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RESEARCH SAFETY VEHICLE

PHASE I — FINAL REPORT
VOLUME II
AUTOMOBILE USAGE TRENDS, ACCIDENT FACTORS

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FORD MOTOR COMPANY
THE AMERICAN ROAD
DEARBORN, MICHIGAN 48121

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16. Abstract

This is Volume II of three volumes - RSV Phase I Final Report

Vol. I -- Introduction, Executive Summary
Vol. III -- Vehicle Characterization, Performance Specifications

In response to the requirements of the Statement of Work an analytic approach was developed which:

. Predicts the accident exposure environment for the mid-1980's time period based on factors influencing automobile usage.
. Employs the principal elements of this prediction as input to a mathematical model which simulates the various types of accidents (front, side, etc.) occurring in that environment.
. Tests multiple combinations of RSV structural and restraint system configurations to determine that combination which predicts achievable safety performance, given practical constraints on size, weight, and cost.
. Evaluates the cost-benefits of various candidate configurations to select an optimized vehicle design concept for an RSV weighing less than 3,000 pounds which operates in the projected mid-80's traffic environment.
. Establishes recommended performance specifications for the optimized design concept.

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TABLE OF CONTENTS

Page

VOLUME III -- Vehicle Characterization, Performance Specification

Section 3

PROGRAM DEFINITION FOUNDATION

Two major activities have been identified for the first phase of the Research Safety Vehicle (RSV) program: a forecast of the traffic environment for the middle of the next decade; and the development of an RSV design concept consistent with that forecast. This section, Program Definition Foundation, identifies the projected traffic environment for the mid-1980's, assesses current accident data, projects these data to the mid-1980's and characterizes the RSV optimization methodology.

3.1 Automobile Usage Trends

This section discusses various traffic factors projected to be operating in 1985 which were considered in setting safety performance specifications for the RSV. The methods and simulations used in forecasting are described and the results are presented.

3.1.1 Factors Influencing Automobile Usage

A systematic examination of relevant highway/vehicle/driver factors is essential in the determination of the traffic environment projections for the mid-1980's. The historical and current trends in demographics, roadway development, and traffic regulations are developed and studied with due consideration for the potential impact of future economic factors and alternative modes of transportation.

3.1.1.1 Demographic Considerations

Many possible demographic influences were considered during the program definition study. However, only the projected number of families is used explicitly as a modifier of automobile usage trends.

The suburbanization of the nation is expected to continue. Future expected increases in personal disposable income are implicit in the projection of the percentages of families owning two or more cars. The total effect of the increasing car population due to these factors, along with a tendency toward more usage of cars due to urban sprawl, only partially damped by the economic factors of fuel price, is reflected in the increasing vehicle miles projected for 1985.

Census Bureau data are the basis for the projection of the number of families through 1985. An increase in the number of families is indicated by an exponential curve fit to the Census Bureau data.

3.1.1.2 Impact of Alternative Transportation Modes

During the time period to 1985, it is assumed that alternative modes of transportation will have no measurable effect on automobile usage trends. The following considerations support this judgment. The increased fuel costs for cars will be paralleled by increased fuel costs for the alternative modes, i.e., public transportation. Furthermore, public transportation is subject to rapidly increasing labor costs. In contrast, once a person has a car, the incremental cost of a trip is relatively small, and the perceived cost is even smaller. Furthermore, an added passenger on public transportation pays at least two-thirds of a full fare, while an added passenger in a car costs the owner only an imperceptible amount. Volume of automobile use is another consideration. If only 1.6 percent of the passenger miles carried by automobiles in 1972 had been diverted to trains and buses, it would have doubled their entire load (1). The capital cost of increasing train and bus capacity to handle a significant fraction of the automobile vehicle passenger miles would be overwhelming, and even if attempted, the time frame is too short for such a major undertaking. Even the passenger miles of air carriers was only 5.7 percent as much as the automobile passenger miles in 1972 (2).

A car provides more security, privacy, comfort, convenience, and flexibility of route and schedule. As Lawrence J. White says on Page 236 of his book (3):

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(1) Summary of National Transportation Statistics, Final Report, Prepared for the U.S. Department of Transportation, June 1975.

(2) Ibid.

(3) Lawrence J. White, The Automobile Industry Since 1945, Harvard University Press, Cambridge, Massachusetts, 1971.

"A car perhaps represents one of the last bastions of privacy in modern America, where a man is away from his family and his boss and colleagues. He can sing, shout, scratch his ears, turn the radio on loud, and make threatening gestures and shout obscenities at other motorists, all without fear of social rebuke. Is it a coincidence that most transportation studies find average commuter car occupancy rates only slightly higher than one per car? A car is responsive to the driver's wishes; it is he who is actually controlling 4,000 pounds of steel and complex machinery. He has control over his immediate environment to a degree probably not equaled anywhere else in his daily routine."

Anything which reduces automobile usage -- short of prohibition or its fiscal equivalent -- reduces congestion and therefore makes automobile usage more attractive. The result is a convergence or adaptation to a steady state usage rate that will be insensitive to any moderate attempts to manipulate such usage.

For these reasons, it is felt that the transportation balance will shift even more toward the car in the next decade and that the decline of public transportation will likely continue. Even allowing for individual instances of mass transit turnarounds, such as dial-a-ride and go-to-work commuting, mass transit will account for only a very small portion of total person trips, even with large subsidies. As an example, the Ann Arbor dial-a-ride system has had a negligible effect on car usage even though the fare is only $.25, while the trip cost is from $1.50 to $1.75 -- the difference being subsidized. These conclusions are supported by a recent study by the American Enterprise Institute for Public Policy Research, entitled Federal Transit Subsidies, published in 1974 (4).

(4) George W. Hilton, Federal Transit Subsidies, The Urban Mass Transportation Assistance Program, American Enterprise Institute for Public Policy Research, Washington, D.C., 1974.

Any further consideration of these matters is really beyond the historical and institutional context of the RSV program, and any additional study of alternative modes should be undertaken in an appropriately conceived project scaled for that purpose.

3.1.1.3 Roadway Development

Although roadway development tends to encourage automobile usage, an even more dramatic effect is the decrease in fatality and injury rates on the interstate highway system.

Highway Safety. Fatality and injury rates, listed in Tables 1 and 2 are an indication of the effectiveness of highway design in reducing accidents (5). The U. S. Interstate System fatality rate is approximately one-half of the aggregated and non-interstate highway system's. Injury rates, on the other hand, are even less by a factor of about one-third.

Table 1

Fatality Rates on U. S. Interstate and Non-Interstate Systems

	RURAL			URBAN		
Year	I.S. Final Fatality Rate*	Non-I.S. Fatality Rate*	I.S. Vehicle Miles (Millions)	I.S. Final Fatality Rate*	Non-I.S. Fatality Rate*	I.S. Vehicle Miles (Millions)
1967	3.68	7.53	55,144	2.12	3.80	56,339
1968	3.77	7.50	62,300	2.21	3.74	63,973
1969	3.51	7.50	71,886	2.30	3.60	73,232
1970	3.45	7.16	79,516	1.95	3.35	81,532
1971	3.24	6.79	89,183	1.96	3.19	89,955
1972	2.96	6.78	98,393	1.91	3.10	100,439
1973	2.75	6.48	106,035	1.87	3.04	108,429

*Rates are per 100 million vehicle miles.

(5) "Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems/1973," Federal Highway Administration, Department of Transportation.

Table 2

Injury Rates on U.S. Interstate and Non-Interstate Systems

	RURAL			URBAN		
Year	I.S. Final Injury Rate*	Non-I.S. Injury Rate*	I.S. Vehicle Miles (Millions)	I.S. Final Injury Rate*	Non-I.S. Injury Rate*	I.S. Vehicle Miles (Millions)
1967	40.81	116.10	55,144	64.20	240.94	56,339
1968	41.26	121.79	62,300	65.90	232.00	63,973
1969	39.91	120.93	71,886	67.99	232.65	73,223
1970	37.30	115.93	79,516	65.04	223.80	81,532
1971	38.74	114.23	89,183	65.54	209.75	89,955
1972	36.66	115.91	98,393	64.98	201.02	100,439
1973	35.13	114.36	106,035	62.51	200.87	108,429

*Rates are per 100 million vehicle miles.

In addition, the Department of Transportation is administering a program called TOPICS (Traffic Operations to Increase Capacity and Safety), directed to the immediate solution of today's urban traffic problems. TOPICS has grown in six years from a pilot program to a fully accepted nationwide program (6).

In its 1974 annual report on TOPICS, DOT describes the results of intersection improvements, signalization and signal modernization, route improvement, continuous left turn lanes, left turn bays, elimination of street offset, system improvement reversible lane, elimination of bottlenecks, ramp metering, impact attenuators, pedestrian overpasses, and other improvements.

Using before and after comparisons, the DOT cite examples and submit statistics showing the results of highway modifications in reducing and eliminating accidents. In terms of cost effectiveness, TOPICS appears to be very promising (7).

(6) "The 1974 Annual Report on Urban Area Traffic Operations Improvement Programs (TOPICS)," Federal Highway Administration, U.S. Department of Transportation, December 1973.

(7) Ibid.

Highway Growth. Table 3, taken from the 1972 National Highway Needs Report (8), lists the anticipated percentage growth in nationwide highway miles for rural and urban areas. Table 4 shows the nationwide estimate of U. S. highway miles for 1990 (9). The total 1990 highway miles of 3,923,763 represents a ten percent increase over the 1968 figure. The 41 percent increase in fully controlled access highways in the rural areas represents an extension of the interstate system from 22,539 miles in 1968 to 31,552 in 1990.

Table 3

Percentage Growth in U. S. Nationwide Highway Miles from 1968 to 1990

	Rural	Urban
Fully Controlled Access	41	222
Partial/No Control of Access	*	64

*Less than 1%.

Table 4

Nationwide Estimate for U. S. Highway Miles for 1990

	Rural	Urban	Total
Fully Controlled Access	31,552	29,510	61,062
Partial/No Control of Access	3,075,637	787,064	3,862,701
TOTAL	3,107,189	816,574	3,923,763

(8) "Part II of the 1972 National Highway Needs Report," Communication from the Secretary of Transportation, House Document No. 92-266, Part II, April 10, 1972.

(9) Ibid.

3.1.1.4 Traffic Regulations

This study does not attempt to prescribe environmental factors such as roadway characteristics or traffic regulations for the mid-1980's. Therefore, possible changes in traffic regulations, with the exception of speed, are assumed, for the purpose of this study, to have no impact on automobile usage trends.

Traffic Speed. It is assumed that the present 55 mph speed limit will not be in effect in 1985. Consideration is given to the speed distribution of vehicles and to speed by type of vehicle and type of road, with projections made to the mid-1980's.

Speed distribution data from the Federal Highway Administration (10) for rural interstate, urban interstate, urban primary, and rural secondary highways are fitted with a series of modified Weibull distributions, and extrapolations of 1985 speed distributions are made.

Passenger car average speed since 1961, on interstate and rural secondary highways, has been generally increasing (see Figure 1), while passenger car average speed on primary urban highways has been decreasing (see Figure 2). It is assumed that both these trends will continue through 1985.

Projected 1985 traveling speed distributions for passenger cars, trucks, and buses on various types of highways are shown in Tables 5, 6, and 7.

Table 5

Projected 1985 Percent of Passenger Cars Exceeding K Miles Per Hour

K	Interstate		Non-Interstate	
MPH	Rural	Urban	Secondary Rural	Primary Urban
35	100	100	100	70
40	100	100	94	55
45	100	99	87	38
50	99	95	63	33
55	94	86	51	17
60	84	45	32	8
65	72	17	12	2
70	38	14	4	1
75	12	1	1	0

(10) "Traffic Speed Trends," U. S. Department of Transportation, Federal Highway Administration, 1960-1973.

Figure 1

Average Speed of Passenger Cars on Rural
Interstate and Rural Secondary Roads

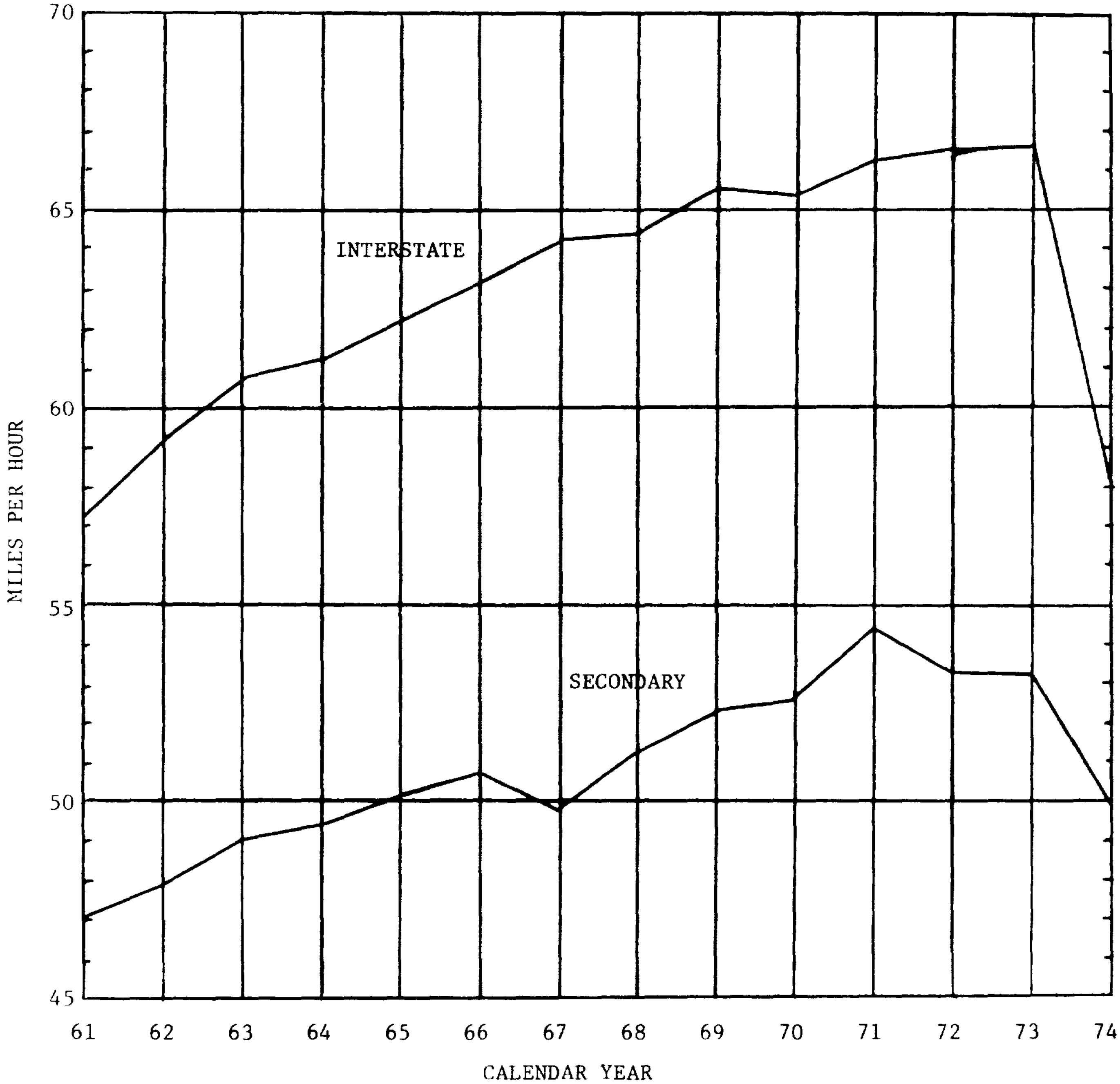

Figure 2

Average Speed of Passenger Cars on Urban
Interstate and Urban Primary Roads

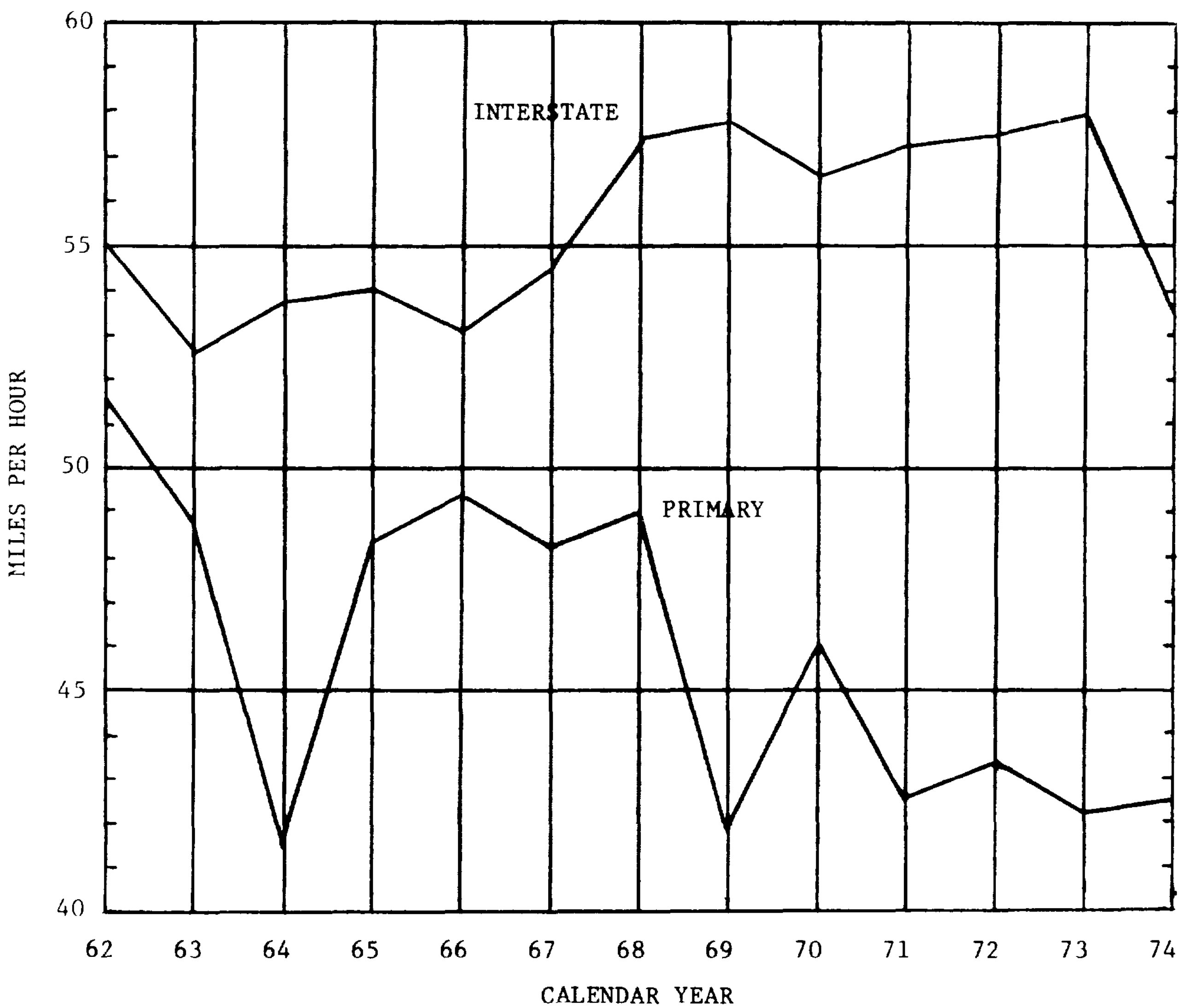

Table 6

Projected Percent of Trucks Exceeding
K Miles Per Hour for 1985

	Interstate		Non-Interstate	
K MPH	Rural	Urban	Secondary Rural	Primary Urban
35	100	100	96	52
40	100	97	90	23
45	100	95	78	20
50	98	72	56	13
55	93	50	41	6
60	74	19	27	3
65	16	4	5	0
70	7	1	2	0
75	2	0	0	0

Table 7

Projected Percent of Buses Exceeding
K Miles Per Hour for 1985

	Interstate		Non-Interstate	
K MPH	Rural	Urban	Secondary Rural	Primary Urban
35	100	100	100	54
40	100	99	98	36
45	100	97	85	26
50	100	78	78	11
55	95	71	48	9
60	93	26	17	5
65	48	10	13	0
70	13	1	2	0
75	0	0	0	0

3.1.1.5 Economics

As a consequence of the current economic turbulence, the influence of many economic factors could not be projected. Because some economic factors are considered important in the estimation of both car usage and age and weight distribution of the car population, such parameters as the projected price of fuel, the elasticity of fuel price with respect to car usage, the relative worth of small and large cars, and the worth and repair costs of cars are postulated and factored into the projections.

3.1.2 Vehicle Projections

The forecasts of total number of vehicles, their distribution by weight and age and the total vehicle miles of travel, based on an assumed continuation of current trends, are presented.

3.1.2.1 Total Number of Vehicles

Demographics, alternative transportation modes, and economics have no short term effect on the total number of vehicles. Therefore, the forecasts are based on a continuation of current trends.

Number of Cars. The total number of cars is computed by adding the number of commercial and public cars to the number of families owning one car plus twice the number owning two cars plus thrice the number owning three or more cars. The number of families owning one, two, or three or more cars is given by the total number of families times the fraction owning one, two, or three or more cars, respectively.

The number of commercial and public cars is computed by a linear function. The number of families is derived from an exponential curve that was fit to the Census Bureau forecasts of number of families. The fractions are computed from logistic curves fit to the fractions of families owning one or more, two or more, and three or more cars. The saturation values for the three curves are about 82.0, 45.1, and 9.6 percent, respectively.

Number of Motorcycles, Trucks, and Buses. The number of vehicles of each type is derived by computing the historical vehicle-to-car ratio, fitting a curve over the period 1957 to 1973, extrapolating the ratio along the curve through 1986, and then multiplying the forecast ratio by the forecast number of cars.

Logistic curves are used to extrapolate the motorcycle-to-car ratio and the school bus-to-car ratio. A linear curve is used for the truck-to-car ratio, while an exponential curve is used for the commercial bus-to-car ratio.

Table 8 shows the total number of each vehicle type for the years 1981 through 1986.

Table 8

Forecasts of Number of Vehicles by Type
as of January 1, 1981 through 1986
(In Millions)

Year	Cars	Motorcycles	Trucks	School Buses	Commercial Buses
1981	103.5	7.5	28.0	.452	.095
1982	105.5	7.8	29.1	.468	.095
1983	107.9	8.1	30.3	.484	.095
1984	110.3	8.4	31.5	.500	.095
1985	112.7	8.7	32.7	.533	.094
1986	115.2	9.0	33.9	.533	.094

3.1.2.2 Car Distribution by Age

The knowledge of how many cars of each model year are in operation in a given year is important because characteristics such as use, incident rate per mile, and worth are highly dependent upon age. Furthermore, car distribution by age is also important for safety and emissions evaluations -- different model year cars meet different requirements.

Number of Cars Scrapped by Age. The basic assumption used is that a car is scrapped when the cost to maintain it exceeds its worth.

Incidents such as collisions and component failures occur and require a direct expenditure of money to restore the vehicle to operating condition. The fraction of cars scrapped in a given age class equals the expected mileage times the incidents per mile times the probability of the repair cost exceeding the worth of the car. Note that driving a car less means a smaller fraction scrapped, all else being equal.

Car Miles by Age. An exponential curve was constructed from the miles/year versus age data given in the 1972 Columbia report, Dynamics of Automobile Population and Usage (11). The expected miles traveled in each age class is then computed, using that exponential curve. The computed mileage is modified to reflect the influence of changes in fuel economy, rationing, and total fuel available for cars.

Computations are performed to determine how much fuel would be consumed if the cars drove the expected amount, modified by the elasticity times the percent price change of fuel, and adjusted for rationing, if any. Next, the resulting amount of fuel is compared with the amount assumed available. If it is more, then the driving is scaled down so as to use up the available fuel. If it is less and there is rationing, the excess fuel is redistributed, with the preference going to the new cars. If it is less and there is no rationing, nothing is done.

Incidents Per Mile by Age. The incident rate per mile (of incidents requiring the expenditure of money for repairs) increases exponentially, and at a slightly greater rate than car miles driven is decreasing with age. Consequently, older cars have a higher incident rate.

Car Worth by Age. The worth of a car decreases exponentially with time until it is nine years old. Thereafter the worth does not depreciate as fast.

Computation Procedure. The total number of cars is computed for the initial year and distributed over the age classes in the same proportions as were the actual age classes that year. The following events are among those that take place in the model thereafter for each simulated year:

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(11) James A. Fay and Scott Mingledorf, Dynamics of Automobile Population and Usage, Massachusetts Institute of Technology, Cambridge, 1972.

- Prices, fuel supply and economy, usage, and the basic incident rates are changed by the assumed annual rate.
- The number of cars scrapped from each age class is computed and accumulated to give total scrappage.
- Each age class past the first receives the survivors of the next younger age class. The survivors of the last age class remain in it.
- The growth is computed by taking the difference between the next year's total number of cars and the current year being simulated.
- New car sales, which equal the total scrappage plus the growth, are distributed into the first and second age classes.
- Statistics such as sales, scrappage, percent scrapped, total vehicle miles, total gallonage, etc., are computed.

An example of the car distribution by age as of January 1, 1986 is shown in Table 9.

3.1.2.3 Vehicle Distribution by Weight

The weight distribution of vehicles on the road have important implications for accident exposure.

Percent of Cars by Weight. Cars produced in the model years 1965-1973 are divided into curb weight classes by adding the number of each model produced as given by the Automotive News Almanac (12) to the total in its curb weight class. The models are split by station wagon or V-8 if the weight classes are changed by these options. The percent in each weight class and the cumulative percents are computed. The percent of cars produced with a curb weight less than 2,500, 3,000, 3,500, 4,000, and 4,500 pounds are determined for those model years.

(12) Automotive News Almanac, Marketing Service, Inc., Detroit, Michigan, published annually.

Table 9

Forecasts of Scrappage, Mileage, and Total Number of Cars by Age as of January 1, 1986

Model Year	Number Scrapped ($X10^6$)	Miles Driven ($X10^3$)	Total Number on Road ($X10^6$)
1970	0.187	4.017	0.423
1971	0.151	4.373	0.330
1972	0.273	4.761	0.601
1973	0.459	5.184	1.062
1974	0.676	5.686	1.623
1975	0.943	6.238	2.483
1976	1.296	6.845	3.788
1977	1.687	7.514	5.545
1978	1.843	8.249	7.533
1979	1.802	9.059	9.560
1980	1.343	9.950	11.202
1981	0.834	10.932	12.381
1982	0.424	12.014	13.127
1983	0.172	13.207	13.497
1984	0.053	14.522	13.766
1985	0.012	12.666	14.079
1986	0.001	2.574	4.153
TOTAL	12.156		115.153

The percent of cars less than 2,500 pounds is reasonably well explained by a linear regression of the following parameters: the ratio of the price of a standard to subcompact car; the ratio of the weight of a standard to subcompact car; the log of the fuel price. The percent of cars less than 4,500 pounds is almost as well explained by a linear regression of standard car curb weight.

The weight distribution of cars to be produced in future model years is determined by projecting the parameters, computing the percents less than 2,500 and 4,500, and assuming intermediate weights are given by a Weibull distribution. Knowing the weight distribution of cars by model year, the total weight distribution for a given calendar year is computed by multiplying the number of cars surviving in each model year by the fraction produced in each weight class, and summing over the model years for each weight class.

The percent of cars in operation in each weight class on January 1 for the years 1981 through 1986 is given in Table 10. The means and standard deviations of a Weibull fit to the cumulative distribution is included. The only cars weighing less than 2,000 pounds are certain import models such as the VW Beetle. Unfortunately, some of the other VW models weigh more, such as the Square Back Sedan and the Super Beetle. Since neither Wards Auto World, Automotive News, nor R. L. Polk and Company give foreign car sales by model within each make, the same Weibull was used to estimate the percent of cars up to 1,999 pounds.

Table 10

Forecasts of Percent of Cars by
Weight Class as of January 1, 1981 through 1986

Year	Weight Class (lbs.)							Mean	Standard Deviation
	Up to 1999	2000 -2499	2500 -2999	3000 -3499	3500 -3999	4000 -4499	4500 And Up		
1981	8.11	10.52	13.11	17.99	19.63	15.92	14.71	3458	1014
1982	8.91	10.84	13.98	18.01	18.86	15.11	14.29	3417	1024
1983	9.76	11.24	14.83	18.15	18.21	14.30	13.52	3368	1028
1984	10.55	11.68	15.64	18.41	17.72	13.50	12.51	3316	1024
1985	11.28	12.15	16.44	18.74	17.39	12.70	11.30	3262	1012
1986	11.93	12.66	17.28	19.19	17.09	11.90	9.95	3206	994

Percent of Trucks by Weight. Truck weight distributions are obtained for the years 1961, 1963, 1967, and 1972. The 1961 data is taken from the 1962 Motor Truck Facts (13), while the others are taken from the respective years' Truck Inventory and Use Survey by the U. S. Department of Commerce (14). Truck sizes are divided into light, medium, light-heavy, and heavy-heavy for the gross vehicle weights of 10,000 or less, 10,001 to 20,000, 20,001 to 26,000, and greater than 26,000 pounds, respectively. The distribution for each year is fit with a Weibull, and then the Weibull parameters are extrapolated to give the forecast of the weight distributions. The total number of trucks in millions of units as of January 1 of each specified year, and the number and percent in each weight class are shown in Table 11.

Table 11

Forecasts of Number of Trucks and Percent
bt Weight Class as of January 1, 1981 through 1986
(In Millions)

Year	Total	Light		Medium		Light-Heavy		Heavy-Heavy	
	No.	No.	%	No.	%	No.	%	No.	%
1981	28.0	21.4	76.5	3.8	13.4	1.0	3.6	1.8	6.5
1982	29.1	22.3	76.7	3.9	13.4	1.0	3.5	1.9	6.4
1983	30.3	23.3	76.9	4.0	13.3	1.1	3.5	1.0	6.3
1984	31.5	24.3	77.1	4.2	13.2	1.1	3.5	2.0	6.3
1985	32.7	25.2	77.2	4.3	13.1	1.1	3.4	2.0	6.2
1986	33.9	26.3	77.4	4.4	13.1	1.2	3.4	2.1	6.1

Truck Miles by Weight. Table 12 shows for each of three years, 1963, 1967, and 1972, average miles in thousands driven by each weight class of truck.

(13) Motor Truck Facts, 1962 Edition, Automobile Manufacturers Association, Inc., Detroit, Michigan, published annually.

(14) Truck Inventory and Use Survey, U.S. Bureau of the Census, Census of Transportation, 1972, U.S. Summary, TC72-T52, U.S. Government Printing Office, Washington, D.C., 1973.

