SAFETY CONSIDERATIONS FOR A DEMONSTRATION PROGRAM OF ELECTRIC VEHICLES

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James O'Day
Lily Huang

Highway Safety Research Institute
The University of Michigan
Ann Arbor, Michigan 48109

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16. Abstract

This report was prepared in connection with a broader study of the opportunities and risks associated with a demonstration program defined by the Congress of the United States in the Electric and Hybrid Research, Development, and Demonstration Act of 1976. This report has been used in the preparation of the interim report of the Opportunity and Risk Assessment (OPRA) program conducted under the direction of the Purdue University Institute for Interdisciplinary Studies. The problems addressed by this particular part of that study are to develop estimates of the number of accidents, injuries, and fatalities which might obtain in an electric and hybrid vehicle demonstration program of varying constitution, number, and time.

In order to derive such an estimate, we have referred to existing accident data banks for small internal combustion engine cars operating primarily in urban areas, and have extrapolated from that data to some assumed electric vehicle populations. In addition, we have considered some particular problems of electric vehicles which might produce new dangers, such as electric shock, battery acid, and low acceleration capability. The desirability of imposing existing or new safety standards on these vehicles is considered.

It is concluded that most of the current motor vehicle safety standards would have to be modified or waived in part in order for electric vehicles to satisfy the letter of the law. The preliminary analysis presented here indicates that selected waiving of safety regulations would not significantly increase the probability of serious injury and death in urban applications. Further, it is concluded that the process of developing such regulations at this time specifically for the electric and hybrid vehicles could substantially delay production and increase costs of the vehicles, and that this delay would not be consistent with the intent of the demonstration program.

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James O'Day and Lily Huang
University of Michigan
Highway Safety Research Institute

INTRODUCTION

One stated goal of the demonstration program is to "foster the commercialization of the electric vehicles." With regard to safety, the risk statement might be worded "What choices can be made relative to the safety of the vehicle (or its operating system) which will increase or decrease the probability of success in the program (in terms of the goal stated above).

Several choices in the implementation of a demonstration may have safety consequences. Qualitatively we can suggest that heavier vehicles, vehicles complying with all of the Federal Motor Vehicle Safety Standards, vehicles with passive restraint systems (e.g., airbags), vehicles with power supplies less likely to fail on the highway, vehicles with special shields to protect occupants from damaged contents of the battery compartment, etc., would be safer--i.e., they would exhibit a lower probability of producing an injury or a fatality than their alternatives. Similarly, vehicles driven by selected "good" drivers, vehicles operated in a sheltered environment, vehicles operated only in the daytime, vehicles operated only on city streets, etc., would associate with a lower probability of untoward events. In the environmental area, vehicles that are better maintained, batteries that are charged under commercial (as opposed to home) conditions, vehicles that are operated only in "good" weather, etc., would be less likely to cause safety problems than their counterparts.

It is clear that if we wished to define the vehicle-driver-environmental characteristics purely to minimize the probability of error (injury, fatality, property damage), we could proceed to satisfy all of the FMVSS's, create new standards--e.g., regarding protection of battery electrolyte, acceleration capability, etc., choose the best drivers we could find, and install the test fleet in the least demanding environment. But all of these choices are not consistent with the goal stated above--to foster the commercialization of the electric vehicle. Individual safety advances--for example, the requirement to satisfy FMVSS-215*--could lead to heavier vehicles (with less range), which would lead to less flexibility in placing the vehicles in service, which might ultimately lead to a lower probability of success of the "commercialization" program.

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One could compare the safety benefits and the program risks with regard to each of the current motor vehicle safety standards, with regard to new (as yet undefined) standards, or with regard to driver and environmental choices for the demonstration program. We will attempt to show here that the disbenefits of accidents likely to occur in a year of test fleet operation are not much different from those that would be experienced with an equivalent number of conventional cars, and suggest that safety benefits of such rulemaking at this time would generally be outweighed by the risk of program failure.

IMPLEMENTATION ELEMENTS

Although Public Law 94-413 makes several mentions of electric and hybrid vehicle safety, there are essentially no mandates for particular safety standards--only a mandate that the Administrator "consult and coordinate with the Secretary with respect to...safety and damageability programs." Further, the Administrator is required to promulgate rules establishing performance standards...taking into account...vehicle safety and insurability. Section 7(b) notes that "Initial performance standards under paragraph (b) (1) shall be set at such levels as the Administrator determines are necessary to promote the acquisition and use of such vehicles for transportation purposes which are within the capability (as determined by the Administrator) of electric and hybrid vehicles.

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*The "exterior protection" standard.

Thus the decision as to which (safety or other) standards should be promulgated is left to the Administrator, and he is evidently required to make the judgment as to the level (say, of safety standard) that will promote the acquisition and use of such vehicles. Indeed, one might read the law as requiring that decisions regarding standards be based not on safety considerations at all, but simply on whether they promote acquisition and use.

External factors that may affect either the imposition or application of safety standards include decisions of the manufacturers. While waivers of certain FMVSS's have been granted to present electric car manufacturers, it is possible that manufacturers of conventional ICE vehicles entering the electric car field may choose to comply with or exceed present safety standards--either to minimize differences between components for different car lines, or to minimize product liability. It would seem that, even though the Administrator did not promulgate extensive motor vehicle safety standards, some of the vehicles produced may comply.

Some federal rule-making activity has approached the state of the art in setting standards. Engine emission requirements for the 1980's certainly exceed the state of present production, and are evidently close to the state of the art. Such state-of-the-art standards for electric car safety are possible--e.g., a requirement that cars be built with certain capability to prevent electrolyte spillage, or that all cars have passive restraint systems (as specified by FMVSS 208). Whether such requirements would be consistent with the promotion of "acquisition and use of electric vehicles" must be decided by the Administrator.

BACKGROUND

Having introduced the problem of safety risk and the implementation elements of that area, we will proceed to characterize the risk of operating a small experimental fleet of electric cars. For discussion purposes we will discuss the likely safety problems in operating a pilot fleet of approximately 2500 electric cars for a period of a year in the U.S. The vehicle characteristics are assumed to be those of existing (i.e., near-term) electric cars--generally between 1500 and 2500 pounds with a speed and range capability most compatible with urban operation. A range of compliance with current federal motor vehicle safety standards seems possible--at the low end, compliance with none of the present standards, and at the high end compliance with all. In addition, special standards may be developed for electric vehicles, and compliance or non-compliance with these will be considered. Ultimately it is likely, if not quite clear, that there will be a set of safety standards for both Electric Vehicles and Electric Hybrid Vehicles; but the present problem is whether such standards should be applied to a first test fleet of 2500 cars.

A LISTING OF POSSIBLE PROBLEMS

Possible problems in operating a fleet of electric vehicles will be divided into: (1) chemical problems, (2) electrical dangers, (3) crashworthiness, (4) the electric vehicle as a member of the traffic stream, and (5) applicability of current or future motor vehicle safety standards.

Chemical problems may result primarily from the batteries, and could include leaks (with or without crashes), acid burns, and the possibility of explosion during charging operations.

Electric dangers may arise because of the use of relatively lethal voltages (greater than 100 volts) in some of the vehicles. In addition, the NHTSA has recently expressed concern about electrical failures in piston-engine cars shutting down the cars in traffic, and thus endangering the occupants. Similar reliability problems might be addressed when the prime power source is electrical.

Crashworthiness may be considered with respect to the power system (will battery spills result from crashes, will there be electrical danger in crashes?), and with respect to occupant protection. It will be instructive to compute the expected number of untoward events--crashes, injuries, fatalities, explosions, etc., for fleets of particular size and composition.

Finally, an estimate will be made of the benefits of requiring cars in the test fleet to conform to existing or future safety standards--again in terms of the likelihood of accident, injury, etc.

A SCENARIO

We wish to estimate the extent of the safety problems associated with the introduction of a fleet of, 2500 electric passenger cars into the population in about 1979. To provide a framework for calculation, we suggest the following scenario:

Fleet = 2500 passenger cars in non-commercial service,
Car type = mostly small, may be built to comply with FMVSS; some of the cars may be larger,
Where = cars mainly operated in urban, suburban, and small city areas. Almost never on freeways or high-speed rural roads,
Drivers = the same as the general population of drivers--i.e., not mostly young, or mostly old,
Trips = mainly urban--shopping, to and from work, local social and recreational trips.
Occupancy = an average of 1.5 passengers per trip

METHODOLOGY

For chemical and electrical problems, we will determine from the literature the possible effects of exposed high voltage or spilled battery acid; then,from a combination of this information with data on crash severity, we will make estimates of the number of cases of injuries to be expected from this source.

