1,076	7.08
ALL BUSES	1,519	878	2,397	2,086	4,483	297.9	15,049	838	2,813	5.35
All passenger vehicles	232,817	89,958	322,775	327,079	649,854	70,140	9,265	46,084	657	14.10
Cargo vehicles:										
Single-unit trucks	50,043	25,981	76,024	49,729	125,753	12,654	9,938	12,348	976	10.18
Trailer combinations	19,900	1,302	21,202	8,614	29,816	706	42,232	6,084	8,618	4.90
TOTAL	69,943	27,283	97,226	58,343	155,569	13,360	11,644	18,432	1,380	8.44
ALL MOTOR VEHICLES	302,760	117,241	420,001	385,422	805,423	83,500	9,646	64,516	773	12.48

[1] For the 50 States and District of Columbia, 1963 data have been adjusted, based in part on the 1963 Census of Transportation Truck Inventory and Use Survey, to provide data separately for single-unit trucks and trailer combinations.

[2] Includes taxicabs and motorcycles: 786,318 in 1963, 984,763 in 1964, and 1,381,956 in 1965, estimated to account for less than 1 percent of all travel: 1963, 0.5 percent; 1964, 0.6 percent; 1965, 0.7 percent, respectively.

Data for other than the average case is far less readily available. In fact, practically no published information is available.

One brief study within the Office of Research and Development indicates that, in averaged-sized cities of over 100,000 population, 96.5% of all vehicles travel no more than 60 miles on a typical day.

Another study of over 800 representative drivers in New York State showed the following results:

(Source: C. E. Billion, "Community Study of the Characteristics of Drivers and Driver Behavior Related to Accident Experience", Highway Research Board Bulletin 172, 1958)

Range

Low: 0 - 7,600 mi. in $2\frac{1}{2}$ yr = 0 - 3,040 mi/year by 243 drivers
Medium: 7,601 - 18,100 mi in $2\frac{1}{2}$ yr = 3,040 - 7,250 mi/yr by 231 drivers
High: 18,101 - 161,000 mi in $2\frac{1}{2}$ yr = 7,250 - 64,000 mi/yr by 217 drivers

Average within above range groups, by sex

	Male	Female
Low:	2,860 mi	1,510 mi
Medium:	6,940 mi	3,470 mi
High:	16,150 mi	7,940 mi

Approximate Average Daily Mileages

(Based on values above divided by 365)

	Male	Female
Low:	8	4
Medium:	19	10
High:	44	22

Approximate Maximum Daily Mileage (other than vacations, etc.)

$$\frac{64,000}{365} = 175 \text{ miles}$$

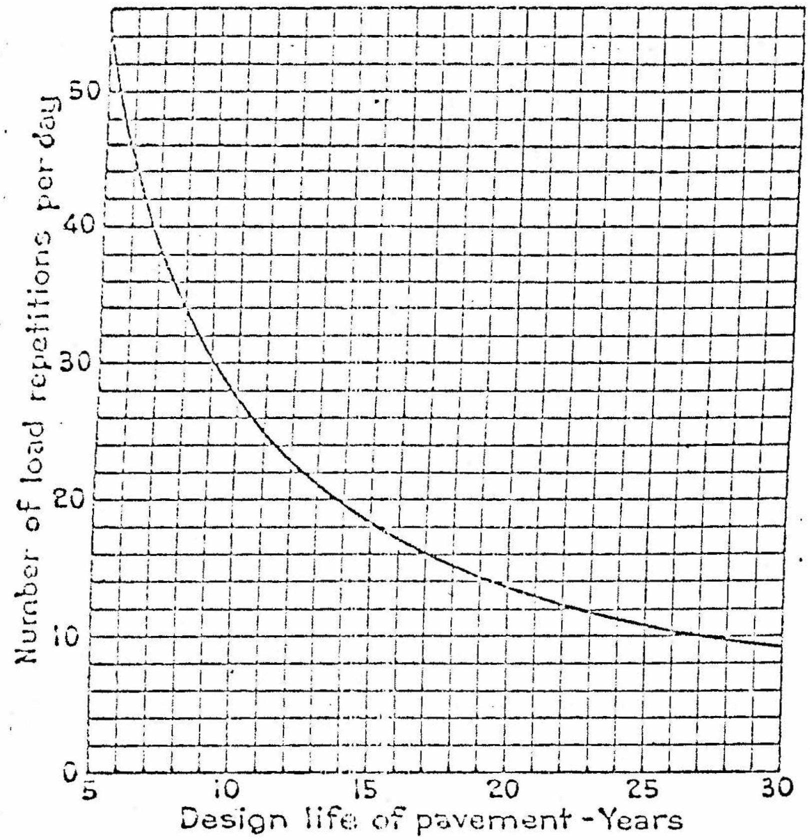
Supplementary Data

Appendix II presents other tabulated data related to the subject of highway utilization.