Table 12

Average Miles Traveled Per Truck, by Weight Class, During 1963, 1967 and 1972 and Average for the Three Years

Truck Weight	1963	1967	1972	Average
Light (to 10,000 lbs.)	10.4	9.4	10.6	10.1
Medium (10,001 to 20,000 lbs.)	11.2	9.4	10.4	10.3
Light-Heavy (20,001 to 26,000 lbs.)	12.0	12.3	10.6	11.6
Heavy-Heavy (over 26,000 lbs.)	33.3	33.4	34.7	

Since there is no uniform trend in miles driven per year for the first three weight classes, it is assumed that those classes will be driven at their respective averages, shown in the last column. The heavy-heavy weight class, on the other hand, was fit with an exponential, and the forecast is computed from that. This method gives 36.9 thousand miles for the average heavy-heavy truck by January 1, 1986.

3.1.2.4 Total Vehicle Miles of Travel

Total car miles is computed by multiplying the number of cars in each age class by the expected miles for each vehicle of that age class, and then summing over the age classes. For motorcycles, it was assumed, as does the Highway Statistics (15) publication, that each would travel 4,500 miles a year. For trucks, the percent in each weight class is multiplied by the total number of trucks, giving the number in each weight class. This product is then multiplied by the miles forecast for that class. School bus mileage, 7,500 miles per year, is obtained by averaging the annual miles for the years 1963 through 1972 given in Highway Statistics (16). The average annual miles per commercial bus declined during the years 1963-1972, and is fit with an exponential. To get the total miles driven by all buses for a given year, the number of school buses forecast for that year is multiplied by 7,500 miles and added to the number of commercial buses forecast for that year, times the forecast miles per commercial bus.

(15) Highway Statistics, U.S. Federal Highway Administration, U.S. Government Printing Office, Washington, D.C., published annually.

(16) Ibid.

Table 13 shows miles driven per year in billions for each type of vehicle and total miles driven for all vehicles. The percent of total vehicle miles by vehicle type for 1986 is given.

Table 13

Forecasts of Miles Traveled Per Year by Vehicle Type
(In Billions)

Year	Cars	Motor-Cycles	Trucks				Buses		Total
			Light	Medium	Light-Heavy	Heavy-Heavy	School	Commer-cial	
1971	817.0	14.8	132.0	26.2	8.1	45.8	2.3	2.9	1049.1*
1972	852.8	16.7	139.5	27.4	8.4	47.6	2.4	2.9	1097.6*
1973	889.4	18.7	147.2	28.5	8.8	49.4	2.5	2.9	1147.3*
1974	826.2	20.7	155.1	29.7	9.1	51.2	2.6	2.9	1097.5
1975	837.3	22.6	163.3	31.0	9.4	53.1	2.7	2.8	1122.3
1976	855.3	24.6	171.6	32.2	9.8	55.0	2.8	2.8	1154.2
1977	879.6	26.5	180.1	33.5	10.1	57.0	2.9	2.8	1192.5
1978	910.0	28.4	188.8	34.7	10.5	59.0	3.0	2.7	1237.2
1979	946.9	30.2	197.7	36.0	10.8	61.1	3.2	2.7	1288.6
1980	990.6	31.9	206.8	37.4	11.2	63.2	3.3	2.7	1347.0
1981	1041.3	33.5	216.1	38.7	11.6	65.3	3.4	2.6	1412.5
1982	1090.7	35.1	225.5	40.0	11.9	67.5	3.5	2.6	1476.8
1983	1124.6	36.6	235.1	41.4	12.3	69.7	3.6	2.6	1525.8
1984	1158.4	38.0	244.9	42.8	12.7	72.0	3.8	2.5	1575.0
1985	1191.5	39.3	254.9	44.2	13.1	74.3	3.9	2.5	1623.6
1986	1224.3	40.6	265.1	45.6	13.5	76.6	4.0	2.5	1672.2
1986% =	73.2	2.4	15.9	2.7	0.8	4.6	0.2	0.1	

*Since these totals were computed with the model described above, they do not agree precisely with published totals computed by other methods.

Vehicle Miles in Urban and Rural Areas. Percentages of vehicle miles driven in urban and rural areas for cars and motorcycles during the years 1962 through 1972 are computed from information taken from Highway Statistics (17). Logistic curves are then fit to these computed data. The urban versus rural split for trucks and buses is assumed equal to the average for the same years. Using these assumptions, Table 14 is developed for January 1, 1986.

Table 14

Forecast Percent of Miles Driven by Cars and Motorcycles, by Trucks and Buses, Divided Between Urban and Rural Areas, as of January 1, 1986

	Urban	Rural	Total
Cars and Motorcycles	45.7	29.4	75.1
Trucks and Buses	9.5	15.4	24.9
TOTALS	55.2	44.8	100.0

3.1.3 Summary

The historical trends of increased automobile usage will continue through the mid-1980's. Population growth and shift to the suburbs tends to increase dependence on the automobile. Increases in the miles of convenient limited access highways available and the assumed return to higher traveling speeds support the increase in automobile usage. The automobile is used for over 90 percent of the nation's passenger car miles even though other transportation modes are heavily subsidized. This pattern is expected to continue through the mid-1980's.

The projected 1985 traffic environment for the RSV will contain 115.2 million cars, of which 48.2 million will be less than 3,000 pounds. There will be nine million motorcycles and 33.9 million trucks of which 26.3 million will be light, 4.4 million medium, 1.2 million light-heavy, and 2.1 million heavy-heavy. Finally, there will be 533,000 school buses and 94,000 commercial buses. These vehicles will be driven a total of 1,672.2 billion vehicle miles during the year, of which 1,224.3 billion will be car miles, 40.6 billion will be motorcycle miles, 400.8 billion will be truck miles, and 6.5 billion will be bus miles, and most of these miles traveled will be at higher average speeds than prevailed in 1973, the last year for which the data are available.

(17) FHWA, Op. Cit.

3.2 Accident Factors

The establishment of an estimate of accident exposure for the mid-1980's is an essential requirement of the Research Safety Vehicle project. For this assumed accident environment, the RSV System Model will determine the vehicle safety countermeasure levels required to minimize fatalities and injuries, subject to the constraints of cost, weight, and overall product feasibility. Vehicle and occupant dynamics are determined by exercising mathematical models for a set of representative collision types over the complete spectrum of accident severity. The resulting occupant dynamics are transformed into injury levels through a biomechanical model, and numbers of fatalities and injuries are calculated by forming a probability weighted average of those injury levels, weighted over collision type and severity.

3.2.1 Vehicle Accident Exposure

Within the context of the RSV System Model, accident exposure is characterized by the frequency of occurrence for each collision type (from a set of representative collision types) and by the accident severity associated with each collision type. Collision types are classified by mode or direction of impact force (e.g., front, side, rear, and rollover) and by struck object (e.g., fixed or movable). Accident severity is defined by relative speed at impact and the weight and "stiffness" of the object impacted.

To estimate current accident exposure, it would be desirable to examine a random sample of accidents taken from the population of all accidents occurring within the time period and geographic area (entire United States) of interest. However, useful data from such a random sample of accidents are nonexistent. Available accident data generally fall into one of two categories -- very detailed data from a small, poorly defined sample of accients, or very general data from a large sample of accidents (usually more representative of a random sample) which contain little or no detail. Regrettably, the capability of drawing statistical inferences about the national accident picture is severely limited with these data -- in the former category because of poor sampling techniques, and in the latter because of a lack of detail in the information available.

The general problem of inadequacy in the current federal accident data collection system is widely recognized, particularly the lack of representativeness caused by poor sampling techniques, and the resulting limited usefulness of the data for performing cost-benefit analyses of changes in vehicle and highway designs. Suggestions have been advanced to correct this unfortunate situation, but there is no immediate alternative to using existing accident data, as inadequate as they may be for the RSV estimate of current accident exposure.

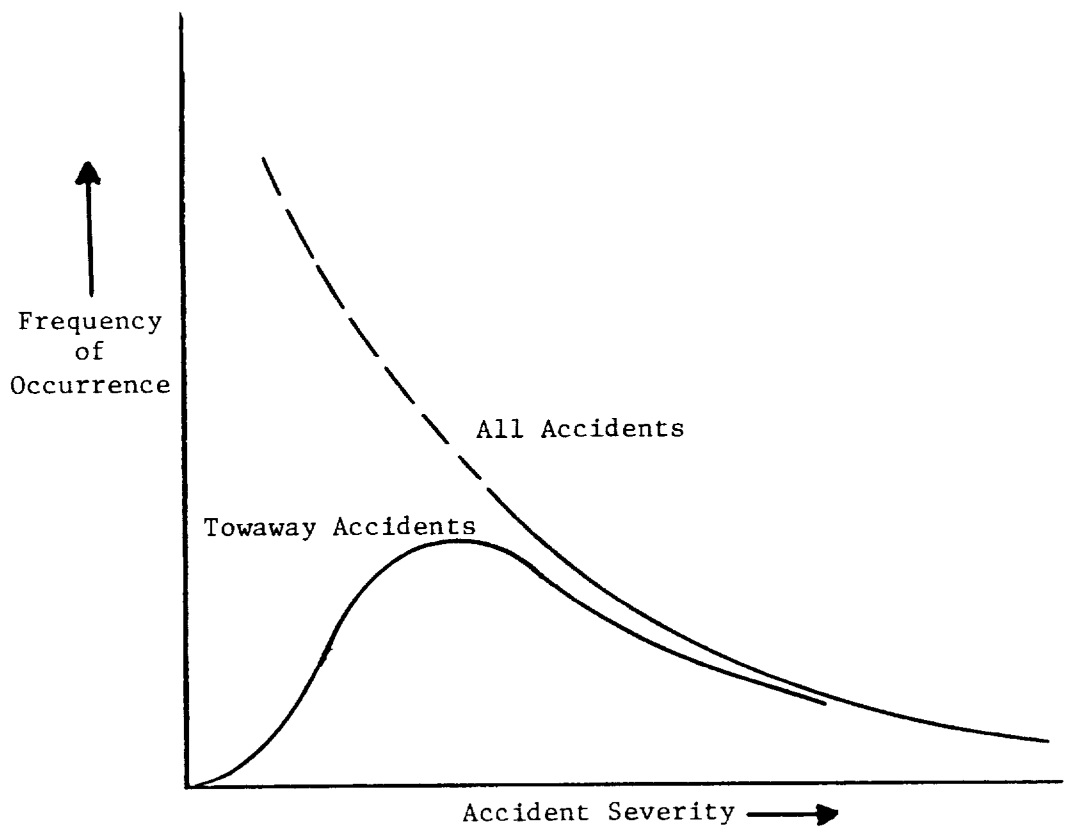
3.2.1.1 Collision Types - Frequency of Occurrence

Frequency of occurrence trends for the six basic collision types (pedestrian, fixed object, and rollover for single vehicle; and front, side, and rear for multi-vehicle) were initially determined from information representative of the total population of all motor vehicle accidents. The available accident severity data, however, apply to a more restricted sub-population of accidents -- those which require a vehicle to be towed from the accident location. Therefore, the distributions of frequency by collision type are revised to be more compatible with the accident severity distributions developed to represent the RSV accident environment.

The accident sub-population used for determining frequency of occurrence is "towaway" accidents. Figure 3 shows conceptually how this sub-population of towaway accidents fits into the more general population of all accidents. The dashed portion of the "all accidents" curve indicates that the estimates of the number of accidents which occur at the very low end of the severity spectrum are rather imprecise and quite variable. However, the set of crashes not included in the population of towaway accidents are those in which injury is unlikely. Because this study is primarily concerned with the performance of a safety vehicle in mitigating injuries, such very minor accidents are considered outside the scope of concern. Notice that, as accident severity increases, the chance of vehicle disablement requiring towing also increases until towaway accidents comprise essentially the entire accident population. These more severe accidents include those most likely to result in injury. Thus, the set of towaway accidents is presumed to include virtually all those which might result in injury.

<u>Figure 3</u>

Relationship Between Populations
of All Accidents and Towaway Accidents



Number of Towaway Accidents. There is no direct method available for estimating the number of towaway accidents. A jointly sponsored study, still in progress, does for the first time consider the relationship between towaway and injury-producing accidents, permitting a projection of towaway accidents from available injury producing accident data.

The Federal Highway Administration (FHWA) estimates that there were about 1.8 million non-fatal injury-producing accidents in 1972 (18). That is the latest year completely devoid of energy shortage implications. The estimate of 1.8 million non-fatal injury accidents is somewhat higher than the National Safety Council estimate of 1.4 million, presumably due to either different counting techniques or different definitions of what constitutes an injury. The higher number is used to ensure that no accident which might possibly be relevant in this study is excluded. In addition to the non-fatal injury accidents, the FHWA data indicate there were about 50,000 fatal injury accidents, or a total of 1.85 million accidents, which produced fatal or non-fatal injury. An NHTSA sponsored analysis of the National Accident Survey prepared by HSRI, estimated about 1.8 million injury and fatal accidents for 1971,which agrees favorably with FHWA (19).

Data from the jointly sponsored study (20), shows 55 percent of the towaway accidents resulted in injury. The same proportion is applied to our nationwide estimate of 1.85 million injury accidents -- that is, if we assume this 1.85 million represents 55 percent of the towaway accidents which occurred that year -- an estimate of about 3.4 million towaway accidents in 1972 is obtained.

Not all of these accidents involved passenger cars. The National Safety Council in Accident Facts estimates that the proportion of vehicles in accidents which are passenger cars is in the 70-80 percent

(18) "Fatality and Injury Accident Rates," U.S. Department of Transportation, Federal Highway Administration, 1972.

(19) P. S. Carroll, et al, "Current Information on Frequency of Injury and Death by Crash Configuration and Speeds," Highway Safety Research Institute, UM-HSRI-SA-73-6, DOT-HS-031-2-343, August 1973.

(20) Accident data collection and analysis investigations sponsored by NHTSA and MVMA and conducted at the Highway Safety Research Institute, Southwest Research Institute, and Calspan Corporation.

range, depending on the type of accidents. The HSRI analysis (21), suggests that some 5/6 of all vehicles in injury accidents are passenger cars. Thus, it appears that passenger cars comprise about 80 percent of the vehicles in the population under consideration. Therefore, about 2.7 million (out of a total of 3.4 million) towaway accidents involving passenger cars are assumed to have occurred in 1972.

The 2.7 million accident estimate for 1972 must be projected to 1985. The U. S. Bureau of the Census estimates that the total U. S. population will increase from 208.2 million in 1972 to 239.5 million in 1985, an increase of 15 percent. An analysis of historical trends in selected accident exposure parameters indicates concurrent increases during the period 1972 to 1985 of 34 percent in miles of travel, 34 percent in the number of registered vehicles, and 22 percent in the number of licensed drivers. Based on these anticipated increases, the number of accidents in 1985 is estimated from a regression model to be about 28 percent more than the number which occurred in 1972. Thus, the estimate of 2.7 million towaway accidents in 1972 is increased 28 percent to 3.5 million for 1985.

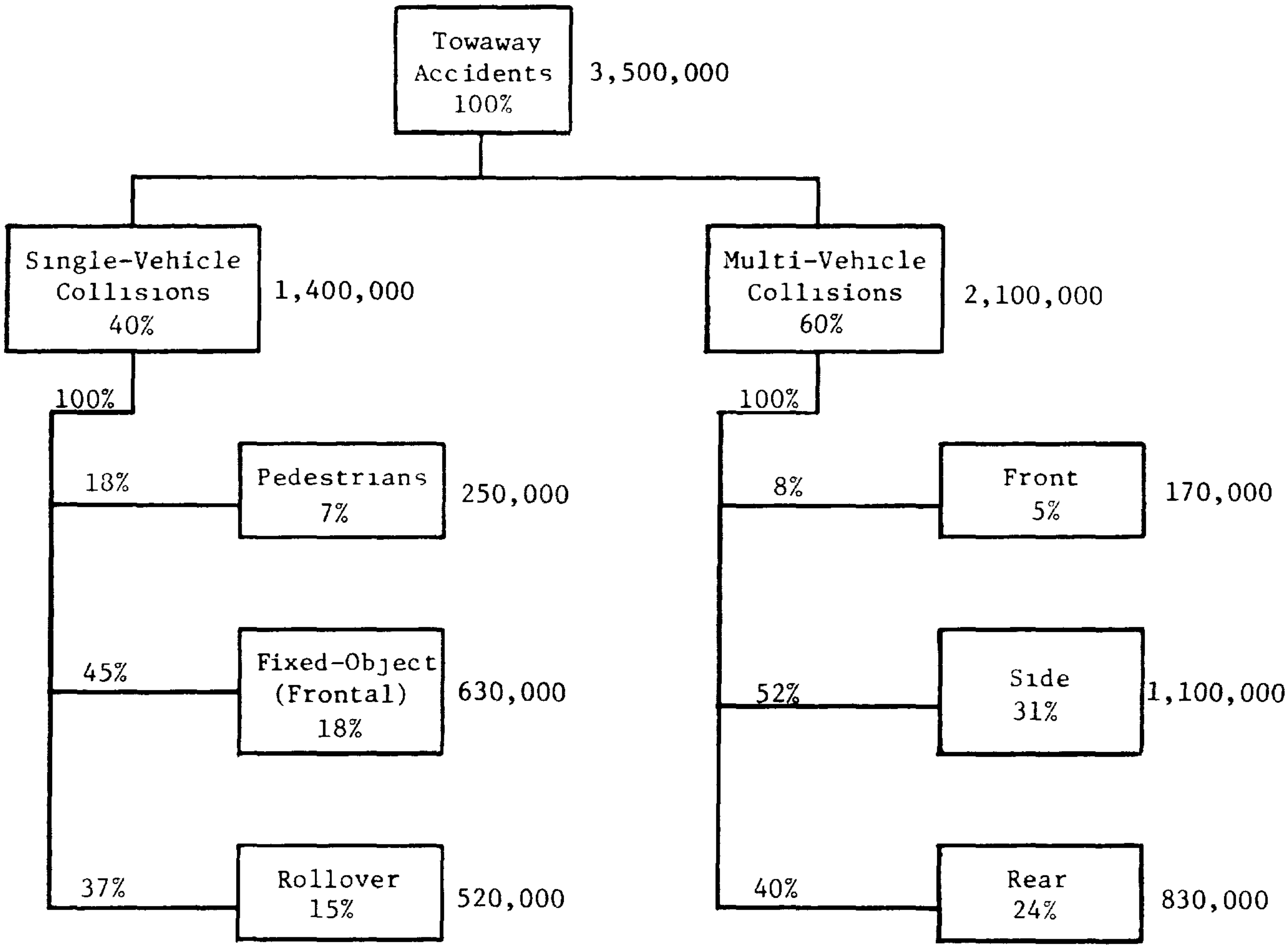
Frequency of Collision Types. The HSRI analysis of the National Accident Summary (22) also served as the source for the distribution of towaway accidents by collision type. The relative percentage distribution for fatal and injury-producing accidents is taken from Tables 13 and 14 of Appendix C from the HSRI study. No forthcoming change in automobile design or usage, or societal structure, roadway design, etc., that would affect this distribution is foreseen. It is assumed, therefore, that the 1985 distribution will be relatively the same as reported by HSRI. The resulting predicted distribution of these towaway accidents for 1985 is shown in Figure 4. The category identified as Fixed-Object in this table comprises those accidents designated in the source material as: Non-Motor Vehicle; Fixed Object: or Other Object. The Rollover category includes those accidents designated in the HSRI study as: Run Off Road or Overturned. The other classifications in the projected distribution are the same as those used in the source document.

(21) Carroll, et al, Op. Cit.

(22) Ibid.

Figure 4

Projected 1985 Percentage Distribution of Towaway Accidents by Collision Type



<u>Computation of Collision Probabilities</u>. The collision probabilities of interest are those involving RSV's in single-vehicle and two-vehicle collisions with other cars. The 1985 projections of vehicle-mix for cars are grouped into four weight classes -- 2,000 pounds, (24.6%); 3,000 pounds, (36.5%); 4,000 pounds, (29.0%); and 5,000 pounds, (10.0%), where cars make up 73 percent of all vehicles on the road.

In the following example of the methodology, it has been assumed that RSV's make up 50 percent of the car population in the 3,000 pound weight group. Therefore, RSV's make up 18.2 percent of the car population in this example. However, RSV's constitute 100 percent of all 3,000 pound cars in the system model. This percentage is a user-specified variable that can be any number between 0 and 100 percent. By varying the proportion of RSV's in the car population of 1985, the change in benefits for different RSV percentages can be computed. In all operations of the system model and in the results presented in Volume III, all 3,000 pound cars (100%) are assumed to be RSV's, and the optimal performance specifications are also obtained for that condition. It is only for the sake of completeness in the presentation of the analysis that a group of "non-RSV" 3,000 pound cars are considered in this section. The collision probabilities used in the operation of the system model (100% RSV's) are presented in Section 4.9 of Volume III. For all collisions, it is assumed that a lighter vehicle is as likely to be involved in an accident as a heavier vehicle. Thus, for single-vehicle collisions, the probability of involvement for any size vehicle is directly proportional to the percent of that size vehicle on the road.

The probability of a vehicle in a certain weight class being involved in a two-vehicle collision is independent of the probability of any other vehicle in the same or different weight class being so involved. Therefore, the joint probability of the event "two-vehicle collision," is the product of the probabilities of the two independent random events. For example, the probability of an RSV colliding with another RSV is 0.182 times 0.182 or 0.0331 (3.31%).

The development of the probabilities of involvement for different types of collisions is shown in the tree diagram, Figure 5. The product of the probabilities along any branch equals the probability of involvement for that type of collision and that size of vehicle(s) involved.

Table 15 presents the probabilities of involvement after similar collision types involving the same size vehicle(s) are grouped together from Figure 5.

Tables 16 and 17 are derived from Table 15 and represent conditional probabilities of involvement by weight class given that a single-vehicle or two-vehicle collision has occurred.

No distinction is made between the striking vehicle and the struck vehicle for two RSV's involved in front, side, or rear collisions; or for an RSV and any other vehicle in a frontal (head-on) collision. For all other RSV involvements in side and rear impacts, the RSV will be equally divided between the struck vehicle and the striking vehicle.

Figure 5

Collision Probability Tree for 1985

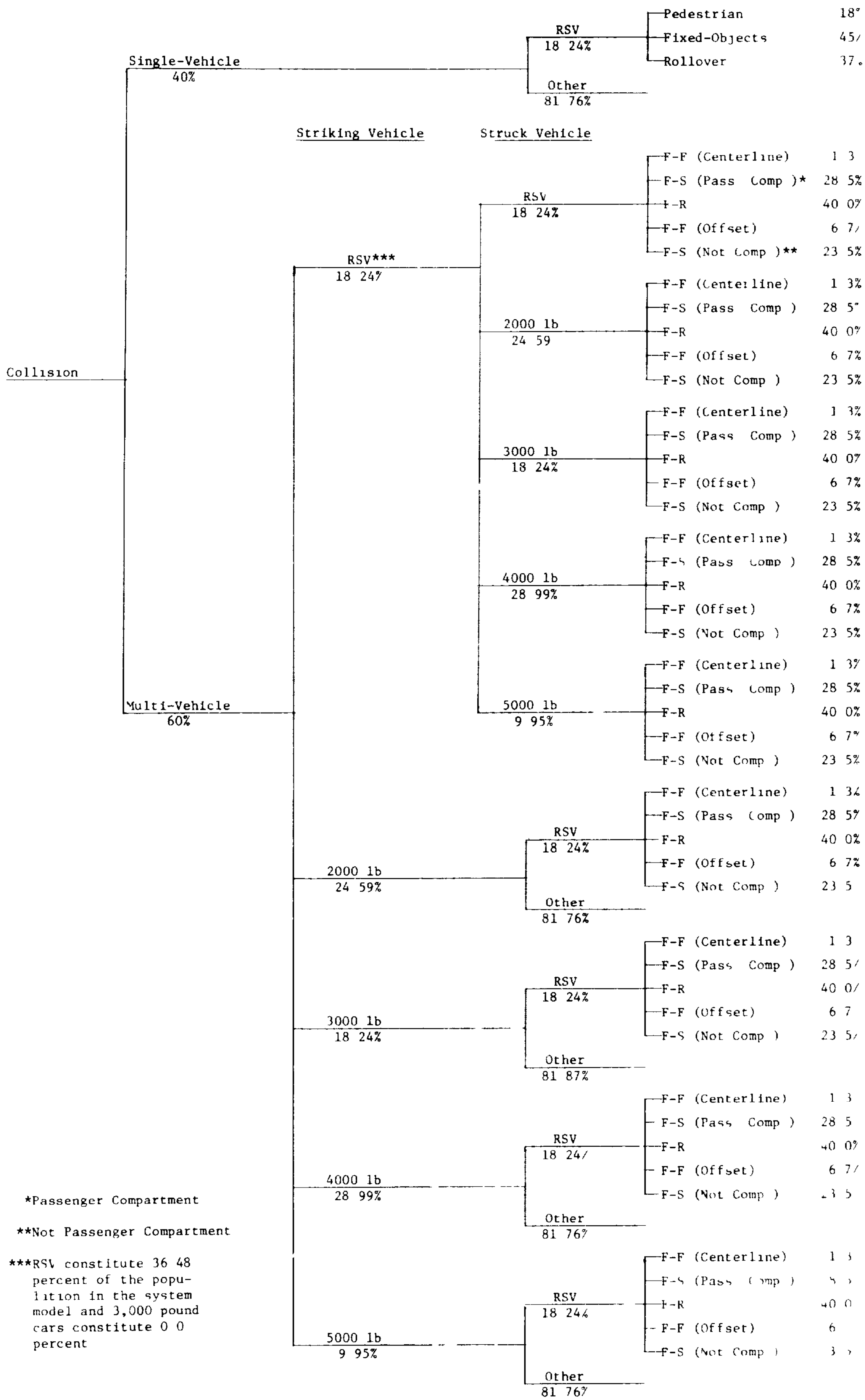


Table 15

Probability of Involvement for Single-Vehicle and Two-Vehicle Collision Configurations

Vehicles Involved	Single-Vehicle Collision Configuration: Pedestrian	Fixed-Objects (Frontal Only)	Rollover	Total
RSV	.0131	.0328	.0270	.0730
Other	.0589	.1472	.1210	.3270
TOTAL	.0720	.1800	.1480	.4000

Vehicles Involved	Two-Vehicle Collision Configuration: Front-Front (Center-line)	Front-Front (Off-set)	Front-Side (T-Type)	Front-Side (L-Type)	Front-Rear	Total
RSV-RSV or RSV-RSV	.0003	.0013	.0057	.0047	.0080	.0200
RSV-2000 or 2000-RSV	.0007	.0036	.0154	.0127	.0215	.0538
RSV-3000 or 3000-RSV	.0006	.0026	.0114	.0094	.0160	.0399
RSV-4000 or 4000-RSV	.0008	.0043	.0181	.0149	.0254	.0635
RSV-5000 or 5000-RSV	.0003	.0014	.0062	.0052	.0088	.0219
Other	.0051	.0270	.1142	.0942	.1673	.4009
TOTAL	.0077	.0403	.1710	.1410	.2400	.6000

Table 16

Probability of Involvement for
Single-Vehicle Collisions

Vehicles Involved	Collision Configuration: Pedestrian	Fixed-Object (Frontal Only)	Rollover	Total
RSV	.0328	.0821	.0675	.1824
Other	.1472	.3679	.3025	.8176
TOTAL	.1800	.4500	.3700	1.0000

Table 17

Probability of Involvement for
Two-Vehicle Collisions

Vehicles Involved	Collision Configuration: Front-Front		Front-Side			
	Center-line	Off-set	(T-Type)	(L-Type)	Front-Rear	Total
RSV-RSV or RSV-RSV	.0004	.0023	.0095	.0078	.0133	.0333
RSV-2000 or 2000-RSV	.0011	.0061	.0256	.0211	.0359	.0897
RSV-3000 or 3000-RSV	.0008	.0045	.0190	.0156	.0266	.0665
RSV-4000 or 4000-RSV	.0013	.0072	.0302	.0249	.0423	.1058
RSV-5000 or 5000-RSV	.0004	.0025	.0104	.0086	.0146	.0365
Other	.0084	.0451	.1904	.1570	.2673	.6682
TOTAL	.0126	.0674	.2850	.2350	.4000	1.0000

To determine the proportion of RSV involvements in two-vehicle collisions with heavier and lighter vehicles, the probabilities of Table 17 can be combined as shown in Table 18.

Table 18

Probability of RSV Collision Involvement

Two-Vehicle Involvements	Probabilities
RSV with 2,000 pound car	0.0897
RSV with RSV	0.0333
RSV with 3,000, 4,000, 5,000 pound vehicles	0.2088
All RSV Involvements	0.3318
Other Two-Vehicle Involvements	0.6682
	1.0000

It is expected that the RSV will be involved in 33.2 percent of two-vehicle collisions. However, given that an RSV is involved in a two-vehicle collision, it will be involved with a lighter vehicle 27 percent (0.0897/0.3318) of the time, another RSV ten percent (0.0333/0.3318) of the time, and a 3,000, 4,000, 5000 pound car 63 percent (0.2088/0.3318) of the time.

Sensitivity Study. In order to study the sensitivity of these collision probabilities to the projected mix of vehicles for 1985, the following analysis is presented. To keep the analysis simple, the vehicle population is broken down into light (L) and heavy (H) vehicles. Some typical notations are given below:

P(L): probability of a light vehicle involved in a single-vehicle accident

P(L-H): probability of a light car striking a heavier car in a two-vehicle collision

P(L-H;H-L): probability of a light and heavy vehicle involved in a collision; this is equal to P(L-H) + P(H-L)

The probabilities of involvement for cars in single-vehicle and two-vehicle collisions in the two weight classes are given in Tables 19 and 20 and Figures 6 and 7.

If light vehicles comprised between 33 percent and 67 percent of all vehicles on the road, there would be more collisions between vehicles of different weights than between vehicles of equal weights. The light vehicle percentage would have to exceed 67 percent before collisions of two light vehicles are more frequent.