With regard to injuries directly from impact forces, we will measure the crash severity and casualty frequency in a surrogate population of vehicles in accidents. Specifically, we will use data from the State of Texas* from 1971-1975 and investigate the crashes of small (mini) cars,

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*It would be more appropriate to use a representative set of national data for this study, but no national data with detailed identification of vehicle make and size and other details (such as crash severity) are available. We have maintained a set of Texas crash data for several years because of its detail, and offer it as typical if not representative of the country. There is, of course, less snow in Texas, and no doubt more hot weather than the average of the U.S. But the population density of Texas is about the same as that of the nation, and there is an adequate distribution of rural and urban areas. For the present purpose, determining an overall accident rate and the likely casualties within the subset of small cars in urban areas, we believe the Texas data to provide a useful estimate.

comparing them with the experience of larger cars. Data for cars older than the 1968 model year will be used to simulate cars lacking conformance with the present Federal Motor Vehicle Safety Standards; data on more recent car models will be used to simulate those vehicles complying with current standards.[*]

RESULTS

Chemical Dangers

In Texas accident reports the police officer records a damage severity rating for each involved vehicle called the TAD (Traffic Accident Data) scale. This is a seven point scale, and a number is assigned by the officer with reference to a photograph of damaged vehicles. Briefly, level 1 involves minor damage to the car bumper (for a frontal crash), level 2 involves severe damage to the bumper, level 3 involves damage to the radiator, etc. For purposes of estimation here we will first assume that vehicles damaged to level 4 or greater will be sufficiently deformed to crush all or part of the battery compartment, potentially releasing acid. Determining the extent of acid release as a function of design has, of course, not been done, and the present estimates are for illustrative purposes only. At any rate, of one thousand cars in the population operating primarily in urban service, we might expect about 46 of these to be involved in a reportable crash (see below). In urban areas the crash severity is such that about 9% of these would suffer damage to TAD level 4 or greater, but only 3.5% at TAD level 5 or greater. Multiplying, we might expect in each year 4 cars (6 passengers) per thousand in service to exhibit a "battery acid spill" problem if this occurred at TAD level 4, and 1.6 cars (2.4 passengers) per thousand if at TAD-5.

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[*] See Appendix A for a fuller discussion of the accident data base and the analysis method.

The severity of burn from the battery acid depends on the location on the body, age of the victim, quantity of acid, condition of the battery, and, most importantly, the length of time between the accident and treatment. For a new battery, if the time between the accident and treatment (wash with plenty of water) is between 10 and 15 minutes, a normal adult skin will have 2nd degree burn (partial thickness); if the time is 15 to 30 minutes, the severity will be 3rd degree burn (full thickness). Eyelid, back of hand, forehead, cheek, and neck will probably have 3rd degree burn, if the acid is in large quantity and the time length is between 10 and 15 minutes. Cornea damage is likely to be much more severe; one can have complete cornea damage within several minutes. All such damage is more severe for children, because they have a higher absorbing ratio. The Burn Center does not recommend any other treatment except plain water. The basic steps one should take are (1) get acid out of eye, (2) remove clothing which has acid as soon as possible. Baking soda may neutralize acid a little bit; however, it stays in the skin and may cause further burn.

Since the time lag between the accident and treatment is so critical, the ambulance arrival time may be the critical element in determining the severity of a battery acid burn. If indeed cars are likely to produce acid spills in as many as 9% of all crash involvements, it may be appropriate for each car to be equipped with a small tank of water to flood affected areas.

If one depends on ambulance arrival for treatment and washing away of the acid, the time between the accident and the ambulance would determine the burn severity. According to a 1969 Michigan survey, 53% of the ambulance arrivals at the accident site were within ten minutes of the accident; 19.5% were within 10 to 15 minutes; and 28% took longer than 15 minutes. Assuming these figures to hold for urban accidents (and assuming that crash severity and ambulance arrival time are independent) we may estimate the distribution of the number of persons burned to various degrees for the two conditions: first, if acid spills are a problem at crashes of TAD level 4, and second for TAD level 5. These are presented in the table below.

TAD DISTRIBUTION

The distribution of crash severity in urban service may be estimated from a record of the TAD distribution in Texas data. The table below shows TAD distribution for cars which have crashes in urban areas vs. rural areas. It can be seen that urban crashes are, in general, much less severe. For example in the urban case only 9% of the vehicles are damaged to level 4 or above, vs. 27% in the rural area.

Table 1

TAD Crash Severity Distributions

TAD	Rural	Urban
1	.227	.43
2	.237	.294
3	.269	.185
4	.116	.057
5	.061	.020
6	.050	.010
7	.040	.005

However, the National Institute for Burn Medicine has provided the following information which could indicate the possible hazard of acid spill from the electrical car.

Table 2

Estimated Acid Burn severity incidence in EHV operation

	TAD-4 and greater	TAD 5 and greater
Burn Severity 1 or less	2.19*	0.85
Burn Severity 2	0.79	0.31
Burn Severity 3	1.16	0.45

*Expected number of persons injured to burn severity levels 1, 2, or 3 per year per thousand vehicles in service

ELECTRICAL SHOCK

Voltages of the sort proposed for the electric vehicles under consideration in this program are potentially lethal. Two principal mechanisms of electric shock are fibrillation of the heart and paralysis of the respiratory/cardiac center at the base of the brain. Actual currents in the body depend on skin conductivity, the availability of electrodes, the voltage, etc., but anything over 100 volts with large current capability should be considered dangerous. Consequently it would seem imperative that electric cars have some sort of protective disconnect circuitry to minimize this hazard in a crash. To our knowledge the sort of problem created by the electric car has not existed to date--i.e., the possibility of a large battery of electrical cells crashing at high speed. We may assume that careful attention to design will eliminate this problem--i.e. it should be so rare as have a probability approaching zero in a fleet of a few thousand vehicles. But it does deserve thought in the design stage.

Many non-fatal but permanently disabling electrical injuries are possible. These are not discussed further in the present memo, but deserve study.

CRASH (INJURY, FATALITY) FREQUENCY

Using 1971-75 Texas accident data, we will estimate the number of accident involvements, the number of injuries, the number of fatalities, and the distribution of damage severity for mini-cars as well as for comparison populations. In addition, to simulate cars conforming or not conforming to present federal motor vehicle safety standards, we will divide the analyses into pre-1968-model cars and 1968-and-later-model cars.

In addition to the state-provided accident data, we have used car registration information for the same period (as provided by R.L. Polk and Company), and some usage information from a 1970 national exposure survey. (Ref. Carroll 1971). Results in general will be presented in percentages, or in terms of a 1000-car fleet.

We have assumed that the electric cars will be operated entirely within urban areas, and will not travel on freeways. The 1970 exposure data indicate that 53% of the minicar travel was performed on such (city street) areas; for all cars (generally those larger than minicars) this figure was 58%. Also from this exposure survey, estimated annual mileage for all passenger cars was about 10,000 miles; but this varies markedly with vehicle age. A plot of car age vs. 30 day mileage (Figure 1) illustrates this, and it is seen to be a log-linear relationship. Assuming that the electric cars will replace all of the urban trips but none of the rural (or urban freeway) trips, the average electric car should travel approximately 5300 miles per year. If the electric car is driven more like a brand new ICE vehicle, this might average as high as 6300 miles per year; but the lower assumption will be used for computations here.

From the Texas data, then, we calculate the expected number of crash involvements per thousand cars to be 87 (for a 10,000 mile year) or 46 for a 5300 mile urban year. In the actual accident data new cars have somewhat more accidents per year than old (and this is roughly proportional to their increased mileage). Further, small cars have more accidents per year than large cars, and much of this can be attributed to the age of the drivers of small cars.[**] We will assume that the expected number of crashes per year for an electric car in urban service is equal to the measured number of accidents in the present data for the average urban-operated vehicle. Thus we might expect 46 accident involvements[*] per 1000 electrical cars in a one-year period.

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[*] To be meaningful any accident count estimate must be accompanied by a definition of an accident. In the present case we define an "accident" as one which is reported by a police agency in the state of Texas. Other states, using different reporting criteria, would produce different estimates. The TAD distribution for Texas-reported urban accidents will also be presented, and this should illustrate more clearly just what a "Texas" accident is.

[**] For example, in Michigan accident data the mean age of Volkswagen drivers in accidents reported to the police was about 25; drivers of full-size Fords averaged about 33 years, and drivers of Cadillacs averaged about 44 years.

