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-FECTS OF RECENT VEHICLE DESIGN CHANGES ON SAFETY PERFORMANCE
Volume I

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16. Abstract

Design changes in 1974-1977 model year passenger cars have been identified and a preliminary evaluation has been made of the safety effects of design changes inspired by fuel economy requirements. The 1977 General Motors full-size cars and the Volkswagen Rabbit were found to be the only significant design change vehicles. These vehicles do not demonstrate significantly higher risks of fatality in accidents than do other vehicles of similar weight or roominess. Little change is observed in the aggregate characteristics of the 1974-1977 vehicle fleets, although the effects of the 1977 General Motors downsizing are observable. Methodologies have been implemented for the identification of vehicle design changes, for the calculation of observed fatality rates by make and model, and for the projection of future fatality and injury experience based on perceived trends in vehicle design and sales. There are a number of recommendations for further investigation of the effects of vehicle design on safety and for extension of the work to include 1978 and 1979 Model Year cars, Light Trucks and Vans.

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METRIC CONVERSION FACTORS

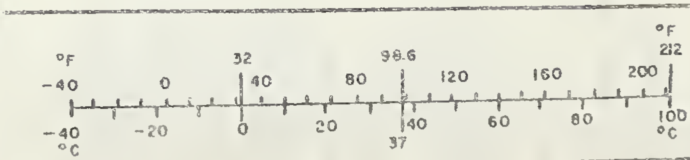
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECTION 1

INTRODUCTION

This interim report presents the results obtained to date under contract DOT-HS-7-01759, "Effects of Recent Vehicle Design Change on Safety Performance".

The analysis conducted is divided into four segments described briefly as follows:

1. Identification of Automobile Design Change 1974-1977

Individual model lines of passenger cars of model years 1974-1977 have been characterized by values of certain descriptive dimensional parameters including curb weight, width, length, height, roominess, and crush lengths for front, side, and rear body sections. Calculations have been performed to compare individual models from year to year, both to earlier versions of the same model and to versions of other models which are similar to given models of interest. In this way, design changes and innovative new model lines were identified and their degree of difference from other and/or earlier models was quantified. Certain models representing significant design changes have been identified. At the same time, overall characteristics of the vehicle fleets of each model year were characterized by frequency distributions over the design parameters and by mean values of those parameters.

2. Analysis of Observed Fatality Rates by Model Year and Make and Model

The Fatal Accident Reporting System (FARS) file was used to calculate observed fatality rates for individual model lines of passenger cars. In this way, the actual safety performance of individual models identified as significant design change vehicles was investigated. At the same time, variations in fatality experience as a function of make and model were obtained. Analysis of this data by model year has allowed examination of the overall effects of ongoing change in automobile design over the years.

3. Relationship of Observed Fatality Rate to Design Parameters

A preliminary regression analysis relating the Observed Fatality Rate by make and model to the values of the design parameters describing those models has been performed. Although a large amount of variability exists in the data due to statistical fluctuations, data uncertainties, and factors not accounted for, some insight into the dependence of safety outcome on design characteristics has been gotten.

4. Assessment of Future Impact

A computer model, the Kinetic Research Accident Environment Simulation and Projection Model (Ref. 1) has been utilized to project fatality and injury experience into the 1980-1990 timeframe. The KRAESP model allows specification of various scenarios of vehicle number, size, and weight mix, vehicle crashworthiness characteristics, restraint system performance, and so on, in order to measure the ultimate effects of design trends now perceived.

Each of these segments constitutes a section of this report. These, together with the Introduction, Summary & Conclusions, and Recommendations, are presented as follows:

Section 1	Introduction
Section 2	Identification of Automobile Design Change 1974-1977
Section 3	Analysis of Observed Fatality Rates By Model Year and By Make and Model
Section 4	Relationship of Observed Fatality Rates to Design Parameters
Section 5	Assessment of Future Impact
Section 6	Summary
Section 7	Conclusions
Section 8	Recommendations

SECTION 2

IDENTIFICATION OF AUTOMOBILE DESIGN CHANGE: 1974-1977

2.1 APPROACH

Two methodologies were used to analyze automobile design changes.

The first is a model by model comparison which quantifies the year to year degree of change for models existing in consecutive years. Alternatively, the degree of design change for a newly introduced model is assessed by comparing its characteristics with models of similar roominess which existed in previous years. This methodology also employs a program which ranks models in any given baseline model year by their degree of similarity to any given subject model in order to determine to what extent a new or changed model might be truly different from earlier makes and models.

The second methodology concerns itself with the aggregate characteristics of the automobile fleet of each model year. In order to measure trends in automotive design over a period of time comparisons between model year fleets are made using the mean values and frequency distributions of various automotive design parameters.

In an analysis which is intended to be a survey of automotive design changes the researcher is restricted to characterizations of automotive design which can be documented for all makes and models with a high degree of completeness. This study has chosen to characterize the design of an individual model of automobile by specification of a set of nine parameters based on specifications used by the Motor Vehicle Manufacturers Association (MVMA). These parameters are as follows (with MVMA codes):

1. Curb Weight (lbs.)
2. Wheelbase (in.) - L101
3. Width (in.) - W103
4. Length (in.) - L103
5. Height (in.) - H101

6. Roominess Index (in.) - the sum of Front and Rear Head, Leg, and Shoulder Room and Front Seat Height.
R. I. = H61+H63+L34+L51+W3+W4+H30

7. Rear Overhang (in.) = L105

8. Front Crush Length (in.) - nominally front of bumper to firewall (Front of Dash). F.C.L. = L104 (Front Overhang) + L101 (Wheelbase) - L127 (Center of Rear Wheel to Body "0" Line)- L130 (Body "0" Line to Windshield Cowl Point or Front of Dash).

9. Body Side Thickness (in.) - one half the difference of interior and exterior dimensions at the rear edge of the front door. B.S.T. = (W117 (Width at B pillar) - W3 (Front Shoulder Room) ÷ 2

These parameters and certain considerations concerning their proper measurement and definition are discussed in the previous progress reports (Ref. 2).

2.2 AUTOMOTIVE DESIGN DATA SETS

Values of the above parameters for makes and models introduced in the years 1974-1977 have been gathered primarily from a data base compiled under DOT-NHTSA contract with Volkswagen, A.G. (Ref. 3) in which MVMA specifications and registration data are provided for a comprehensive list of passenger car makes and models. Problems of completeness and accuracy of data in the VW data set have been discussed in previous progress reports. (Ref. 2). Missing data entries have been supplemented by measurements of automobiles on dealer lots and by estimating values of missing data from known values for similar models either within or across model years. The current state of completeness of the design parameter data is displayed in Table 2-1.

The creation of a design parameter data set in useful form has required considerable manipulation, particularly of make and model designations and of registration data. The original VW data base identifies makes and models at a fine level including variations of body style, engine type, model name and so on. This proliferation of variants in model description causes severe problems in making year to year comparisons and in attempting make and model specific references to other data sets such as the Fatal Accident Reporting System (FARS) files. Given the degree of completeness and accuracy of the data for all the variant models and considering the need to coordinate with accident data (such as FARS), the obvious procedure was to compress the model types into a shorter list which would be more consistent from year to year and data set to data set, and which would allow fewer ambiguities of classification. Consequently, the data sets finally used for this analysis are coded as to make and model by a modified version of the FARS coding scheme effective for the year 1977. This coding scheme is reproduced as Appendix E. Also included are coding tables for converting VW data base codes to modified FARS codes. It should be noted that there are certain potential ambiguities such as the listings under Plymouth for "Satellite/Fury" and Gran Fury/Fury". This ambiguity, for example, comes about by the manufacturer renaming a certain model line without in fact changing the model physically. Thus, in 1975 the old Satellite is renamed Fury and the old full-sized Fury is then marketed under Gran Fury. The coding tables in Appendix E detail these situations.