This sensitivity analysis becomes more complicated when five weight classes are considered. The same notations that have been used in this study were used again in this analysis to represent the five weight classes. To simplify the analysis we have assumed that the percents of 2,000 pound cars (24.6%) and 4,000 and 5,000 pound cars (39.0%) remain unchanged. Then, any increase in the percent of RSV's would only decrease the percent of other 3,000 pound cars, since the percent of 3,000 pound cars must remain unchanged at 36.4 percent of all cars. Table 21 shows the probability of involvement for cars of different weights by vehicle mix. Emphasis was placed only on RSV involvements. This table is then plotted in Figure 8. The curves represent the probability of involvement for various weight combinations of RSV-involved collisions as a function of the percent of RSV's. The vertical distance between the two curves which bound the shaded portion represents how much greater the probability of RSV's colliding with 3,000, 4,000, and 5,000 pound cars is over that of RSV's colliding with other RSV's or 2,000 pound cars. For our projected estimate that RSV's will be 18.24 percent of all cars in 1985, the involvement rate between RSV's and 3,000, 4,000, and 5,000 pound cars is almost twice the involvement rate between any two RSV's or an RSV and a 2,000 pound car. When the percent of RSV's exceeds 33.9 percent, only then will collisions between two RSV's or an RSV and a 2,000 pound car begin to outnumber collisions between RSV's and 3,000, 4,000, and 5,000 pound cars and make the accident picture look safer.

Table 19

Probability of Involvement for
Single-Vehicle Collisions

Vehicle Mix		Probability of Involvement	
Light Vehicle	Heavy Vehicle	Light Vehicle P(L)	Heavy Vehicle P(H)
0%	100%	0	1.0
10	90	.1	.9
20	80	.2	.8
30	70	.3	.7
40	60	.4	.6
50	50	.5	.5
60	40	.6	.4
70	30	.7	.3
80	20	.8	.2
90	10	.9	.1
100	0	1.0	0

Table 20

Probability of Involvement for
Two-Vehicle Collisions

Vehicle Mix		Probability of Involvement		
Light Vehicles	Heavy Vehicles	Two Light Vehicles P(L-L)	One Light and One Heavy Vehicle P(L-H;H-L)	Two Heavy Vehicles P(H-H)
0%	100%	0	0	1.00
10	90	.01	.18	.81
20	80	.04	.32	.64
30	70	.09	.42	.49
40	60	.16	.48	.36
50	50	.25	.50	.25
60	40	.36	.48	.16
70	30	.49	.42	.09
80	20	.64	.32	.04
90	10	.81	.18	.01
100	0	1.00	0	0

Figure 6

Probability of Involvement for
Single-Vehicle Collisions

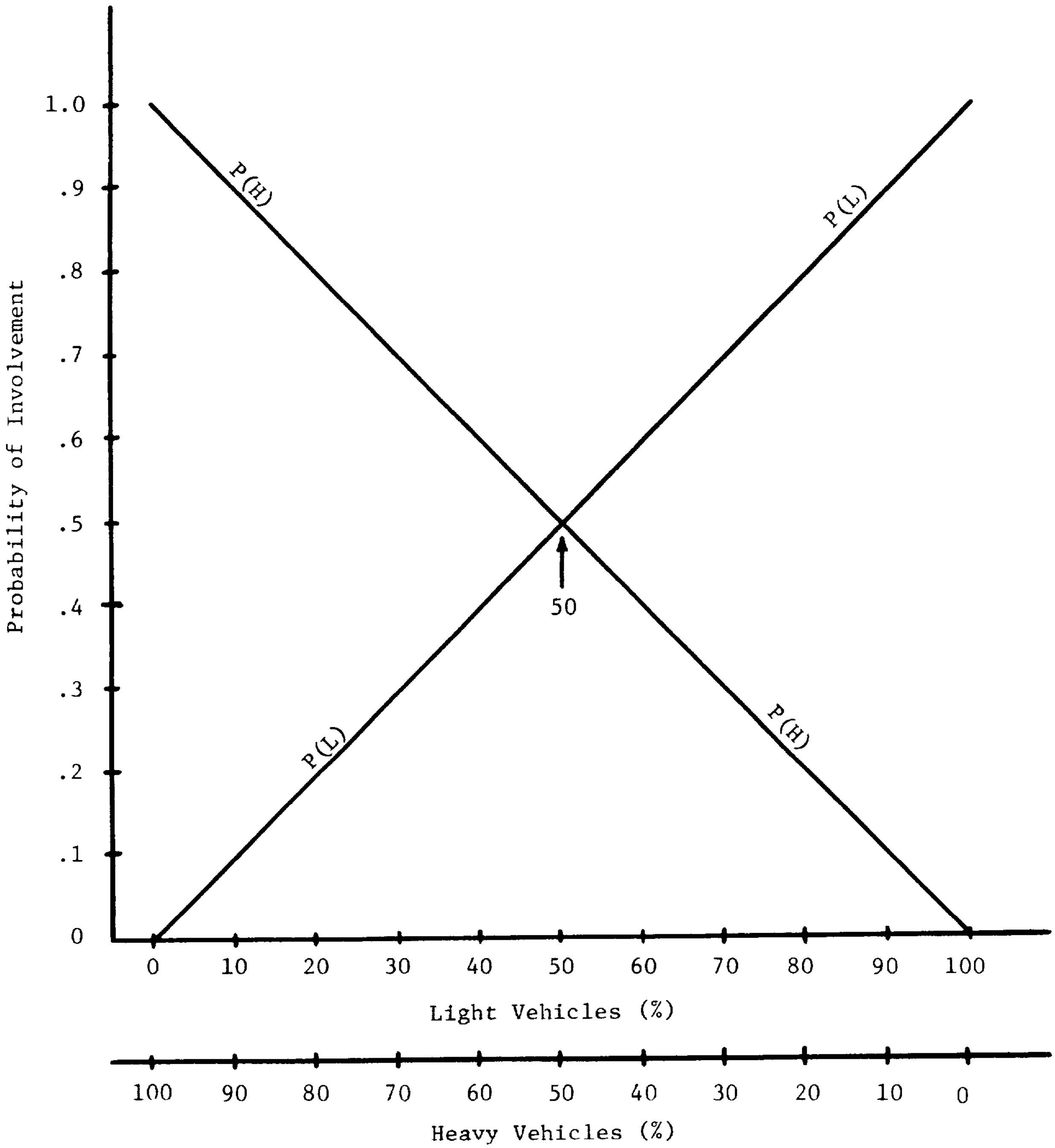


Figure 7

Probability of Involvement for
Two-Vehicle Collisions

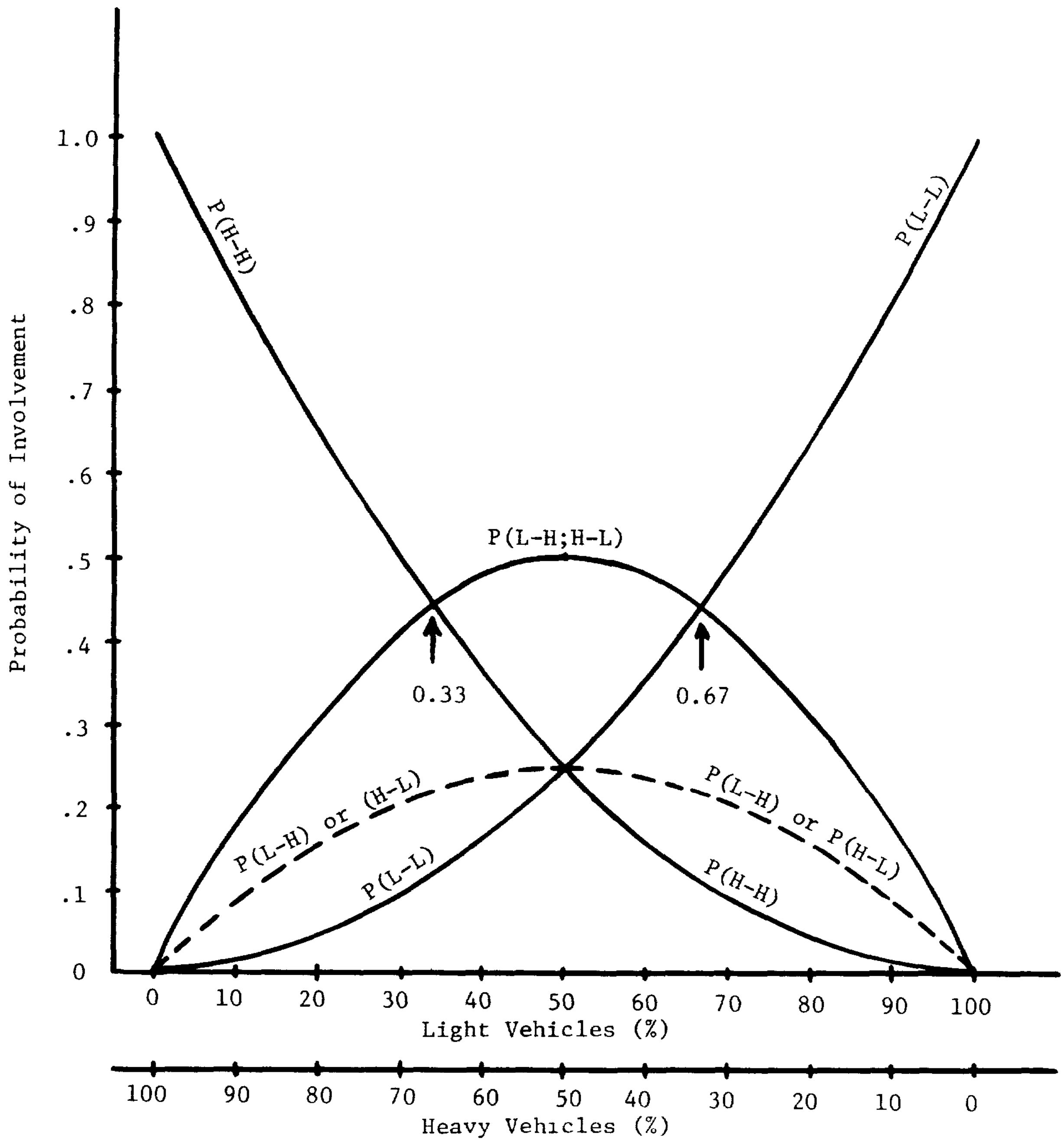


Table 21

Probability of Involvement
of RSV's With Other RSV's
and 2000 lb., 3000 lb., 4000 lb., and 5000 lb. Cars

Vehicle Mix (%)				Probability of Involvement				
2000	RSV	3000	4000 5000	P(2)	P(RSV)	P(3)	P(4) & P(5)	P(OTHER)
24.6	0.0	36.4	39.0	0.0000	0.0000	0.0000	0.0000	1.0000
24.6	5.0	31.4	39.0	0.0246	0.0025	0.0314	0.0390	.9025
24.6	10.0	26.4	39.0	0.0492	0.0100	0.0528	0.0780	.8100
24.6	15.0	21.4	39.0	0.0738	0.0225	0.0642	0.1170	.7225
24.6	20.0	16.4	39.0	0.0984	0.0400	0.0656	0.1560	.6400
24.6	25.0	11.4	39.0	0.1230	0.0625	0.0570	0.1950	.5625
24.6	30.0	6.4	39.0	0.1476	0.0900	0.0384	0.2340	.4900
24.6	35.0	1.4	39.0	0.1722	0.1225	0.0098	0.2730	.4225
24.6	36.4	0.0	39.0	0.1791	0.1325	0.0000	0.2839	.4045

$P(2) = .492P$ where P = proportion of RSV's

$P(RSV) = P^2$

$P(3) = 2P(.364-P)$

$P(4) + P(5) = .78P$

$P(0) = (1-P)^2$

Where $.492P + P^2 + 2P\ (.364-P) + .78P + (1-P)^2 = 1.0$

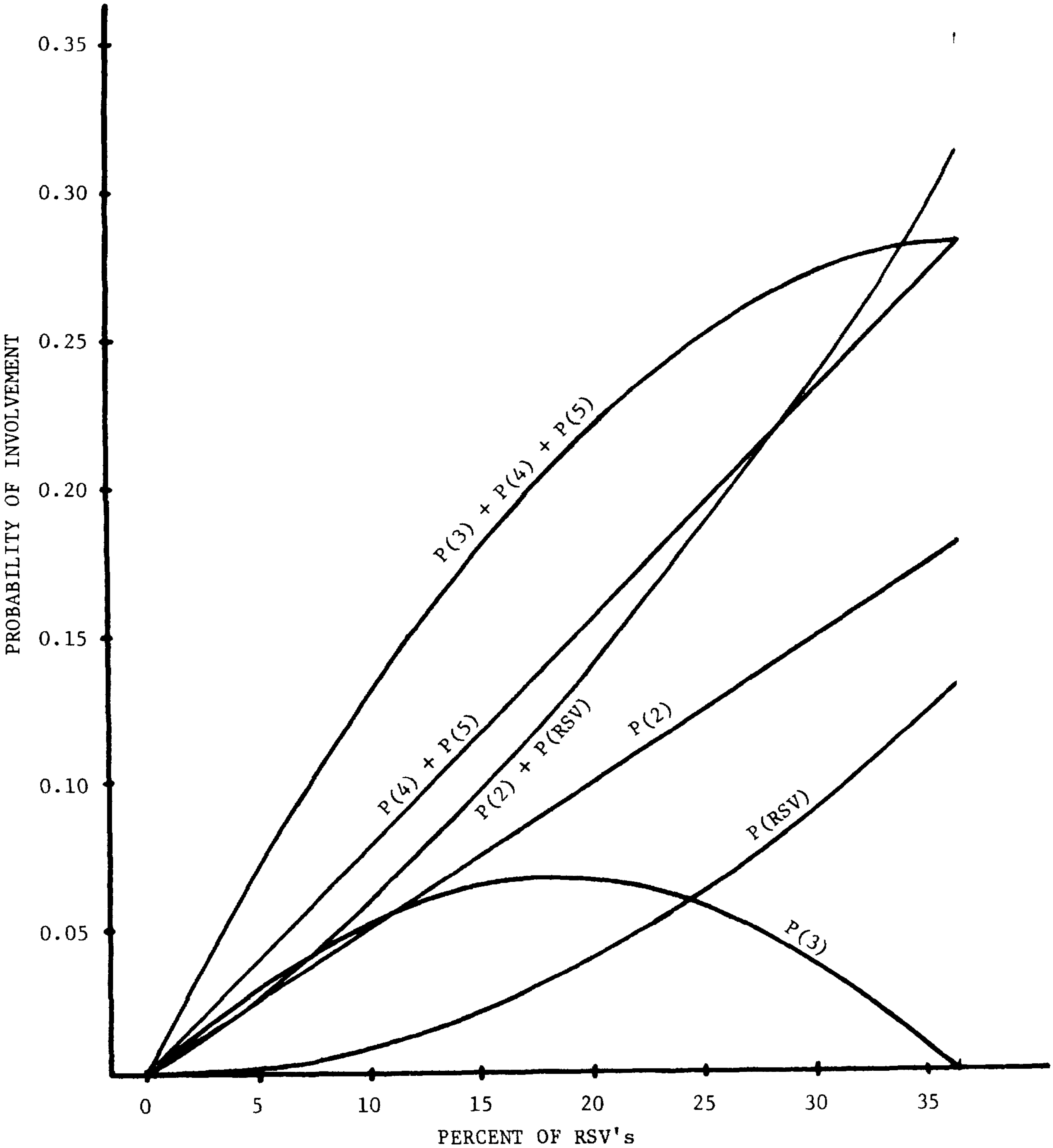
P(2) = P(RSV-2000; 2000-RSV) or a collision involving an RSV and a 2000 lb. car

P(RSV), P(3), P(4), P(5) the same definition

P(0) = other collisions not involving RSV's

Figure 8

Probability of RSV Collision Involvement



Where P(2), P(3), P(4), P(5) and P(RSV) represent the probability of involvement in a collision between RSV and 2,000 lb., 3,000 lb., 4,000 lb., 5,000 lb. cars and RSV, respectively.

3.2.1.2 Accident Severity

The measure of accident severity is defined as the relative speed at impact and the weight and "stiffness" of the object impacted. Estimates for the probability distributions of relative speed at impact (for the current accident environment) are constructed for vehicle-to-vehicle front, side, and rear collision types as well as for single-vehicle frontal fixed object collisions. For this purpose, the CPIR3 (Collision Performance and Injury Report, Revision 3) accident data file maintained by the Highway Safety Research Institute (HSRI) of the University of Michigan (23, 24) is used.

The CPIR3 data file contains detailed reports of accidents, about 5,000 of which have been investigated and reported between 1969 and November 1974. Approximately one-third of those reports were supplied by National Highway Traffic Safety Administration (NHTSA) sponsored MDAI teams, while the remaining two-thirds were provided by accident investigating teams sponsored either by the MVMA or jointly by the MVMA and NHTSA. The accidents reported generally involve new cars (average age of about 1.2 years at the time of the accident) in which some injury usually occurred. The investigating teams are typically associated with university research facilities, research institutes, or medical examiner's offices (a total of 22 different MDAI teams operating at one time or another).

In general, the overall occupant injury severity levels for cases within the CPIR3 accident file are much higher than would be found in a random sample of all accidents taken from the same geographic area, however, those severity levels do seem to be moderating with time, primarily due to changes in the sampling criteria used by some accident investigators. For example, the percentage of fatal involvements in the MDAI cases is about four times that for MVMA "Washtenaw County towaway"

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(23) J. C. Marsh, S. O. Vanek, and S. E. Tolkins, Multidisciplinary Accident Investigation Report Automation and Utilization, 1973 Editing Manual and Reference Information, Highway Safety Research Institute, University of Michigan, Ann Arbor, Michigan, DOT-HS-031-3-589, December 1973.

(24) James O'Day, W. L. Carlson, R. Douglass, and R. J. Kaplan, Statistical Inference from Multidisciplinary Accident Investigation, Highway Safety Research Institute, Ann Arbor, Michigan, DOT-HS-031-2-350, June 1973.

cases, which are intended to be a census of all "towaway" accidents within Washtenaw County, Michigan. The average occupant injury severity level for each investigation year (using the Abbreviated Injury Scale or AIS) has been steadily falling (a small portion of this reduction is attributable to the implementation of new vehicle safety standards) from an AIS of about 2.7 in 1969 to an AIS of about 1.0 in 1972, the last year for which this indicator was calculated.

Data Analysis. In utilizing the CPIR3 data file to establish an estimate of accident severity for the current traffic environment, single-impact two-car vehicle-to-vehicle front, side, and rear collision types as well as single-impact one-car frontal fixed object collision types are each subdivided into two mutually exclusive impact configurations -- "direct" impacts which may have significant injury producing potential, and "indirect" or "offset" impacts which often result in only superficial vehicle damage and little or no occupant injury. These impact configurations are essentially determined from the damage sustained by the vehicles involved -- for instance, the "direct" impact configuration for the front-to-front collision type is characterized by "barrier" type vehicle damage (distributed frontal damage) to both vehicles.

As a preview of the accident data analysis which follows, Table 22 enumerates the impact configuration vehicle damage descriptors which are assigned to each collision type. The impact configurations shown for each of the collision types are those which are simulated in the RSV System Model. The appropriate relative speeds at impact for each collision type were defined as closing speed, striking speed, or impact speed. The remaining portion of this section details the techniques employed to obtain approximations of these measures of accident severity.

Accident Severity Measure. As an input to the RSV System Model, accident severity is measured by the relative speed at impact and the weight and "stiffness" of the object impacted. This characterization of accident severity should be contrasted with the frequently employed "barrier equivalent speed" measure of severity, which is defined to be that speed at which a particular vehicle would have to impact a rigid immovable barrier to produce the same residual

Table 22

Descriptors of Relative Impact Speed
and Vehicle Damage for Single-Impact
Two-Car Vehicle-to-Vehicle and
One-Car Frontal Fixed Object Collisions
by Collision Type and Type of Damage

COLLISION TYPE	IMPACT CONFIGURATION	
	"DIRECT" IMPACTS	"INDIRECT" IMPACTS
FRONT-TO-FRONT	CLOSING SPEED "BARRIER" TYPE DAMAGE	CLOSING SPEED "NON-BARRIER" TYPE DAMAGE
FRONT-TO-SIDE	STRIKING SPEED LEFT SIDE RIGHT SIDE "OCCUPANT COMPARTMENT" DAMAGE	STRIKING SPEED LEFT SIDE RIGHT SIDE "NON-OCCUPANT COMPARTMENT" DAMAGE
FRONT-TO-REAR	CLOSING SPEED "BARRIER" DAMAGE	CLOSING SPEED "NON-BARRIER" DAMAGE
FRONTAL FIXED OBJECT (POLES AND TREES)	IMPACT SPEED "CENTER" DAMAGE	IMPACT SPEED "NON-CENTER" DAMAGE

crush as was experienced in an actual collision. For vehicle structures in which crush force is a function of only crush distance, the energy absorbed in plastic deformation of the vehicle structure in a rigid barrier impact at the barrier equivalent speed would be the same as that absorbed in an actual collision. For this reason, barrier equivalent speed is sometimes considered to be an "equal energy" measure of collision severity, that is, the structure of a vehicle involved in an actual collision absorbs the same amount of energy as it would be in a rigid barrier impact at the corresponding barrier equivalent speed.

Analytical studies of vehicle-to-vehicle collisions indicate that barrier equivalent speed is not a sufficiently accurate measure of accident severity for the purposes of the RSV System Model. It is entirely possible for the same vehicle to undergo different impacts which have the same barrier equivalent speed measure of severity yet have significantly different vehicle (and occupant) dynamics. Only in special cases, such as vehicle-to-vehicle impacts in which the vehicle structural stiffness to weight ratio is approximately the same for both vehicles (typical of many of today's vehicles) does barrier equivalent speed portray an accurate description of accident severity.

In addition to barrier equivalent speed being an imprecise measure of accident severity, it is also an inappropriate one for the system model, in which it is desirable that any measure of severity be independent of vehicle structural properties. If barrier equivalent speed were to be the measure of accident severity, changes in the exposure distributions of barrier equivalent speeds would be required as vehicle structural assumptions were altered within the system model optimization algorithm. Measuring accident severity in a manner independent of vehicle design minimizes the complexity of the system model.

CPIR3 Data File Structure. Because of the structure of the CPIR3 accident data file, the details of impact configuration are best reconstructed by careful examination of the Vehicle Deformation Index or VDI -- a seven character alpha-numeric descriptor of the collision induced vehicle structural damage. The VDI provides a coarse description of the primary impact force direction, the general location of the structural damage, the specific damaged area, and the depth or "extent" of penetration in that area. In spite of its imprecision, evaluation of the VDI is usually the only practical method of determining the most probable impact configuration. The alternative is to locate the original CPIR3 report (not always readily available due to a wide variety of sources), to read the accident investigator's commentary (not necessarily complete), and examine photographs of vehicle damage (not usually available). Unfortunately, a detailed account of the sequence of events and a precise description of the impact configuration are not coded in the CPIR3 data file and can be obtained only from the accident investigator's written commentary.

Due to a number of idiosyncracies related to the structure of the data, it was essential that the contents of the CPIR3 file be carefully "filtered" or screened to prevent any possible misinterpretations. For the RSV accident severity analysis, interpretation of the data was performed with the following anomolies in mind.

1. For each accident, there may be as many CPIR3 reports entered into the data file as there were vehicles involved. To avoid "counting" some accidents more than once (about 15 percent of the accidents have two or more CPIR3 reports), all but the first CPIR3 report submitted for each accident were ignored.
2. Some reports in the file provide complete information for the "case vehicle" but inadequate information for the "other vehicle" in vehicle-to-vehicle collisions. Since impact configurations were defined by the VDI, those reports (about 15 percent of the total) which did not contain that level of detail were discarded. (This situation is particularly prevalent with some MVMA-sponsored teams which do not obtain complete "other vehicle" information -- for instance, "Washtenaw County towaway" cases.)
3. In multiple impact cases, the reported "primary VDI" may not be associated with an impact at the reported "speed at first impact." To be certain that the vehicle damage being assessed was a consequence of impact at the reported speed, all multiple colli-

sion cases (about ten percent of the total) were discarded.

4. The "collision configuration" categories defined in the CPIR3 data file are somewhat ambiguous -- for instance, it wasn't unusual to find a reported impact with essentially "sideswipe"-type vehicle damage categorized as a "head-on" frontal impact. Characterizing impact configurations on the basis of vehicle damage (VDI) helped reduce this ambiguity.

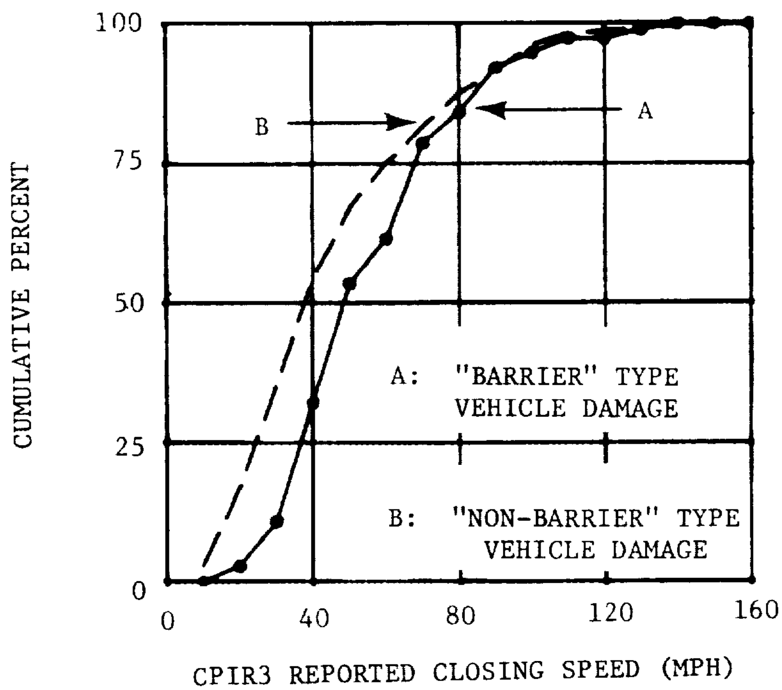
CPIR3 Reported Closing Speeds for Front-to-Front Collisions. Cumulative percentage distributions of CPIR3 reported closing speeds for all levels of injury and fatality in two-car front-to-front collisions are shown in Figure 9 by type of vehicle damage. The CPIR3 reported closing speed is simply the sum of the reported speeds (relative to ground) "at first impact" for both vehicles involved. (These reported collision speeds are the result of an accident investigation and reconstruction by trained accident investigators and are not police-reported speeds.) "Barrier" type vehicle damage is defined to be distributed frontal damage for both vehicles (impact force directions were all 11, 12, or 1 o'clock). "Non-Barrier" type damage accidents were made up of about 40 percent of "offset" and 60 percent "heavy sideswipe" impacts. Notice that about 23 percent of the 75 "Barrier" type damage accidents resulted in one or more fatalities, compared to only eight percent for the 400 "Non-Barrier" type damage cases.

CPIR3 Approximated Closing Speeds for Front-to-Front Collisions. Figure 10 exhibits cumulative normal probability distributions approximating the CPIR3 reported closing speed distributions shown in Figure 9.

In establishing a procedure for approximating the CPIR3 reported collision speed distributions, primary consideration was given to the following two criteria. First non-randomness of the sample precluded any meaningful goodness-of-fit test. A simple functional form which approximated the salient characteristics of the CPIR3 reported collision speed distribution would be appropriate. Anything more could hardly be supported by the quality of the data. Second, conventional

Figure 9

Cumulative Percentage Distributions
of CPIR3 Reported Closing Speeds
for All Levels of Injury and Fatality
in Two-Car Front-to-Front Collisions
by Type of Vehicle Damage



Legend

A: "BARRIER" TYPE VEHICLE DAMAGE -- Both vehicles sustained distributed frontal damage (75 accidents, 17 involving one or more fatalities).

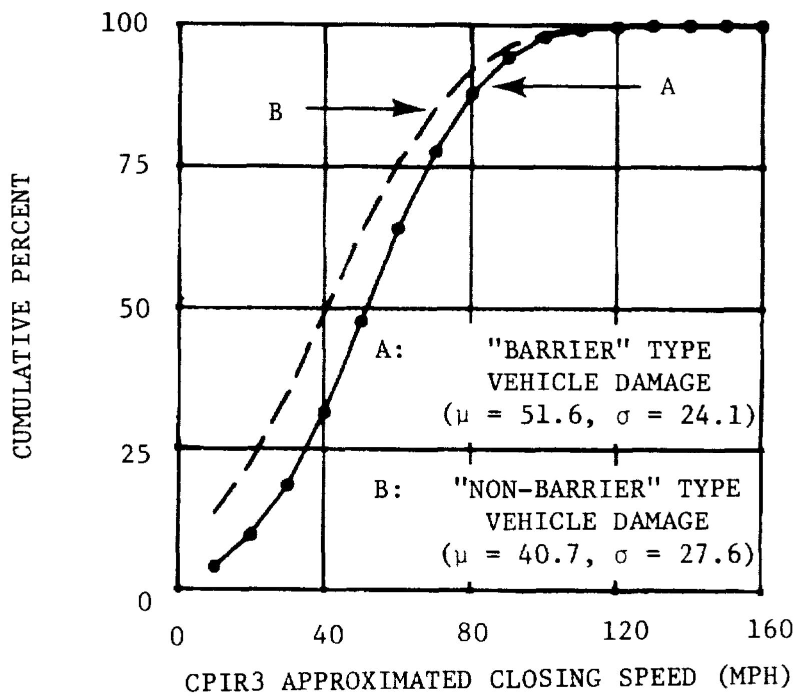
B: "NON-BARRIER" TYPE VEHICLE DAMAGE -- Both vehicles did not sustain distributed frontal damage (400 accidents, 33 involving one or more fatalities).

Source

Highway Safety Research Institute CPIR3 accident data file as of November, 1974. (Vehicle-to-vehicle head-on collision configuration for accidents involving only two cars in a single impact.)

Figure 10

Cumulative Percentage Distributions
of CPIR3 Approximated Closing Speeds
for All Levels of Injury and Fatality
in Two-Car Front-to-Front Collisions
by Type of Vehicle Damage



Legend

A: "BARRIER" TYPE VEHICLE DAMAGE -- Both vehicles sustained distributed frontal damage (75 accidents, 17 involving one or more fatalities). Normal approximation:

μ = mean = 51.6 MPH, σ = standard deviation = 24.1 MPH.

B: "NON-BARRIER" TYPE VEHICLE DAMAGE -- Both vehicles did not sustain distributed frontal damage (400 accidents, 33 involving one or more fatalities). Normal approximation:

μ = mean = 40.7 MPH, σ = standard deviation = 27.6 MPH

Source

Highway Safety Research Institute CPIR3 accident data file as of November, 1974. (Vehicle-to-vehicle head-on collision configuration for accidents involving only two cars in a single impact.)

parameter estimation techniques based upon random sample assumptions should be avoided. For instance, outliers due to suspected systematic bias toward the sampling of cases of extreme severity would inflate estimates of the population mean and variance.