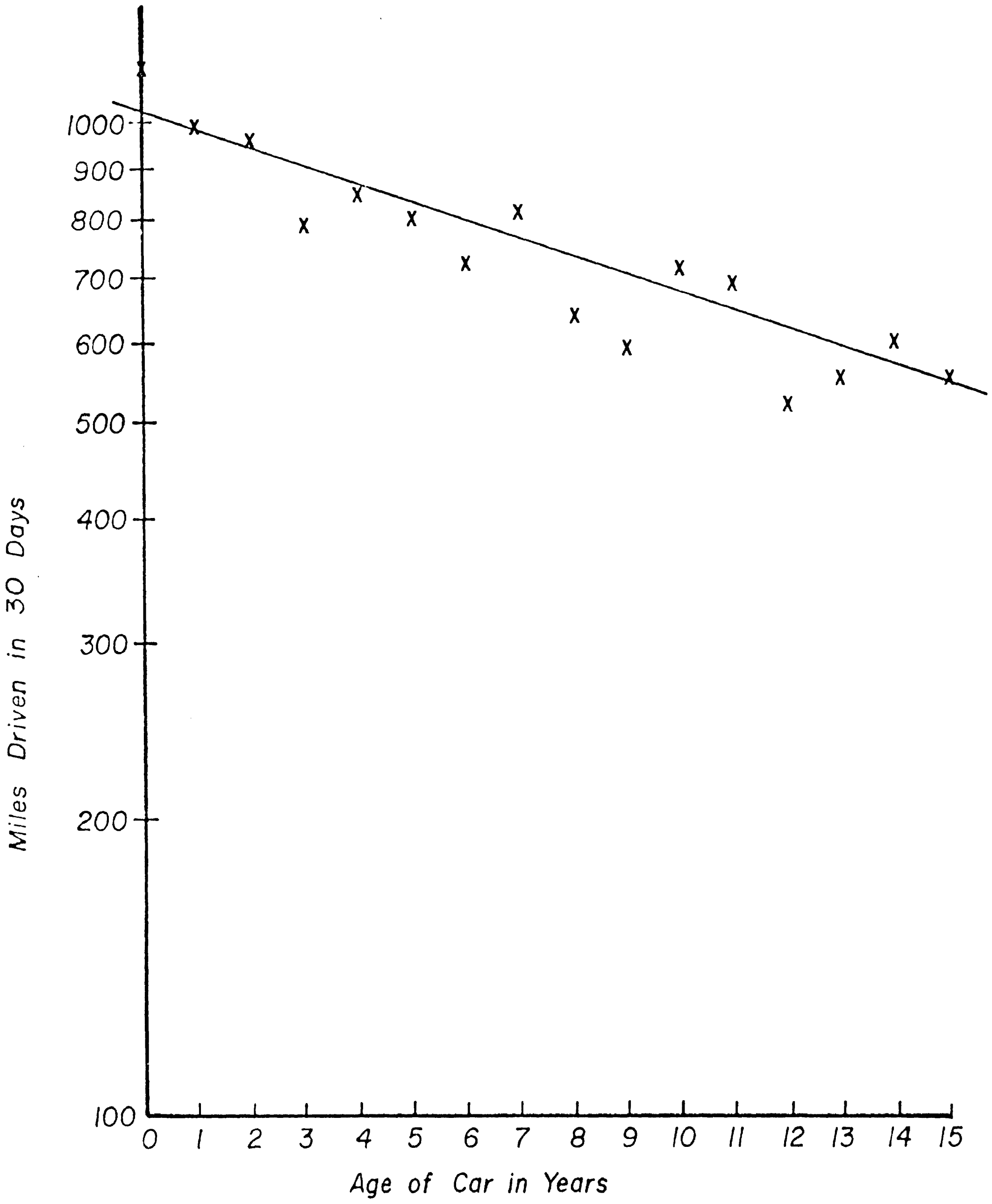

Figure 1. Relationship between Age of Car and 30 Days Driven Mileage (1970 National Exposure Survey)

INJURY SEVERITY

Injury severity, as we define it here, should depend both on the size of the car and on the age (the latter being used as a surrogate for compliance with the FMVSS). Tables 3 and 4 show the distribution of injury by severity vs. accident location (rural vs. several degrees of urbanization) for mini and large cars,respectively. The severity of injury clearly depends on the size of the car and the location. In an urban area (categories 2, 3, & 4 combined) there are about 25 casualties per 100 crash involvements for the pre-1968 minicars, about 19 casualties per 100 crash involvements for the post-1968 cars. In the same urban environment large cars have about 13 casualties for the pre-1968 models, and about 11 in the post-1968 models. Fatality estimates are also presented in the tables, and are approximately 3, 2, 1.5, and 1.1 per thousand accidents for mini-pre-68, mini-post-68, big-pre-68,and big-post-68 models respectively.

Assuming that the minicars represent the injury and fatality experience of the electric vehicles operating in an urban areas, we may multiply these rates by the expected number of crashes (per thousand vehicles) with the following results:*

Table 5

Expected Number of Casualties and Fatalities
for FMVSS and Non-FMVSS Car

Expected number of	1 year operation of 1000 car fleet of Non-FMVSS Elec. Car	1 year operation of 1000 car fleet of FMVSS Elec. Car
Casualties	11.5	8.7
Fatalities	0.14	0.09

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*The injury and fatality rates for minicars are, of course, derived from an environment in which most of the cars are large, and thus in which most (2-car) minicar inovlvements place the minicar at a weight disadvantage. Although the mean weight of the car population is decreasing in response to energy usage problems, it will be several years before this will make enough difference to change the estimates presented here appreciably. By the early 1980's the change may be noticeable, but we have not tried to estimate that effect here.

Table 3

Urban Classification
Injury Severity
1971-1975 Texas Minicars

				Injury #/100 Acc.			
Urban Class	Standard	Acc. Total	Death	A	B	C	Total
Rural	pre-68	257	3.26	16.73	30.35	8.76	58.90
	post-68	441	4.75	12.65	29.93	19.27	66.60
<10,000 town	pre-68	206	0.55	5.82	14.07	6.31	26.75
	post-68	534	0.56	2,99	10.87	6.92	21.34
>10,000 <250,000	pre-68	897	0.30	2.34	14.15	6.82	23.71
	post-68	2408	0.22	2.82	9.67	5.94	18.65
>250,000	pre-68	1280	0.28	4.29	12.03	7.97	24.57
	post-68	3831	0.17	2.53	7.70	7.67	18.07

Table 4

Urban Classification
Injury Severity
1971-1975 Texas Big Cars

			Injury (# persons/100 acc.)				
Urban Class	Standard	Acc. #	Death	A	B	C	Total
Rural	pre-68	177	2,79	9.04	14.69	6.78	33.3
	post-68	475	1.62	8.42	13.68	9.89	33.61
Town <10,000	pre-68	238	0.53	1.26	5.46	5.46	12.71
	post-68	539	0,29	2.60	4.27	4.47	11.63
Big City 10,000-250,000	pre-68	1007	0.13	0.60	5.86	6.16	12.75
	post-68	1925	0,12	0.94	4.26	4.47	9.79
Metro >250,000	pre-68	1373	0.09	2.69	5.17	5.97	13.92
	post-68	2987	0.07	0.84	4.12	6.66	11.69

Fatal and casualty distributions for different fleet numbers. Based on the data in the above table, we may compute the probability of having a particular number of fatalities (and n or more casualties) for a fleet of 2500 vehicles operating in the defined service for one year. These results are presented in the tables below.

Table 6
Exact probability of n fatalities in a fleet of 2500 cars operated in one year*

n	Mini-pre-68-model	Mini-post-68-model
0	.705	.799
1	.247	.180
2	.043	.020
3 or more	.005	.001

Table 7
Probability of n or more casualties in a fleet of 2500 cars operated for one year*

n	Mini-pre-68-model	Mini-post-68-model
10	1.00	1.00
15	.995	.93
20	.95	.64
25	.75	.25
30	.41	.04
35	.12	.00
40	.02	.00
45	.00	.00

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*See Appendix A for estimates of these parameters in larger populations.

Regardless of the degree of FMVSS compliance, the probability of having 3 or more fatalities in one year is essentially zero. Also in both cases there is a very high probability (0.7 or 0.8) of no fatalities. Casualties, defined here as the sum of injuries and fatalities, should not exceed 50 in the worst case, and would be unlikely to be less than 15 in the best case. Note that these estimates are for casualties to occupants of the vehicles in the test fleet. We have not, at this point, estimated casualties to pedestrians or occupants of other vehicles in accidents with those of the test fleet.