The FARS data base is also unsatisfactory in that it does not provide up to date coding for certain newly introduced models, which are coded by FARS as "unknown" or "other". These models have been assigned codes in Appendix E but are listed separately to indicate this variation from the official version of FARS. The models in question are:

1977 Ford LTD II	211,661 Registrations
1977 Dodge Diplomat	13,409 Registrations
1977 Chrysler LeBaron	24,855 Registrations
1977 Lincoln Versailles	6,367 Registrations
1977 Datsun F10	45,688 Registrations
1977 Datsun 810	23,100 Registrations
1977 Datsun 200SX	35,143 Registrations
1976 Datsun F10	14,211 Registrations

Certain other problems also exist in the registration data. Chief among these is the fact that the 1977 VW data file does not contain registration figures for the 1977 model year, nor were we able to obtain 1977 model year figures of the type used by VW in previous years. However, R. L. Polk & Co.'s National Motor Vehicle Population Profile listing models by model year registered as of July 1, 1976 and July 1, 1977 was available.*

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*Registrations in the State of Oklahoma are not included.

TABLE 2-1. - NUMBER AND PERCENT OF REGISTRATIONS FOR WHICH DATA IS UNKNOWN

MODEL YEAR	TOTAL REGISTRATIONS*	CURB WEIGHT	WHEELBASE	WIDTH	LENGTH	HEIGHT	ROOMINESS	REAR OVERHANG	FRONT CRUSH LENGTH	BODY SIDE THICKNESS
1974	9,813,162	96,642	96,642	96,642	96,642	96,642	384,215	574,079	574,079	574,079
		1.0%	1.0%	1.0%	1.0%	1.0%	3.9%	5.9%	5.9%	5.9%
1975	7,453,350	108,118	108,118	108,118	108,118	108,118	197,882	344,581	344,581	344,581
		1.5%	1.5%	1.5%	1.5%	1.5%	2.7%	4.6%	4.6%	4.6%
1976	9,343,810	215,324	215,324	215,324	215,324	215,324	384,141	477,751	477,751	477,751
		2.3%	2.3%	2.3%	2.3%	2.3%	4.1%	5.1%	5.1%	5.1%
1977	10,352,262	108,256	108,256	108,256	108,256	108,256	226,198	433,909	433,909	433,909
		1.0%	1.0%	1.0%	1.0%	1.0%	2.2%	4.2%	4.2%	4.2%

*Based on estimated total registrations.

Since for 1977 these are partial year figures only, and since earlier model year cars are depleted by scrappage, it was necessary to compare the 1977 and 1976 figures to each other and to the VW figures for 1974-1976 model years in order to estimate values for original total registrations of each model of automobile.

Table 2-2 displays the ratios between the various registration figures for the model years 1974-1976 in the 1976 Population Profile, the 1977 Population Profile and the original year end registrations used by VW in order to evaluate scrappage rates and make the projection between mid-year and estimated total original registrations. It is evident from the tables that there are some problems with data consistency among the three sets of registrations figures, especially for imports. Some of the difficulties in accounting for import car registrations have been discussed in Ref. 2. The data set currently in use contains three registrations figures for each make, model, and model year.

1. Actual July 1, 1977 registrations.
2. Actual July 1, 1976 registrations.
3. Estimated total original registrations.

The estimated registrations are based on July 1, 1977 figures which are then multiplied by the following factors derived from Table 2-2.

Factor to Multiply July 1, 1977 Registrations
To Derive Total Original Registrations

Model Year	Domestic	Import
1974	1.06	1.06
1975	1.03	1.03
1976	1.00	1.00
1977	1.402	2.024

These estimated total original registrations are used in computing design change values and aggregate distributions. The appropriate 1976 and 1977 mid-year registrations are to be used for exposure data in calculating accident rates.

TABLE 2-2. COMPARISON OF 1976 AND 1977 NATIONAL MOTOR VEHICLE POPULATION PROFILE WITH VW DATA BASE REGISTRATIONS BY MODEL YEAR

MODEL YEAR	1976 NMVPP/VW	1977 NMVPP/VW	1977 NMVPP/ 1976 NMVPP
Domestic Cars			
1974	1.013	.995	.982
1975	1.051	1.032	.982
1976	.722	1.012	1.402
Imported Cars			
1974	1.330	1.282	.964
1975	.788	.717	.910
1976	.577	1.168	2.024

AVERAGE VALUE OF 1977 NMVPP/1976 NMVPP FOR MODEL YEARS 1974 AND 1975	
Domestic	0.982
Import	0.943
Weighted Average	0.974

It should be noted that the ideal information to have would be actual end of year registrations by model year. In general the procedures used here may slightly overestimate both original total figures and year end figures, especially for imports.

The final versions of the design parameters and registration data are kept on computer files under the names 74VW., 75VW., and 76VW., and 77VW. for which the data items are:

Index (Make and Model Code)
Estimated Total Original Registrations
Curb Weight
Wheelbase
Width
Length
Height
Roominess Index
Rear Overhand
Front Crush Length
Body Side Thickness
1976 Midyear Registrations
1977 Midyear Registrations
Model Name

2.3 ANALYSIS OF THE DATA

The identification of automotive design change for 1974-1977 passenger cars includes the following subanalyses:

1. Calculation of degree of change from year to year for models existing in successive years (Section 2.3.1).

2. Identification of new and discontinued models in each model year. Calculation of the degree of difference between new models and 1974 model year vehicles of similar roominess. This calculation is actually presented for all previously existing models as well (Section 2.3.2).

3. Identification of previously existing models which are similar to any new or apparently changed models (Section 2.3.3).

4. Summary list of significant design change vehicles for the years 1974-1977 based on the criteria in 1 to 3 above (Section 2.3.4).

5. Computation of averages and frequency distributions for the vehicle fleet as a function of model year. Display of average values of each design parameter as a function of roominess (Section 2.3.5).

6. Development of regression models for curb weight as a function of other design parameters (Section 2.3.6).

7. Summary and conclusions (Section 2.3.7).

2.3.1 Degree of Change for Vehicles Existing in Successive Years

Analysis of design change for models which exist in successive years is carried out by comparison of the values of each of the design parameters of the new year model with corresponding values for the old year model. In addition the average of the absolute value of the change over all the parameters is calculated as well as degree of change weighted by registrations.

The formula for this computation is:

$$\text{Change}_i = \frac{a'_i - a_i}{a_i} \times \text{SCALE}_i$$

where i refers to one of the nine design parameters, a-prime indicates the new model year value, a-unprimed is the old model year value, and SCALE is a parameter which expresses the size of the change as a fraction of the total variation possible in each parameter.

The values of SCALE are determined by the relative size of the range of values in each parameter as computed below:

Parameter	Range	Middle of Interval	Ratio of Range to Middle of Interval	$\text{SCALE}=\text{Ratio}^{-1}$
Curb Weight (lbs)	1500-6000	3750	1.20	.83
Wheelbase (in.)	85-135	110	.45	2.22
Width (in.)	57-82	69.5	.36	2.78

Parameter	Range	Middle of Interval	Ratio of Range to Middle of Interval	SCALE= Ratio^{-1}
Length (in.)	150-240	195	.46	2.17
Height (in.)	47-60	53.5	.24	4.16
Roominess (in.)	240-300	270	.22	4.55
Rear Overhang (in.)	35-80	57.5	.78	1.28
Front Crush Length (in.)	25-65	45	.89	1.12
Body Side Thickness (in.)	4-10	7	.86	1.16

The use of this factor compensates for the fact that a small absolute change in a certain parameter (e.g. height) may be a significant change relative to the range of variation of the values of that parameter.

The formula for weighted change in a parameter is:

$$\text{Weighted Change}_i = 10^7 \times \text{Change}_i \times \frac{(\text{Registrations}'+\text{Registrations})}{2} \div \frac{(\text{Total Registrations}'+\text{Total Registrations})}{2}$$

In other words weighting is based on the average registrations of the subject model over the two years in question as a fraction of the total average registrations of all cars in those two years. The factor of 10^7 scales the values to a representative automobile fleet of ten million cars. Appendix A contains output for all vehicles ranked by average absolute value of change, weighted average change, change in curb weight, and weighted change in curb weight for each of the years 1975, 1976, and 1977 relative to 1974, for 1976 relative to 1975, and for 1977 relative to 1976. Appendix B is a listing of changes in all parameters for all cars for the same sets of years as in Appendix A but no rankings or weightings are applied.