APPENDIX I

The Overall Transportation System Aspects

Figures 1 thru 5



Load repetitions per day that will produce 100,000 stress repetitions during design life of pavement.

Figure 1

Reference: Concrete Pavement Design, Published by Portland Cement Association, 1951, pg. 38.

Pavement Design for Class II Highway, Primary Route in a Rural Area

Case I—Protected corners
Design life = 30 years
Subgrade modulus, k = 100 psi per in.; Modulus of rupture of concrete = 700 psi.

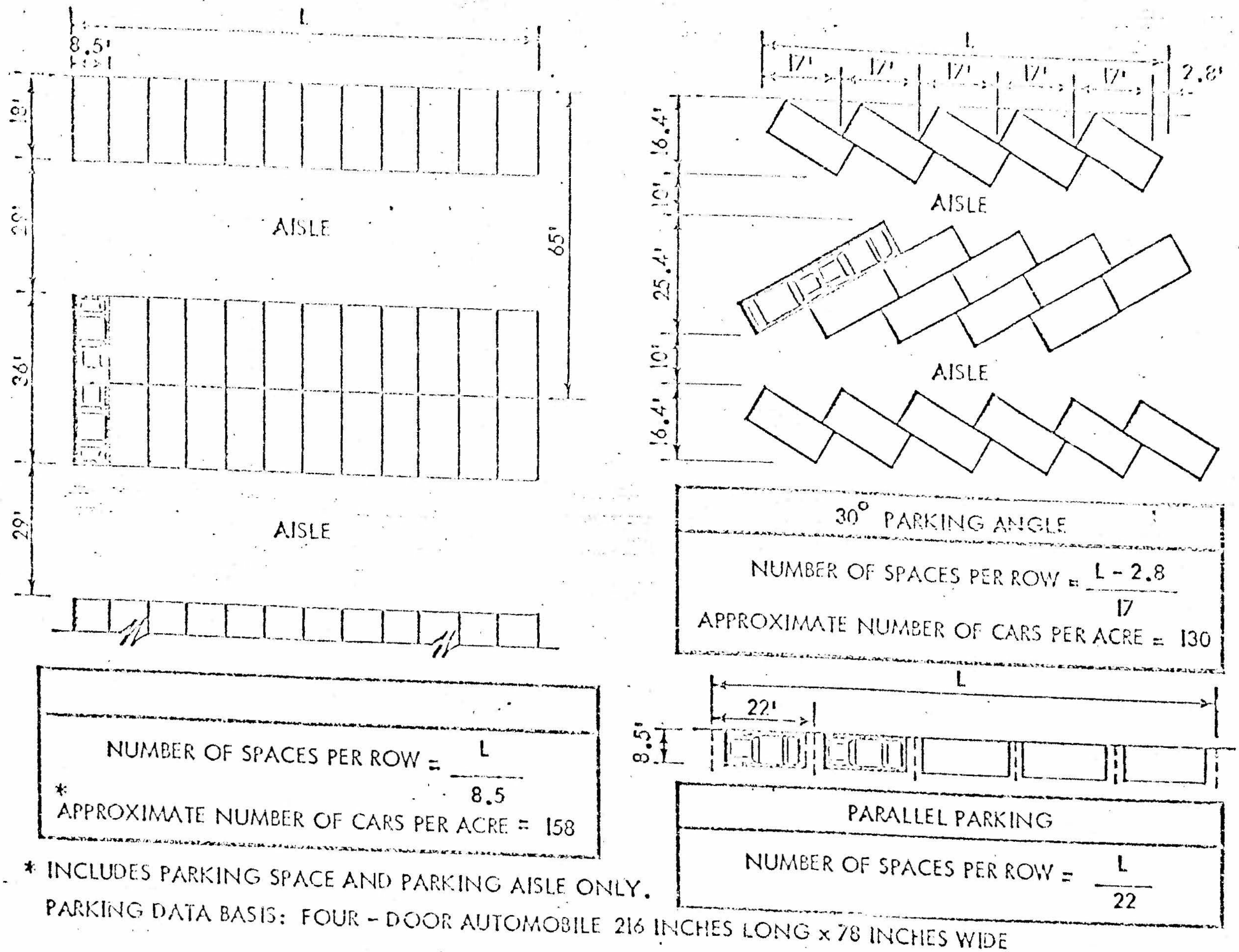
1	2	3	4	5	6	7	8	9
Wheel load lb.		Load repetitions			Analysis of design selected 10-7-10 with 2-ft. 4-in. slope d = 8.24 in.			
By groups, static	Maximum for group plus 20 per cent impact	Number per day, one direction	Anticipated for 30 year period	Determination of "Controlling Wheel Load" and Indicated d	Actual stress, psi.	Actual safety factor	Actual allowable number of stress repetitions	Fatigue resistance consumed by each load group, per cent
under 4,000	4,800	733	over 100,000		under 350	over 2.0	unlimited	
4,000 — 5,000	6,000	54	over 100,000		under 350	over 2.0	unlimited	
5,000 — 6,000	7,200	51	over 100,000		under 350	over 2.0	unlimited	
6,000 — 7,000	8,400	60	over 100,000		under 350	over 2.0	unlimited	
7,000 — 8,000	9,600	64	over 100,000		under 350	over 2.0	unlimited	
8,000 — 9,000	10,800	61	over 100,000		under 350	over 2.0	unlimited	
9,000 — 10,000	12,000	30	over 100,000		under 350	over 2.0	unlimited	
10,000 — 11,000	13,200	10	109,500	11,000 × 4.4 = 48,400	under 350	over 2.0	unlimited	
11,000 — 12,000	14,400	3.4	37,230	12,000 × 3.4 = 40,800	347	2.02	unlimited	
12,000 — 13,000	15,600	1.0	10,950	13,000 × 1.0 = 13,000	373	1.87	56,000	20
13,000 — 15,000	18,000	0.3	3,285	15,000 × 0.3 = 4,500	421	1.66	22,000	15
				9.1 — 106,700				35 Total (for wheel loads having S.F. less than 2.0)