In consideration of these criteria, approximating distributions of collision speeds were constructed by fitting normal probability distribution functions (linear least squares estimators on normal probability paper) to the actual CPIR3 reported collision speed distributions between the 20 percent and 80 percent cumulative distribution points. This procedure produced a simple functional form for the approximating distribution functions which fit the reported data well over a wide area and minimized the influence of alleged outliers.

These approximating distributions of closing speed are assumed to be representative of the relative speeds at impact for the front-to-front collision type within the current accident environment.

Calculated Speed Change During Front-to-Front Impact. An extremely interesting comparison is displayed in Figure 11 between reported closing speed, reported impact speed (relative to ground), and calculated speed change during impact for the "Barrier" type vehicle damage accidents. For this well-defined front-to-front colinear impact configuration, the plausible assumptions of inelastic collision and conservation of linear momentum lead to a simple relationship between speed change during impact (ΔV), closing speed ($V_{closing}$), and vehicle weights (W).

$$\Delta V_1 = \frac{W_2}{W_1 + W_2} V_{closing} \qquad [1]$$

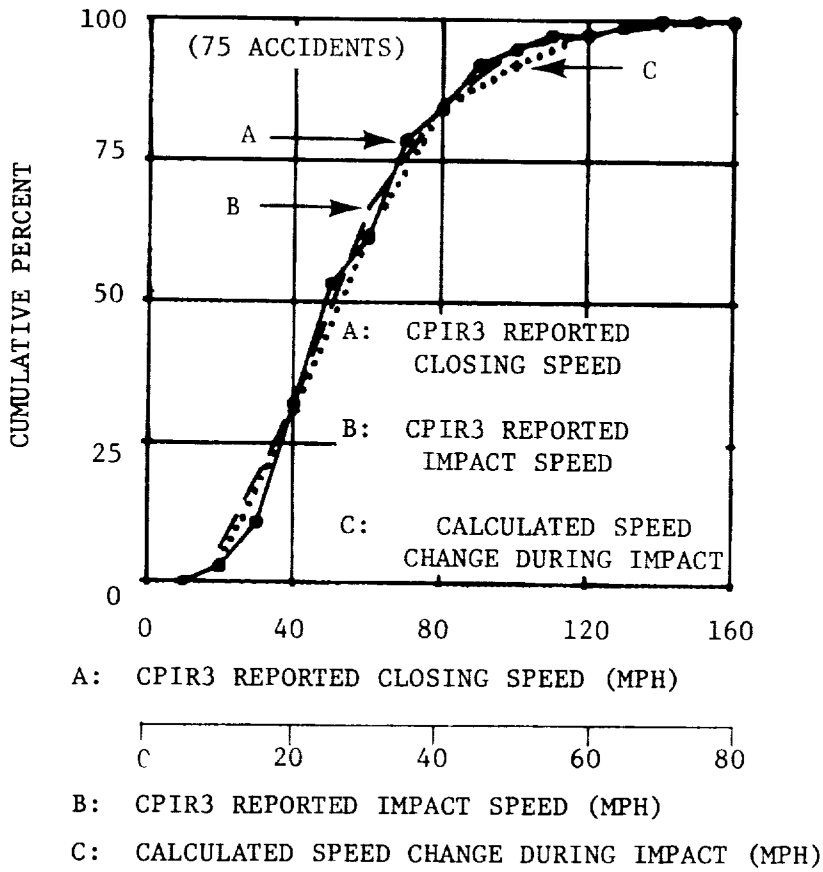
$$\Delta V_2 = \frac{W_1}{W_1 + W_2} V_{closing} \qquad [2]$$

(Subscripts denote arbitrary vehicle designations 1 and 2.) For instance, Vehicle 1 will experience an overall speed change during impact equal to the closing speed multiplied by the ratio of the weight of Vehicle 2 to the combined weight of Vehicles 1 and 2. (For the special case in which the weights of both vehicles are the same, each vehicle will experience a change in speed during impact equal to one-half the closing speed).

The distribution of calculated speed change during impact shown in Figure 11 was obtained by applying Equations [1] and [2] to the CPIR3

Figure 11

Cumulative Percentage Distributions
of CPIR3 Reported and Calculated Speeds
for All Levels of Injury and Fatality
in Two-Car Front-to-Front Collisions
with "Barrier" Type Vehicle Damage



Legend

A: CPIR3 REPORTED CLOSING SPEED -- The sum of the CPIR3 reported impact speeds for both vehicles in two-car front-to-front collisions (75 accidents, 75 reported closing speeds).

B: CPIR3 REPORTED IMPACT SPEED -- The CPIR3 reported vehicle speed (relative to ground) "at first impact" (75 accidents, 150 reported impact speeds).

C: CALCULATED SPEED CHANGE DURING IMPACT -- The change in vehicle speed during impact (utilizing the CPIR3 reported impact speeds and assuming inelastic collision with conservation of linear momentum) for each vehicle in two-car front-to-front collinear collisions (75 accidents, 150 calculated speed changes).

Source

Highway Safety Research Institute CPIR3 accident data file as of November, 1974. (Vehicle-to-vehicle head-on collision configuration for accidents involving only two cars in a single impact. All vehicles sustained distributed frontal damage.)

reported closing speeds and reported vehicle weights for the front-to-front "Barrier" type vehicle damage accidents. (Note that the reported closing speed scale represents 40 mph per division while the other scales represent 20 mph per division.) The interesting observation here is that the cumulative distributions of these interrelated measures of impact severity are essentially identical.

As a further reflection on the implications of Figure 11, consider calculating the energy absorbed (in structural deformation) by each of the vehicles in the front-to-front "Barrier" type damage accidents. Assuming a constant slope (K, force/length) structural "stiffness" (or force-deflection characteristic) for each vehicle, and perfect plastic deformation, it can be shown that the energy absorbed (E) by, for instance, Vehicle 1 is given by Equation [3].

$$E_1 = \frac{1}{2} \frac{W_1}{g} \Delta V_1{}^2 \frac{(1 + W_1/W_2)}{(1 + K_1/K_2)} \qquad [3]$$

(Where ΔV_1 is given by Equation [1] and "g" is the gravitational constant of acceleration.) For an energy "equivalent" frontal fixed barrier impact at a "barrier equivalent speed" of V_B, the barrier impact kinetic energy (E_B) dissipated in structural deformation (under the same assumption of perfect plastic deformation) would be equal to E_1 (Equations [3]) and would be given by Equation [4].

$$E_1 = E_{B1} = \frac{1}{2} \frac{W_1}{g} V_{B1}{}^2 \qquad [4]$$

For the case of Vehicle 1, combining Equations [3] and [4] results in Equation [5].

$$\frac{\Delta V_1}{V_{B1}} = \sqrt{\frac{(1 + K_1/K_2)}{(1 + W_1/W_2)}} \qquad [5]$$

That is, the ratio of the speed change during impact (for Vehicle 1) to the barrier equivalent speed is given by the expression on the right hand side of Equation [5]. For these two speeds to be equal, K_1/W_1 must be equal to K_2/W_2 -- a condition thought to be generally characteristic of most domestic passenger cars.

Hence, if the "stiffness to weight ratio" for each of the vehicles in the CPIR3 front-to-front "Barrier" type vehicle damage accidents was assumed to be essentially constant, then the (estimated) distribution of barrier equivalent speeds for those accidents would be the same as that for the calculated speed change during impact given in Figure 11. With this proviso, the cumulative distributions of impact speed, speed change during impact, barrier equivalent speed, and (one-half) closing speed would be virtually identical for this very special impact configuration.

Calculated Closing Speeds for Front-to-Front Collisions. In order to establish some measure of confidence in the accuracy and consistency of the CPIR3 accident data, the reported closing speed distribution for front-to-front "Barrier" type vehicle damage accidents was compared with an estimated closing speed distribution based upon the extent of vehicle damage. Since the CPIR3 in-depth data were collected by trained accident investigators at considerable expense, they would be expected to be at least accurate and consistent. The lack of representativeness caused by poor sampling techniques is unfortunate, but generally conceded.

For the front-to-front "Barrier" type vehicle damage accidents (essentially colinear), the assumptions of inelastic collision and conservation of linear momentum lead to a simple relationship between total energy absorbed (E_T) in structural deformation of both vehicles, closing speed ($V_{closing}$), and vehicle weights (W).

$$E_T = \frac{W_1 W_2}{2g(W_1 + W_2)} V^2_{closing} \qquad [6]$$

If the total absorbed energy (E_T) could be estimated from vehicle damage, then an estimate of the closing speed at impact could be calculated with Equation [6]. In particular, if a barrier equivalent speed (V_B) is estimated for each vehicle, then an estimated closing speed would be calculated from Equation [7].

$$V_{closing} = \sqrt{\frac{W_1 + W_2}{W_1 W_2} (W_1 V_{B1}{}^2 + W_2 V_{B2}{}^2)} \qquad [7]$$

To estimate an (energy) equivalent frontal fixed barrier impact speed for vehicles with distributed frontal damage, it is common practice to measure the residual vehicle crush and compare it with fixed barrier test data for similar vehicles. Regrettably, residual vehicle crush is re-reported only for "case" vehicles (and not "other" vehicles) in the CPIR3 data file. As an estimate of residual vehicle crush (for the "other" vehicle), the VDI damage extent -- which often is available for the "other" vehicle -- may be employed, but it is a highly variable measure of this collision parameter.

At the conclusion of this section a method of estimating frontal barrier impact speed as a function of VDI damage extent is presented for this very special "Barrier" type vehicle damage impact configuration. The estimation technique is based upon published frontal barrier impact test data and the relationship between residual vehicle crush and CPIR3 reported VDI damage extent for the "case" vehicles involved in this impact configuration (75 accidents). Figure 12 summarizes the analysis by defining a "least squares" estimator of barrier impact speed.

With the relationship shown in Figure 12, barrier equivalent speeds can be estimated from VDI damage extent, and estimated closing speeds can be calculated with Equation [7]. The results of applying this procedure to the 75 "Barrier" type vehicle damage accidents are displayed in Figure 13. Since the distributions of CPIR3 reported closing speed and calculated closing speed (based upon estimated vehicle damage) are substantially the same, some measure of credence can be assigned to the consistency within the data, if not their accuracy.

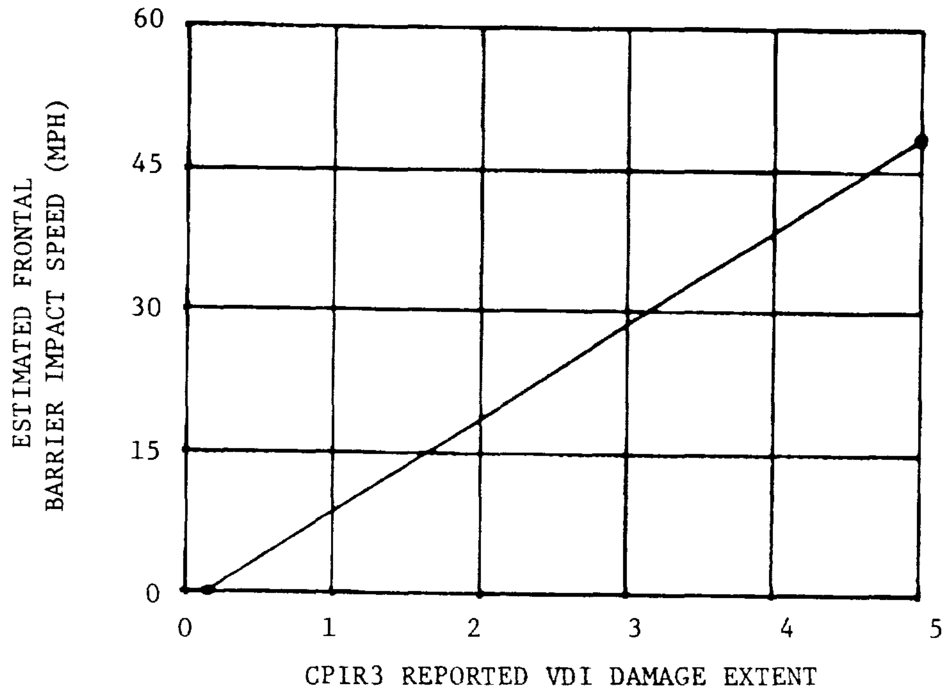
Therefore, in the absence of any evidence to the contrary, the CPIR3 reported impact speeds will be accepted as essentially accurate for all collision types and impact configurations.

The CPIR3 approximated closing speed distribution for the two-car front-to-front "Barrier" type vehicle damage impact configuration is compared in Figure 14 with two other well-known frontal collision speed distributions. Note that the CPIR3 and the NHTSA distributions are for all injury collisions, including those with fatalities, while the Ford ACIR distribution is for fatal accidents only.

A comparison of the CPIR3 front-to-front "Barrier" and "Non-Barrier" type impact configuration closing speed distributions with the NHTSA (injury) barrier equivalent speed distribution is shown in Figure 15. Because there are 400 accidents included in the "Non-Barrier" type impact configuration, versus only 75 accidents of the "Barrier" type, the overall distribution of CPIR3 closing speed for all accidents of the front-

Figure 12

Estimated Frontal Barrier Impact Speed
as a Function of CPIR3 Reported VDI Damage Extent
for All Levels of Injury and Fatality
in Two-Car Front-to-Front Collisions
with "Barrier" Type Vehicle Damage



Legend

[ESTIMATED FRONTAL BARRIER IMPACT SPEED (MPH)] = -1.55 + 10* [CPIR3 REPORTED VDI EXTENT]

"Least squares" estimate of energy equivalent frontal barrier impact speed for 75 CPIR3 two-car front-to-front collisions with "barrier" type vehicle damage.

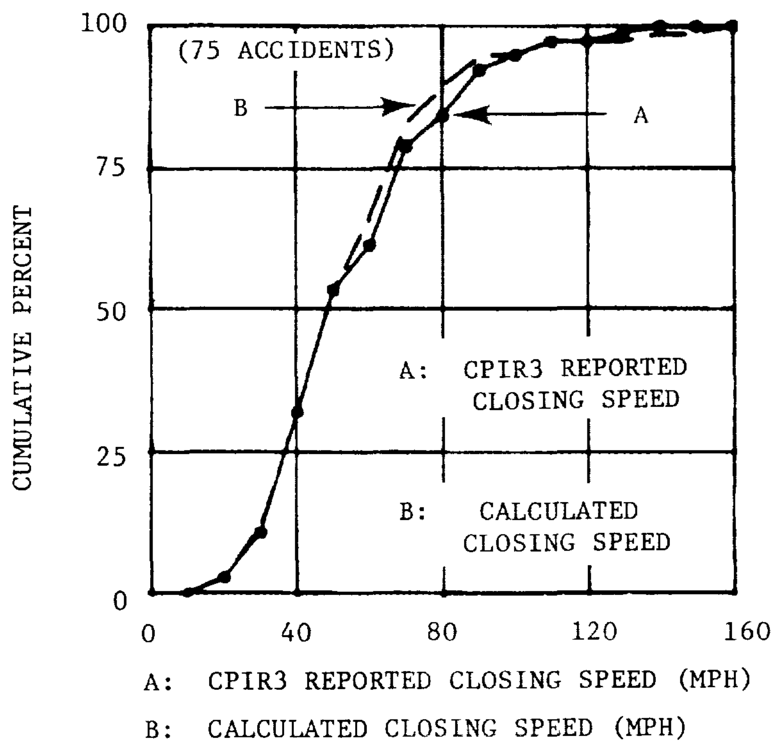
Source

Highway Safety Research Institute (CPIR3 accident data file as of November, 1974. (Vehicle-to-vehicle head-on collision configuration for accidents involving only two cars in a single impact. All vehicles sustained distributed frontal damage.)

K L. Campbell, "Energy Basis for Collision Severity," Proceedings, Third International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, New York, July, 1974.

Figure 13

Cumulative Percentage Distributions
of CPIR3 Reported and Calculated Closing Speeds
for All Levels of Injury and Fatality
in Two-Car Front-to-Front Collisions
with "Barrier" Type Vehicle Damage



Legend

A: CPIR3 REPORTED CLOSING SPEED -- The sum of the CPIR3 reported impact speeds for both vehicles in two-car front-to-front collisions (75 accidents, 75 reported closing speeds).

B: CALCULATED CLOSING SPEED -- The speed of one vehicle relative to the other at impact (utilizing the CPIR3 Vehicle Deformation Index to estimate crush energy dissipated, and assuming inelastic collision with conservation of linear momentum) in two-car front-to-front collinear collisions (75 accidents, 75 calculated closing speeds).

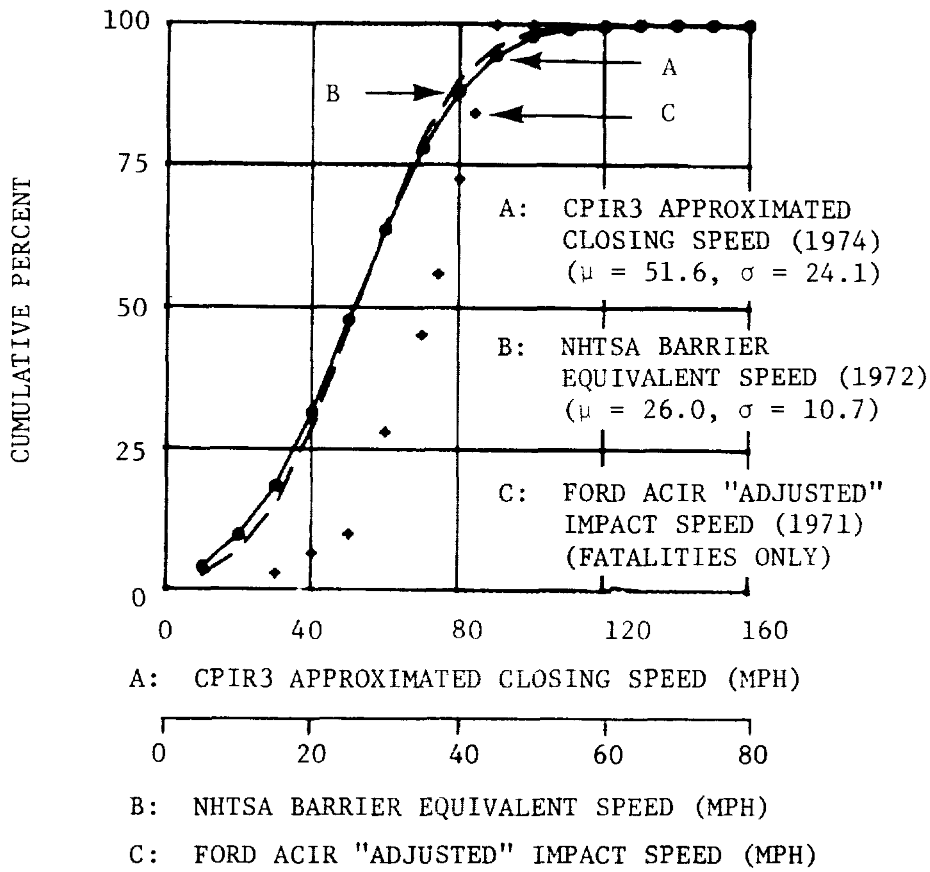
Source

Highway Safety Research Institute CPIR3 accident data file as of November, 1974. (Vehicle-to-vehicle head-on collision configuration for accidents involving only two cars in a single impact. All vehicles sustained distributed frontal damage.)

K. L. Campbell, "Energy Basis for Collision Severity," Proceedings, Third International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, New York, July, 1974.

Figure 14

Cumulative Percentage Distributions
of Passenger Car Frontal Collision Speeds
by Level of Injury and Source of Data



Legend

A: CPIR3 APPROXIMATED CLOSING SPEED -- All levels of injury and fatality in two-car front-to-front collisions with both vehicles sustaining distributed frontal damage. (75 accidents, 17 involving one or more fatalities.) Normal approximation: μ = mean = 51.6 MPH, σ = standard deviation = 24.1 MPH.

B: NHTSA BARRIER EQUIVALENT SPEED -- "Dynamically equivalent" frontal barrier impact speeds for injury producing passenger car frontal collisions involving one or more vehicles. Normal approximation: μ = mean = 26.0 MPH, σ = standard deviation = 10.7 MPH.

C: FORD ACIR "ADJUSTED" IMPACT SPEED -- "Accident location" adjusted and "center of gravity" adjusted barrier equivalent speeds (estimated from ACIR severity ratings) for ACIR single impact passenger car collisions involving at least one fatality in vehicles sustaining frontal damage (11, 12, and 1 o'clock impact force direction).

Source

A: Highway Safety Research Institute CPIR3 accident data file as of November, 1974. (Vehicle-to-vehicle head-on collision configuration for accidents involving only two cars in a single impact. All vehicles sustained distributed frontal damage.)

(Source: cont'd)

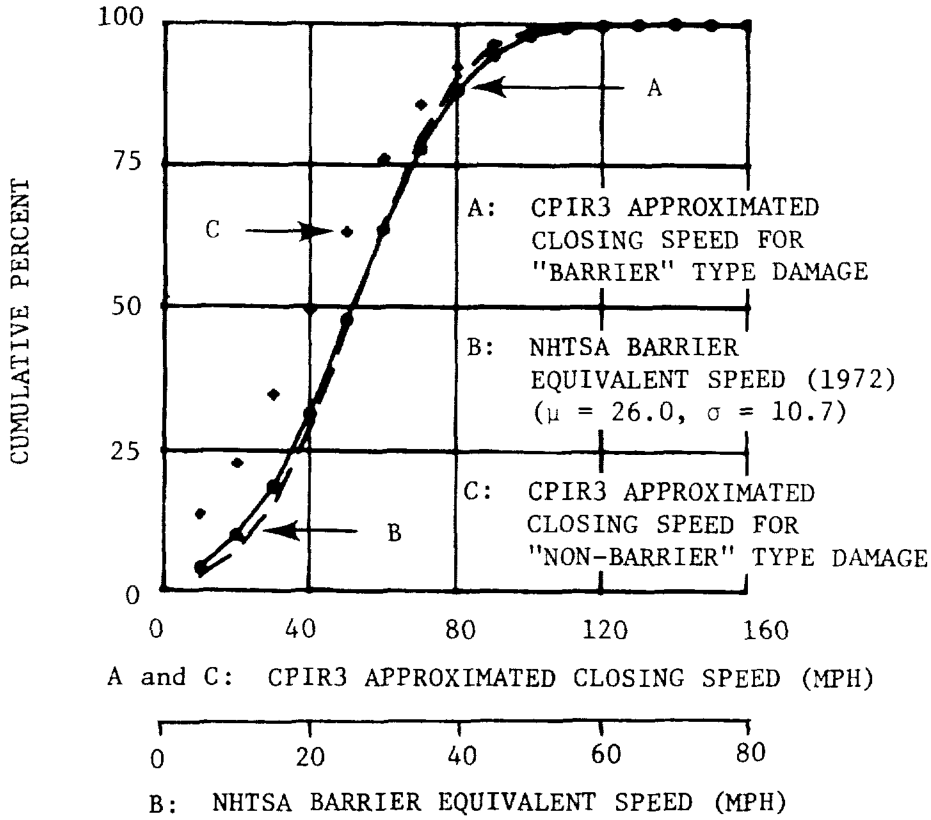
Figure 14 -- Source: (cont'd)

B: R. L. Carter, Passive Protectıon at 50 Miles Per Hour, Second International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, New York, (SAE 720445), May, 1972.

C: E. S. Grush, S. E. Henson, and O. R. Ritterling, Restraint System Effectiveness, Ford Automotive Safety Planning and Research Office, Federal Docket 69-7, Notice 9, ITem 119, September, 1971.

Figure 15

Cumulative Percentage Distributions
of Passenger Car Frontal Collision Speeds
by Type of Vehicle Damage and Source of Data



Legend

A: CPIR3 APPROXIMATED CLOSING SPEED FOR "BARRIER" TYPE VEHICLE DAMAGE -- All levels of injury and fatality in two-car front-to-front collisions with both vehicles sustaining distributed frontal damage. (75 accidents, 17 involving one or more fatalities.) Normal approximation: μ = mean = 51.6 MPH, σ = standard deviation = 24.1 MPH.

B: NHTSA BARRIER EQUIVALENT SPEED -- "Dynamically equivalent" frontal barrier impact speeds for injury producing passenger car frontal collisions involving one or more vehicles. Normal approximation: μ = mean = 26.0 MPH, σ = standard deviation = 10.7 MPH.

C: CPIR3 APPROXIMATED CLOSING SPEED FOR "NON-BARRIER" TYPE VEHICLE DAMAGE -- All levels of injury and fatality in two-car front-to-front collisions with both vehicles not sustaining distributed frontal damage. (400 accidents, 33 involving one or more fatalities.) Normal approximation: μ = mean = 40.7 MPH, σ = standard deviation = 27.6 MPH.

Source

A and C: Highway Safety Research Institute CPIR3 accident data file as of November, 1974. (Vehicle-to-vehicle head-on collision configuration for accidents involving only two cars in a single impact.)

B: R. L. Carter, Passive Protection at 50 Miles Per Hour, Second International Conference on Passive Restraints, Society of Automotive Engineers, Inc., New York, New York, (SAE 720445), May, 1972.

to-front collision type will be dominated by those of the "Non-Barrier" type and thus the overall distribution would be approximately the same as for the "Non-Barrier" impact configuration.

CPIR3 Reported Traveling Speeds for Front-to-Front Collisions. Figure 16 contrasts the CPIR3 reported impact speed and reported traveling speed distributions for two-car front-to-front collisions with "Barrier" type damage, and Figure 17 for "Non-Barrier" type vehicle damage. In both instances, the means of the traveling speed distributions appear to be about 10 miles per hour higher than the corresponding impact speed distributions.

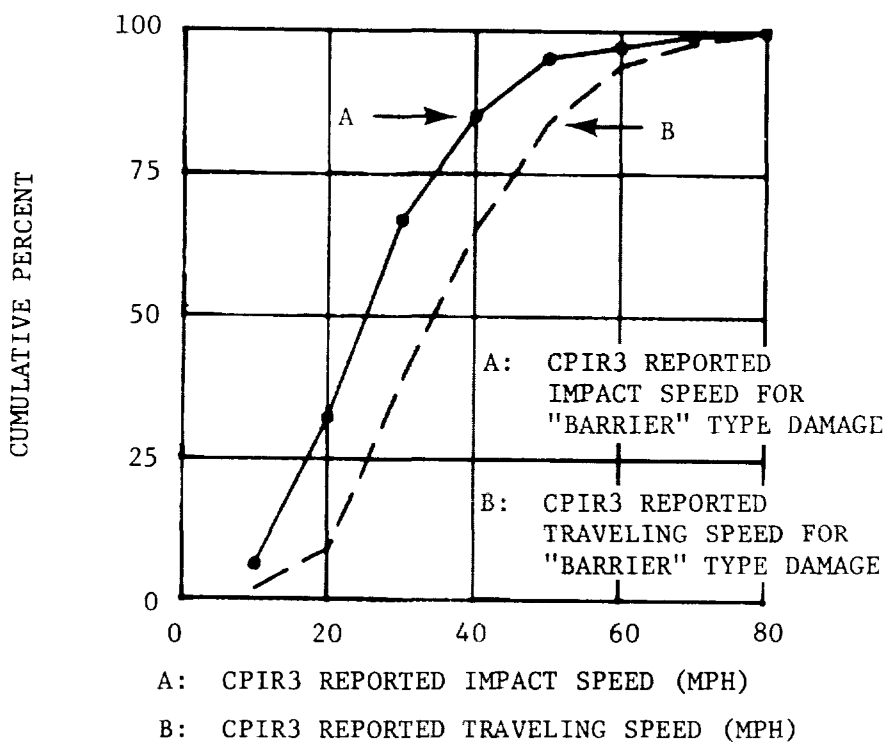
CPIR3 Reported Striking Speeds for Front-to-Side Collisions. Figure 18 exhibits the distributions of CPIR3 reported striking speed (and the means and standard deviations of their normal approximations) for two-car front-to-left side and Figure 19 for front-to-right side collision type, where the "direct" impact configuration has been defined to be primary damage in the area of the occupant compartment. The frequency of occurrence of impacts to the left and right sides are substantially the same, but the striking speeds appear to be slightly more severe for the left side.

CPIR3 Reported Closing Speeds for Front-to-Rear Collisions. The distributions of CPIR3 reported closing speed (and the means and standard deviations of their normal approximations) for two-car front-to-rear collision types are shown in Figure 20. As in the case of front-to-front collisions, "Barrier" type vehicle damage has been defined as distributed frontal or rear damage to both vehicles.

CPIR3 Reported Impact Speeds for Frontal Pole and Tree Collisions. Since "poles and trees" represent the largest single category of struck fixed objects within the CPIR3 data file (by a margin of more than two-to-one), this category was selected for detailed analysis as representative of the frontal fixed object collision type. Figure 21 defines the distributions of CPIR3 reported impact speed for this collision type in which the "direct" impact configuration has been defined to be distributed frontal or center frontal vehicle damage.

Figure 16

Cumulative Percentage Distributions
of CPIR3 Reported Speeds
for All Levels of Injury and Fatality
in Two-Car Front-to-Front Collisions
with "Barrier" Type Vehicle Damage



Legend

A: CPIR3 REPORTED IMPACT SPEED FOR "BARRIER" TYPE DAMAGE -- The CPIR3 reported vehicle speed (relative to ground) "at first impact" in two-car front-to-front collisions (75 accidents with both vehicles sustaining distributed frontal damage, 150 reported impact speeds).