Table 2-3 is a list of those vehicles which had changes greater than 5% in the average of all parameters or greater than 10% in curb weight. Also listed in this table is the rank relative to roominess class, which will be discussed in the next section.

It can be seen in this table that only in 1977 do design changes occur that have a significant impact measured by number of vehicles and magnitude of change. This is particularly true if one is looking for downsizing effects inspired by fuel economy requirements. One should note that the changes for Datsun 260Z are really a reflection of new model introductions in the 240-260-280 series and that the changes in Opel correspond to a shift from the German made Opel to the Japanese Opel by Izuzu. Similarly the data for Honda is affected by addition of the Accord to the Civic line.

Regarding the 1977 design changes, the effects of the downsizing of the 1977 General Motors full-size lines dominate the tables with reductions in curb wieght of ten to fifteen percent. Ford Thunderbird also participates in this downsizing. The remaining models represented are a scattering of imports and the Chrysler Corporation intermediates which seem to have suffered some significant weight increases in the years 1974 to 1977.

The use of the Rank by Comparison to Roominess Class is to determine if any of the significant design change vehicles identified in Table 2-3 represent innovations in design. It can be seen from the ranks, as will be discussed more fully in the next section, that almost uniformly these vehicles are not remarkable different from previously existing cars of similar roominess.

One should be aware that the existence of a major design change in a given model line does not necessarily represent an innovation or even a trend in design. This is the case if the new model, as different as it may be from the previous model of the same line, is nevertheless very similar to some other model line previously existing. It will be seen that this is the case to greater or lesser degrees for most of the design change vehicles identified in this analysis.

2.3.2 Analysis of New and Discontinued Models

The analysis of Section 3.1 is not applicable to models which are new introductions or are discontinued in a given year.

TABLE 2-3 - LIST OF SIGNIFICANT DESIGN CHANGE VEHICLES BASED ON AVERAGE CHANGE GREATER THAN 5% OR CHANGE IN CURB WEIGHT GREATER THAN 10%

Years	Model Name	Average Change	Rank by Comparison to Roominess Class	Change in Curb Weight	Rank by Comparison to Roominess Class
1974-1975	Datsun 260Z	.067	--	.125	--
1975-1976	Opel	.118	17	-.069	19
1976-1977	Colt	.104	14	-.077	21
	98	.100	57	-.141	25
	Deville	.099	51	-.139	49
	Riviera	.099	43	-.135	28
	Estate Wagon	.094	42	-.174	35
	LeSabre	.092	35	-.156	6
	Electra	.087	49	-.147	22
	Catalina	.086	27	-.116	20
	Thunderbird	.085	64	-.144	58
	Bonneville	.083	28	-.154	14
	Delta 88	.083	37	-.159	8
	Fleetwood	.078	33	-.109	84
	Cougar	.077	46	.023	43
	Impala/Caprice	.065	21	-.063	30
	Mazda	.050	--	.058	--
1974-1976	Opel	.122	17	-.061	26
	Datsun 260Z	.061	--	.083	--
	Corolla	.042	10	.132	38
	Honda	.037	3	.103	8
1974-1977	Opel	.115	18	-.024	41
	98	.103	67	-.153	36
	Deville	.100	65	-.125	60

TABLE 2-3 (CONTINUED)

Years	Model Name	Average Change	Rank by Comparison to Roominess Class	Change in Curb Weight	Rank by Comparison to Roominess Class
1974-1977 (continued)	Riviera	.099	43	-.143	32
	Cougar	.098	34	.046	35
	Estate Wagon	.094	42	-.176	43
	Delta 88	.087	41	-.175	12
	Porsche	.085	--	.119	--
	Colt	.085	26	-.041	42
	Catalina	.084	30	-.116	24
	Bonneville	.083	35	-.160	14
	Electra	.080	62	-.160	27
	LeSabre	.079	40	-.163	10
	Fleetwood	.076	33	-.104	72
	260Z	.073	--	.089	--
	Thunderbird	.073	77	-.150	69
	Impala/Caprice	.069	22	-.057	39
	Corolla	.069	25	.100	47
	Honda	.069	3	.143	9
	Satellite/Fury	.068	46	.126	53
	Charger/Crnt/ Monaco	.062	44	.125	52
	Matador	.057	45	.061	28
	Fiat	.055	--	.059	7
	LeMans	.053	37	-.028	26
	Capri II	.041	14	.105	18
	Hornet	.026	82	.100	81

There are two ways to measure the impact of model introductions and discontinuations. One is to examine the lists of previously existing or continuing models for those which are similar to the subject model. In this way one can determine if the subject model is an innovation or a unique design which may be characteristic of a trend. Results of this type of analysis are discussed in Section 2.3.3. A second method to use with new and discontinued cars is to compare these cars with previously existing cars that are in some way perceived as being "similar" to the subject model.

This analysis utilizes the roominess index as an appropriate parameter by which cars can be classified into groups of a similar type. Generally speaking such a classification would want to provide model groupings which coincide with perceptions of market class and thereby compares given models with those it would replace or compete with in the vehicle mix. Assuming that interior space is a major factor in the choice of an automobile and that roominess measures generally correspond with the traditional vehicle size classes, roominess index constitutes an appropriate parameter by which vehicles may be classified. Classification by roominess has the advantage that it is a numberical measure that can be applied systematically and unambiguously. The main disadvantage is that the roominess may be unknown for some cars, resulting in a loss of information. Table 2-4 contains a listing of all 1974-1977 models by groups in ten inch increments of roominess.

Using groupings by roominess one may compare vehicles in a given year to vehicles of similar roominess in some previous year. This analysis involves the computation of the registration weighted average value of each of the design parameters. The average is computed over all vehicles of a given year whose roominess index falls within five inches positive or negative of each value of roominess from 230" to 310" in one inch increments. These sets of average values are then used as "typical" models in each year for each value of roominess. One can then make comparisons between these "typical" models and models in succeeding years in exactly the same way that design changes were analyzed in the previous section. Appendix C contains a listing of these comparisons for all models in all years relative to 1974 models and for 1976 models relative to 1975 and 1977 models relative to 1976 models. These listings are ranked by

TABLE 2-4 - MODELS BY ROOMINESS IN TEN INCH GROUPS 1974-1977

Roominess Index	Model Year 1974	1975	1976	1977
245 to 255	Mustang II	Mustang II	Chevette	Chevette
	Beetle	Beetle	Mustang II	Mustang II
	Datsun B210	Scirocco	Skyhawk	Skyhawk
	Capri II	Opel	Beetle	Starfire
	Colt	Datsun B210	Scirocco	Beetle
	Honda	Capri II	Opel	Scirocco
		Colt	Datsun B210	Opel
		Honda	Datsun 710	Datsun B210
			Datsun F10	Datsun 710
			Capri II	Datsun F10
			Honda	Corolla
			Arrow	Celica
				Capri II
				Colt
				Honda
				Arrow
255 to 265	Camaro	Camaro	Camaro	Camaro
	Vega	Vega	Vega	Vega
	Pinto	Monza	Monza	Monza
	Barracuda	Pinto	Pinto	Pinto
	Dasher	Firebird	Firebird	Firebird
	Gremlin	Astre	Astre	Astre
	Javelin	Skyhawk	Sunbird	Sunbird
	Opel	Starfire	Starfire	Dasher
	Datsun 610	Dasher	Dasher	Rabbit
	Datsun 710	Rabbit	Rabbit	Bobcat
	Corolla	Bobcat	Bobcat	Gremlin
	Corona	Gremlin	Gremlin	Corona
	Celica	Datsun 610	Datsun 610	
		Datsun 710	Corolla	
		Corolla	Corona	
		Corona	Celica	
		Celica	Colt	

TABLE 2-4 (CONTINUED)