$\frac{106{,}700}{9.1}$ = 11,725 lb. = controlling wheel load

11,725 × 1.2 = 14,070 lb. = gross controlling wheel load (includes 20% impact).
Indicated d = 8.15 in.

Figure 2

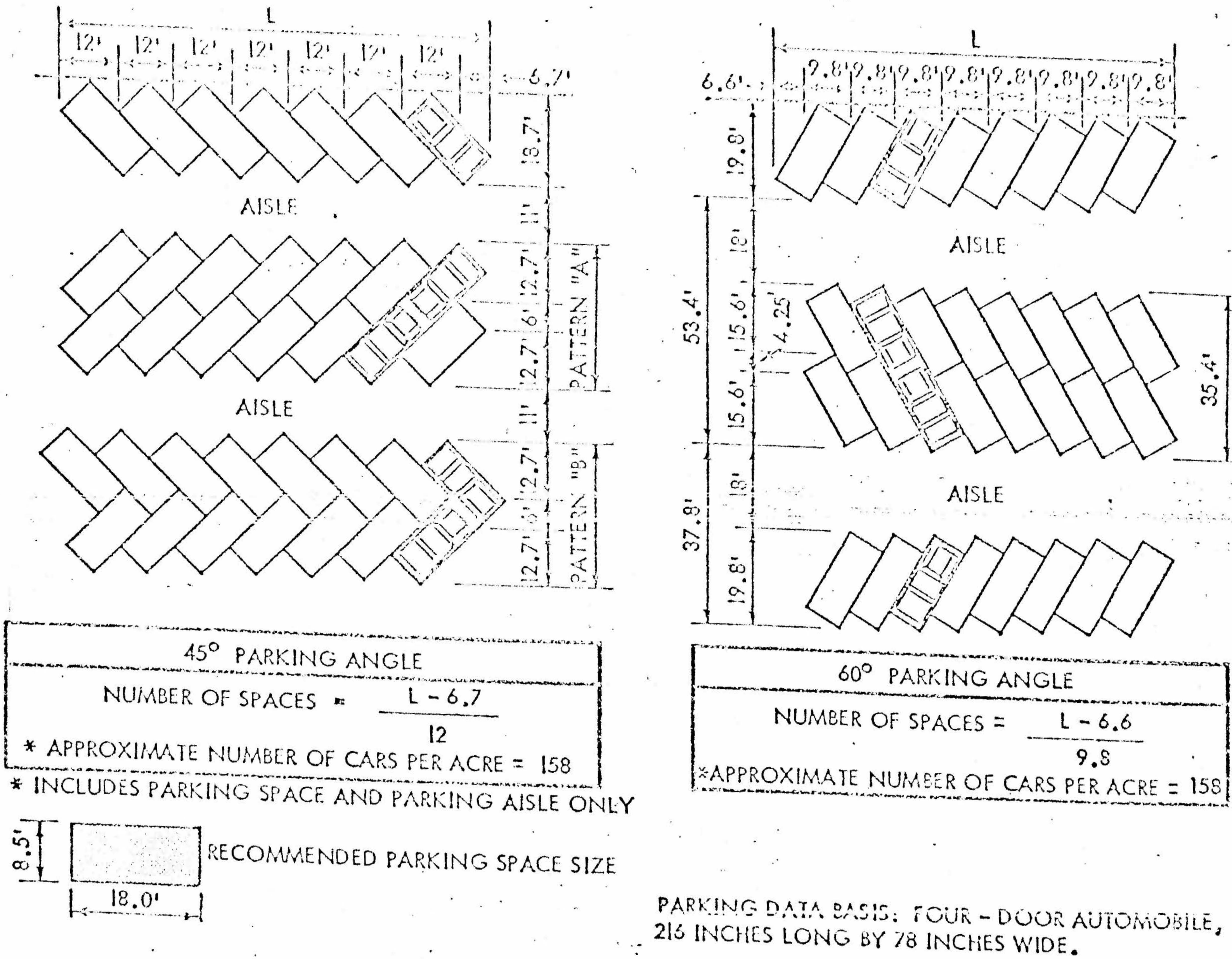
Reference: Concrete Pavement Design, Published by Portland Cement Association, 1951, pp. 36.