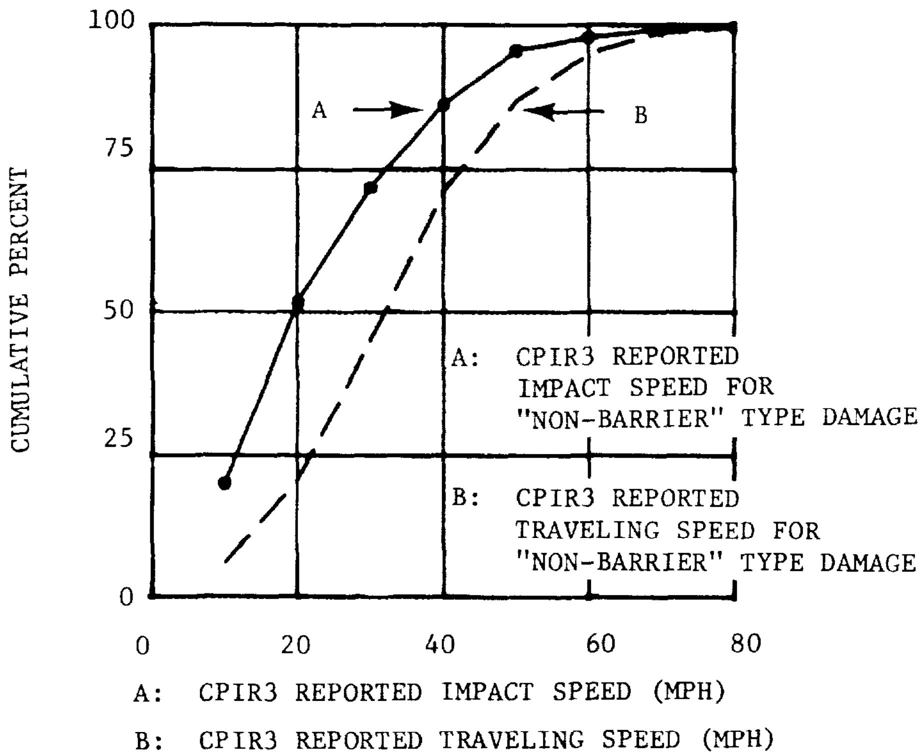
B: CPIR3 REPORTED TRAVELING SPEED FOR "BARRIER" TYPE DAMAGE -- The CPIR3 reported vehicle speed (relative to ground) "prior to impact" in two-car front-to-front collisions (75 accidents with both vehicles sustaining distributed frontal damage, 150 reported traveling speeds).

Source

Highway Safety Research Institute CPIR3 accident data file as of November, 1974. (Vehicle-to-vehicle head-on collision configuration for accidents involving two cars in a single impact. All vehicles sustained distributed frontal damage.)

Figure 17

Cumulative Percentage Distributions
of CPIR3 Reported Speeds
for All Levels of Injury and Fatality
in Two-Car Front-to-Front Collisions
with "Non-Barrier" Type Vehicle Damage



Legend

A: CPIR3 REPORTED IMPACT SPEED FOR "NON-BARRIER" TYPE DAMAGE -- The CPIR3 reported vehicle speed (relative to ground) "at first impact" in two-car front-to-front collisions (400 accidents with both vehicles not sustaining distributed frontal damage, 800 reported impact speeds).

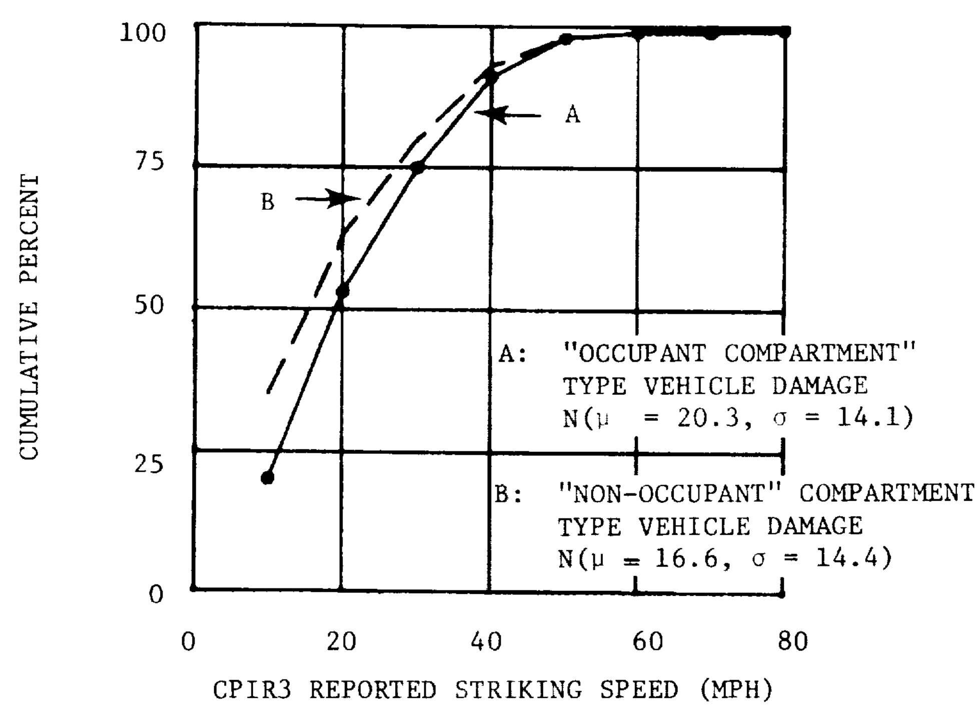
B: CPIR3 REPORTED TRAVELING SPEED FOR "NON-BARRIER TYPE DAMAGE -- The CPIR3 reported vehicle speed (relative to ground) "prior to impact" in two-car front-to-front collisions (400 accidents with both vehicles not sustaining distributed frontal damage, 800 reported traveling speeds).

Source

Highway Safety Research Institute CPIR3 accident data file as of November, 1974. (Vehicle-to-vehicle head-on collision configuration for accidents involving only two cars in a single impact. Both vehicles did not sustain distributed frontal damage.)

Figure 18

Cumulative Percentage Distributions
of CPIR3 Reported Striking Speeds
for All Levels of Injury and Fatality
in Two-Car Front-to-Left Side Collisions
by Type of Vehicle Damage



Legend

CPIR3 REPORTED STRIKING SPEED -- The CPIR3 reported vehicle speed (relative to ground) "at first impact" for the striking vehicle in two-car front-to-left side collisions.

A: "OCCUPANT COMPARTMENT" TYPE VEHICLE DAMAGE -- The struck vehicle sustained primary damage in the left side occupant compartment area (160 accidents). Normal approximation: μ = mean = 20.3 MPH, σ = standard deviation =14.1 MPH.

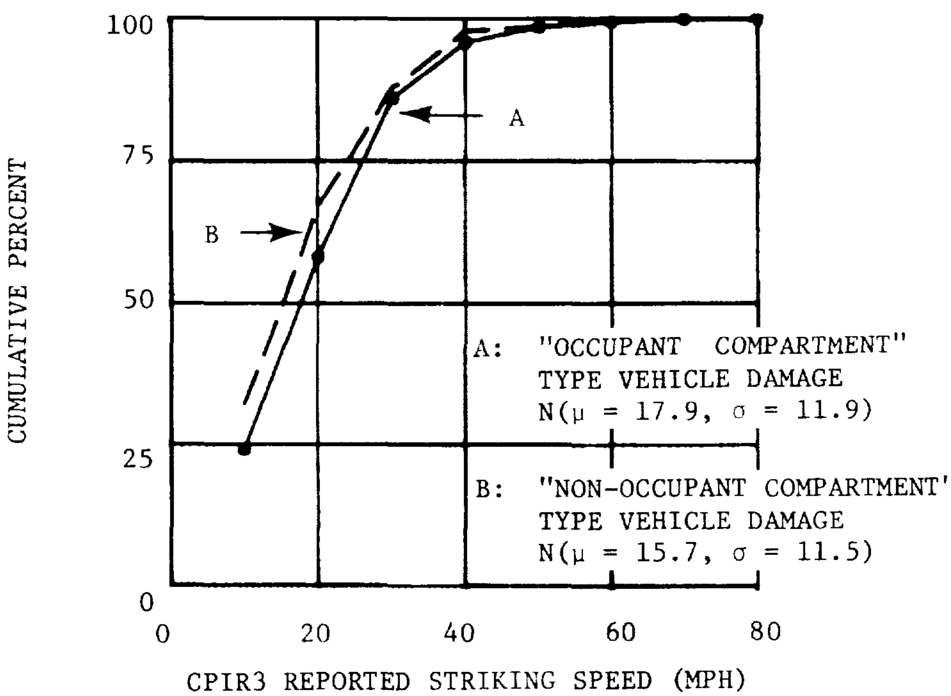
B: "NON-OCCUPANT COMPARTMENT" TYPE VEHICLE DAMAGE -- The struck vehicle sustained primary damage in the left side but not in the occupant compartment area (157 accidents). Normal approximation: μ = mean = 16.6 MPH, σ = standard deviation = 14.4 MPH.

Source

Highway Safety Research Institute CPIR3 accident data file as of September, 1974. (Vehicle-to-vehicle intersection types T and L collision configuration for accidents involving only two cars in a single impact.)

Figure 19

Cumulative Percentage Distributions
of CPIR3 Reported Striking Speeds
for All Levels of Injury and Fatality
in Two-Car Front-to-Right Side Collisions
by Type of Vehicle Damage



Legend

CPIR3 REPORTED STRIKING SPEED -- The CPIR3 reported vehicle speed (relative to ground) "at first impact" for the striking vehicle in two-car front-to-right side collisions.

A: "OCCUPANT COMPARTMENT" TYPE VEHICLE DAMAGE -- The struck vehicle sustained primary damage in the right side occupant compartment area (201 accidents). Normal approximation: μ = mean 17.9 MPH, σ = standard deviation = 11.9 MPH.

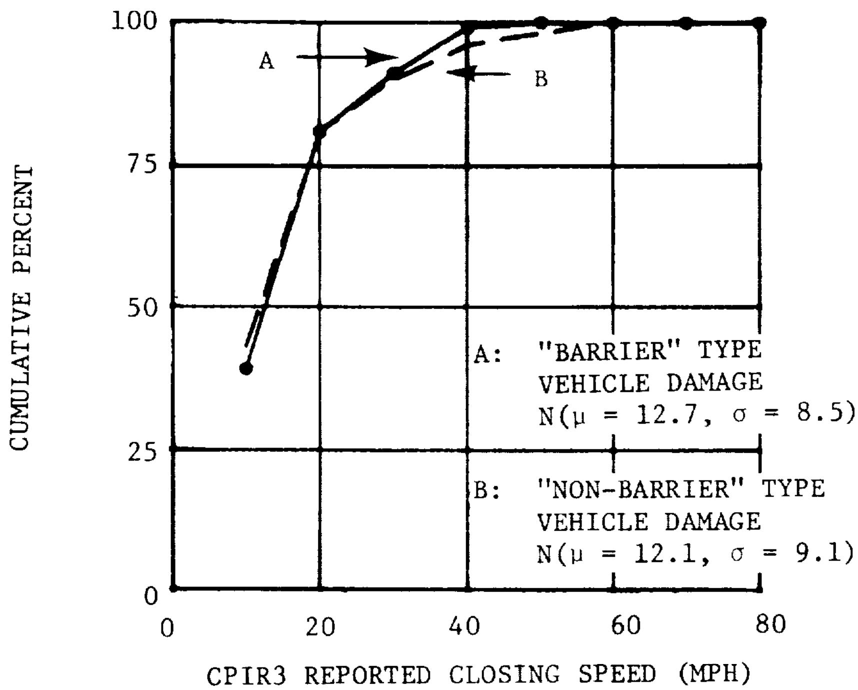
B: "NON-OCCUPANT COMPARTMENT" TYPE VEHICLE DAMAGE -- The struck vehicle sustained primary damage in the right side but not in the occupant compartment area (142 accidents). Normal approximation: μ = mean = 15.7 MPH, σ = standard deviation = 11.5 MPH.

Source

Highway Safety Research Institute CPIR3 accident data file as of September, 1974. (Vehicle-to-vehicle intersection types T and L collision configuration for accidents involving only two cars in a single impact.)

Figure 20

Cumulative Percentage Distributions
of CPIR3 Reported Closing Speeds
for All Levels of Injury and Fatality
in Two-Car Front-to-Rear Collisions
by Type of Vehicle Damage



Legend

CPIR3 REPORTED CLOSING SPEED -- The sum of the CPIR3 reported impact speeds (vehicle speeds, relative to ground, " at first impact") for both vehicles in two-car front-to-rear collisions.

A: "BARRIER" TYPE VEHICLE DAMAGE -- Both vehicles sustained distributed (frontal or rear) damage (64 accidents). Normal approximation: μ = mean = 12.7 MPH, σ = standard deviation = 8.5 MPH.

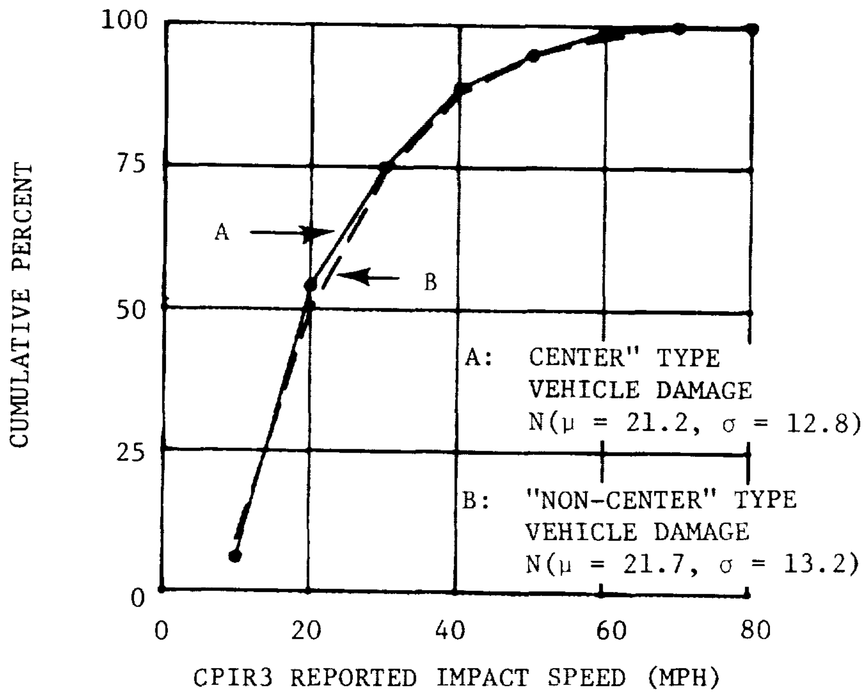
B: "NON-BARRIER" TYPE VEHICLE DAMAGE -- Both vehicles did not sustain distributed (frontal or rear) damage (292 accidents). Normal approximation: μ = mean = 12.1 MPH, σ = standard deviation = 9.1 MPH.

Source

Highway Safety Research Institute CPIR3 accident data file as of September, 1974. (Vehicle-to-vehicle rear-impact collision configuration for accidents involving only two cars in a single impact.)

Figure 21

Cumulative Percentage Distributions
of CPIR3 Reported Impact Speeds
for All Levels of Injury and Fatality
in One-Car Frontal Pole and Tree Collisions
by Type of Vehicle Damage



Legend

CPIR3 REPORTED IMPACT SPEED -- The CPIR3 reported vehicle speed (relative to ground) "at first impact" in one-car frontal pole and tree collisions.

A: "CENTER" TYPE VEHICLE DAMAGE -- The vehicle sustained distributed or center frontal damage (65 accidents). Normal approximation: μ = mean = 21.2 MPH, σ = standard deviation = 12.8 MPH.

B: "NON-CENTER" TYPE VEHICLE DAMAGE -- The vehicle did not sustain distributed or center frontal damage (188 accidents). Normal approximation: μ = mean = 21.7 MPH, σ = standard deviation = 13.2 MPH.

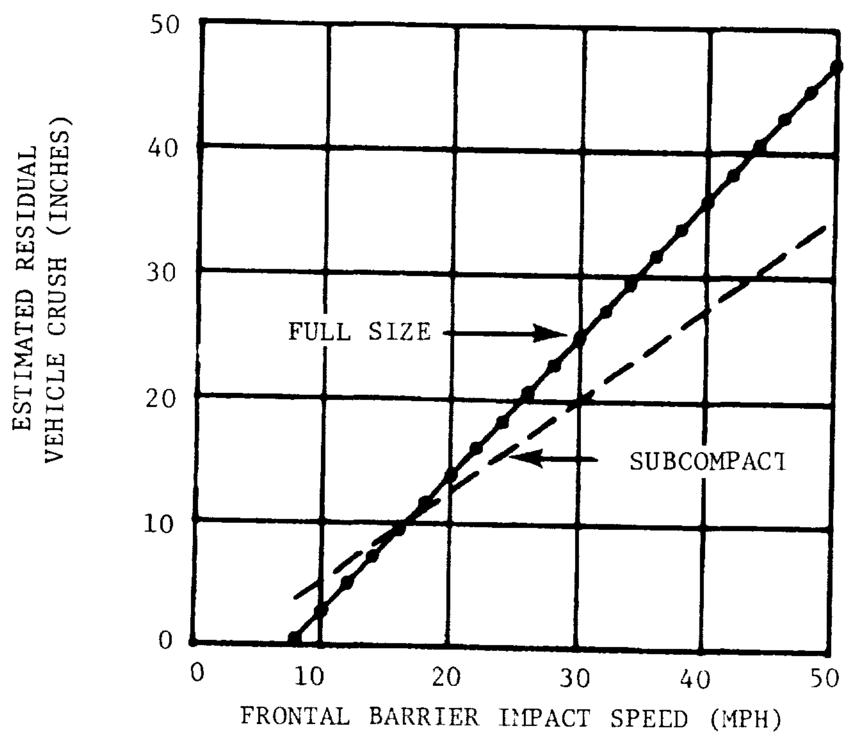
Source

Highway Safety Research Institute CPIR3 data file as of September, 1974. (Vehicle-to-object collision configuration for accidents involving only one car in a single impact.)

Estimated Frontal Barrier Impact Speed/VDI Damage Extent. The comparison shown in Figure 12 between calculated closing speeds and CPIR3 reported closing speeds (for front-to-front collisions with "Barrier" type vehicle damage) was performed by estimating an (energy) equivalent frontal fixed barrier impact speed from each vehicle's CPIR3 reported VDI damage extent. This estimation technique, applied to frontal barrier impact test data reported by K. L. Campbell of General Motors, produced the results displayed in Figure 22 for full size and subcompact vehicles. It is assumed that these data are representative of all passenger cars within the current traffic environment.

Figure 22

Estimated Residual Vehicle Crush
as a Function of Frontal Barrier Impact Speed
by Type of Vehicle (1973-1974)

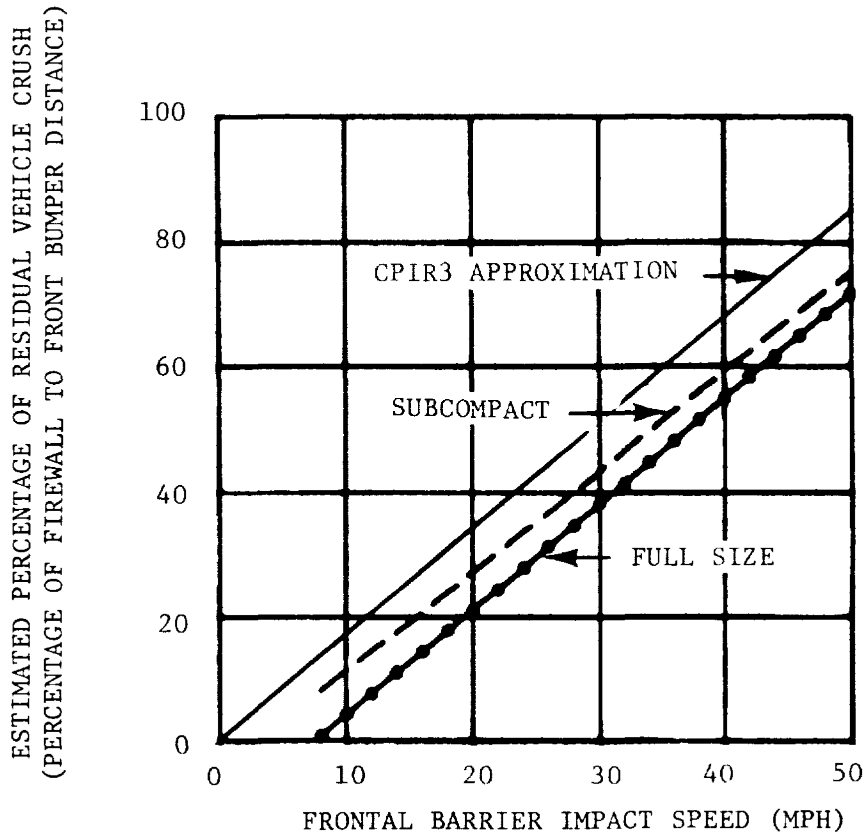


Source of Data for Figure:
K. L. Campbell, "Energy Basis for Collision Severity," Proceedings, Third International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, New York, July 1974.

By converting residual vehicle crush in inches to its equivalent percentage of firewall to front bumper distance, Figure 22 is easily transformed into Figure 23. That is, both subcompact and full size vehicles have estimated percentages of residual vehicle crush which are proportional to their barrier impact speeds in excess of their respective maximum "no residual crush" impact speeds. Since the proportionality constants (the slopes of the residual crush characteristics in Figure 23) are substantially the same for both subcompact and full size vehicles (approximately 1.68 percent/mph), and since the "no residual crush" impact speeds of the majority of the vehicles in the CPIR3 data file (not equipped with energy absorbing bumpers) are essentially zero, the residual crush (as a percentage of firewall to front bumper distance) for all vehicles in the CPIR3 data file will be approximated by 1.68 times their frontal barrier impact speed (in mph) as shown by the approximating characteristics in Figure 23.

Figure 23

Estimated Percentage of Residual Vehicle Crush as a Function of Frontal Barrier Impact Speed by Type of Vehicle (1973-1974)



CPIR3 APPROXIMATION:

Assuming the majority of CPIR3 vehicles are not equipped with "energy absorbing" bumpers.

$$\begin{bmatrix} \text{PERCENTAGE RESIDUAL} \\ \text{VEHICLE CRUSH} \end{bmatrix} \cong 1.68 * \begin{bmatrix} \text{FRONTAL BARRIER} \\ \text{IMPACT SPEED} \end{bmatrix}$$

Source of Data for Figure:

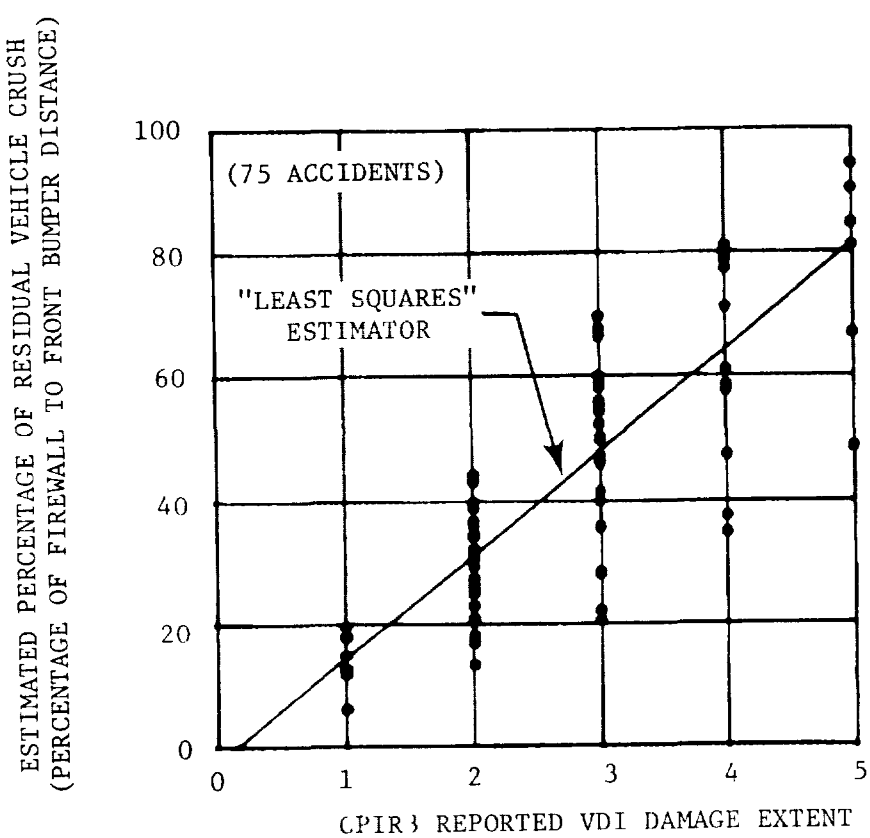
K. L. Campbell, "Energy Basis for Collision Severity," Proceedings, Third International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, New York, July, 1974.

Passenger Car and Truck Accident Investigators Manual, Motor Vehicle Manufacturers Association, Inc., Detroit, Michigan, published annually.

Figure 24 displays CPIR3 reported residual vehicle crush, and its "least squares" estimator, as a function of CPIR3 reported VDI damage extent for the 75 "case" vehicles involved in two-car front-to-front collisions with "Barrier" type damage (residual vehicle crush is not reported for the "other" vehicle).

Figure 24

Estimated Percentage of Residual Vehicle Crush as a Function of CPIR3 Reported VDI Damage Extent for All Levels of Injury and Fatality in Two-Car Front-to-Front Collisions with "Barrier" Type Vehicle Damage



Source of Data for Figure:

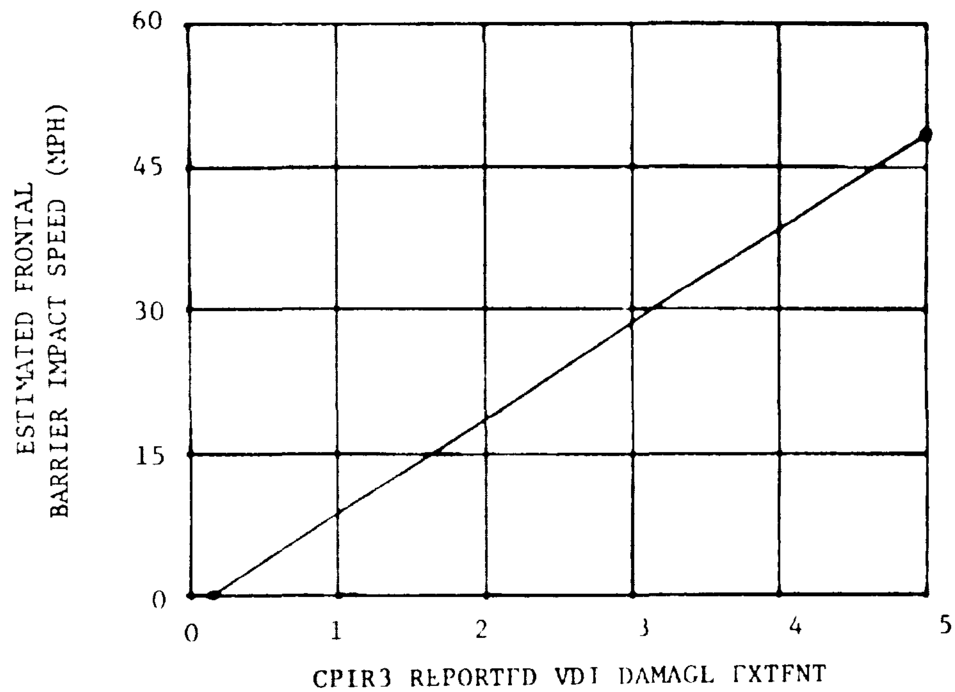
Highway Safety Research Institute CPIR3 accident data file as of November, 1974. (Vehicle-to-vehicle head-on collision configuration for accidents involving only two cars in a single impact. All vehicles sustained distributed frontal damage.)

Passenger Car and Truck Accident Investigators Manual, Motor Vehicle Manufacturers Association, Inc., Detroit, Michigan, published annually.

Combining the approximation of Figure 23 with the "least squares" estimator of Figure 24 results in Figure 25 (identical to Figure 12) -- a "least squares" estimate of the energy equivalent frontal barrier impact speed for 75 CPIR3 two-car front-to-front collisions with "Barrier" type vehicle damage. The estimation technique defined by Figure 25 was employed in establishing Figure 13.

Figure 25

Estimated Frontal Barrier Impact Speed as a Function of CPIR3 Reported VDI Damage Extent for All Levels of Injury and Fatality in Two-Car Front-to-Front Collisions with "Barrier" Type Vehicle Damage



Legend: [ESTIMATED FRONTAL BARRIER IMPACT SPEED (MPH)] = -1.55 + 10* [CPIR3 REPORTED VDI EXTENT]

"Least squares" estimate of energy equivalent frontal barrier impact speed for CPIR3 two-car front-to-front collisions with "barrier" type vehicle damage.

Source of Data for Figure:

Highway Safety Research Institute (CPIR3 accident data file as of November 1974. (Vehicle-to-vehicle head-on collision configuration for accidents involving only two cars in a single impact All vehicles sustained distributed frontal damage.)

K. L. Campbell, "Energy Basis for Collision Severity," Proceedings, Third International Conference on Occupant Protection, Society of Automotive Engineers, Inc., New York, New York, July 1974.

3.2.1.3 Exposure Projections

It is assumed that the accident environment for the RSV in 1985 is defined by the number of towaway accidents of each collision type, the severity or speed distributions for these accidents, and the weight distribution of the vehicles involved. The projections of the number of accidents, collision type, and collision speeds were made from current data with the realization of the limitations of that data. Modifications which were made to this projected exposure as a function of system model validation are described in Volume III.

Collision Type. An analysis of the National Accident Summary (25) served as the source for the distribution of towaway accidents by collision type. No changes in automobile design or usage, roadway design, traffic regulations, etc., that would affect this distribution are foreseen. It is, therefore, assumed that the 1985 distribution will be the same. (Figure 20)

Collision Speeds. Average collision speeds are approximately ten miles per hour less than average traveling speeds. The projection of traveling speeds to 1985 presents a mixed picture. Speeds on interstate and rural secondary highways are expected to increase somewhat, while speeds on urban highways will continue to decrease. Because of these uncertain trends in traveling speeds, the collision speed distributions summarized in Table 23 are projected as the 1985 collision speed distributions and will be used as such in the RSV System Model.

Vehicle Weight Distribution. The projected 1986 percentage distribution of passenger car weights by weight class, as described in Section 3.1.2.3 of this report are shown in Figure 27. Within the RSV System Model, the simulation of vehicle-to-vehicle collisions will be performed over the entire spectrum of accident severity as defined in this distribution of passenger car weights and by the projected mid-1980 distributions of relative speed at impact.

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(25) Carroll, Op. Cit.