Roominess Index	Model Year 1974	1975	1976	1977
265 to 275	Nova Monte Carlo Maverick Firebird Ventura Apollo/Skylark Valiant Omega Dart Challenger Montego Cougar Comet Hornet Audi	Nova Monte Carlo Maverick Elite Granada Ventura Apollo/Skylark Valiant Omega Dart Cougar Comet Monarch Hornet Pacer Audi	Nova Monte Carlo Maverick Elite Granada Ventura Apollo/Skylark Valiant Volare Omega Dart Aspen Cougar Comet Monarch Seville Hornet Pacer Volvo Audi	Nova Monte Carlo Maverick Granada Grand Prix Ventura Apollo/Skylark Omega Diplomat Comet Monarch Seville Hornet Pacer LeBaron Versailles Datsun 810 Volvo Audi
275 to 285	Malibu Torino Thunderbird LeMans Grand Prix Century Satellite/Fury Cutlass Vista Cruiser Charger/Crnt/ Monaco ElDorado Matador Mark IV Volvo	Malibu Torino LTD/Galaxie Thunderbird LeMans Grand Prix Century Satellite/Fury Cutlass Vista Cruiser Charger/Crnt/ Monaco Montego ElDorado Cordoba Mark IV Volvo	Malibu Torino Thunderbird LeMans Grand Prix Century Satellite/Fury Cutlass Vista Cruiser Charger/Crnt/ Monaco Montego Marquis ElDorado Cordoba Mark IV	Malibu Thunderbird LTD II Century Satellite/Fury Volare Cutlass Vista Cruiser Charger/Crnt/ Monaco Aspen Cougar ElDorado Cordoba Mark V

TABLE 2-4 (CONTINUED)

Roominess Index	Model Year 1974	1975	1976	1977
285 to 295	Impala/Caprice LTD/Galaxie Catalina Bonneville Grand Ville LeSabre Riviera Fury/Grand Fury Delta 88 Toronado Monaco Monterey Marquis Calais DeVille Fleetwood Ambassador Newport New Yorker Town & Country Imperial Continental	Impala/Caprice Catalina Bonneville Grand Ville LeSabre Riviera Fury/Grand Fury Delta 88 Toronado Monaco Marquis Calais DeVille Matador Newport New Yorker Town & Country Imperial Continental	Impala/Caprice LTD/Galaxie Catalina Bonneville LeSabre Riviera Estate Wagon Fury/Grand Fury Delta 88 98 Toronado Monaco/Royal Monaco Calais DeVille Fleetwood Matador Newport New Yorker Town & Country Continental	Impala/Caprice LTD/Galaxie LeMans Catalina Bonneville LeSabre Electra Riviera Estate Wagon Fury/Grand Fury Delta 88 98 Toronado Monaco/Royal Monaco Marquis DeVille Fleetwood Matador Newport New Yorker Town & Country Continental
295 to 305	Electra Estate Wagon 98	Electra Estate Wagon 98 Fleetwood	Electra	
Two Seaters	Corvette Karmann Ghia Datsun 260Z Porsche MG	Corvette Datsun 260Z Porsche MG	Corvette Datsun 260Z Porsche MG	Corvette Datsun 260Z Porsche MG
Missing Roominess Index	411/412 Mark II Mazda Fiat Subaru	Mark II Mazda Fiat Subaru	Mark II Mazda Fiat Subaru	Mazda Fiat Subaru

differences in the average of all parameters, by differences in curb weight, and by registration weighted values of the overall difference and of the difference in curb weight. The registration weighting is based on total estimated registrations in each subject model and model year expressed as a fraction of total model year registrations normalized to a ten million car fleet.

The difference in a given parameter is expressed as:

$$\text{DIFFERENCE}_i = \frac{a_i' - \bar{a}_i}{\bar{a}_i} \times \text{SCALE}_i$$

where i indicates one of the nine design parameters, a_i-prime is the subject car value, $\bar{a}_i$ is the average value of parameter i over all cars in the selected base line year which have roominess within five inches of the roominess of the subject car. SCALE_i is as before.

The weighted difference is expressed as:

$$\text{WEIGHTED DIFFERENCE}_i = 10^7 \times \text{DIFFERENCE}_i \times \frac{\text{(REGISTRATIONS)}}{\text{(TOTAL REGISTRATIONS)}}$$

where REGISTRATIONS are the estimated total registrations of the subject model in the subject year and TOTAL REGISTRATIONS are the total estimated registrations of all cars in the subject year.

The tables in Appendix C do not, of course, include models which have unknown roominess. Two seaters are excluded as well. The missing cars, by year, are:

1974	Corvette	1975	Corvette
	Karmann Ghia		Datsun 260Z
	411/412		Mark II
	Datsun 260Z		Mazda
	Mark II		Fiat
	Mazda		Porsche
	Fiat		MG
	Porsche		Subaru
	MG		
	Subaru		
1976	Corvette	1977	Corvette
	Datsun 260Z		Datsun 260Z

1976	Mark II	1977	Mazda
	Mazda		Fiat
	Fiat		Porsche
	Porsche		MG
	MG		Subaru
	Subaru		

Since the comparisons made in this section are relative to a distribution of models rather than to one particular model, it is necessary to evaluate how large a difference from the average of that distribution should be considered significant. This can be done by stating the mean and standard deviation of the differences for 1974 model year vehicles when compared to models of similar roominess in 1974. These values are as follows:

	Average	Standard Deviation
Curb Weight	-.006	.082
Wheelbase	-.004	.052
Width	-.006	.101
Length	-.006	.066
Height	+.005	.120
Rear Overhang	-.005	.075
Front Crush Length	-.004	.087
Body Side Thickness	-.004	.123
Average Absolute Value of All Parameters	.060	.049

All parameters are scaled as described previously.

One can use the above data to formulate criteria for identifying innovative or atypical vehicles among new deisgn introductions.

Looking in Appendix C at differences in curb weight and average overall difference one finds only a handful of vehicles which exceed three standard derivations from the average for any model year compared to 1974. These models are:

Audi	1974-1977
Cougar	1974
Volvo	1974-1975
Honda	1974-1977
Dasher	1974

Mark IV	1974-1976
Mustang II	1976
Rabbit	1975-1977

Of these only Rabbit is a new model introduction. The Datsun 200 SX is a new model but is anomalous in that its roominess at 238 inches leaves it in a category with no comparable 1974 model. Hence, no results are reported for this model. In any case, the 200 SX is characteristic, like Mustang II, of those cars which implement sporty styling and performance capability in a vehicle which is of low roominess and increased weight. The remaining cars are either roomy, compact sized imports or large over-weight luxury cars. Rabbit, therefore, is the only new model introduction which falls on the extremes of design characteristic. Even so, there are still pre-existing vehicles which share Rabbit's ability to accomplish high roominess in a low size and weight vehicle. Indeed the Audi designs and VW Dasher are fore-runners of the front wheel drive, thin body shell approach typified by Rabbit. The main difference is Rabbit's unusually short rear overhang and the fact that it competes in a different size and price class.

If one examines the list of models exceeding two standard deviations from the average difference measure in curb weight or in average of all parameters, the following additional vehicles are found:

Thunderbird	1974-1976
Corolla	1974
Firebird	1975-1976
Camaro	1977
Monza	1975
Starfire	1975-1976
Skyhawk	1976-1977
Datsun	1977
Pacer	1975-1977
Mark V	1977
Dasher	1975-1977
Volvo	1977

of these Mark V, Datsun 810, Monza, Starfire, and Skyhawk are new models. Mark V is really a continuation of Mark IV and although the new model is somewhat lighter in weight it is still heavy for its roominess class. These cars and Thunderbird fall in that same class of large personal luxury cars quoted before. Similarly Camaro, Firebird, Monza, Starfire, and Skyhawk are, like Mustang II and Datsun 200 SX, examples of relatively heavy, sport styled, low height, low roominess vehicles. Corolla and Datsun 810 are the typical efficient import design. Pacer, however, is probably unique in its short length and exaggerated body side thickness but does not seem to have led to any new trend in design.