. *Passenger Car Parking Requirements.*

Figure 3

Reference: Airport Terminal Buildings, Published by U. S. Federal Aviation Agency, Airports Division, 1960, pg. 83.



Passenger Car Parking Requirements.

Figure 7

Reference: Airport Terminal Buildings, Published by U. S. Federal Aviation Agency, Airports Division, 1960, pg. 84.

COMBINED EFFECT OF LANE WIDTH AND RESTRICTED LATERAL CLEARANCE ON CAPACITY AND SERVICE VOLUME OF UNDIVIDED MULTILANE HIGHWAYS WITH UNINTERRUPTED FLOW

DISTANCE FROM TRAFFIC LANE EDGE TO OBSTRUCTION (FT)	ADJUSTMENT FACTOR,[a] W, FOR LATERAL CLEARANCE AND LANE WIDTH							
	OBSTRUCTION ON RIGHT SIDE ONLY, OF ONE-DIRECTION TRAVELED WAY (INCLUDES ALLOWANCE FOR OPPOSING TRAFFIC ON LEFT)				OBSTRUCTIONS ON BOTH SIDES OF ONE-DIRECTION TRAVELED WAY[b,c]			
	12-FT LANES	11-FT LANES	10-FT LANES	9-FT LANES	12-FT LANES	11-FT LANES	10-FT LANES	9-FT LANES
(a) 4-LANE UNDIVIDED HIGHWAY, ONE DIRECTION OF TRAVEL								
6	1.00	0.95	0.89	0.77	N.A.	N.A.	N.A.	N.A.
4	0.98	0.94	0.88	0.76	N.A.	N.A.	N.A.	N.A.
2	0.95	0.92	0.86	0.75	0.94	0.91	0.86	N.A.
0	0.88	0.85	0.80	0.70	0.81	0.79	0.74	0.66
(b) 6-LANE UNDIVIDED HIGHWAY, ONE DIRECTION OF TRAVEL								
6	1.00	0.95	0.89	0.77	N.A.	N.A.	N.A.	N.A.
4	0.99	0.94	0.88	0.76	N.A.	N.A.	N.A.	N.A.
2	0.97	0.93	0.86	0.75	0.96	0.92	0.85	N.A.
0	0.94	0.90	0.83	0.72	0.91	0.87	0.81	0.70
(c) DIVIDED HIGHWAYS, ONE DIRECTION OF TRAVEL								
Use adjustment factors from Table 9.2								

[a] Same adjustments for capacity and all levels of service.
[b] Appropriate for use only where normally undivided roadway is temporarily separated into two roadways by obstructions such as centerline barrier, bridge structural elements, piers, and the like, which are closer than would be the opposing traffic.
[c] N.A. = Not applicable; use adjustment for obstruction on right side only. (In these cases, clearance is temporarily greater than the usual separation from opposing traffic, but adjustment for this temporary improvement is not feasible).