Figure 26

Projected 1985 Percentage Distribution
of Towaway Accidents by Collision Type

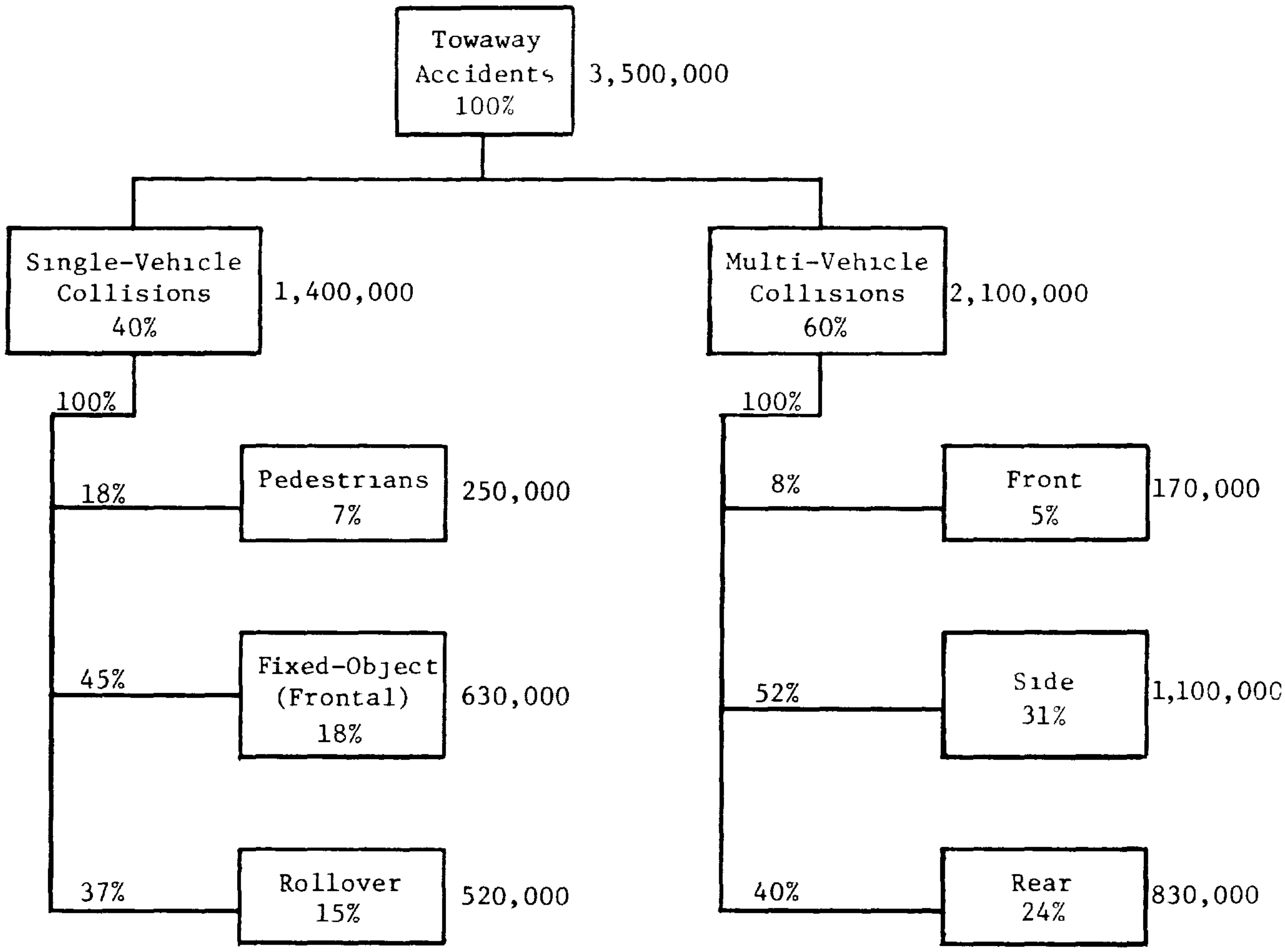


Table 23

CPIR3 Approximated Collision Speeds
for All Levels of Injury and Fatality
In Single-Impact Two-Car Vehicle-to-Vehicle
and One-Car Frontal Fixed Object Collisions
by Collision Type and Type of Damage

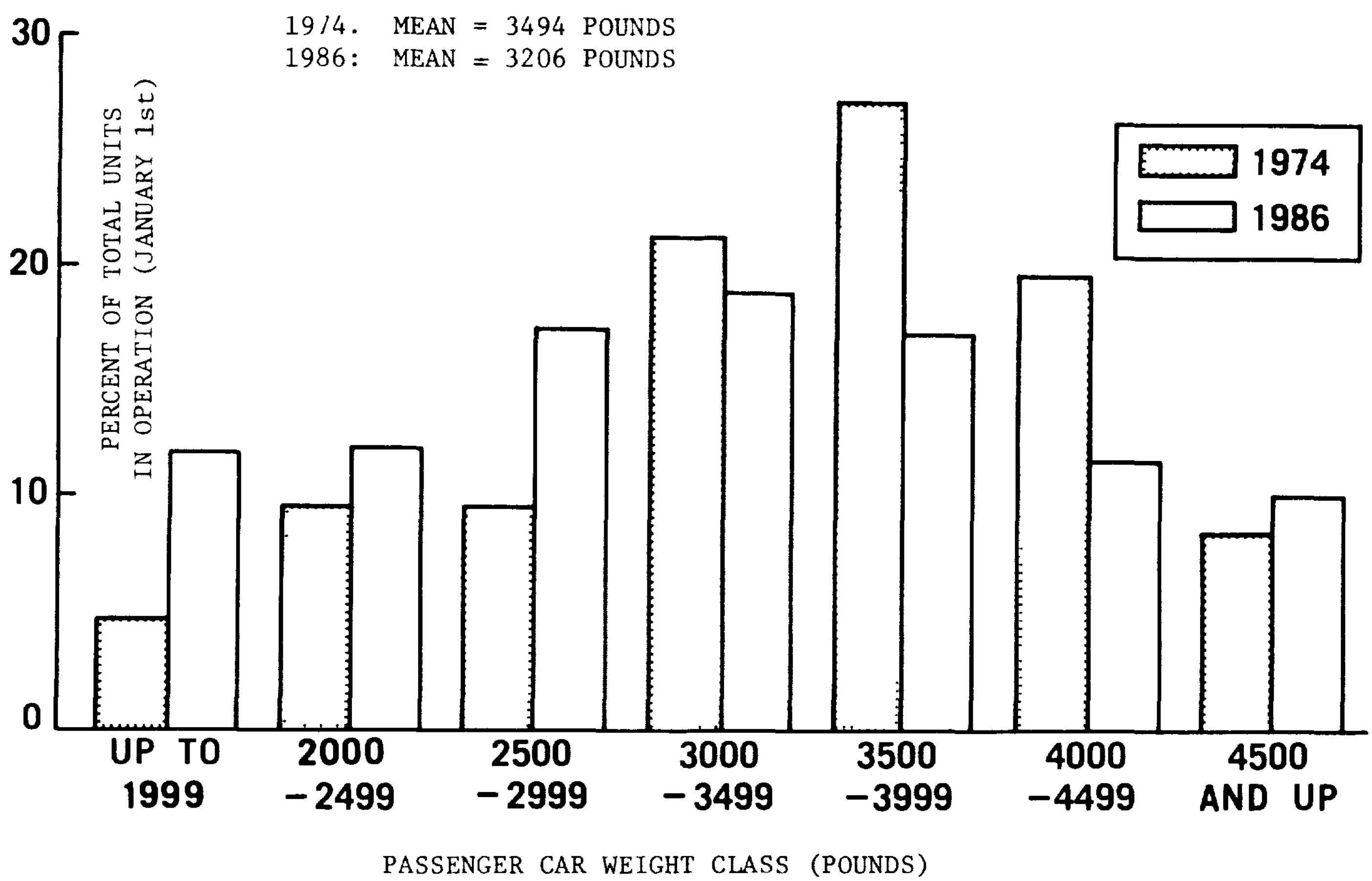
COLLISION TYPE	IMPACT CONFIGURATION	
	"DIRECT" IMPACTS	"INDIRECT" IMPACTS
FRONT-TO-FRONT	CLOSING SPEED *μ = 51.6, σ = 24.1, n = 75 "BARRIER" TYPE DAMAGE	CLOSING SPEED μ = 40.7, σ = 27.6, n = 400 "NON-BARRIER" TYPE DAMAGE
FRONT-TO-SIDE	STRIKING SPEED LEFT SIDE μ = 20.3, σ = 14.1, n = 160 RIGHT SIDE μ = 17.9, σ = 11.9, n = 201 "OCCUPANT COMPARTMENT" DAMAGE	STRIKING SPEED LEFT SIDE μ = 16.6, σ = 14.4, n = 157 RIGHT SIDE μ = 15.7, σ = 11.5, n = 142 "NON-OCCUPANT COMPARTMENT" DAMAGE
FRONT-TO-REAR	CLOSING SPEED μ = 12.7, σ = 8.5, n = 64 "BARRIER" DAMAGE	CLOSING SPEED μ = 12.1, σ = 9.1, n = 292 "NON-BARRIER" DAMAGE
FRONTAL FIXED OBJECT (POLES AND TREES)	IMPACT SPEED μ = 21.2, σ = 12.8, n = 65 "CENTER" DAMAGE	IMPACT SPEED μ = 21.7, σ = 13.2, n = 188 "NON-CENTER" DAMAGE

μ = mean value in Miles Per Hour (MPH)
σ = standard deviation (MPH)
n = number of accidents

Source
Highway Safety Research Institute CPIR3 accident data file, September-November, 1974. (Single impact accidents involving only two cars in vehicle-to-vehicle collisions and only one car in frontal fixed object collisions.)

Figure 27

Projected 1986 Percentage Distribution
of Passenger Car Weights by Weight Class



Source
Research Safety Vehicle, Program Definition, Ford Motor Company, Dearborn, Michigan, DOT-HS-4-00842, September 18, 1974.

3.2.2 Vehicle Occupants

This section discusses driver age and sex, seating position occupancy, and occupant size.

The distribution of accidents by collision type and vehicle occupant size is, in part, a function of the expected driver profile.

Occupant size and seating position frequency are used in the evaluation of occupant protection countermeasures for 1985.

3.2.2.1 Driver Age and Sex

Past studies have shown a strong correlation between the age and sex of drivers and certain types of accidents (26, 27). Therefore, any significant shift in the driver profile which can be anticipated for 1985 must be considered.

As the population increases, the number of drivers increases. However, the distributions by age and sex remain essentially unaffected between 1972 and 1985 and, therefore, do not affect the accident environment distributions.

The remainder of this section is a description of the analysis conducted which supports this conclusion.

Source Data. Two groups are selected to categorize the age of drivers. The breakpoint between younger drivers and older drivers -- 25 years -- is chosen because many studies have used these categories to distinguish "high-risk" and "low-risk" groups. In addition, insurance companies consider these age groups in their rate structures. Above 25 years of age, the probability of having an accident drops sharply. The high percentage of younger drivers involved in accidents is illustrated as follows (28):

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(26) B. J. Campbell, Driver Age and Sex Related to Accident Time and Type, Automotive Crash Injury Research, Cornell Aeronautical Laboratory, Inc., CAL Report No. VJ-1823-R-10, October 1964.

(27) E. A. Narragon, Sex Comparisons in Automobile Crash Injury, Automotive Crash Injury Research, Cornell Aeronautical Laboratory, Inc., CAL Report No. VJ-1823-R-15, February 1965.

(28) Accident Facts, National Safety Council, Chicago, Illinois, published annually.

Age Group	Percent of Drivers Within Each Age Group Involved in Accidents
Under 20	43
20 - 24	41
25 - 29	28
30 - 34	24
Over 35	10

Marital status is not considered in this study because of the lack of information.

Table 24 shows the potential driving population while Table 25 shows the number of licensed drivers by age group and sex. The potential driving population refers to everyone who has reached the age of 16, since this is the age in most states at which a person is first allowed to drive.

Table 26 shows the percent of persons by sex in each age group holding drivers' licenses. The data show that an increasing proportion of females have held drivers' licenses in recent years, while the male proportion has remained relatively stable.

Table 27 through 30 show population and licensed driver composition on a percentage basis. Table 29 and Table 30 show the percent by sex in each age group of the potential driving population and the licensed drivers, respectively.

Figures 28 through 32 are obtained by plotting the data for the years given in the tables. Figure 28 shows the population growth through the year 1990. Note that as the population grows, the younger population peaks around 1980 and then starts to decline through 1990. The older population turns up sharply after 1975 and continues to grow through 1990.

Results. Figure 29 shows the percent of persons of a given age group and sex holding drivers' licenses. Data shown in Table 26 for the years 1965 through 1972 were plotted and then extrapolated to 1985, based on the following assumptions: that the percent of male drivers, both younger and older would remain relatively constant, and that the greatest increase in the percent of the population of drivers holding licenses would be due to females, both younger and older. Eighty percent for younger females and 77 percent for older females were projected for 1985, based on the current rate of increase in licensing among females. The other percentages were then derived from the above percentages.

Figures 30 and 31 were plotted from the data of Tables 24 and 25. These two figures each compare the number of licensed drivers to the population of a given age group and sex. Projections to 1985 for licensed drivers are based on the percentages obtained from Figure 29.

Table 24

Potential Driving Population by Age Group and Sex (29)
(Millions)

Age Group	Sex	Year 1950	1960	1970	1972	1975	1980	1990
Younger 16 thru 24	Males	10.1	11.0	16.5	17.4	18.3	18.9	16.3
	Females	10.1	10.9	16.1	16.9	17.8	18.4	15.8
	TOTAL	20.2	21.9	32.6	34.3	36.1	37.3	32.1
Older 25 and Over	Males	43.8	48.4	52.3	53.7	56.3	61.3	71.8
	Females	45.1	51.6	58.2	60.1	63.1	68.6	79.6
	TOTAL	88.9	100.0	110.5	113.8	119.4	129.9	151.4
All 16 and Over	Males	53.9	59.4	68.8	71.1	74.6	80.2	88.1
	Females	55.2	62.5	74.3	77.0	80.9	87.0	95.4
	TOTAL	109.1	121.9	143.1	148.1	155.5	167.2	183.5

(29) Statistical Abstract of the United States, (94th Edition), U.S. Bureau of the Census, Washington, D.C., 1973.

Table 25

Number of Licensed Drivers by Age Group and Sex (30)
(Millions)

Age Group	Sex	1965	1966	1967	1968	1969	1970	1972
Younger 16 thru 24	Males	11.5	12.1	12.4	12.7	13.1	13.7	14.4
	Females	8.5	9.0	9.2	9.5	10.2	10.9	11.8
	TOTAL	20.0	21.1	21.6	22.2	23.3	24.6	26.2
Older 25 and Over	Males	46.8	47.4	48.0	48.5	49.2	49.6	51.6
	Females	31.7	32.5	33.6	34.7	35.8	37.3	40.5
	TOTAL	78.5	79.9	81.6	83.2	85.0	86.9	92.1
All 16 and Over	Males	58.3	59.5	60.4	61.2	62.3	63.3	66.0
	Females	40.2	41.5	42.8	44.2	46.0	48.2	52.4
	TOTAL	98.5	101.0	103.2	105.4	108.3	111.5	118.4

Table 26

Percent of Persons in Each Age Group and Sex
Holding Drivers' Licenses (31, 32)

Age Group	Sex	1965	1966	1967	1968	1969	1970	1972
Younger 16 thru 24	Males	83.6	84.6	83.5	82.5	82.1	83.0	82.8
	Females	63.0	64.2	63.3	63.1	65.5	67.7	69.8
	TOTAL	73.4	74.5	73.5	72.9	73.9	75.5	76.4
Older 25 and Over	Males	92.9	93.4	93.9	94.1	94.8	94.8	96.1
	Females	57.7	58.5	59.8	61.0	62.2	64.1	67.4
	TOTAL	74.6	75.2	76.0	76.8	77.7	78.6	80.9
All 16 and Over	Males	91.0	91.5	91.5	91.5	91.8	92.0	92.8
	Females	58.8	59.6	60.5	61.4	62.9	64.9	68.1
	TOTAL	74.3	75.0	75.5	75.9	76.8	77.9	79.9

(30) Automobile Facts and Figures, (1967 through 1973/74 Editions), Motor Vehicle Manufacturers Association, Detroit, Michigan, Published Periodically.

(31) U.S. Bureau of Census, Op. Cit.

(32) MVMA, Ibid.

Table 27

Percent of Population by Sex in Each Age Group

Age Group	Sex	1950	1960	1970	1972	1975	1980	1990
Younger 16 thru 24	Males	50.0	50.2	50.6	50.7	50.7	50.7	50.8
	Females	50.0	49.8	49.4	49.3	49.3	49.3	49.2
	TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Older 25 and Over	Males	49.3	48.4	47.3	47.2	47.2	47.2	47.4
	Females	50.7	51.6	52.7	52.8	52.8	52.8	52.6
	TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0
All 16 and Over	Males	49.4	48.7	48.1	48.0	48.0	48.0	48.0
	Females	50.6	51.3	51.9	52.0	52.0	52.0	52.0
	TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 28

Percent of Licensed Drivers by Sex in Each Age Group (33)

Age Group	Sex	1965	1966	1967	1968	1969	1970	1972
Younger 16 thru 24	Males	57.5	57.3	57.4	57.2	56.2	55.7	55.0
	Females	42.5	42.7	42.6	42.8	43.8	44.3	45.0
	TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Older 25 and Over	Males	59.6	59.3	58.8	58.3	57.9	57.1	56.0
	Females	40.4	40.7	41.2	41.7	42.1	42.9	44.0
	TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0
All 16 and Over	Males	59.2	58.9	58.5	58.1	57.5	56.8	55.7
	Females	40.8	41.1	41.5	41.9	42.5	43.2	44.3
	TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0

(33) MVMA, Op. Cit.

Table 29

Percent of Population by Each Group and Sex (34)

Age Group	Sex	1950	1960	1970	1972	1975	1980	1990
Younger 16 thru 24	Males	9.3	9.0	11.5	11.7	11.8	11.3	8.9
	Females	9.3	8.9	11.3	11.4	11.4	11.0	8.6
	TOTAL	18.5	18.0	22.8	23.2	23.2	22.3	17.5
Older 25 and Over	Males	40.1	39.7	36.5	36.3	36.2	36.7	39.1
	Females	41.3	42.3	40.7	40.6	40.6	41.0	43.4
	TOTAL	81.5	82.0	77.2	76.8	76.8	77.7	82.5
All 16 and Over	Males	49.4	48.7	48.1	48.0	48.0	48.0	48.0
	Females	50.6	51.3	51.9	52.0	52.0	52.0	52.0
	TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 30

Percent of Licensed Drivers by Age Group and Sex (35)

Age Group	Sex	1965	1966	1967	1968	1969	1970	1972
Younger 16 thru 24	Males	11.7	12.0	12.0	12.0	12.1	12.3	12.2
	Females	8.6	8.9	8.9	9.1	9.4	9.8	9.9
	TOTAL	20.3	20.9	20.9	21.1	21.5	22.1	22.1
Older 25 and Over	Males	47.5	46.9	46.5	46.0	45.4	44.5	43.6
	Females	32.2	32.2	32.6	32.9	33.1	33.5	34.2
	TOTAL	79.7	79.1	79.1	78.0	78.5	77.9	77.9
All 16 and Over	Males	59.2	58.9	58.5	58.1	57.5	56.8	55.7
	Females	40.8	41.1	41.5	41.9	42.5	43.2	44.3
	TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0

(34) U.S. Bureau of Census, Op. Cit.

(35) MVMA, Op. Cit.

Figure 28

Potential Driving Population by Age Group and Sex

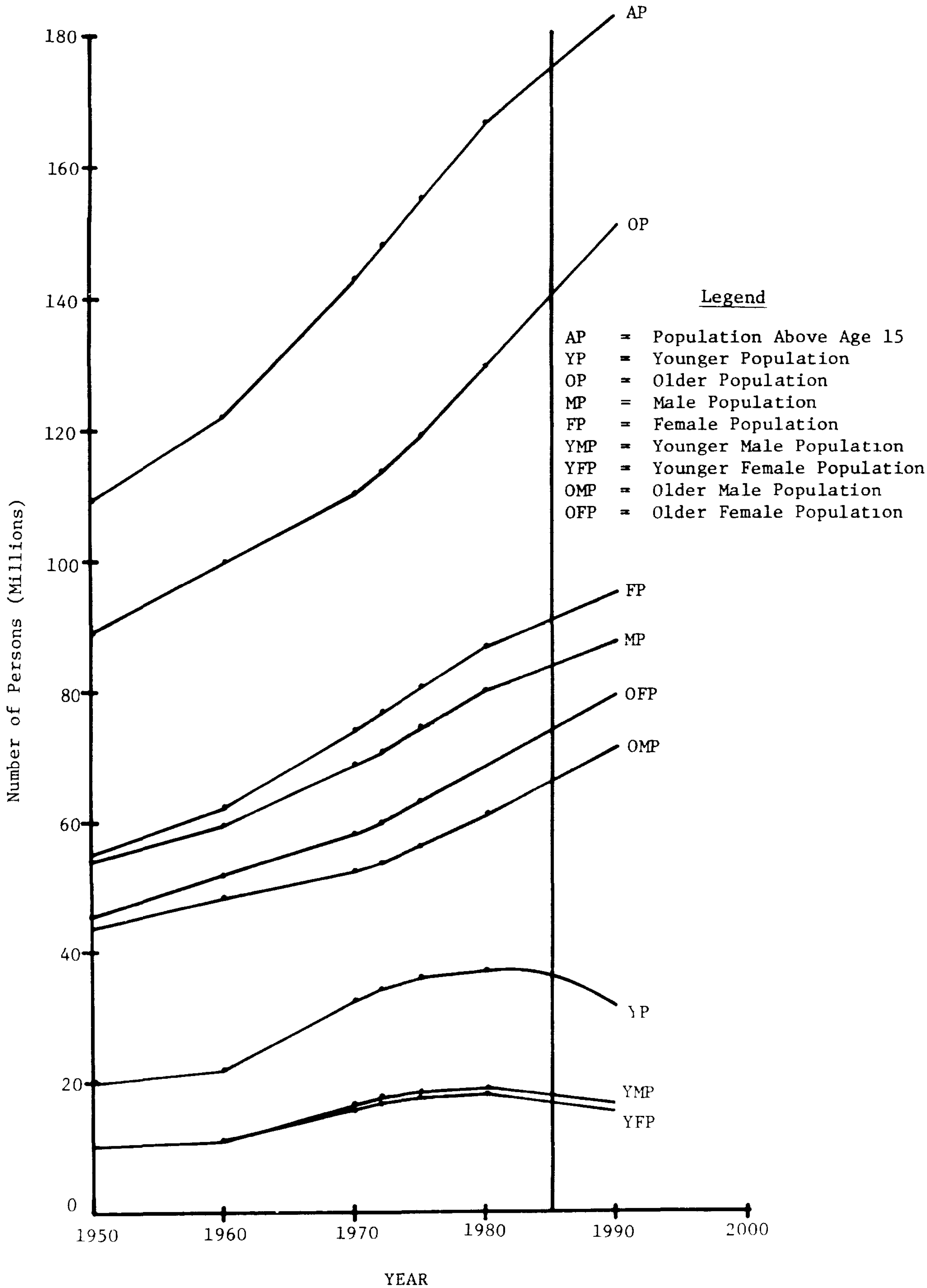

Figure 29

Percent of Persons Holding Drivers' Licenses by Age Group and Sex

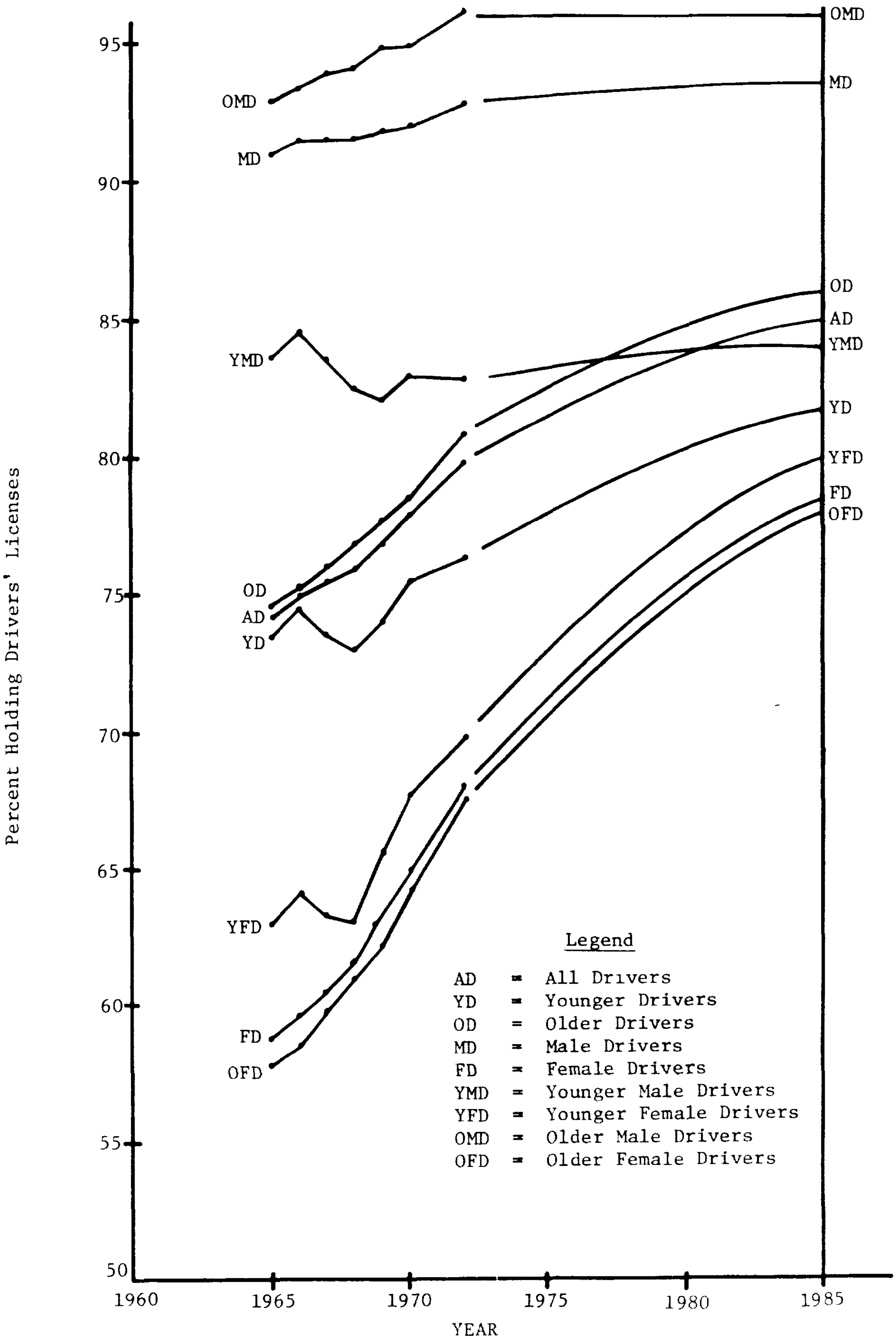

Figure 30

Younger Licenses Drivers and Population by Sex

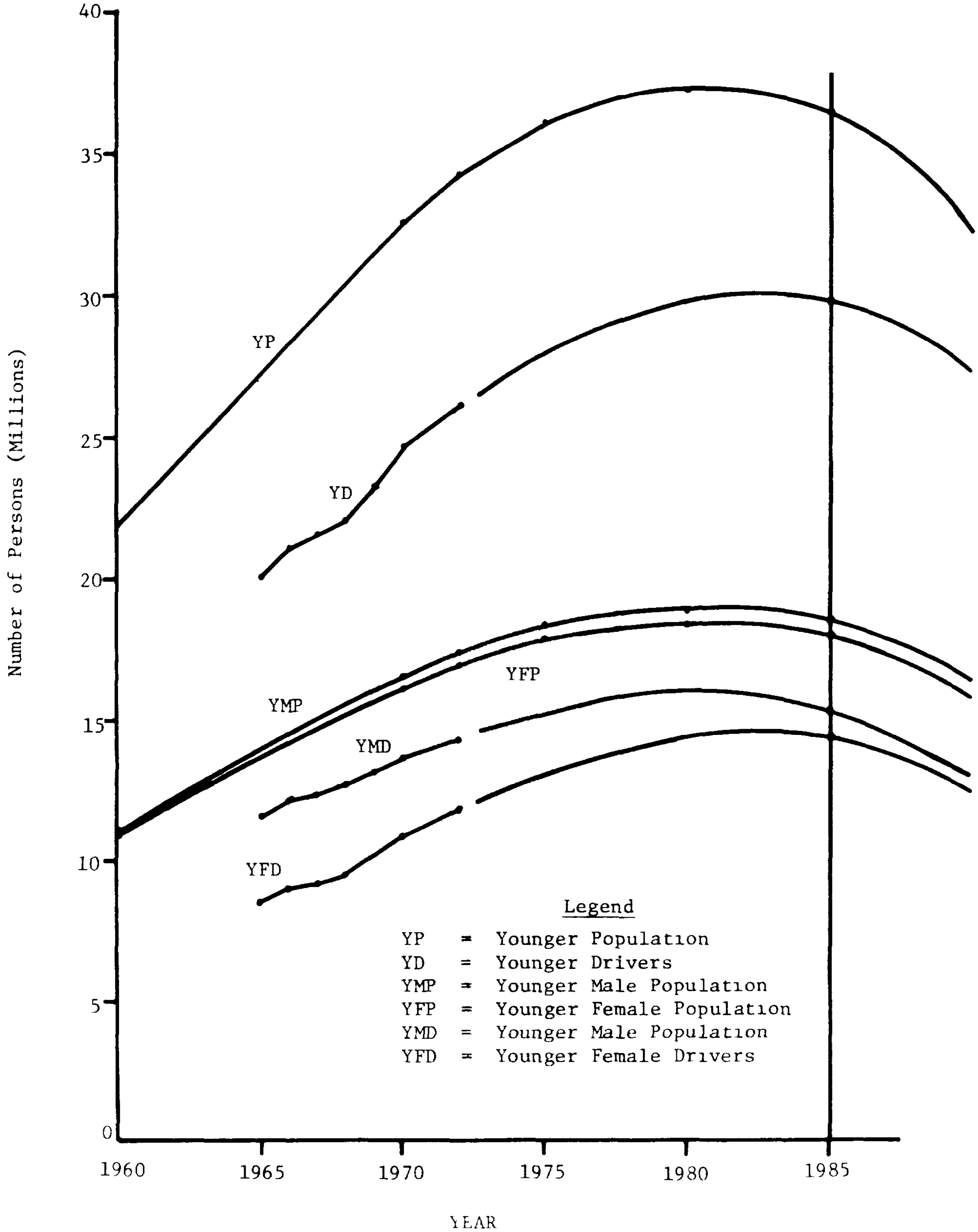

Figure 31

Older Licensed Drivers and Population and All Licensed Drivers and Population by Sex