RATIONALE

We have made a series of estimates of casualties, fatalities, crashes, etc., for a fleet of small electric vehicles operating in urban service, based on existing accident records of small vehicles. There are, of course, several factors that may increase or decrease these figures. The purpose of this section is to present a discussion of such factors, and estimate at least the direction of the adjustments to the data presented for them.

TIME OF OPERATION

We have assumed a "normal" distribution of trip patterns, i.e., the same trip types taken by the drivers in the accident data base. Probability of crash involvement varies with time of day--rush hour vs. late evening, etc., with a generally higher probability in hours of darkness than in daytime.

Area of Operation: We have assumed that the electric car usage will be completely in urban areas. If instead these cars are operated on high-speed roads and in rural areas, the accident frequency would probably increase at least in proportion to increased mileage, and injuries would increase disproportionately.*

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*With the low estimated maximum speed capability of most of the electric cars, the accident rate on rural roads might increase disproportionately.

Table 8 indicates that the accident frequency on city streets is about in proportion to the amount of driving thereon. In rural driving, however, the accident frequency is relatively low on expressways, high on conventional rural roads.

Injury severity for large cars and minicars is tabulated in Tables 9 and 10, respectively,as a function of road type. The fatality rate on roads other than city streets is several times higher than in the city, and thus if electric cars are operated on such roads we might expect an increase in both the number of fatalities and injuries over the present estimates. Tables 3 and 4 present similar injury and fatality statistics as a function of urbanization of the area in which the accident occurred, also indicating the higher casualty rates in rural areas. These data are summarized graphically in Figures 2 and 3 .

Driver Factors: We have assumed an average population of drivers for these vehicles...average in the sense that their age distribution, their trip patterns, drinking/driving activity, etc., are like those of the general driving population.

With regard to age, Michigan data indicate that under-25 drivers, consisting of 27% of the driving population, are involved in 42% of the accidents. In past data the young driver predominates in small cars, and if that propensity would carry forward to the electric car fleet we might expect the accident rate to be higher than estimated above. This would be countered in the injury rates to some extent,because young occupants are more resistant to injury.

With regard to driver sex, driving patterns (trip purposes, times of travel, etc.) would be likely to differ with a shift from predominantly male to female drivers. According to K. Weber's report "Are men or women better drivers?", we might expect about the same number of collisions, but of an average severity somewhat less if the proportion of female drivers was greater than that used for the estimates above. If the electric cars turn out to be primarily "ladies' cars," then we might expect a reduced number of injuries and fatalities.

Table 8

Accident Frequency Compared with Road Usage

	All Cars		Mini Cars	
	Accident % (1973-1975)	Road usage % (1970 exp.)	Accident % (1973-1975)	Road usage % (1970 exp)
Expressway	9.77	26.9	11.0	35.5
Rural Road	37.6	15.2	35.6	11.3
City Street	52.57	57.8	53.4	53.2
Total	100	100	100	100

Table 9
Road Classification
Injury Severity
1973-1975 Texas Big Cars

Road	Standard	Acc. #	Injury (# persons/100 acc.) Death	A	B	C
Express.	pre 68	127	0.61	3.94	4.72	7.87
	post 68	469	0.30	5.33	5.97	8.53
State Road	pre 68	383	0.64	1.83	8.62	9.14
	post 68	1207	0.41	2.90	5.05	6.71
Secondary	pre 68	82	0.85	3.66	7.32	4.88
	post 68	261	0.44	1.92	4.21	7.66
City	pre 68	807	0.29	3.22	11.40	10.41
	post 68	2273	0.13	1.23	5.94	7.22
Rural Rd.	pre 68	465	0.68	2.15	8.39	8.39
	post 68	1468	0.42	2.72	4.90	6.88

Table 10

Road Classification
Injury Severity
1973-1975 Texas Minicars

Road	Standard	Acc. #	Injury Severity (#persons/100 acc) Death	A	B	C
Expressway	pre-68	138	1.12	7.24	21.0	8.69
	post-68	606	0.70	2.31	8.75	10.7
State Road	pre-68	374	0.97	3.82	15.5	7.75
	post-68	1467	0.77	3.68	12.4	9.47
Rural Road	pre-68	499	1.06	5.21	19.04	8.22
	post-68	1900	0,81	3.58	12.58	9.68
Secondary	pre-68	125	1.34	13.6	29.6	9.60
	post-68	433	0.94	3.23	13.2	10.4
City Street	pre-68	732	0.2186	3.96	10.4	5.6
	post-68	2865	0.18	2.58	8.31	5.2

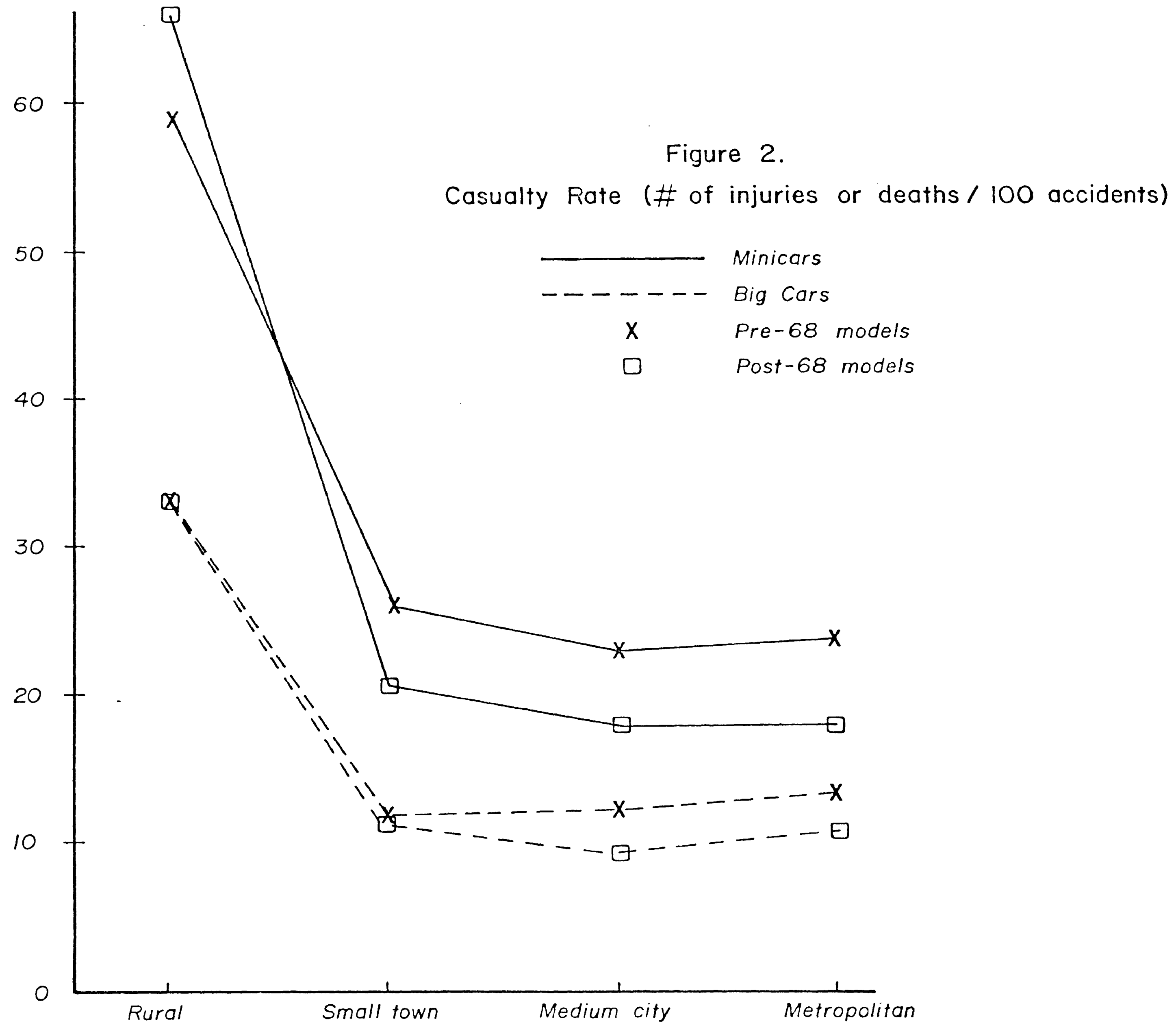

Figure 2.