Figure 5

Reference: Highway Capacity Manual - 1965, pg. 286.

APPENDIX II

Highway Utilization

Average Miles Per Vehicle

	Passenger Cars	Buses	Trucks	Total		Passenger Cars	Buses	Trucks	Total
1947	9,732	24,153	9,955	9,839	1956	9,348	18,059	10,813	9,623
1948	9,573	23,277	10,030	9,716	1957*	9,391	16,640	10,328	9,571
1949	9,401	22,379	10,040	9,547	1958	9,494	15,963	10,348	9,658
1950	9,020	20,910	10,776	9,369	1959	9,529	16,408	10,552	9,720
1951	9,154	20,820	10,790	9,410	1960	9,446	16,004	10,583	9,652
1952	9,378	21,062	10,940	9,690	1961	9,465	15,661	10,461	9,648
1953	9,370	18,234	10,927	9,674	1962	9,441	15,507	10,406	9,618
1954	9,308	18,918	10,883	9,603	1963	9,378	15,049	10,569	9,590
1955	9,359	17,658	10,697	9,615	1964	9,421	15,110	10,694	9,646

NOTE: Alaska and Hawaii included for the first time in 1959.

*Data for 1957 is not strictly comparable with previous years.

SOURCE: U.S. Department of Commerce, Bureau of Public Roads.

116 Million Motor Vehicle Registrations Forecast for 1975

"If present trends continue, we can expect Total Motor Vehicle Registrations to reach 116 million by 1975. They will include 97 million autos, and 19 million trucks and buses. . . . This year motor vehicles will travel 870 billion vehicle-miles, and use up 70 billion gallons of fuel doing it. . . . By 1970, it should reach 80 billion gallons and by 1975, we as a nation will be using 93 billion gallons of fuel per year."

E. M. Cope, Chief, Highway Statistics Division, Office of Planning, Bureau of Public Roads, August 30, 1965.

Annual Mileage Per Car

Age of Maintainer	Average Miles
Under 35	11,080
35-54	9,340
55 and Over	8,300

City Size	Average Miles
Metropolitan Area Centers	
500,000 and Over	9,200
Under 500,000	8,980
Metropolitan Area Suburbs	10,520
Outside Met. Areas (Non-Farm)	9,410
All Farm	9,750

Household Income	Average Miles
Under $5,000	7,920
$5,000-9,999	9,910
$10,000 and Over	10,950

SOURCE: Alfred Politz Research, Inc., *National Automobile and Tire Survey, 1965*, sponsored by LOOK magazine.

Distance Traveled to Work

	Location of Residence				
	In Standard Metropolitan Statistical Areas		Not In Standard Metropolitan Statistical Areas		
Distance to Work**	In Central City	Outside Central City	Nonfarm	Farm	All Locations
Works at Home	3%	5%	6%	50%	8%
Less than 3 Miles	28	22	46	14	21
3 to 5 Miles	26	18	13	9	19
6 to 10 Miles	21	25	11	6	18
11 Miles or More	16	23	18	13	18
No fixed place of Work	6	7	6	8	6
All Distances	100%	100%	100%	100%	100%

*Includes only work commuters who have public transportation available whether used or not.

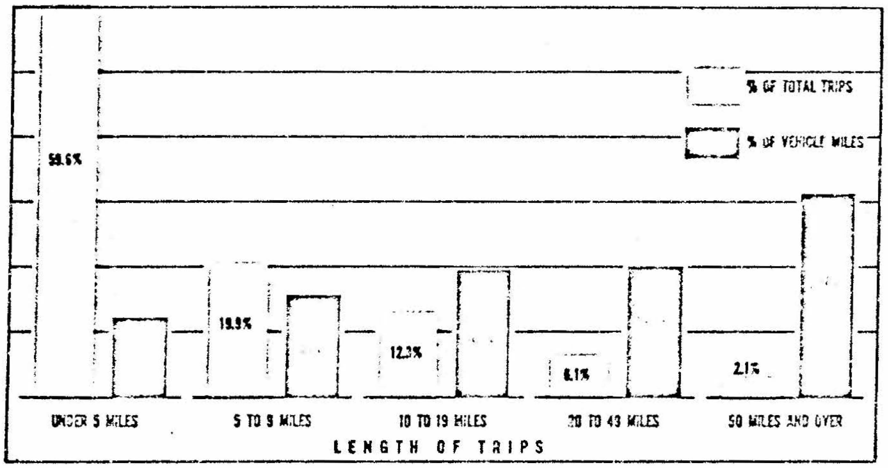
** Includes "All workers".