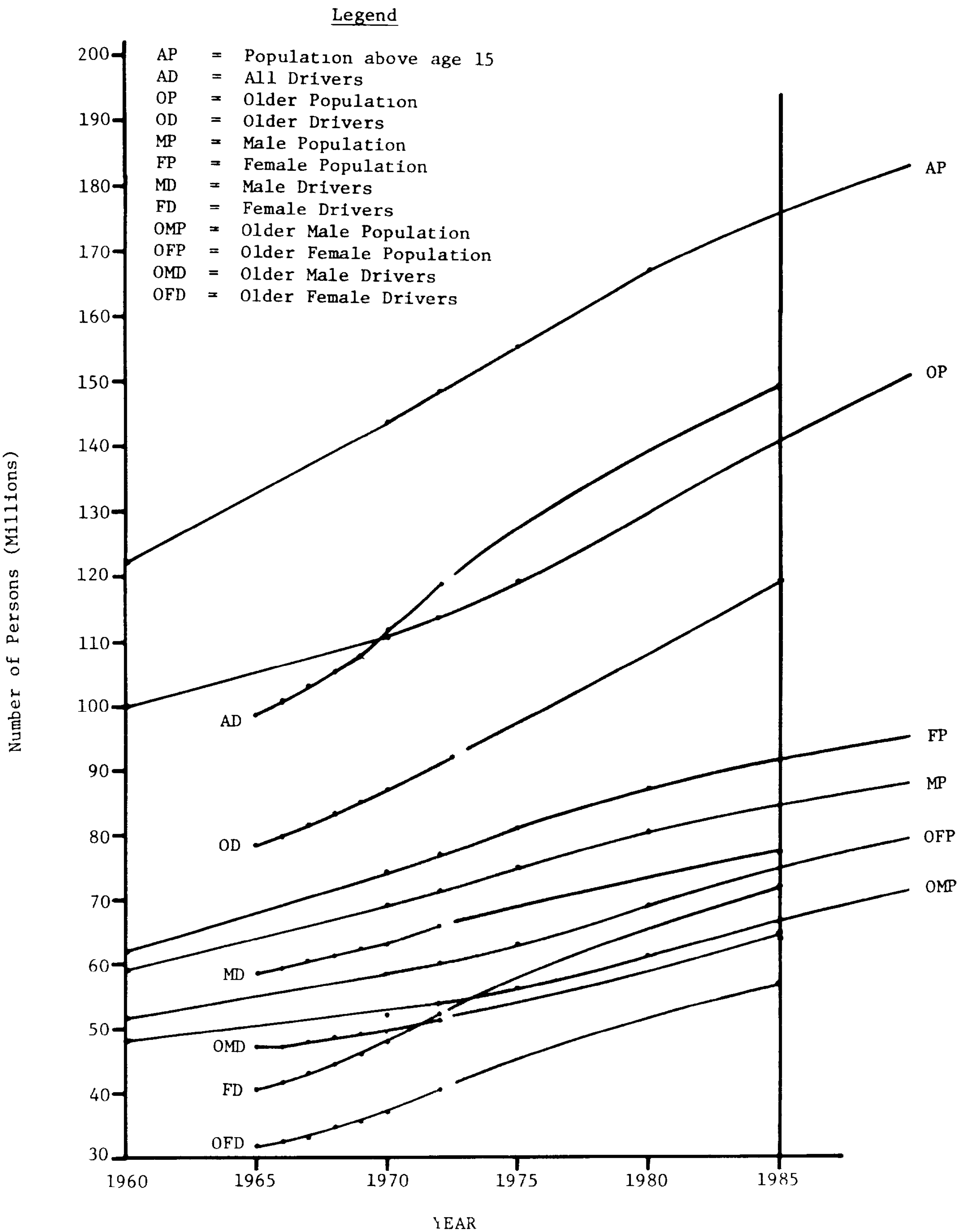

Figure 32

Licensed Drivers by Age Group and Sex as a Percent of All Licensed Drivers

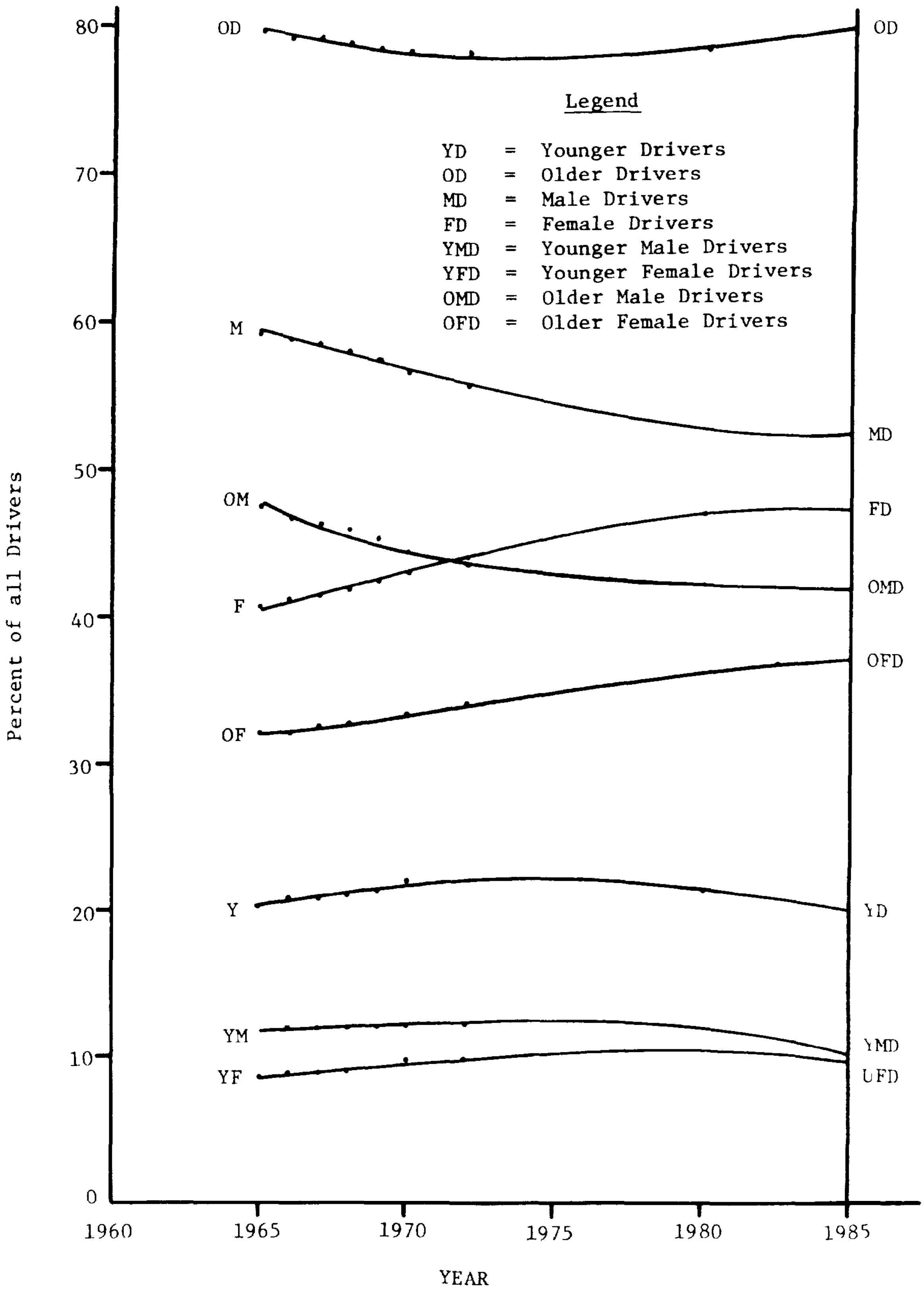

Figure 32 shows the trend in the distribution of licensed drivers by age group and sex. The trend shows a slight percentage decrease for younger drivers, from 22.1 percent in 1972 to 19.9 percent in 1985, although the number of younger licensed drivers actually increased 3.3 million, from 26.6 million to 29.9 million. The reason for this is that the growth rate of the older drivers is much greater than that for the younger licensed drivers. The percentage of drivers who are males will decrease from 55.7 percent in 1972 to 52.5 percent in 1985. The male's rate for obtaining drivers' licenses is expected to keep pace with the population growth rate. So, the relative decline in the proportion of male drivers will be due largely to the increasing rate of females getting drivers' licenses (see Figure 29), only because the number of non-driving females is large and the fact that females outnumber males.

A comparison between the current (1972) and projected (1985) population and licensed drivers is shown in Figures 33, 34, and 35. Figure 33 shows that as the population increases, the proportion of males and females remain unchanged while the proportion by age group is shifting toward older persons. Figure 34 shows that more persons within each age group and sex will be holding drivers' licenses in 1985. Figure 35 summarizes all changes in the number and percent of licensed drivers which is expected to affect the projection of accident statistics.

3.2.2.2 Seating Position Occupancy

Percentage of occupancy for each seating position is required for a reasonable evaluation of occupant protection countermeasures. The most representative automobile occupancy study (data from every state) is Strate's "National Personal Transportation Survey" (36). The findings of this report include the following:

1. "Average car occupancy of incorporated areas for all trip purposes combined was found to be 1.9 occupants per trip."

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(36) H. E. Strate, "National Personal Transportation Survey," Report I, U.S. Department of Transportation, Federal Highway Administration, April, 1972.

Figure 33

Current and Projected

Population Above Age 15

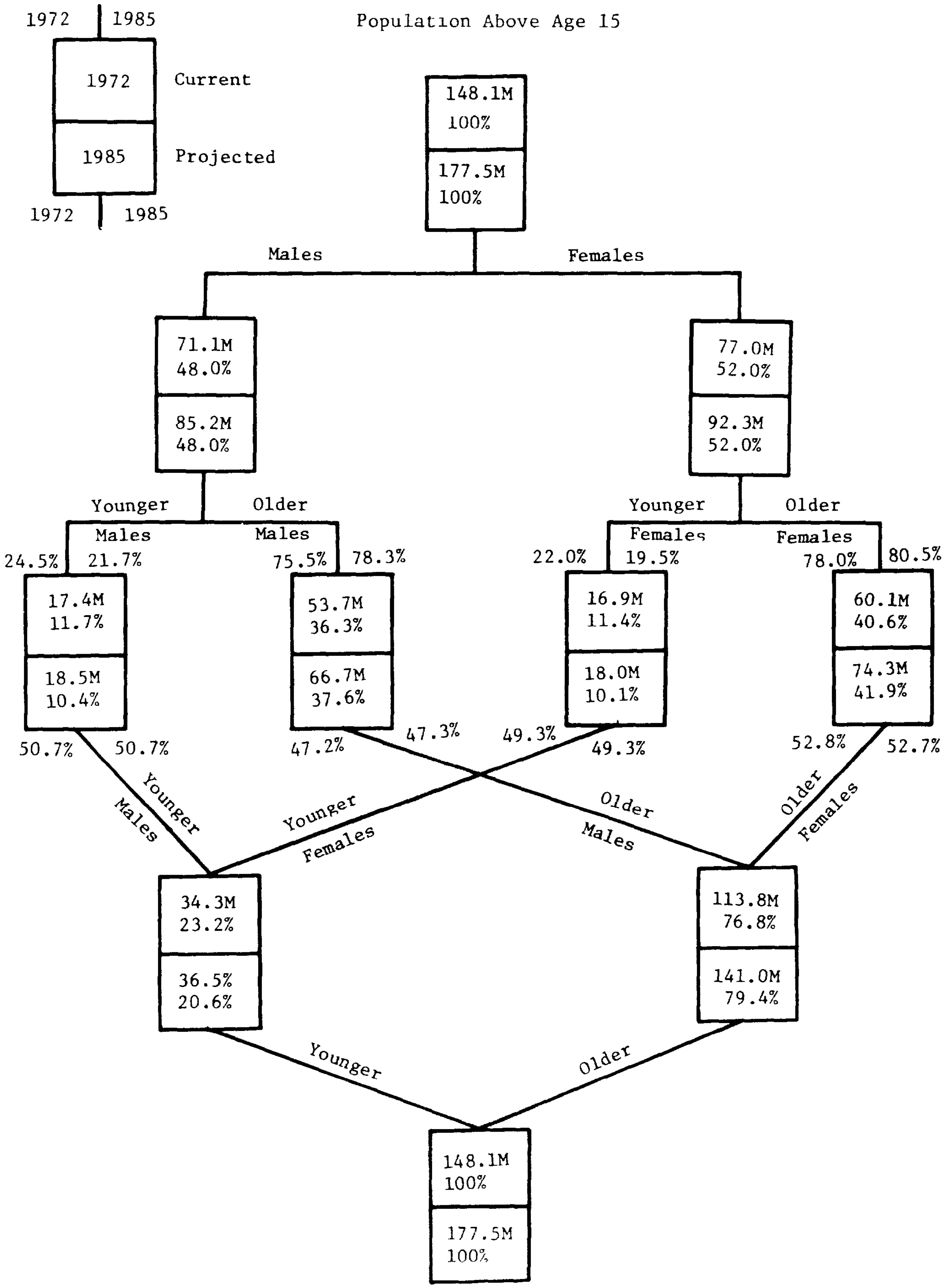


Figure 34

Current and Projected

Percent of Population Holding Drivers' Licenses

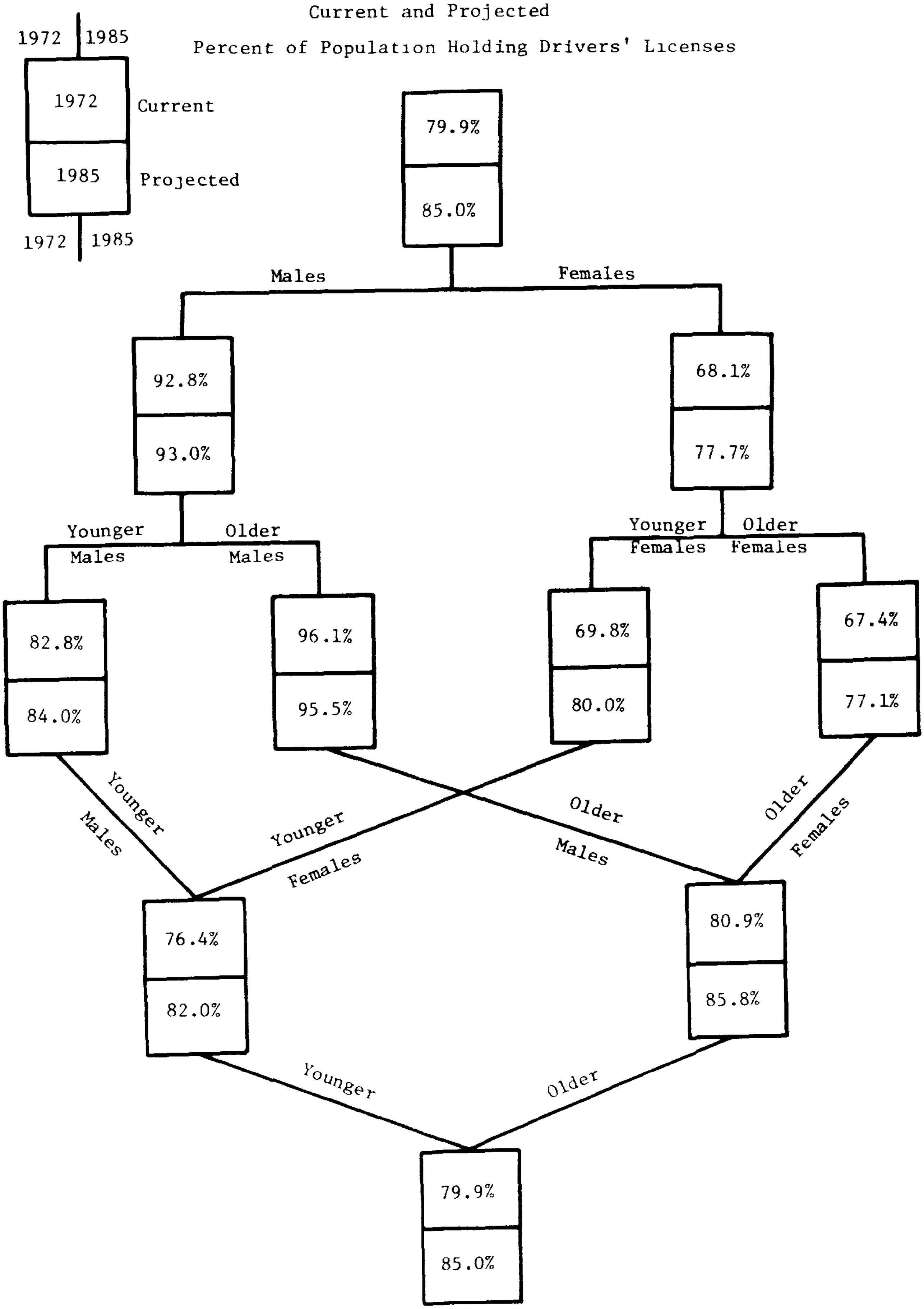
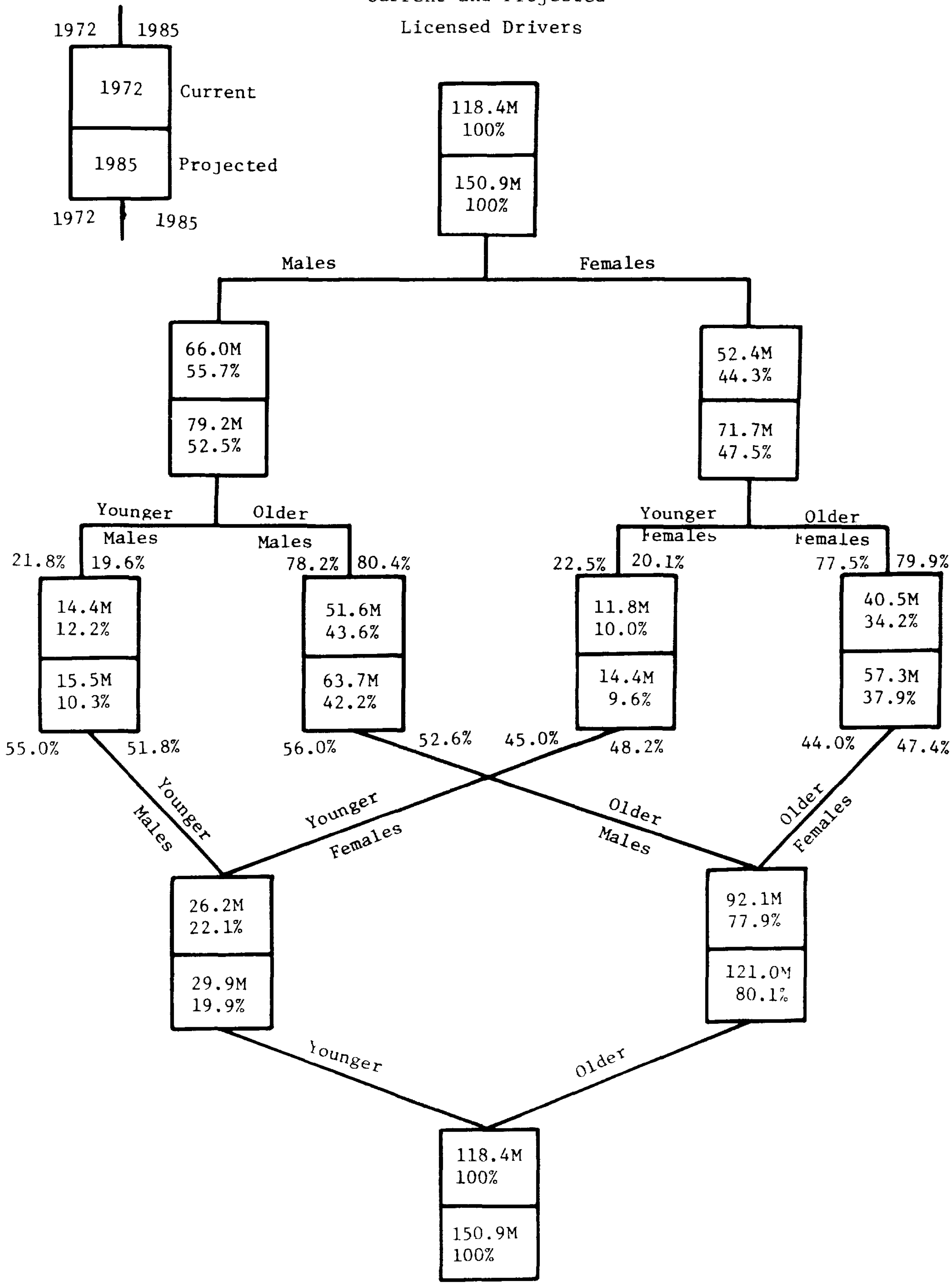


Figure 35

Current and Projected
Licensed Drivers



2. "Residents of unincorporated areas reported 2.0 occupants per trip for all purposes combined."
3. "Average car occupancy varied from a high 3.3 occupants per trip for vacation trips to a low of 1.4 occupants per trip for to-and-from work trips."
4. "Average car occupancy generally increases with increasing trip length."
5. "Average occupancy per automobile trip shows occupancy to be higher on weekends."
6. "One-occupant trips represent 50.2 percent of all trips."
7. "Approximately 73.5 percent of trips to-and-from work were in one-occupant cars."

This study, however, did not contain the occupant seating distribution within the vehicle or the type of highway traveled. There are, however, several studies which include the occupant seating distribution.

Table 31 shows the percentages of seating occupancy found by Green (37), Jack (38), and Tourin (39) in samples drawn from the states of California, Michigan, and New York. Green and Tourin used injury data file to compute their percentages. Jack's data, however, represents a sample from the non-injury vehicle population traveling over a selection of highways in Michigan and New York. This data does not include distribution by highway type.

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(37) J. A. Green, "Vital Statistics of Passenger Car Occupants for Each Seating Position," HIT Lab Reports, April 1971.

(38) D. Jack, "Preliminary Data Analysis from Observations of Seat Position Occupancy Frequencies in Urban and Rural Locations," Ford Motor Company, Automotive Safety Research Office, 1972.

(39) B. Tourin and J. W. Garrett, "A Report on Safety Belts to the California Legislature," Cornell Aeronautical Laboratory, SRL367, 1969.

Table 31

Percentage Distribution of Occupants Over Front and Rear Positions

State	Average Occupancy	Front Seat Passengers Driver	Front Seat Passengers Center	Front Seat Passengers Right	Rear Seat Passengers Left	Rear Seat Passengers Center	Rear Seat Passengers Right
California	1.7	100 (53980)*	9.5 (5126)	41.9 (22628)	9.7 (5246)	4.0 (2136)	9.8 (5317)
Washtenaw County Michigan	1.6	100 (17456)	7.2 (1252)	35.4 (6178)	7.5 (1316)	4.2 (734)	9.1 (1592)
Michigan, New York	2.0	100 (2511)	8.7 (218)	55.8 (1402)	15.0 (377)	8.3 (208)	17.1 (429)

*Numbers in parentheses indicate the observed frequency.

To obtain the occupant seating position distribution by highway type, a computer search of the accident data contained in the Highway Safety Research Institute (HSRI) files was made. Three files, the CPIR3, Calspan Level II, and Washington State-King County were interrogated. Each of the three files had different average occupancy rates per vehicle, making comparisons of the percentage distributions of occupant seating positions difficult. To normalize the data, each percentage distribution was adjusted to reflect the same average occupancy rate -- 1.9 occupants per vehicle as given by Strate (40).

The reported data and the normalized data for each file are shown in Table 32, Table 33, and Table 34. The normalized data from each file correlates. As an example, the right front seat occupancy for a rural highway is 61.0% for the CPIR3 file, 59.6% for the Calspan Level II file, and 61.1% for the Washington State-King County file.

Because data from the samples are reasonably consistent, Table 35, for use in further analysis, is constructed representing the best judgment for distribution of seating position occupancy.

(40) Strate, Op. Cit.

Table 32

Percentage Distribution of Occupants Over Front and Rear Seat Positions

Collision Performance and Injury File - Revision 3

	Number of Cases	Ave. Occ.		Front Seat Driver	Front Seat Center	Front Seat Right	Rear Seat Left	Rear Seat Center	Rear Seat Right
URBAN									
Fully Controlled Access	515	1.6	Actual	100	3.7	37.5	6.8	3.1	8.4
			Adjusted	100	5.5	56.3	10.2	4.6	12.6
Partial/ No Control of Access	3856	1.6	Actual	100	4.7	36.6	6.3	4.1	8.1
			Adjusted	100	7.0	55.0	9.5	6.1	12.1
RURAL									
Fully Controlled Access	493	1.7	Actual	100	6.6	39.5	11.5	3.5	11.2
			Adjusted	100	9.4	56.5	16.4	5.0	16.0
Partial/ No Control of Access	3040	1.6	Actual	100	4.5	37.4	7.1	3.9	10.3
			Adjusted	100	7.5	62.2	11.8	6.5	17.2

Table 33

Adjusted Percentage Distribution of Occupants Over Front and Rear Seat Positions

1972-1973 Calspan (New York State) Accident Data File

	Actual Occupancy	Cases		Front Seat Driver	Front Seat Center	Front Seat Right	Rear Seat Left	Rear Seat Center	Rear Seat Right
Urban	1.2	10658	Actual	100	2.2	12.1	2.1	1.0	2.5
			Adjusted	100	9.9	54.5	9.5	4.7	11.4
Rural	1.5	5443	Actual	100	5.0	29.8	5.3	2.9	6.9
			Adjusted	100	10.1	59.6	10.5	5.9	13.9

Table 34

Adjusted Percentage Distribution of Occupants
Over Front and Rear Seat Positions

(King County-Washington State 1970-1973)

	Number of Cases	Act. Occ.		Front Seat			Rear Seat		
				Driver	Center	Right	Left	Center	Right
URBAN									
Fully Controlled Access	12296	1.2	Actual	100	1.7	12.5	1.8	1.2	2.7
			Adjusted	100	7.5	56.3	8.3	5.6	12.3
Partial/ No Control of Access	77665	1.2	Actual	100	1.9	12.9	1.8	1.0	2.4
			Adjusted	100	8.8	57.9	8.0	4.4	10.8
RURAL									
Fully Controlled Access	963	1.5	Actual	100	4.0	29.6	6.1	3.2	7.0
			Adjusted	100	8.0	59.3	12.3	6.4	14.0
Partial/ No Control of Access	3119	1.4	Actual	100	4.4	24.6	3.9	2.6	4.6
			Adjusted	100	11.0	61.3	9.7	6.5	11.5

Table 35

Assumed Percentage Distribution of Seating Positon Occupancy

	Front Seat			Rear Seat		
	Driver	Center	Right	Left	Center	Right
Urban	100	8	56	9	5	12
Rural	100	9	60	12	6	15

3.2.2.3 Occupant Size Distribution

Occupant kinematics and injury in a collision are dependent to some extent on the size of the occupant. In order to design a vehicle that is optimized for driver and passenger protection, it is necessary that each countermeasure be evaluated over all occupant sizes.

The percentage of adult males and females in height increments of two inches was obtained from the U. S. Department of Health, Education and Welfare (41) and is shown in Table 36. The occupant population for the system model is obtained by weighting the male and female distributions in the same proportion as projected for male and female drivers in 1985 -- 52.5 and 47.5 percent, respectively. It is assumed that the ratio of average number of annual miles driven by males and females in 1985 is the same as in 1974 (42). This ratio is modified by the slight expected shift in the driver population by sex to give weights of 0.699 for males and 0.301 for females.

Table 36

Occupant Height Distribution for 1985
(69.9% Male, 30.1% Female)

	Percent in Height Group		
Occupant Height (Ins.)	Male	Female	Population
57	0.0	0.8	0.3
59	0.0	4.6	1.4
61	0.4	15.7	5.0
63	2.3	28.8	10.3
65	9.1	28.8	15.1
67	21.0	15.7	19.4
69	28.8	4.6	21.6
71	23.3	0.7	16.5
73	11.3	0.1	7.9
75	3.1	0.0	2.2

(41) Weight, Height, and Selected Body Dimensions of Adults: United States 1960-1962. U. S. Department of Health, Education and Welfare; Public Health Service Publication No. 1000 - Series 11 - No. 8, June 1965.

(42) 1973/74 Automobile Facts and Figures, Motor Vehicles Manufacturers Association, New York.

3.2.3 Pedestrian Factors

A thorough review of the available information related to the pedestrian impact problem has been carried out in the course of this project. It has been concluded that the interaction between pedestrian and vehicle is both too poorly understood and too complex for the scale of effort needed to parameterize it to the point of significantly affecting RSV function.

The interaction of a pedestrian with a motor vehicle is one which is poorly understood from a trauma causation standpoint. Clearly, the collision of the pedestrian with an object of much greater mass is the most important factor in injury causation. The exact mechanism of pedestrian trauma appears to be a function not only of vehicle and pedestrian kinematics, but is also related to the size, age, and orientation of the pedestrian at time of impact, and to the magnitude and distribution of force on the pedestrian.

Is the predominant cause of impact trauma to a pedestrian the first collision with the vehicle or the second collision with the ground or with another vehicle or object? Are the gross kinematics of child-to-vehicle impact truly different from adult-to-vehicle impact, i.e., do motor vehicles tend to run "under" adults and "over" children?

Further study may well indicate that the only effective way of mitigating pedestrian injuries may be an isolation of the pedestrian from the external vehicle environment. Consider, for example, the current solutions being proposed to isolate the human being from the internal vehicle environment in a crash: belt restraints, air cushion restraints, and various combinations thereof. If one considers the occupant and the vehicle as two dynamically interacting systems, then restraint systems can be thought of as coupling devices of appropriate "impedance" providing a smooth "transfer of energy" during the impact event. In the interaction of pedestrians with vehicles, a gradual "transfer of energy" during the impact is difficult to imagine. A large "impedance mismatch" typically occurs in such impacts.

Not all the unknowns related to pedestrian/vehicle interactions are confined to the area of trauma mitigation. Accident statistics relating to pedestrian injuries are not well defined with regard to type of injury. A relationship of pedestrian accident severity (e.g., AIS level) with vehicle impact speed may be misleading since completely different modes of injury can be reported with similar AIS levels. For example, severe lacerations of AIS level 3 may be the result of a completely different injury mechanism than a fractured pelvis of AIS level 3. A better definition of injury rating for pedestrian impacts appears necessary before an accurate cost/benefit analysis aimed at reducing pedestrian trauma is possible.