A second way of examining the data in Appendix C is to list all the new and discontinued models with their ranks relative to difference in curb weight and average difference in all parameters. This is done in Table 2-5. Models ranking in the top tne in any category are marked with an asterisk. The only models so ranking either in the raw or the weighted scores are:

1975 Monza
1975 Elite
1975 Granada
1975 Rabbit
1975 Pacer
1976 Chevette

We have already noted the typical characteristics of large luxury cars, of which Elite is an example and of sporty cars like Monza. The only model in the above list which ranks in the top ten in all columns of Table 2-5 is Rabbit. Chevette and Granada are only there by virtue of a large number of registrations. Pacer, again, is found to offer an anomalous combination of dimensions but is not remarkably deviant in weight from other cars of its roominess class. Pacer's design is evidently not motivated by desires to improve fuel economy.

Table 2-6 is a listing of discontinued models with their different rankings relative to 1974 models. Only Elite and Mark IV are significant, and both of these are typical of the large personal/luxury category, but are hardly trends in fuel economy inspired design change efforts. In fact, Mark IV is really continued as the Mark V. Elite leaves the scene after a tenure of two years just as oversized for its roominess as when introduced, relative to other cars in the respective years.

TABLE 2-5 - LIST OF NEW MODELS IN EACH MODEL YEAR BY RANK IN CATEGORIES OF DIFFERENCE RELATIVE TO MODELS OF SIMILAR ROOMINESS IN 1974

Year	Model Name	Curb Weight	Weighted Curb Weight	Average	Weighted Average
1975	Monza	9*	2*	18	9*
	Elite	15	8*	28	18
	Granada	49	13	44	6*
	Astre	38	40	32	35
	Skyhawk	12	31	19	46
	Starfire	11	30	20	47
	Rabbit	5*	3*	3*	2*
	Scirocco	13	44	8	51
	Monarch	40	32	39	30
	Bobcat	25	38	27	50
	Pacer	51	46	6*	11
	Cordoba	64	45	71	42
1976	Chevette	16	5*	16	5*
	Sunbird	29	37	27	41
	Volare	44	13	45	11
	Aspen	37	12	35	15
	Seville	17	26	42	46
	F-10	19	57	13	67
	Arrow	57	66	46	65
1977	LTD II	77	49	69	27
	Diplomat	83	84	72	83
	LeBaron	82	83	73	78
	Mark V	8*	21	19	30
	Versailles	58	82	60	84
	810	16	52	8*	49

*Indicates rank in the top ten.

TABLE 2-6 - LIST OF DISCONTINUED MODELS IN EACH MODEL YEAR BY RANK IN CATEGORIES OF DIFFERENCE RELATIVE TO MODELS OF SIMILAR ROOMINESS in 1974

Year	Model Name	Curb Weight	Weighted Curb Weight	Average	Weighted Average
1974	Barracuda	36	68	18	63
	Challenger	55	71	17	59
	Karmann Ghia	--	--	--	--
	411/412	--	--	--	--
	Monterey	68	72	65	71
	Ambassador	20	45	40	60
	Javelin	32	52	14	45
1975	Grand Ville	67	74	80	80
	Imperial	21	62	30	76
1976	Torino	44	21	45	20
	Elite	7*	3*	17	10*
	Valiant	36	41	42	41
	Dart	40	49	43	49
	Montego	43	56	60	72
	Calais	31	75	57	85
	Mark IV	2*	15	7*	26
	Datsun 610	33	68	21	66
	Mark II	--	--	--	--

*Indicates rank in the top ten.

2.3.3 Identification of Previously Existing Model Similar to New, Discontinued, or Significantly Changed Models

The fact that a certain model line undergoes considerable change in a given year or that it is a new model which is different from previous models of similar roominess does not necessarily imply that any change of significance has occurred. If a changed vehicle or new vehicle is very similar to any one model which existed before, the major impact of the new or changed vehicle will be to alter the marketing distribution over vehicle model lines and not to establish a new vehicle type or trend in vehicle types in the automobile population.

Appendix D provides a set of tables in which each of the models pointed out by the analysis of the previous two sections has been matched to those 1974 model year vehicles which are most similar to the subject vehicle. This calculation is based on the same formula for calculation of a degree of difference or change that has been used in the previous sections, including the use of a SCALE factor. Listings are ranked by average difference over all non-missing parameters.

The models in these listings that have no model within five percent overall and within ten percent in each parameter are:

1975-1977	Rabbit
1975-1977	Skyhawk
1975-1977	Pacer
1975-1977	Monza
1976-1977	Chevette
1976-1977	Opel
1977	200SX
1977	Riviera
1977	Cougar
1977	Estate Wagon
1977	Delta 88
1977	Catalina
1977	Bonneville
1977	Electra
1977	LeSabre
1977	Fleetwood
1977	260Z
1977	Impala

1977 Corolla
1977 Honda
1977 LeMans
1977 Colt

In addition the following models have the characterisitics that they are similar only to themselves in 1974:

260Z
Honda
Corolla
Audi
Volvo
Dasher
Cougar
Hornet
Capri II
Mustang II
Camaro/Firebird

These lists may be divided into certain categories consisting of:

1. 1977 General Motors Downsizing
2. Rabbit, Audi, Volvo, Dasher -- models which are of moderate roominess and high roominess to weight characteristics. These are also high priced imports.
3. Pacer
4. Monza, Skyhawk, Starfire, Mustang II, 200SX, Camaro, Firebird, Capri II, 260Z -- models which are of sporty design and low roominess to weight characteristics.
5. Cougar, Hornet, LeMans -- miscellaneous American cars
6. Corolla, Colt, Opel, Chevette, Honda -- models which are small and of economical design.

It is clear that among the new models or versions of models Rabbit and the 1977 General Motors downsized cars demonstrate designs which make efficient use of materials to achieve designs light in weight with good roominess. Interestingly enough, the 1974 Ambassador and Matador models are consistently high in similarity to the latter models. The main discrepancy for those models is generally a longer wheelbase and thicker body sides. Whether one would want to say that these new cars, based on scaled differences in parameters, are really terribly different from certain 1974 models or not may be a question of judgement. Comments regarding this judgement were made in Ref. 2 and are reproduced in Appendix F. In that reference, the essential similarities between the 1977 Impala and 1975 Matador and LeMans and between 1977 Rabbit and 1974 Fiat are discussed pointing out that the new cars are not necessarily all that new compared to certain pre-existing models.

The general changes characteristic of the cars in category 6 above, are increases in weight over time and a good (but not equal to Rabbit) roominess to weight ratio. Opel, of course, has undergone a change from German to Japanese origin and hence really represents a new model which is of its own type but much in the general category with Honda, Corolla, Suburu, etc.

The cars in category 4 are characteristic of the sporty, performance-image, version of the compact car. They all represent counter trends to fuel economy induced design trends but also represent a significant portion of the automotive market.

2.3.4 Summary List of Significant Design Change Vehicles For 1974-1977

Three methods have been utilized to identify innovations in automotive design for 1974-1977 model year passenger cars:

1. Degree of change for vehicles manufactured in consecutive years.

2. Degree of difference from previous models of similar roominess for new model introductions.

3. Identification or lack of identification of previously existing models of similar roominess.

Based on the material presented in Sections 2.3.1 to 2.3.3., corresponding to the above methods of analysis one can present a summary of the apparent innovative or significantly changed models.

Based on significant changes from previous designs of the same model line one should nominate the 1977 GM downsizing effort as the only significant fuel economy related or trend setting design change in the period 1974-1977. Models so included are:

1977 Deville
1977 Riviera
1977 Estate Wagon
1977 LeSabre
1977 Electra
1977 Catalina
1977 Bonneville
1977 Delta 88
1977 Fleetwood
1977 Impala/Caprice

Based on significant variation from models of similar roominess the new models which can be cited as innovative designs responsive to fuel economy imperatives would be:

Rabbit

It is noted that the issues of how new any of these are in fact is open to discussion and that there are certainly many vehicles on the market which are both unique in design and responsive to demands for good fuel economy. At the same time, it should be noted that there are some distinctive styles of cars and some new model introductions which are counter-productive to attempts at weight reduction and improved fuel economy.