Casualty Rate (# of injuries or deaths / 100 accidents)

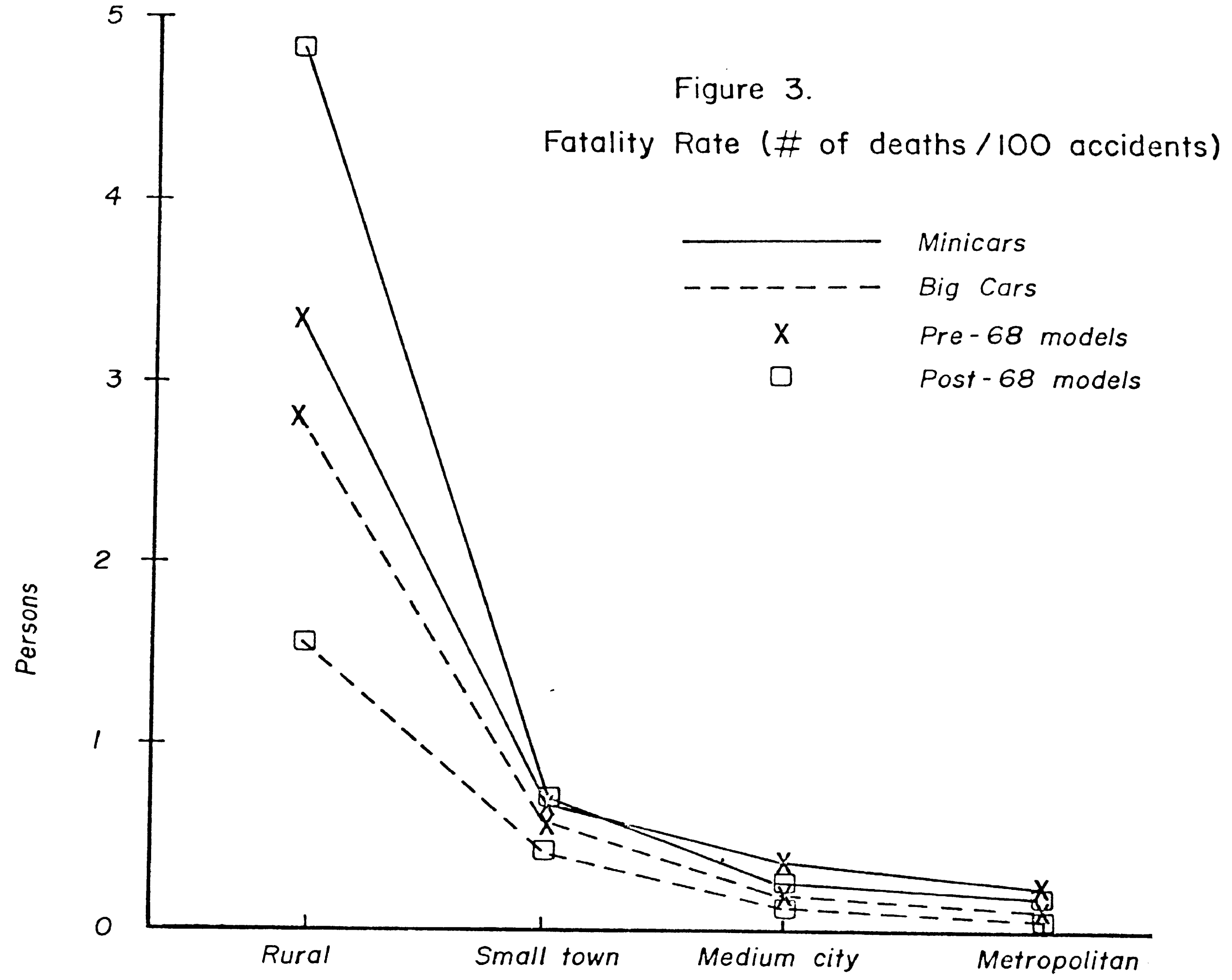

Figure 3.
Fatality Rate (# of deaths / 100 accidents)

There is not much question that drinking/driving increases the probability of collision. The data used to make estimates here include the normal share of drinking/driving, and any departure from this in the test fleet might increase or decrease accident frequency. In one of the recent airbag test fleets,there was speculation that the method of selecting drivers (leasing to salesmen) would increase the proportion of drinking driving, thus leading to a higher than normal accident rate. No data to support this speculation are at hand.

Vehicle Design: Factors in vehicle design that may affect accident and injury rates include the visibility of the cars, the occupant protection systems, the controllability or maneuverability of the vehicle, and possibly the degree of pedestrian protection.

Small traffic units, such as motorcycles, bicycles, and perhaps small cars, would seem to be at a disadvantage in the traffic stream because they are not as visible as larger vehicles. Conspicuity of pedestrians, bicyclists, and motorcyclists has been enhanced by the use of brightly colored clothing, scotchlight striping, day-glo orange helmets, and the like. Several reported experiments or observations support the idea that brightly colored vehicles are less likely to be involved in crashes. A Daimler-Benz experiment showed that brightly colored vehicles could be seen from 2 to 4 times the distance of dark vehicles. Black striping on a yellow background has been standardized for school bus rear ends to improve their visibility. The U.S. Post Office has conducted a comparative test of olive drab and red-white-and-blue vehicles, and found that the tri-colored group had 27% fewer accidents, and that rear-end collisions were reduced by 52%. In view of the limited speed capability of the proposed electric cars, and the reported erratic acceleration characteristic, it would seem appropriate to choose bright colors for the test fleet.

With regard to occupant protection, we have mentioned above the problem of acid spill, and suggested that some protective shield is in order for this purpose. It is possible that collisions of the same magnitude for electric cars would be more injurious than for comparable ICE vehicles because of a less substantial structure..i.e., a tradeoff of structural strength for battery weight. Any judgment of this must depend on analysis of particular vehicles, and this has not been attempted to date.

With the exception of the modified acceleration and deceleration characteristics, there seems to be no reason to believe that the electric vehicles will be less "controllable" or "maneuverable" on the road. Weight distribution in the specification of several vehicles is appropriately the same as in ICE vehicles, and the generally low center of gravity should make these vehicles more stable than their ICE counterparts.

One of the problems in operating a vehicle entirely within urban areas is that there are more pedestrian accidents in such regions. The Texas data indicate that, independent of vehicle size, pedestrian accidents occur in about 14 out of 1000 urban accidents. Thus we might expect about 0.64 pedestrian accidents for each thousand cars in the fleet. In exact probability terms, the probability of a 2500 car year with no pedestrian accidents is 0.20, one accident is 0.32, two accidents is 0.26, and the probability of more than two pedestrian accidents is 0.22. One of the problems of the electric car in pedestrian traffic, particular for future electric vehicles, is the silent operation. Perhaps there should be some warning system for pedestrians, e.g., a backup signal, would be in order.

Environmental Problems: Handling of batteries, including replenishing evaporated water, and charging operations present some hazards. Probably the most serious of these is the possibility of fire or explosion from hydrogen released during the recharging process.

Hydrogen is released most rapidly when the batteries are being overcharged, and it is desirable to bound the charging circuit. The potential for explosion from hydrogen released in a closed garage suggests that adequate ventilation should be provided there. Also interlock systems have been suggested to inhibit starting the car until the garage (or perhaps the car) is appropriately ventilated.

THE FEDERAL MOTOR VEHICLE SAFETY STANDARDS

The expected number of crash involvements for a fleet of 2500 EV's operating for one year is 115. This figure has been arrived at by taking the police-reported accident rate for all passenger cars in Texas (averaged over a five year period), and reducing it to the proportion of crashes which occur in urban areas. If we had included all crashes (urban and rural) the expected number would have been 223 per year, but this would be too high for the restricted use vehicles. The expected number of casualties in this same population would range from 22 to 29 depending on whether the vehicles satisfied current standards (in city accidents something on the order of 10% of these injuries would be "serious" according to the police code). The probability of one or more fatalities in the 2500 car-year demonstration would be between 0.2 and 0.3. These accident rates alone would provide no strong reason for imposing vehicle safety standards on the test fleet.

If standards are not imposed, however, there would seem to be a higher probability of product- or experiment-liability suits. Perhaps for these reasons several major manufacturers have indicated that they would meet all applicable standards in any EV's they produce. Similarly, since it is by law responsible for the imposition of motor vehicle standards, the NHTSA might find itself liable if the lack of standard performance led to a casualty. An NHTSA official also observed in discussion with us that the use of non-standard vehicles in a test fleet would not be a realistic demonstration, and for this reason proper compliance with standards would be desirable.