3.2.3.1 Literature Review of Pedestrian Injury Studies

Field Data Statistics. There were 10,500 pedestrian fatalities in 1973 (43). Approximately 22 percent of all highway fatalities are accounted for by pedestrians. Pedestrians account for 2.2 percent of urban and 0.9 percent of rural collisions. Pedestrian accidents are severe, involving a high fatality-collision ratio. Early studies of Yaksich (44) show that between 1948-1957 pedestrians accounted for two-thirds of all traffic fatalities in Washington, D. C. Statistics from other countries bear out the fact that pedestrian fatalities are largely an urban problem (45). Figures in the U. S. show approximately a 2:1 ratio between urban and rural pedestrian fatalities (46).

Several studies present a breakdown of the time of day and pedestrian involvement. In 1972, 54 percent of pedestrian fatalities occurred at night. However, if one takes into account the vehicle and pedestrian travel rate at night, the observed 5,800 nighttime fatalities is 18 times higher than one would expect. Therefore, the night environment is not just slightly more dangerous for the pedestrian, but dramatically so. Nearly 5,500 accidents at night involve factors not present during the day (47).

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(43) Accidents Facts, National Safety Council, Chicago, Illinois, 1974.

(44) S. Yaksich, "A Study of Pedestrian Fatalities in Washington, D.C. (1948-1957)," prepared for AAA, 1975.

(45) G. M. Mackay, "The Other Road Users," Proceedings of 13th American Association for Automotive Medicine Conference, 1969.

(46) Accident Facts, Ibid.

(47) R. L. Austin, D. J. Klassen and R. C. Vanstrum, "Pedestrian Conspicuity Under the Standard Headlight System Related to Driver Perception," Third International Congress on Automotive Safety, 1974.

Pedestrian fatality is mainly a problem of the young and old. Major studies of McLean (48), Cornell Aeronautical Laboratory (49), and Tharp (50) bear out this fact for the United States. Studies from other countries show the same trend (51).

In-Depth Analysis of Field Data. McLean (52, 53, 54, 55) has analyzed data available in the United States and Australia over a period of four years (1970-1974). Some of his analysis will be discussed in the section on vehicle design and pedestrian dynamics. Other detailed analyses of pedestrian accidents have been carried out by Calspan (56) in the U. S. and by Mackay and deFonseka (57) in the United Kingdom, and Robertson, et al (58) in Australia. The results of these studies are summarized below.

Pedestrian Injuries and Car Design. Contrary to popular belief, pedestrians typically are not "run over" by cars. They are "run under." The probable kinematics of the pedestrian in a collision have been deduced

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(48) A. J. McLean, "The Man in the Street. Pedestrian Accidents in the Empire State," Proceedings of 15th American Association for Automotive Medicine Conference, 1971.

(49) P. M. Culkowski, et al, "Research in Impact Protection for Pedestrians and Cyclists," CAL Report No. VS-2672-V-2, May 1971.

(50) K. J. Tharp and N. G. Tsongos, "Factors in Urban Vehicle Pedestrian Collisions," Third International Congress on Automotive Safety, 1974.

(51) J. S. Robertson, A. J. McLean, and G. R. Ryan, "Traffic Accidents in Adelaide," Australian Road Research Board, Special Report No. 1, July 1966.

(52) McLean, Ibid.

(53) A. J. McLean, "Pedestrians and Bicyclists: Vehicle Factors in Accident and Injury Causation," Third International Congress on Automotive Safety, 1974.

(54) A. J. McLean, "Car Shape and Pedestrian Injury," Proceedings of National Road Safety Symposium, Australia, 1972.

(55) A. J. McLean and G. M. Mackay, "The Exterior Collision," International Automotive Safety Conference Compendium, SAE 700434, 1970.

(56) Culkowski, Ibid.

(57) G. M. Mackay and C. P. deFonseka, "Some Aspects of Traffic Injury in Urban Road Accidents," Proceedings of 11th Stapp Conference, 1967.

(58) Robertson, et al, Ibid.

by Ryan and McLean (59) and Robertson, et al (60). The kinematics of an adult pedestrian are different from that of a child pedestrian. The pedestrian collision is a multiple impact and multiple injury phenomenon. A typical accident may involve several injury causing contacts with the car and a secondary contact with the ground when the pedestrian is thrown off the car. The secondary ground contact may be just as dangerous as the primary contact with the car.

Seventy-seven percent of pedestrian impacts involve the front of the car, with the majority of these occurring at velocities less than 20 mph. Seven percent of impacts below 20 mph are in the serious-fatal range, whereas 82 percent of frontal impact injuries at greater than 20 mph are serious-fatal. When considering all serious-fatal accidents, 89 percent occur at velocities below 30 mph. Hence, most pedestrian accidents are relatively low velocity involvements.

Fatal accidents have been studied by McCarroll, et al (61), Solheim (62), Huelke and Davis (63), Jamieson and Tait (64), and Aston and Perkins (65). Injury data have also been analyzed by Hall, et al (66). These studies indicate that when a pedestrian is involved in an accident, that person will receive, on the average, about two injuries. These in-

(59) G. A. Ryan and A. J. McLean, "Pedestrian Survival," Proceedings of Ninth Stapp Conference, 1965.

(60) Robertson, et al, Op. Cit.

(61) M. D. McCarroll, et al, "Fatal Pedestrian Automotive Accidents," Journal of American Medical Association, Vol. 180, No. 2, 1962.

(62) K. Solheim, "Pedestrian Deaths in Oslo Traffic Accidents," British Medical Journal, 1, 81-83, January 1964.

(63) D. F. Huelke and R. A. Davis, "Pedestrian Fatalities," University of Michigan, Highway Safety Research Institute Report No. Bio-9, 1969.

(64) K. G. Jamieson and I. A. Tait, "Traffic Injury in Brisbane," National Health & Medical Research Council, Special Report Series No. 13, Canberra, 1966.

(65) J. N. Aston and T. A. Perkins, "The Clinical Pattern of Injury in Road Accidents," British Medical Journal, Vol. 2 (4881), 200-203, 1954.

(66) R. R. Hall, R. G. Vaughan, and A. J. Fisher, "Pedestrian Crash Trauma and Vehicle Design in New South Wales, Australia," Third International Conference on Automotive Safety, 1974.

juries will most likely be to the limbs, especially the legs, and to the head: almost all pedestrians sustained a leg injury and in one of two cases there was injury to the head. In one out of 20 cases these proved fatal, with an attendant increase in injuries to the head and to a lesser extent to the trunk (67). Calspan (68) reported that, for the adult pedestrian, the predominant injury from vehicle contact is to the leg, followed by the lower torso, the head, arms, and the upper torso. Considering vehicular contact with children; head injuries predominate followed by legs, lower torso, arms, upper torso, and neck injuries. The major points of contact with vehicular components appears to be the hood edge, bumper, forward hood, and the grille. The ground impact causes severe injuries to the head, followed by the legs, arms, and the torso.

The factors recognized in this literature as affecting pedestrian injuries most are:

1. The net kinetic energy at impact.
2. The ratio of vehicle height to pedestrian height, and
3. Vehicle/pedestrian spatial orientation (69).

A model has been formulated by Mayyasi (70) to predict injury to pedestrians. It has a linear relationship with the vehicle heights to pedestrian height ratio and a non-linear relationship with the velocity of impact. It should be noted here that the model formulated is quite simple, is based on accident data, and does not include factors such as length of the hood.

Injury Causation Factors. There are several studies on the injury causation factors, i.e., the injury producing potential of the impact with the car and that of the impact with the ground. The English

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(67) Hall, et al, Op. Cit.

(68) Culkowski, et al, Op. Cit.

(69) A. M. Mayyasi, U. Pooch, P. E. Pulley, and A. E. Harvey, "Pedestrian Injury Model," Proceedings of Third International Conference on Automotive Safety, 1974.

(70) Mayyasi, Ibid.

studies (71, 72) report that the impact with the motor vehicle is more frequently the cause of serious or fatal injuries than the impact with the ground, at least for the class of impact speeds most frequently encountered (12 to 25 mph). This fact is also reported by Tarriere (73). A recent study in Germany (74) shows that the severity of injuries caused by impact with the vehicle increases linearly with speed of the vehicle, whereas the injury severity from the ground contact stays nearly constant with increase in vehicle speed.

Hood Design Factors. The unique sloping hood design of the VW Beetle has been the object of studies by several researchers. The injury producing potential of the VW has been compared to that of a Ford Falcon (75) and to that of a Cadillac (76). Both studies report that there is a difference in the injury producing potentials of the VW when compared with other designs. However, the differences are reported to be statistically insignificant (77, 78), Hall, et al (79), compared the VW with a Ford Falcon and a Morris Mini. This study found that the fatalities are overrepresented for the VW and underrepresented for Falcons. These results disagree

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(71) Mackay and deFonseka, Op. Cit.

(72) "Pedestrian Injuries," Road Research Laboratory, LF. 317, Crawthorne, England, 1972.

(73) C. Tarriere, et al, "The influence of the Shape of the Vehicle on the Severeness of Pedestrian Injuries," Third International Conference on Automotive Safety, July 1974.

(74) U. N. Wanderer and H. M. Weber, "First Results of Exact Accident Data Acquisition on Scene," Proceedings of Third International Conference on Occupant Protection, SAE 740568, 1974.

(75) Ryan and McLean, Op. Cit.

(76) McLean, Op. Cit.

(77) Hall, et al, Op. Cit.

(78) Culkowski, et al, Op. Cit.

(79) Hall, et al, Op. Cit.

with McLean's VW and Cadillac comparisons but agree with the Robertson, et al (80), analysis. This study also indicates that the plan (overhead) view of the front end of cars may be just as important as the side view because both can affect the kinematics of the pedestrian in a collision. This fact is corroborated by Vaughan (81) and Fisher (82).

Geometry and Structural Characteristics. The influence on pedestrian kinematics of vehicle front end geometry and structural characteristics has been the subject of several experimental and analytical simulation studies, as detailed below.

Experimental and Analytical Studies. The Japan Automobile Manufacturers Association conducted a series of tests with highly modified vehicles and anthropomorphic dummies in 1968 (83). There is one instance of a cadaver test on a sled simulating a pedestrian-vehicle impact (84). Further experiments with dummies have been carried out by Calspan (85), Taneda, et al (86) and Fabricius (87).

The investigators claim they have been successful in simulating real world pedestrian accidents. They report that for a given speed the height of the bumper, the shape, height and rigidity of the front end of the vehicle, and the length of the hood control the overall kinematics

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(80) Robertson, et al, Op. Cit.

(81) R. G. Vaughan, "A Study of Measures to Reduce Injuries to Pedestrians," National Road Safety Symposium, Australia, 1972.

(82) A. J. Fisher and R. R. Hall, "The Influence of Car Frontal Design on Pedestrian Accidents and Trauma," Accident Analysis and Prevention, Pergamon Press, Vol. 4, pp. 47-58, 1972.

(83) "Experiments on Behaviors of a Pedestrian in a Collision with a Motor Vehicle," Japan Automotive Manufacturers Association, HSRI-13214, August 1968.

(84) L. M. Patrick, D. J. VanKirk and G. W. Nyquist, "Vehicle Accelerator Crash Simulator," Proceedings of 12th Stapp Conference, 1968.

(85) Culkowski, et al, Op. Cit.

(86) K. Taneda, M. Kondo, and K. Higuchi, "Experiment on Passenger Car and Pedestrian Dummy Collision," Proceedings of International Conference on the Biokinetics of Impact," Amsterdam, June 1973.

(87) B. Fabricius, J. Niklas, and E. Fiala, "Pedestrian Accidents Tests with Catapult," Motor Vehicle Institute Technical University, Research Report No. 40, Berlin, 1968.

of the pedestrian. They go on to state that these factors determine the zone hit by the head, the shape of the trajectory, and the projection speed of the pedestrian hit by the vehicle (88).

Essentially the same conclusions have been asserted by Kühnel (89) after conducting a series of sophisticated tests using moving dummies.

Surprisingly, analytical simulations of pedestrian accidents have lagged behind experimental simulations. Pedestrian simulation is essentially a three-dimensional problem. Ross (90) has verified a 3-D model of the pedestrian with experimental data. However, vehicle shape and structural characteristics have not been investigated by him. The CAL 3-D occupant model has been modified recently to simulate pedestrian accidents (91), but published results of these simulations are not yet available.

Several two-dimensional math models have been used to study the trends of vehicle modifications. Katayama (92) and MacLaughlin (93) have varied several parameters in their two-dimensional models of the pedestrian. MacLaughlin conducted a statistical experiment with his model where pedestrian size and orientation were varied. Also tested were the effects of general vehicle front end design. It was found that introducing any one vehicle modification independently produces no significant beneficial effect. However, several modifications have to be made simul-

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(88) Tarriere, et al, Op. Cit.

(89) A. Kühnel, "Vehicle-Pedestrian Collision Experiments with the Use of a Moving Dummy," Proceedings of 18th American Association for Automotive Medicine Conference, 1974.

(90) H. E. Ross, M. C. White, and R. D. Young, "Drop Tests of Dummies on a Mock Vehicle Exterior," Third International Congress on Automotive Safety, 1974.

(91) "Contact Loads - Experimental Study," Wayne State University, NHTSA Contract DOT-HS-146-3-711, Proposal Date May 4, 1973.

(92) K. Katayama and T. Shimada, "Analysis of Behavior of Pedestrian in Collision -- Mathematical Analysis," Japan Society of Automotive Engineering, Bul. No. 4, March 1972.

(93) T. F. MacLaughlin and S. Daniels, Jr., "A Parametric Study of Pedestrian Injury," Third International Congress on Automotive Safety, 1974.

taneously to achieve beneficial effects according to this model. The effect of adding two inches of padding to the bumper resulted in generally reduced chest accelerations and hip forces, but had negligible effect on head acceleration. This result agrees with the experimental studies conducted in Japan (94).

Recently, there has been an increase of NHTSA sponsored research in pedestrian safety. Experimental work is being carried out at Battelle Columbus Laboratories (95) and Wayne State University (96, 97). An analytical program is being carried out by Boeing Computer Services (98), while an accident data study of rural accidents is being conducted at Texas A & M (99). As of this date, the results of the above studies are not publicly available. However, the main conclusions of the above programs (as gathered from reliable sources) will be discussed briefly.

Battelle Columbus Laboratories (BCL) has just finished a two-year study of the effect of bumper height and stiffness on lower limb injuries. The study was carried out on standing cadavers hit by a test device simulating the front end (bumper and hood only) of a car. The device is described in Reference 100. This study confirms the conclusion of researchers in Japan and Europe that lowering the bumpers by six inches

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(94) Japan Automotive Manufacturers Association, Op. Cit.

(95) "Body - Vehicle Interaction Experimental Study," DOT-HS-361-3-745, Battelle Memorial Institute, Columbus, Ohio.

(96) R. H. Eppinger, "Pedestrian Safety Research," Proceedings of Vehicle Safety Research Integration Symposium, held at NHTSA, Washington, D. C., June 1973.

(97) "Contact Loads - Experimental Study," Op. Cit.

(98) M. K. Gagnon, R. N. Karnes, and J. L. Tocher, "The Design of Motor Vehicles for Reduction of Pedestrian Fatalities," Proceedings of Third International Congress on Automotive Safety, 1974.

(99) R. D. Young, H. E. Ross, and W. F. Lammert, "Simulation of the Pedestrian During Vehicle Impacts," Proceedings of Third International Congress on Automotive Safety, 1974.

(100) J. T. Herridge and H. B. Pritz, "A Study of the Dynamics of Pedestrians and Generally Unsupported Transit System Occupants in Selected Accident Modes," Proceedings of 17th American Association for Automotive Medicine Conference, 1973.

from the present standard will reduce the lower limb injuries most common in pedestrian/car collisions. The effect of bumper stiffness on pedestrian injury remains unclear. There seems to be a change in the mechanism of fracture of the lower limbs and the effect of this on the kinematics of the head and torso is inconclusive. This agrees with the results of tests in Japan where heavily padded bumpers lowered the forces on the lower limbs but did not affect the peak head acclerations. This also confirms the conclusions of mathematical simulations computed by MacLaughlin (101) that lowering of bumper stiffness must be accompanied by changes in hood stiffness and profile to lower the overall trauma to the pedestrian.

A series of pedestrian/car collision experiments is being carried out at Wayne State University (102). The goal of this project is to accurately describe the kinematics of the pedestrian in a crash up to the time the pedestrian hits the ground. Forty-eight channels of acceleration data are being recorded, making this series of experiments the most well instrumented series of tests involving pedestrian research to date. The tests have been conducted employing dummies and full-size American cars. Initial results of this study indicate that higher accelerations are experienced by the dummy upon impact with the ground than upon impact with the vehicle surfaces. Another series of tests will be made using embalmed and unembalmed cadavers. The dummy and cadaver runs will also be simulated mathematically by the Calspan 3-D vehicle occupant model (103). The Calspan 3-D model was employed previously in an attempt to simulate the experimental pedestrian impacts conducted at the Texas Transportation Institute (104).

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(101) MacLaughlin, Op. Cit.

(102) "Contact Loads - Experimental Study," Op. Cit.

(103) J. A. Bartz, "Development and Validation of a Computer Simulation of a Crash Victim in Three Dimensions," Proceedings of the 16th Stapp Car Crash Conference, 1972.

(104) Ross, et al, Op. Cit.

Boeing Computer Services (BCS) has been conducting a theoretical research program in pedestrian safety in an attempt to optimize the profile of the "front end" of a vehicle for minimum pedestrian injury. The methodology to be used was reported by Gagnon, et al (105). The pedestrian model being used is a two-dimensional model developed at BCS. Although the original plan was to use the Krouskop injury model (106) as the objective function to be minimized, an injury model similar to that proposed by Baker (107) will be used as the objective function. The results of this study will be used by Battelle Columbus Laboratories in fabricating the front end of an "optimized" pedestrian interaction vehicle. This structure will be tested against adult and child dummies and further modifications may be made by Battelle to the structure after the initial testing. The results of this additional Battelle study are aimed toward the development of vehicle performance specifications to increase pedestrian safety.

Literature Review Conclusions. Pedestrian accidents are complex events and deserve further research before the potential, if any, for reducing pedestrian trauma through vehicle design changes can be identified. Countermeasures aimed at modifying the vehicle should be undertaken only after detailed experimental and real world data analysis. The efficiency of any proposed modification in vehicle design can then be studied on a cost-effectiveness basis.

3.2.3.2 Roadway Environment Modifications

In the long run, the most effective route to reducing pedestrian accidents may lie in a rethinking of urban roadway design. Contrary to

(105) Gagnon, et al, Op. Cit.

(106) T. A. Krouskop, P. H. Newell, Jr., A. E. Swarts, W. A. Hyman, and L. A. Leavitt, "An Index for Predicting Tissue Damage Due to Impact," Proceedings Third International Congress on Automotive Safety, 1974.

(107) S. P. Baker, B. O'Neill, W. Haddon, and W. B. Long, "The Injury Severity Score: A Method for Describing Patients with Multiple Injuries and Evaluating Emergency Care," The Journal of Trauma, Vol. 14, No. 3, March 1974.

the instantaneous situation that confronts a vehicle occupant when a crash occurs, a pedestrian has more than mere milliseconds before a collision. The vehicle occupant can take no voluntary action prior to impact...the adult pedestrian usually does have time to be alerted and to change his course, speed, and orientation in the roadway environment. Thus, in general, two courses of countermeasures are available to reduce pedestrian injures -- active countermeasures which alert* the pedestrian and allow him to assist in avoiding the accident; and passive countermeasures, which force him to avoid a vehicle accident interaction. Both courses are considered below...however, the latter passive course is believed to be the most promising appraoch.

Interactive Roadway Countermeasures. Man learns and interacts with the environment through five senses. From a practical standpoint, only the senses of feeling, hearing, and seeing are available for an interactive pedestrian warning and accident prevention system. To date, visible walkways and accident preventive systems are the predominant means of attempting to control the pedestrian. Examples of visible control are "walk-no-walk" signs at intersections, striped crosswalks, "cross only at corner" signs posted in mid-block locations, and, of course, the occasional deterrent of a patrol car or policeman stationed half-a-block away. However, recent findings indicate that these controls are not highly effective (108, 109).

Conceivably, more effective systems could be designed to warn or alert the pedestrian of violating forbidden crossing zones between intersections. This would have some effect in reducing pedestrian injuries, since some pedestrians are absentminded, under the influence of alcohol, or simply not aware of their actions until it is too late (110).

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*This is in addition to the extremely important area of pedestrian public safety education, an excellent example of which is given in the report prepared for NHTSA by the San Jose Department of Public Works entitled, "Pedestrian Safety for Urban Streets," PB-225435, 1972.

(108) Accident Facts, Op. Cit.

(109) "The Forgotten Pedestrian," Traffic Safety, Powell Anderson, October 1974.

(110) "The Forgotten Pedestrian," Ibid.

To this end, high-intensity strobe-light warning systems coupled with embedded sensors could be designed and placed in high accident urban mid-block areas. Audible warning systems are also conceivable as "active" pedestrian safety devices. From a practical standpoint, however, these systems could not be justified -- especially from a cost-benefit point of view. It is conceivable, however, that social pressure may override the cost-benefit approach and spur research in the active pedestrian warning area.*

Isolative Roadway Countermeasures. The best and most feasible approach in reducing pedestrian injuries in the next 20 years will be systems that require no action by the pedestrian -- systems that isolate him from the path of the vehicle. The isolation can be divided into three modes:

1. Physical Isolation in One Traffic/Pedestrian Plane
   a. walled isolation in selected blocks between street intersections
   b. gated isolation at selected intersections
2. Physical Isolation in Vertical Planes of Travel
3. Isolation in Time

In general, the aforementioned isolation schemes would be feasible only by integrating them into new or high-renovation type urban construction programs. Physical isolation in one traffic plane could be accomplished by means of low solid barrier or walls,** screen or dense vegetation-type barriers, or conceivably, wide gaps between vehicle lanes and pedestrian walkways.

Some high-accident intersections are "gated" today by school safety patrols and police officers. Low electromechanical "gates" could be embedded in the sidewalk at selected intersections and raised and lowered in conjunction with traffic signal sequencing.

*This may be particularly true for the predominant recipient of "touchable" or "feelable" warning systems -- the blind pedestrian. Pebbled or ribbed crosswalks are already being considered in some sections of the country (111).

(111) "The Forgotten Pedestrian," Op. Cit.

**This, of course, precludes any on-street parking in these areas.

The most practical solution to the pedestrian trauma problem may be the vertical isolation of the pedestrian from the vehicle... the "mall" concept. By restricting vehicular traffic to above or below ground level, complete isolation is possible. Limited applications of this concept exist today as in various mall-type shopping areas and in depressed and elevated urban expressways. Partial depression or elevation (three or four feet) of pedestrian walkways has not been attempted to any appreciable extent but should be given serious consideration.

Finally, the pedestrian and vehicle could be isolated in time. Vehicles could be restricted from traveling in certain urban "high risk" areas, except during certain hours of the day. Of all the passive concepts listed, this would no doubt be the least practical, but in combination with others mentioned above, may yield an effective system to achieve fewer pedestrian injuries in future years.

3.2.3.3 Pedestrian Factors Conclusion

There is some evidence that hood shape, bumper height, front-end softness, and the general vehicle configuration have an effect -- a complex effect -- on pedestrian outcome. But the evidence is not consistent in the direction of the effect, much less its magnitude. The more quantitative of the research evidence available indicates only a very small amount of the variance in pedestrian outcome is associated with variance in vehicle design. The question repeatedly arises of how much of the burden of pedestrian control must be placed on the vehicle; some argue that kinetic energy considerations alone would make it clear that countermeasures are most appropriately placed so as to channelize the separate forms of traffic.

3.2.4 Summary - Accident Factors

Distributions of collision frequency and severity are estimated for 1985 based primarily on towaway accident data because accident severity information for all accidents is not available. The projected 3.5 million towaway accidents are proportioned -- 40 percent single vehicle, 60 percent vehicle-to-vehicle -- the same as today. The accident severity projections for 1985 are based on analysis of accident data collected prior to the 55 mph speed limit.

A representative distribution of passenger car occupant size for 1985 was developed from published male/female data with adjustments for an anticipated passenger car occupant mix of 70 percent male and 30 percent female.

Seating position occupancy rates were developed for the RSV by combining the occupancy rates from accident data files and the best estimates available of the average number of occupants in vehicles on urban and rural highways.

3.3 RSV Methodology

Automobile safety performance specifications for the mid-1980's can be established by either arbitrarily setting the requirements, leaving open the feasibility of their achievement, or by formulating realistic bounds on vehicle component capability, production difficulty and cost, and then search within these bounds for the combination of hardware design parameters which yield the least human injury.

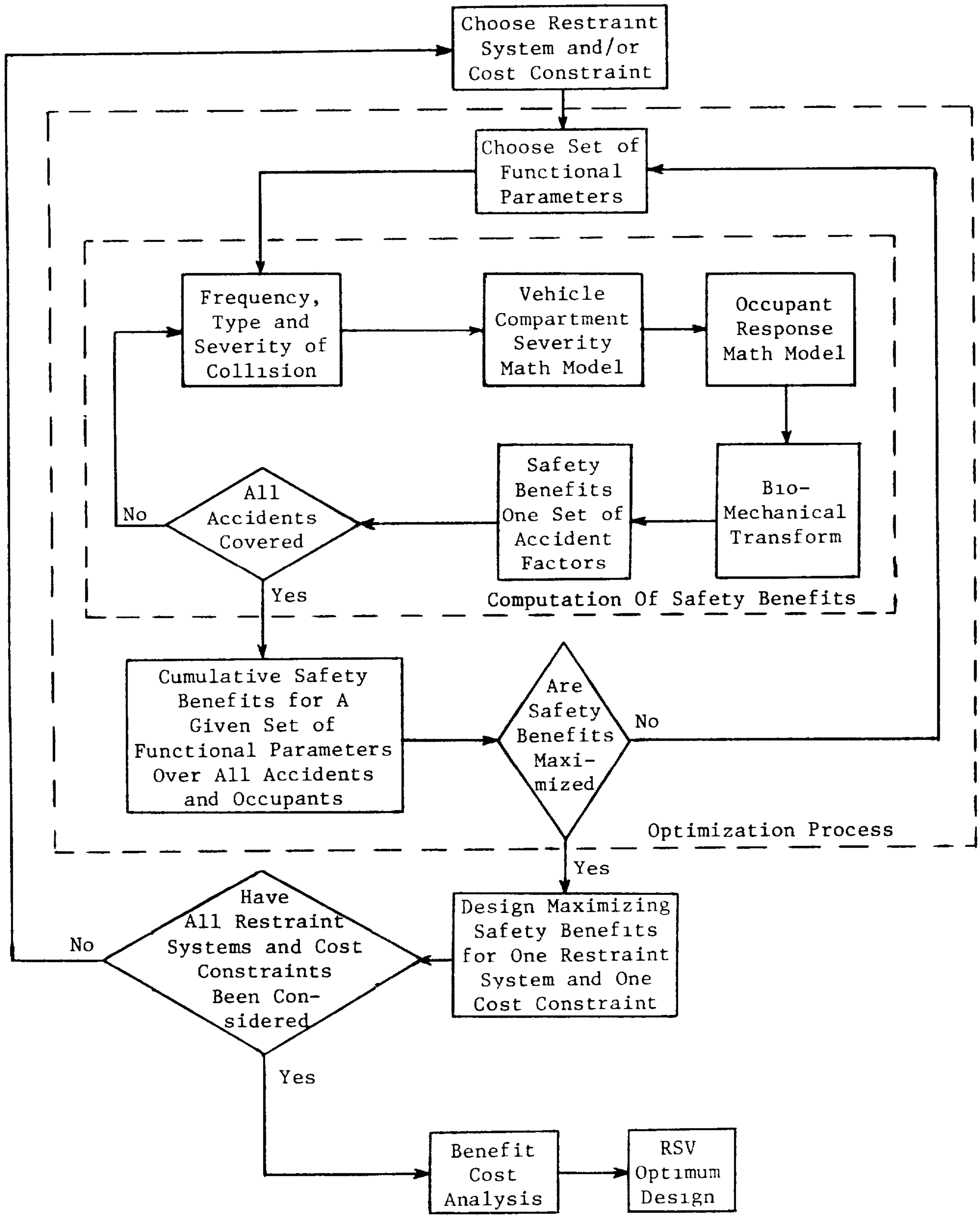
NHTSA objectives for the RSV performance requirements specifically include; "compatibility of these requirements with environmental policies, efficient energy utilization, and consumer economic costs." The approach -- hardware design parameter search -- is used to ensure that the NHTSA objectives are satisfied. The task is then one of determining the allocation of countermeasures among the various elements of the vehicle hardware components in such a way that the casualty measure is minimized. The countermeasures are constrained by total vehicle weight (3,000 pounds), producibility, and cost.

The methodology, depicted in Figure 36, to derive the optimum RSV design consists of selecting one of the candidate occupant restraint systems and a set of practical design constraints, iteratively computing the safety benefits measure and optimizing that occupant restraint/vehicle structure system -- maximizing the safety benefits. When all candidate systems are optimized, the benefit-cost analysis determines which system yields the most effective occupant restraint/vehicle structure combination.

System Model Inputs. The vehicle and occupant restraint functional design parameters, such as front stiffness and air bag deployment

Figure 36

RSV Methodology



time, characterizing a particular vehicle/restraint system to be optimized are defined with their associated weight and cost implications. The allowable range of values for each functional parameter to be optimized is also defined and inputed to the system model.

Computation of Safety Benefits. The array of accidents projected for the RSV environment of 1985 by type, frequency, and severity remains the same for all vehicle/restraint systems considered in the study. The vehicle compartment simulation is accomplished by unique math models developed for each collision mode -- front, side, and rear. Each of these models is exercised over the appropriate portion of the accident array for a set of vehicle functional parameter values to generate the compartment severity. A set of restraint functional parameter values is combined with the compartment severities and occupant size distribution in the occupant response model. The occupant response outputs -- accelerations, etc. -- are converted to a probability of survival by a biomechanical transform. The safety benefits measure for this iteration is computed by summing the products of the number of occupants exposed at each level by the probability of survival for the respective levels.

Optimization Process. The optimization algorithm adjusts the values of the functional parameters after the first interaction in a programed search attempting to find values which will increase the safety benefits. New safety benefits are computed for the adjusted values of the functional parameters. This optimization process continues until the set of functional parameter values are determined which maximize the safety benefits within the basic cost/weight constraint.

Benefit-Cost Analysis. After the safety benefits for all candidate system configurations have been maximized, the total countermeasure cost to equip all RSV's is compared to the corresponding safety benefits to determine the most effective system.

A detailed description of the optimization system is contained in Volume III along with the system results and the RSV performance specifications.

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