NOTE: "Commuter" is defined as a person going from home to a fixed place of work that is more than one-fourth mile from home. These represent about 76% of all workers in the U. S. "Public transportation" refers to buses, street cars, subways, elevated trains, other rapid transit, and railroads. Survey undertaken October, 1963 covered approximately 6,000 households with about 5,200 work commuters.

SOURCE: U.S. Department of Commerce, Bureau of the Census, *Home to Work Travel Survey*.

60% of Car Trips Are Less Than 5 Miles

Distribution of Trips and Vehicle Miles by Passenger Car



Distribution of Trips and Vehicle-Miles of Travel by Cars and Trucks

Trip Length (Miles)	Trips Cars	Trips Trucks	Vehicle Miles Cars	Vehicle Miles Trucks
Under 5	59.6%	53.0%	13.2%	9.4%
5-9	19.9	20.8	15.4	13.0
10-14	8.1	9.3	11.2	10.3
15-19	4.2	5.1	8.2	8.0
20-29	3.7	5.1	10.4	11.1
30-39	1.6%	2.3%	6.5%	7.0%
40-49	0.8	1.1	4.3	4.7
50-99	1.3	2.0	10.8	12.0
100 and over	0.8	1.3	20.0	24.5
Total	100.0%	100.0%	100.0%	100.0%

NOTE: Based on motor-vehicle-use studies 1951-56, covering 19 states for passenger cars and 18 states for trucks.

SOURCE: U.S. Department of Commerce, Bureau of Public Roads, *Highway Transportation*.

[illegible]

Purpose of Travel	Percentage Distribution Trips (1)	Vehicle Miles (2)	Average Trip Length One Way (Miles) (2)	Occupants Per Car (1)
Earning a living:				
To and from work	33.6%	26.8%	6.4	1.3
Related business	12.2	16.8	10.2	1.3
Total	45.8	43.6	—	1.3
Family business:				
Medical and dental	1.6	1.9	9.7	2.0
Shopping	15.8	7.2	3.8	1.9
Other	12.1	9.9	6.8	1.8
Total	29.5	19.0	—	1.9
Educational, civic, and religious	7.6	3.7	4.1	2.4
Social and recreational:				
Vacations	0.1	4.9	296.0	2.7
Pleasure rides	7.2	12.7	14.2	2.5
Other	9.8	16.1	12.3	2.4
Total	17.1	33.7	—	2.4
All purposes	100.0%	100.0%	8.0	1.7

(1) From motor-vehicle-use studies in 16 states 1951-1958.

(2) From motor-vehicle-use studies in 22 states 1951-1958.

Data based on sample surveys. See footnote on page 68.

SOURCE: U.S. Department of Commerce, Bureau of Public Roads, *Public Roads*.

11,750,000 Multi-Car Households in U.S.

Year	Total Households (000)	Car-Owning Households (000)	Percent of Households Owning Cars	Multi-Car Households (000)	Multi-Car Households as percent of: Total Households	Multi-Car Households as percent of: Car-Owning Households
1954.....	47,000	34,270	72.9%	4,150	8.8%	12.1%
1955.....	47,900	35,250	73.5	4,850	10.1	13.8
1956.....	49,000	35,950	73.4	5,000	10.2	13.9
1957.....	49,900	36,450	73.0	6,150	12.3	16.9
1958.....	50,500	37,600	74.4	6,450	12.8	17.2
1959.....	51,400	38,200	74.3	6,950	13.5	18.3
1960.....	52,300	39,500	75.5	7,000	13.4	17.8
1961.....	53,700	40,700	75.8	7,400	13.8	18.1
1962....	54,500	42,050	77.1	7,900	14.4	18.8
1963....	55,900	43,300	77.5	8,700	15.6	20.1
1964....	56,400	44,050	78.1	10,100	17.9	22.9
1965.....	56,950	45,350	79.6	11,750	20.6	25.9