2.3.5 Average Values and Frequency Distributions of Each Design Parameter in Each Model Year

The impact of automotive design change on safety performance as measured in actual accident statistics is, of course, not a direct consequence of innovation or trend in design *per se* but rather reflects the ultimate impact of those changes. This impact is a function of the changes which are produced in the aggregate characteristics of the vehicle fleet of each model year factored by the portion of the total vehicle mix accounted for by cars of each model year.

Figures 2-1 through 2-9 present smoothed frequency distributions of the number of cars in each model year having different values of each of the design parameters under consideration. Their curves were smoothed using a moving average technique

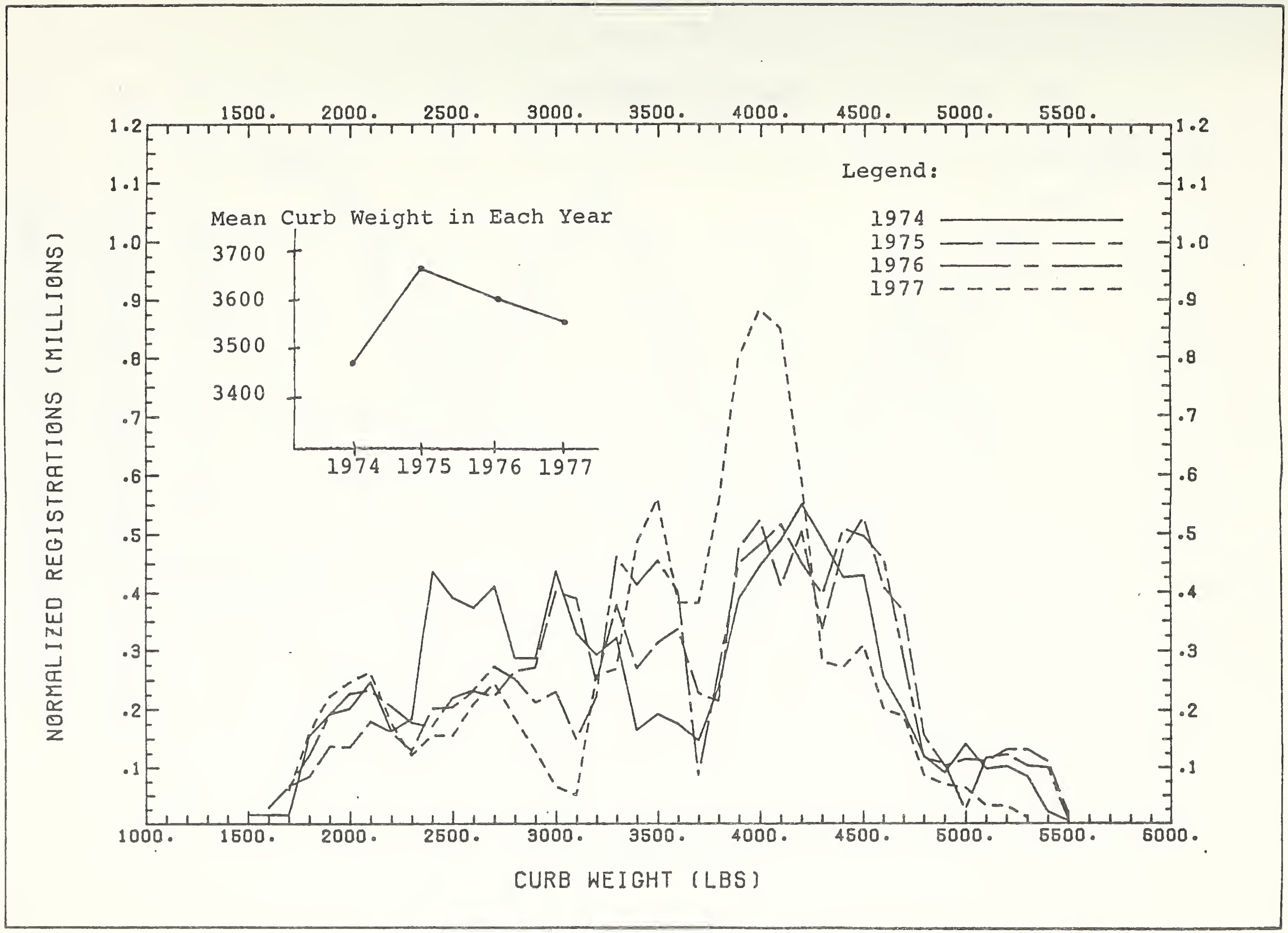

FIGURE 2-1. FREQUENCY DISTRIBUTION OVER CURB WEIGHT 1974-1977.

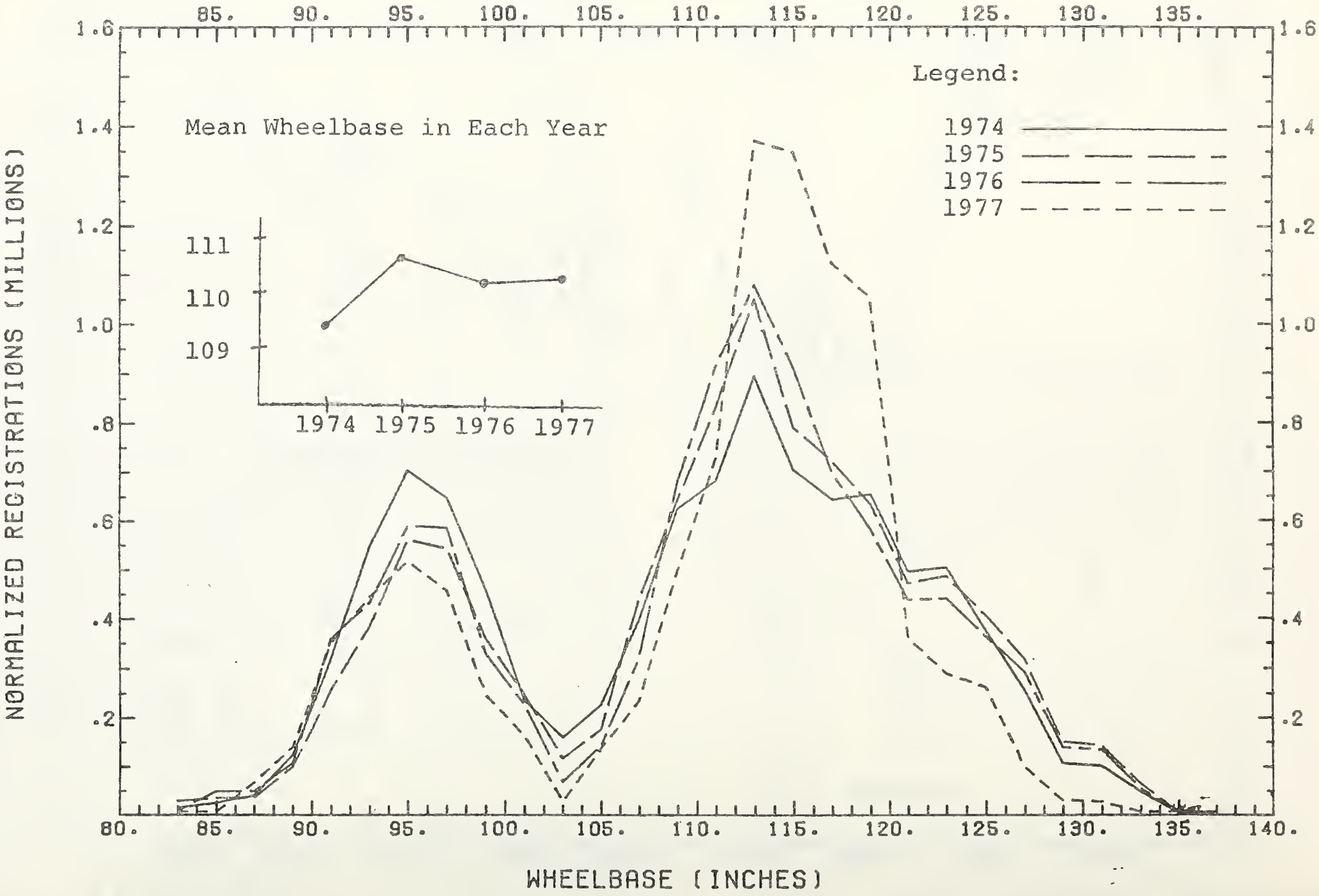

FIGURE 2-2. FREQUENCY DISTRIBUTION OVER WHEELBASE 1974-1977.