If federal motor vehicle safety standards are imposed, it is clear the some modifications will be required. Part 555 of the code of federal regulations specifies the conditions and procedures for granting of temporary exemptions to safety standards by the NHTSA administrator. Exemptions may be allowed by the administrator on the basis of severe economic hardship to the manufacturer, for the facilitation of the development of new motor vehicle safety or low emission features, and of the existence of an equivalent overall level of motor vehicle safety. Final determination on a petition is evidently based on the judgment of the administrator, and exemptions may be granted for part or all of any standards for periods up to three years. At least five electric car manufacturers have been granted exemptions from various standards. For example, the Electric Fuel Propulsion Corporation had modified a production American ICV for electric propulsion, and was granted a temporary exemption from standards 105 (hydraulic brake systems), 201 (occupant protection), 204 (steering column rearward displacement), 215 (exterior protection), 216 (roof crush), and 301 (fuel system). Another electric car exemption (to Elcar) was concerned with windshield defogging, and they argued among other things that the standard required some sort of performance while the vehicle was idling--a term not applicable to EV's.

Part 571 of the Code of Federal Regulation defines a passenger car as a "motor vehicle with motive power (except for multi-purpose vehicles, motorcycles, trailers) designed to carry ten passengers or less." The code further states that the published standards apply to all motor vehicles or items of motor vehicle equipment the manufacture of which is completed on or after the effective date of the standard. It is clear that electrically powered passenger cars are by this code subject to the same standards as ICV's.

But even a cursory reading of the FMVSS shows that these standards were written with ICV's in mind. In the "100" series of standards there are specifications for labelling "hand throttle" controls, having a "starter" interlock, testing brakes at 60 mph and tires for 30 minutes at 85 mph. The "200" series of standards are less tied to the ICV, and for the most part could be applied directly to an EV. But presently planned electric vehicles do not match the speed and acceleration capabilities of ICV's, and one could argue that even the "200" series of standards should be rewritten or returned for the capabilities and limitations of EV's. Urban rollovers (per crash) are much less frequent than their rural counterparts. If an EV is employed strictly as an urban car would the roof crush and rollover standards make these cars more protective of the occupants than "necessary" to meet the intent of the rule?

Under the present regulation the NHTSA administrator could choose one of two alternatives: (1) consider applications for temporary exemptions on a case-by-case basis from manufacturers expecting to contribute vehicles to the demonstration program, or (2) rewrite--through the route of NPRM to final standards--the present standards until they apply properly to the EV population. The history of generating a new FMVSS's by this route is mixed. When there is little or no argument, a minimum time of about six months would be needed. But since 1969, and there have been 10 "100" series NPRM's which have ultimately resulted in rules in that time, the minimum time was 8 months, and the maximum 53--the average about 22. Of course some rules were dropped, and cannot be counted in such an analysis. It is inconceivable that there would be no argument to an EV rewrite of the present standards. If the demonstration program is committed to start (ordering vehicles) within a year, the only feasible route would be that of temporary exemptions.

One alternative, not within the present law, would be a blanket exemption for this experimental program. Congress may have the power to provide for such an exemption for purposes of the demonstration.

SUMMARY

There is not much question that a fleet of 2500 vehicles operated in an environment of present highway traffic conditions, whether limited to urban regions or not, will generate some casualties. Using existing small cars as surrogates, we have estimated that the probability of less than 10 injuries in a year of such operation is essentially zero, but that the probability of more than 50 injuries (for the relatively safe urban operation) is also quite small.

The expected number of fatalities has been computed for small cars without compliance with existing safety standards, and also for those with such compliance. In both cases the expected number is less than one--i.e., it is rather likely that no fatalities will occur, but we should not be surprised if one or two do. We should be quite surprised if there were more than two.

Although there are moderate expected differences in casualty rates between "pre-standard" and "post-standard" vehicles, the practical significance of these differences seems to be negligible. Particularly for the first trial fleet of 2500 vehicles, the imposition of stringent safety standards would have only a marginal safety value, and it might impede attainment of the stated goals of the program by delaying production, limiting the range of vehicles available for test, adding weight to the vehicles, which would reduce performance, etc.

In short, it is our judgment that the safety standard specifications should be minimal, but that the likely safety shortcomings of prospective cars be understood and planned for. Indeed, one of the purposes of the pilot program must be to gather information relevant to future performance specifications, and a no-crash no-injury fleet would not help much in this.

REFERENCES

Carroll, Philip et al.: Acquisition of Information on Exposure and on Non-Fatal Crashes, Vol. I through Vol. VI, May 12, 1971, (Vol. I-V) and July 31, 1971 (Vol. VI). Available from NTIS under PB 201 414-418 and PB 203 718.

Campbell, B.J., et al.: The Traffic Accident Data Project Scale, University of North Carolina. In "Proceedings of Collision Investigation Methodology Symposium", Warrenton, Va. August 24-28, 1969.

Accident data for the State of Texas were taken from the ADAAS (Accident Data Access and Analysis System) at the University of Michigan's Highway Safety Research Institute. Data were originally furnished by the Texas Department of Public Safety.

Vehicle registration data for Texas for the years 1971-75 was kindly furnished by the R.L. Polk Company.

Weber, K. Are Men or Women Better Drivers", published in HIT-LAB Reports, University of Michigan, 1974.

Garrett, J. et al., Final Report on ESV Program, CALSPAN Corporation, 1975.

Appendix A

Casualty and Fatality Probabilities for Fleets of Various Sizes and Several Program Periods

In the report text it has been shown that the probability of having no fatalities is quite high with a fleet of 2500 vehicles operated for one year. This probability decreases, however, as the number of vehicles in the fleet (or the time period of operation) increases. In order to show such probabilities for other demonstration program configurations we will define a quantity "fleet number" as the product of the number of vehicles in the fleet and the number of years of operation. For a fleet number of 50,000 (e.g., 10,000 cars operated for 5 years) the probability of _no_ fatalities is nearly zero. Conversely, the probability of having at least one fatality increases with fleet number.

For the non-FMVSS cars the probability of at least one fatality increases from 30% (for a fleet number of 2500) to nearly 100% for a fleet number of 50,000.

The median number of fatalities also increases with fleet number. For a fleet number of 5000 there is a 50% chance that there would be no fatalities (and of course a 50% chance that there would be one or more); however, when the fleet number is 30,000 there is a 50% chance that there will be at least 5 fatalities (and a 50% chance of four or less). This probability information is depicted in detail for different fleet numbers in Figures 1 and 2 for the non-FMVSS and FMVSS cases. Note that for a fleet number of 50,000 (e.g., 7500 cars operated for six and two-thirds years, the expected number of fatalities (median) is about 5 and 7 for the two cases.

Similar figures are presented for the injury probabilities as Figures 3 and 4. For non-FMVSS vehicles the expected number of injuries for a fleet number of 5000 is 40 to 75; for a fleet number of 20,000 this becomes 200 to 260. The chance of being outside this range is quite small. For the FMVSS vehicles (Figure 4) the expected numbers are about three-fourths of those for the non-complying vehicles.