46% of Households with 2 or More Cars are in Suburbs

INCOME	Percent of Households in Each Group Owning 2 or More Cars	Percent of Total Multi-Car Households
Under $4,000......	2.7%	3.6%
$4,000-4,999......	10.8	4.1
$5,000-6,999......	17.4	22.2
$7,000-7,999......	22.2	10.4
$8,000-9,999......	31.4	18.5
$10,000-14,999....	45.9	25.9
$15,000 or more....	53.7	15.3
Total U. S........	20.6%	100.0%
REGIONS		
Northeast..........	19.7%	24.0%
North Central.......	21.9	29.8
South..............	17.3	25.7
West..............	26.2	20.5
Total U. S.........	20.6%	100.0%

CITY SIZE	Percent of Households in Each Group Owning 2 or More Cars	Percent of Total Multi-Car Households
Metropolitan Area Centers:		
500,000 or over...	11.0%	8.5%
Under 500,000...	19.0	13.9
Met. Area Suburbs...	29.3	45.9
Outside Metropolitan Area (Non-Farm)...	17.9	25.8
All Farms...........	16.9	5.9
Total U. S........	20.6%	100.0%
AGE		
Under 25..........	10.8%	3.7%
25-34.............	20.3	19.1
35-44.............	25.4	27.4
45-54.............	31.1	31.2
55-64.............	21.0	13.7
65 and over........	6.0	4.9
Total U. S.........	20.6%	100.0%

45,350,000 Households Own 58,800,000 Automobiles

U. S. Households Which Own:	HOUSEHOLDS Number	HOUSEHOLDS Percent	CARS OWNED Number	CARS OWNED Percent
One or More Cars................	45,350,000	79.6%	58,800,000	100.0%
One Car.....................	33,600,000	59.0	33,600,000	57.2
Two Cars.....................	10,300,000	18.1	20,600,000	35.0
Three or More Cars............	1,450,000	2.5	4,600,000	7.8
No Cars........................	11,600,000	20.4	—	—
Total........................	56,950,000	100.0%	58,800,000	100.0%

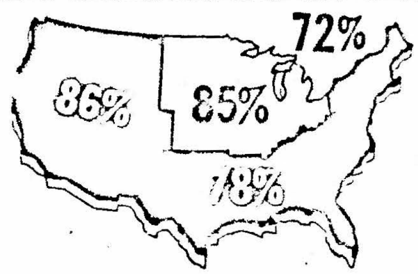
NOTE: The difference between the number of cars owned by households and total registrations is due to the omission from this analysis of cars owned by governments, by Army personnel residing on base, by individuals living in institutions, and by businesses.

This data based on sample surveys. See footnote on page 68.

SOURCE: Alfred Politz Research, Inc., *National Automobile and Tire Survey, 1965*, sponsored by LOOK magazine.

Car Ownership Highest in Suburbs and in West

BY REGION



BY CITY SIZE

METROPOLITAN AREA CENTERS
- CITIES 500,000 OR MORE . 61%
- CITIES UNDER 500,000 . 82%

METROPOLITAN AREA SUBURBS . 89%

OTHER NON-FARM 78%

FARM 82%

CITY SIZE	Percent of Households Owning Cars Within Each Group	Distribution of Households Owning Cars
Metropolitan Area Centers:		
500,000 or over	60.5%	11.5%
Under 500,000..	81.6	15.6
Met. Area Suburbs.	88.9	36.2
Outside Met. Area (Non-Farm).....	77.7	29.2
All Farms.........	81.9	7.5
		100.0%
REGIONS		
Northeast........	72.4	23.1%
North Central.....	85.0	30.0
South...........	77.5	29.6
West...........	85.8	17.3

INCOME	Percent of Households Owning Cars Within Each Group	Distribution of Households Owning Cars
Under $4,000......	52.5%	17.3%
$4,000-4,999.......	78.5	8.0
$5,000-6,999.......	84.9	28.0
$7,000-7,999.......	94.4	11.3
$8,000-9,999.......	93.6	14.4
$10,000-14,999....	94.7	13.9
$15,000 or more....	95.5	7.1
		100.0%
U. S. Total.......	79.6%	100.0%

SOURCE: Alfred Politz Research, Inc., *National Automobile and Tire Survey, 1965*, sponsored by LOOK magazine.