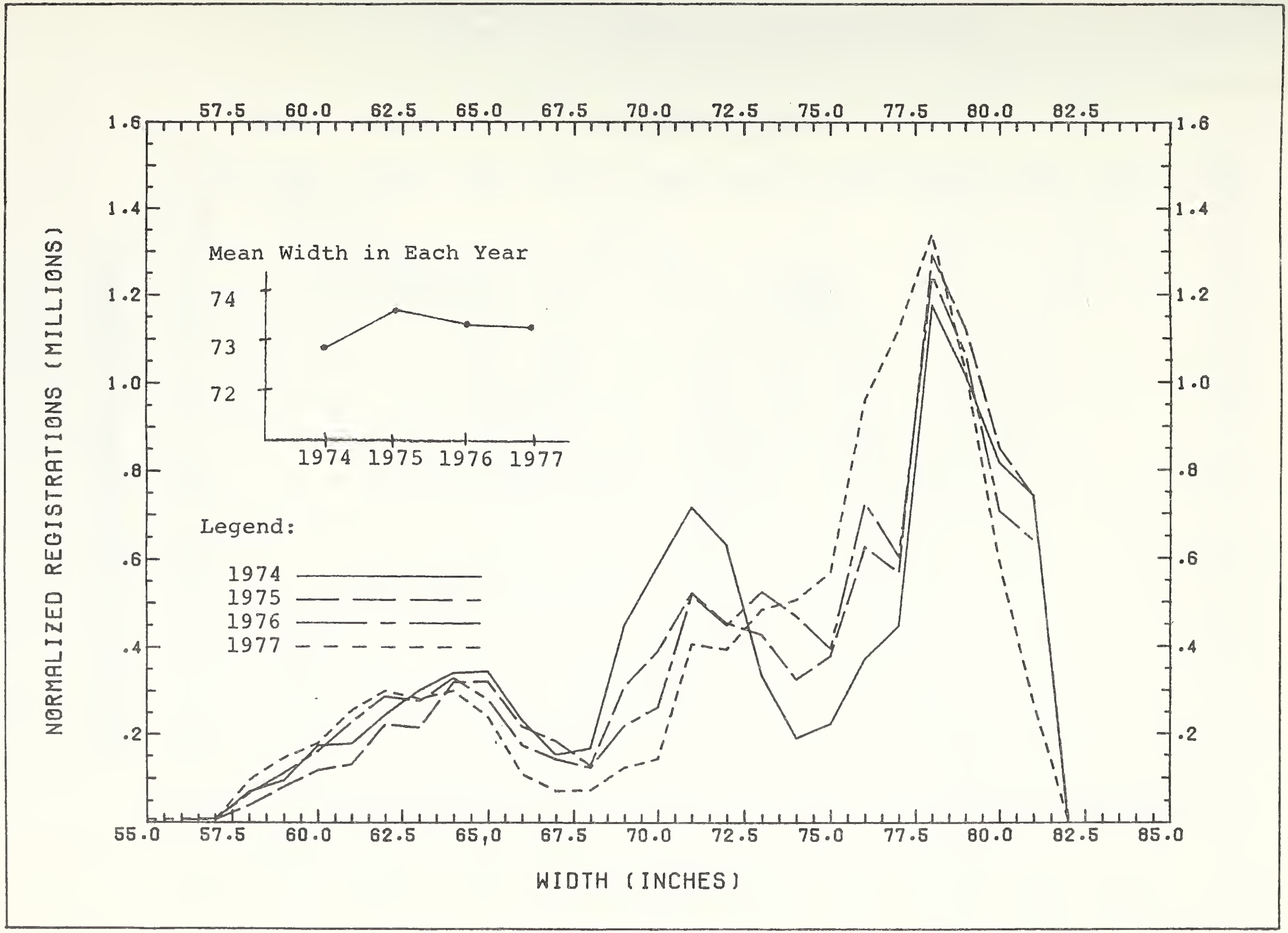

FIGURE 2-3. FREQUENCY DISTRIBUTION OVER WIDTH 1974-1977.

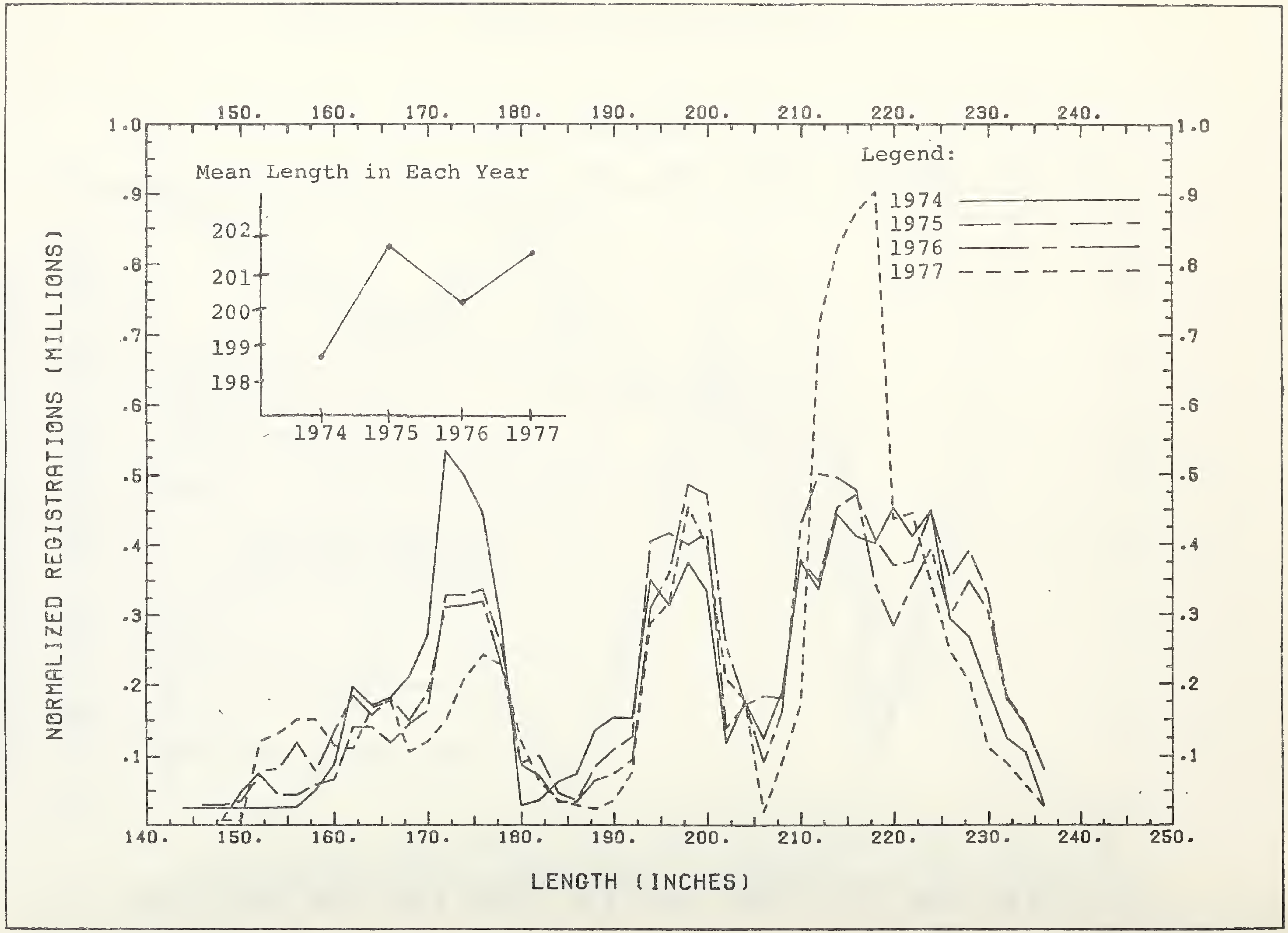

FIGURE 2-4. FREQUENCY DISTRIBUTION OVER LENGTH 1974-1977.