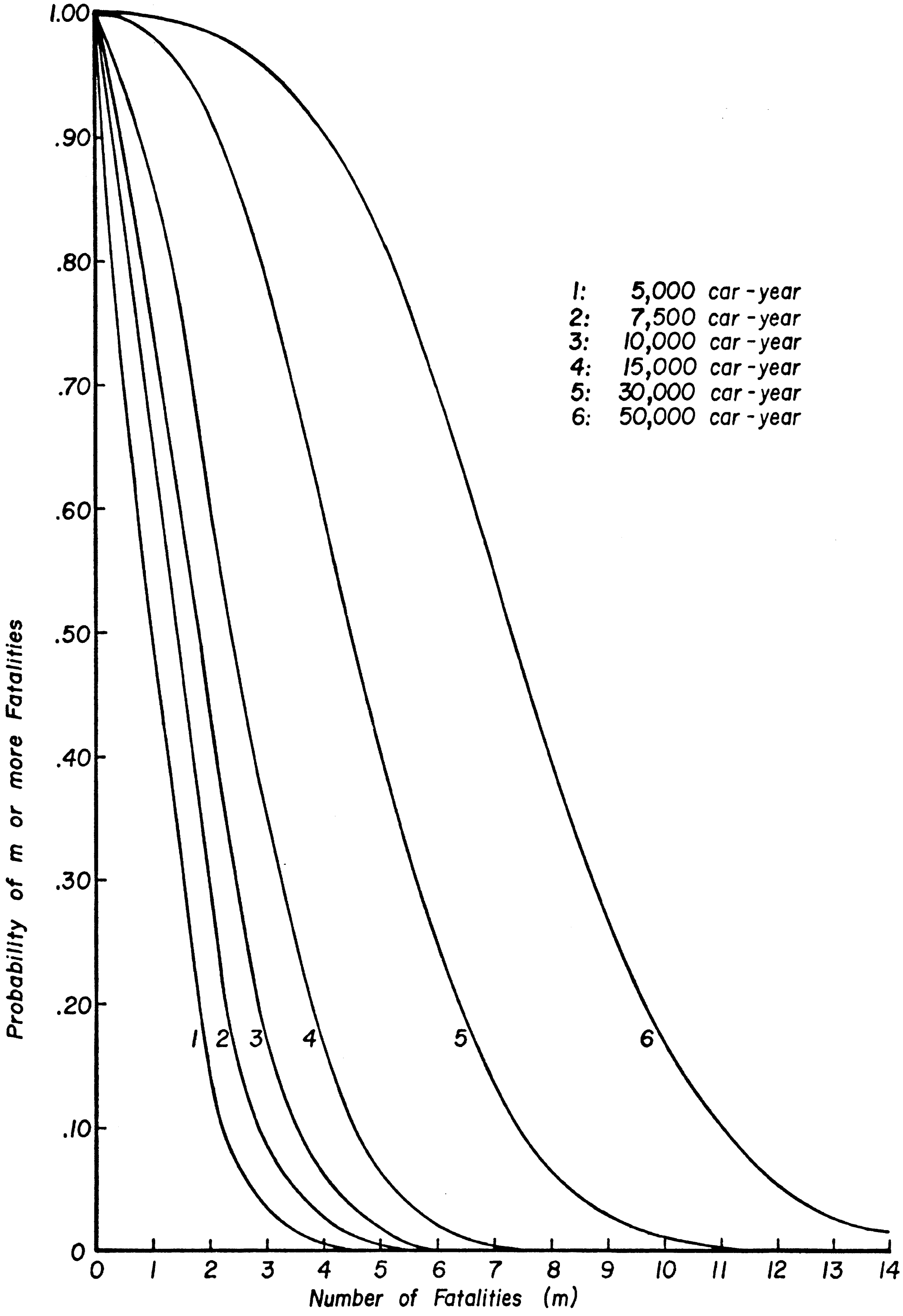

Figure A-1. Non-FMVSS Vehicle

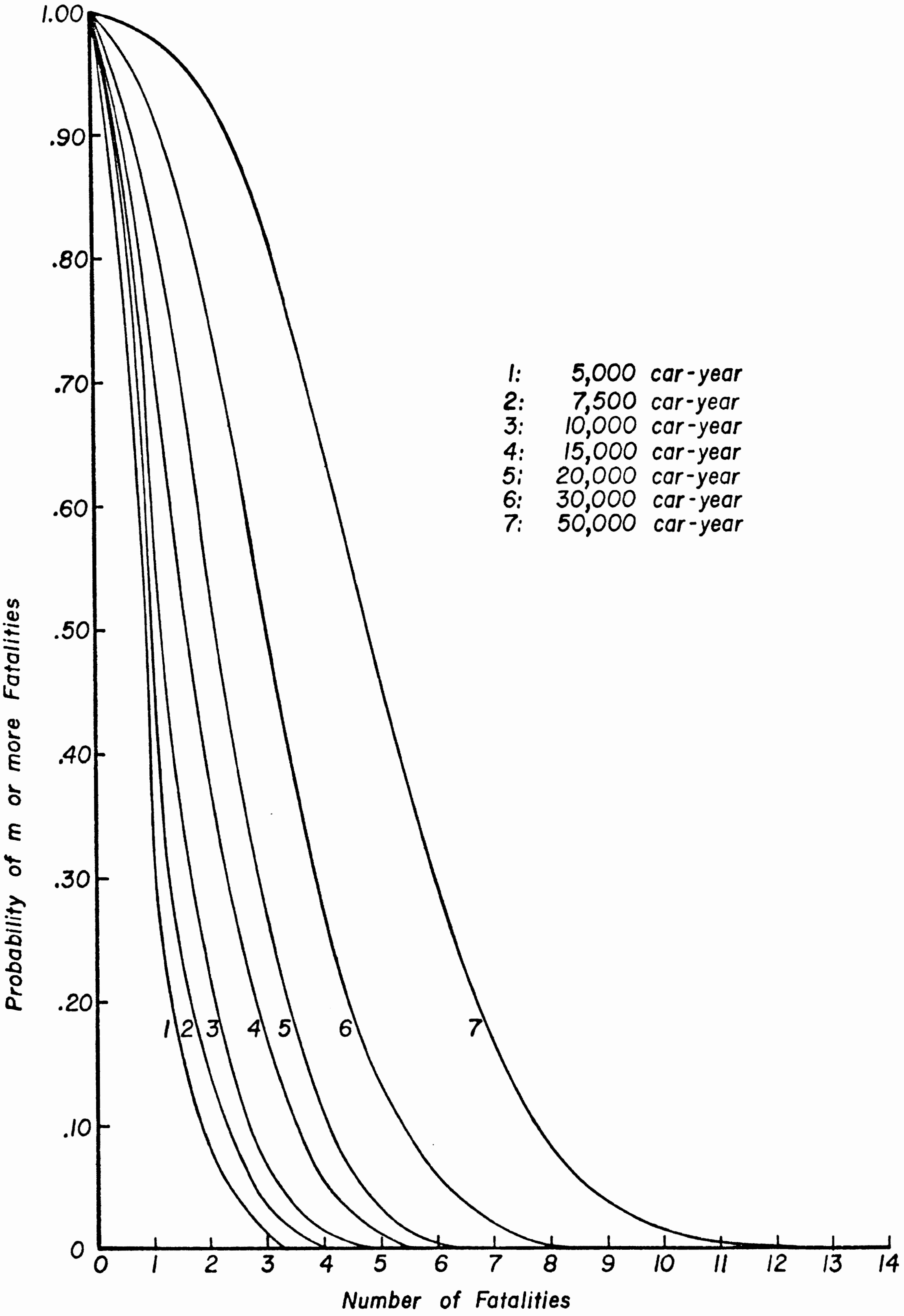

Figure A-2. FMVSS Vehicle

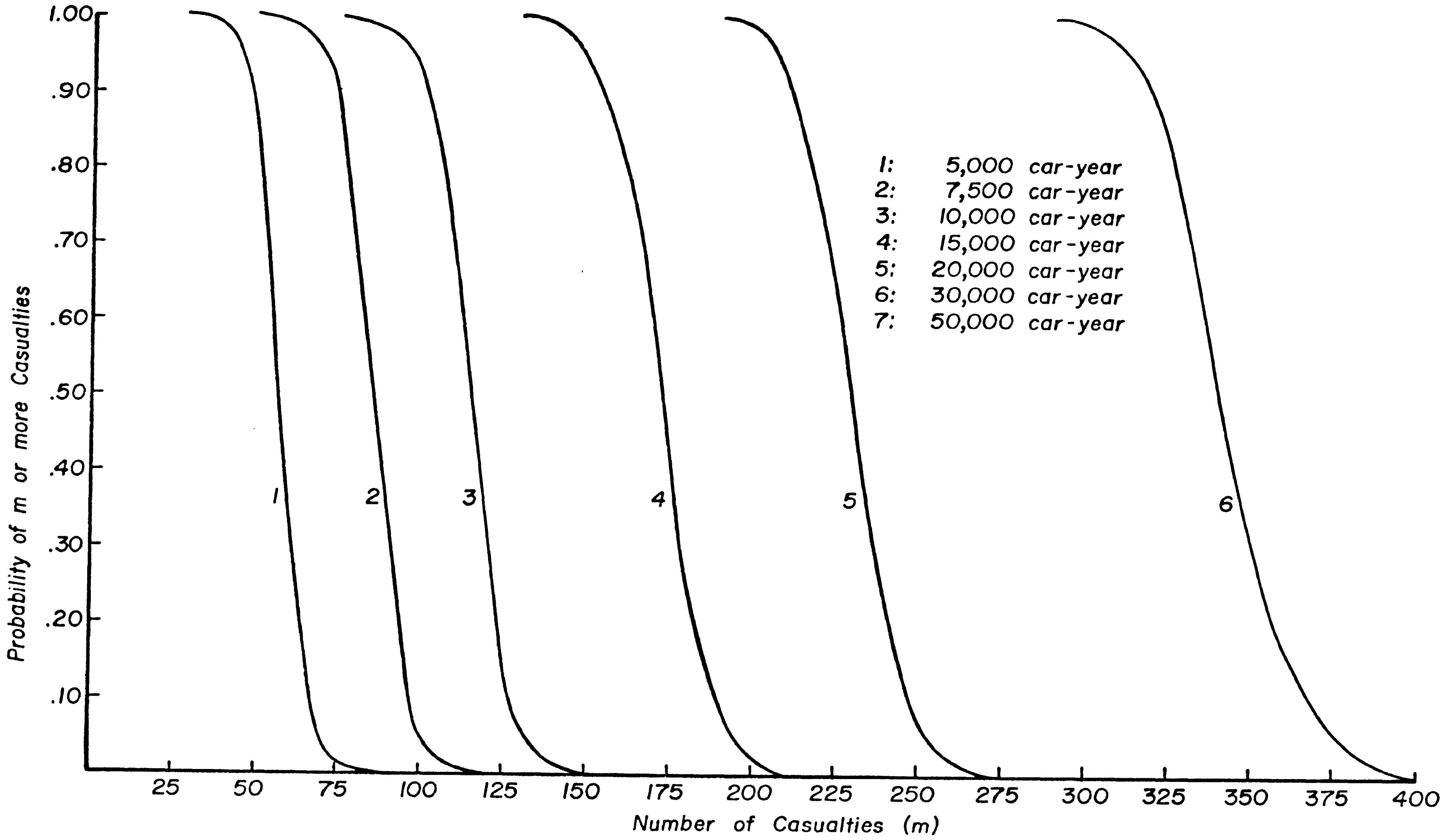

Figure A-3. Non-FMVSS Vehicle

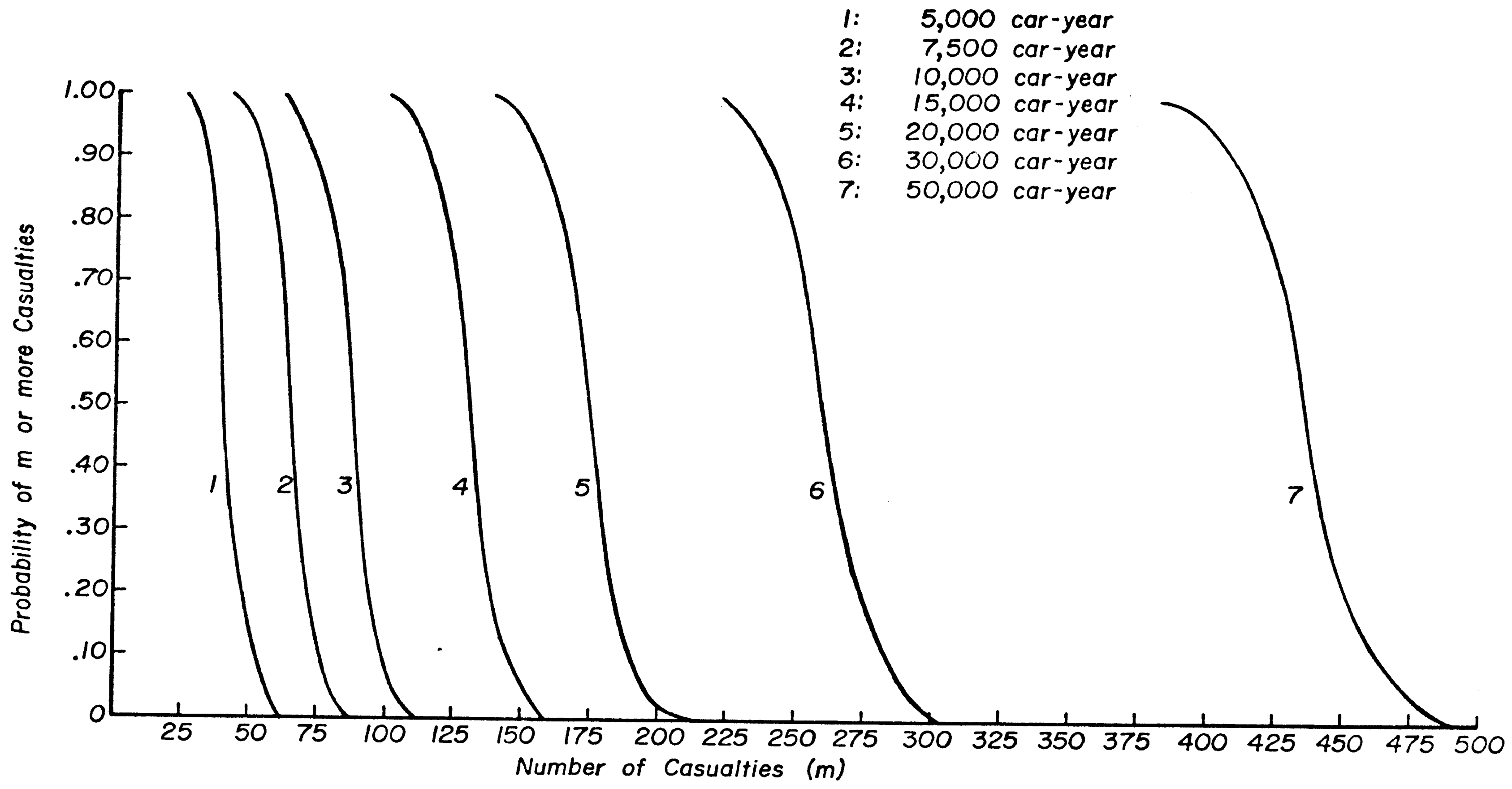

Figure A-4. FMVSS Vehicle

Appendix B

Methodology

Accident data from the state of Texas are maintained in digital form in the Amdahl computer at the University of Michigan. Beginning with the total set of accident data for the state in each year--approximately 450,000 crashes involving 800,000 traffic units--we subset into working files (1) a group of all fatal crashes, (2) a group of all truck accidents, (3) a 5% systematic random sample of all accidents, and other special subsets as needed. There are 179 data elements encoded for each traffic unit, generally concerning the environmental characteristics of the crash (day of week, weather, time of day, county, etc.), the vehicle characteristics (make and model, existence of defects, worst injury in vehicle), driver characteristics (age, sex, violations committee, license status), and police-reported injury status for the various occupants. Of particular value to the present study is the Texas practice of reporting vehicle damage on the Traffic Accident Data (TAD) scale, and the recording of make and model in such a way that vehicles can be categorized into relatively precise size classes.

The total vehicle population for Texas is derived from data provided by the R.L. Polk Company, and is based on their acquisition of motor vehicle registration records at some point during the year. In the analysis performed for this study we have used various combinations of the Polk data, the 5% sample data, and the fatal accident data to arrive at estimates of (1) the number of crash involvements per registered vehicle per year, (2) the number of fatal accidents and the number of persons killed per registered vehicle year and per crash involvement, and (3) the number of persons injured per registered vehicle year and crash involvement.