Automobile Ownership Within Income Groups, Early 1962-65

	Percentage Distribution of Spending Units											
	OWNS								DOES NOT OWN			
	1 Automobile				2 or More							
	1962	1963	1964	1965	1952	1963	1964	1965	1962	1963	1964	1965
All spending units......	58%	39%	56%	57%	14%	18%	19%	19%	28%	23%	25%	24%
Money income before taxes:*												
Under $1,000........	17	22	28	30	1	2	2	5	82	76	70	65
$1,000-$1,999........	34	41	32	41	2	1	3	2	64	58	65	57
$2,000-$2,999........	51	53	59	53	3	6	6	5	46	41	35	42
$3,000-$3,999........	66	58	58	51	6	10	8	10	28	32	34	39
$4,000-$4,999........	68	67	62	67	7	15	10	9	25	18	28	24
$5,000-$5,999........	67	74	66	68	11	12	19	14	22	14	15	18
$6,000-$7,499........	71	72	71	67	20	18	17	22	9	10	12	11
$7,500-$9,999........	69	65	63	62	23	30	31	31	8	5	6	7
$10,000 and over......	54	49	51	53	42	47	45	42	4	4	4	5

*Money income for previous year.

NOTE: A "Spending Unit" consists of all persons living in the same dwelling and related by blood, marriage, or adoption, who pooled their income for major items of expenses. Some families contain two or more spending units.

This data based on sample surveys. See footnote on page 68.

SOURCE: The University of Michigan, Survey Research Center, *Survey of Consumer Finances*.

APPENDIX III

Miscellaneous Highway Plant Data

Automobile Facts and Figures

1965 U.S. Imports of Motor Vehicles (p. 5)

passenger cars new	559,430
passenger cars used	8,000
trucks and buses	30,893
Total	598,323

1965 Domestic and Export Factory Sales
(does not include sales to all Federal Government agnecies) (p. 5)

passenger cars:	
domestic	9,092,000
exports	205,000
total	9,297,000
trucks and buses	
domestic	1,564,000
exports	136,000
total	1,700,000
total motor vehicles	
domestic	10,656,000
exports	341,000
total	10,997,000

1963 Total number of auto repair, auto service 114,459

1963 Total number of auto services except repair
(parking lots, rentals, and service except repair) 25,152

1963 Total 139,611

(p. 36)

Wholesale
1963 Total petroleum bulk stations, terminals 30,873

1963 Estimated number of employees of petroleum bulk stations, terminals 151,613

1963 Payroll of petroleum bulk stations, terminals $791,536,000

1963 Sales or receipts of Petroleum bulk stations, terminals $21,485,414,000

(p. 37)

Statistical Abstract of U.S. - 1965

1963 Total number of gasoline service stations 211,473

(p. 830)

1963 Total sales of gasoline service stations $17,760,000,000

(p. 831)

1963 Total number of auto repair, auto service, garages 139,611

(p. 842) see also Auto Facts (p. 36)

1963 Total receipts $5,444,000,000

(p. 842)

Highway Statistics 1964

1964 Total number of gallons of gasoline(highway) 67,900,779,000

(p. 3)

1964 Motor-vehicle registrations		(total)	86,309,098
	automobiles	(total)	71,984,540
	buses	(total)	305,415
	all other vehicles	(total)	14,019,143

1964 Motor fuel revenue from State taxes
(net receipts) (taxation of motor fuel) $4,206,468,000

other receipts in connection with motor
fuel tax 25,770,000

net total receipts 4,232,238,000

dedicated revenue from non-highway gasoline 14,743,000

Adjusted net total receipts $4,217,495,000

(p. 8)

1964 Federal revenue from taxes on motor fuel:

gasoline	$2,534,478,000
highway special fuel	143,148,000
total	$2,677,626,000

(p. 52)

1964 Estimates of above portions paid by highway users:

gasoline	$2,500,970,000
highway special fuel	143,148,000
total	$2,644,118,000

Percent of revenue paid by highway users:

gasoline	98.68%
highway special fuel	100.00%
total	98.75%

(calculated)

1964 Mileages of road

total rural roads	3,152,577
total municipal roads	491,492
total rural & municipal roads	3,644,069

(p. 130)

1964 Mileages of road:

municipal - nonsurfaced	33,042
surfaced	458,450
total	491,492
rural - nonsurfaced	880,691
surfaced	2,271,886
total	3,152,577