For each calendar year from 1971 through 1975 we have divided the Texas passenger vehicle accident population into three subsets--minicars, (simulating electric vehicles and consisting of all of the Volkswagens, Toyotas, MGs, Fiats, Datsun, Austin, Cortina, Honda, Opel, Renault, Simca, Subaru, Triumph), large cars (for comparison--a group of full size American manufactured passenger cars), and others. Each of the above subsets was further divided into cars manufactured before 1968, and those manufactured in 1968 and later.

For each group in each year, the number of accident involvements was determined, as well as the number of fatal accident involvements and in-car fatalities. These data were summed over the five year period, and the accident rates (crashes per registered vehicle) determined by comparison of the average of the five years of accident data with the registration data for a middle year.

Estimates of the number of accident involvements per registered vehicle were made for cars of different sizes, and for different environments. The value chosen to forecast accident involvements for electric vehicles was based on (1) only urban operation of the vehicle, and thus only urban accidents and (2) an accident rate appropriate for the average vehicle rather than a small vehicle, recognizing that the overrepresentation of small vehicles in the accident (vs. registration) population was likely due to the overrepresentation of the young drivers who operated them.

As noted in the main text, it would be preferable to have a national set of data to make the estimates of numbers of accidents and casualties needed here. Except for fatality information, such a national data set is not available--mainly because of the variability of reporting from one jurisdiction to another. A rough check of the present fatal accident estimates can be made by taking the reported number of in-car fatalities in the nation (about 40,000 per year) and the total number of operating passenger cars (about 80 million) and computing that there would be about one fatality for 4000 registered car-years. For 2500 vehicle years this would predict .625 fatalities, but adjusting for urban operation we should expect much less than this. Our estimate of .09 to .14 fatalities per thousand registered small cars per year is consistent with this.