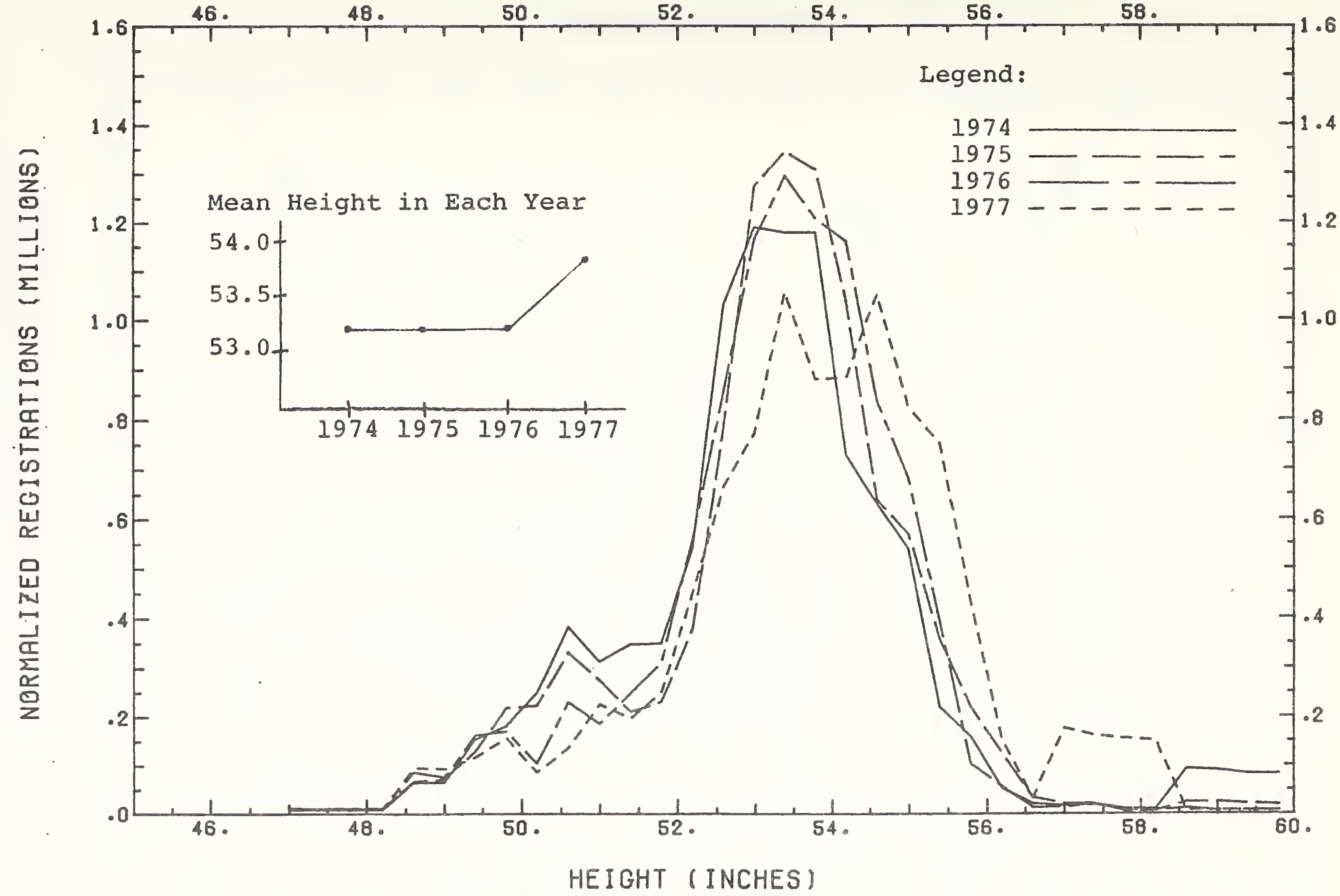

FIGURE 2-5. FREQUENCY DISTRIBUTION OVER HEIGHT 1974-1977.

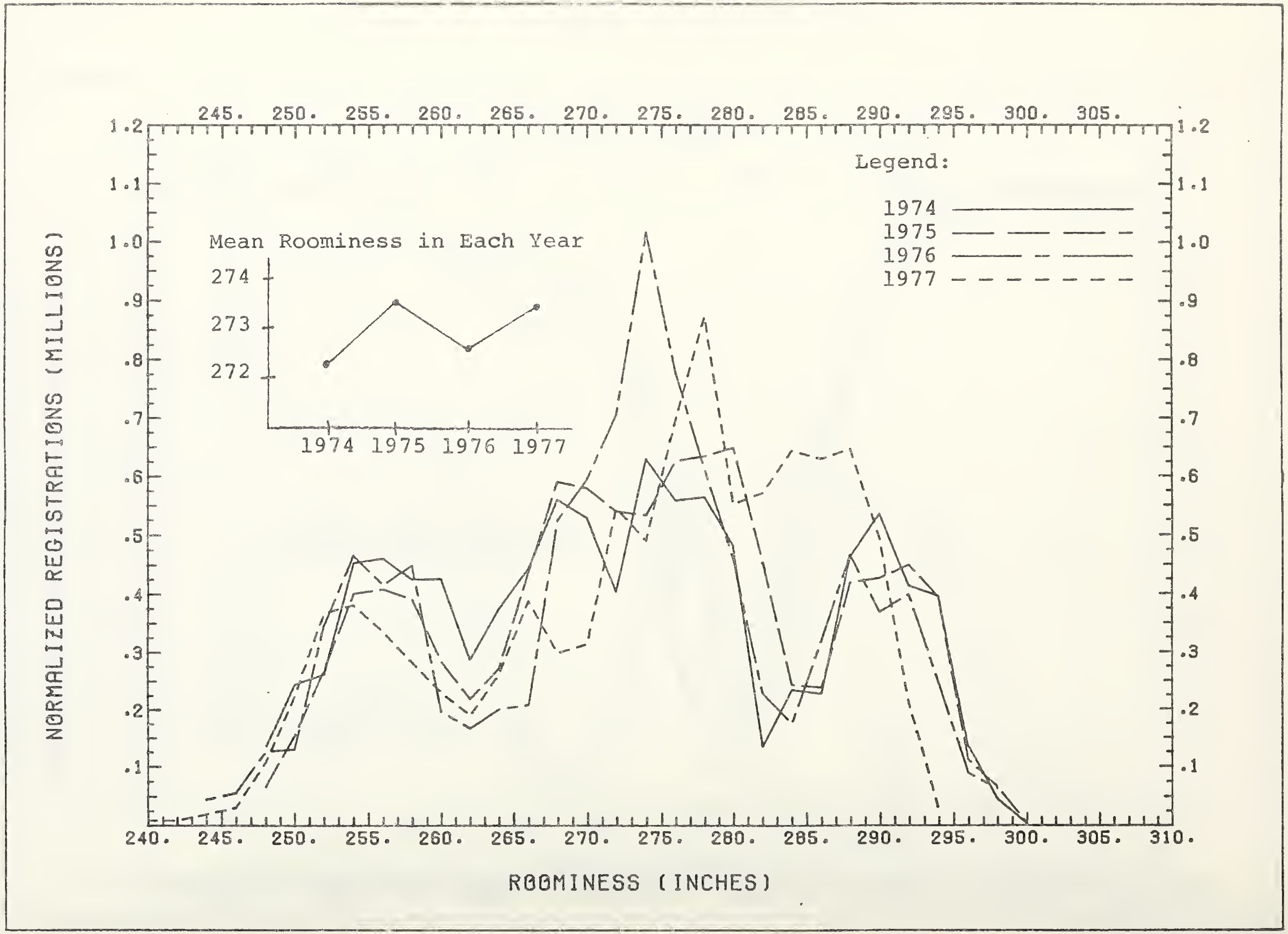

FIGURE 2-6. FREQUENCY DISTRIBUTION OVER ROOMINESS 1974-1977.

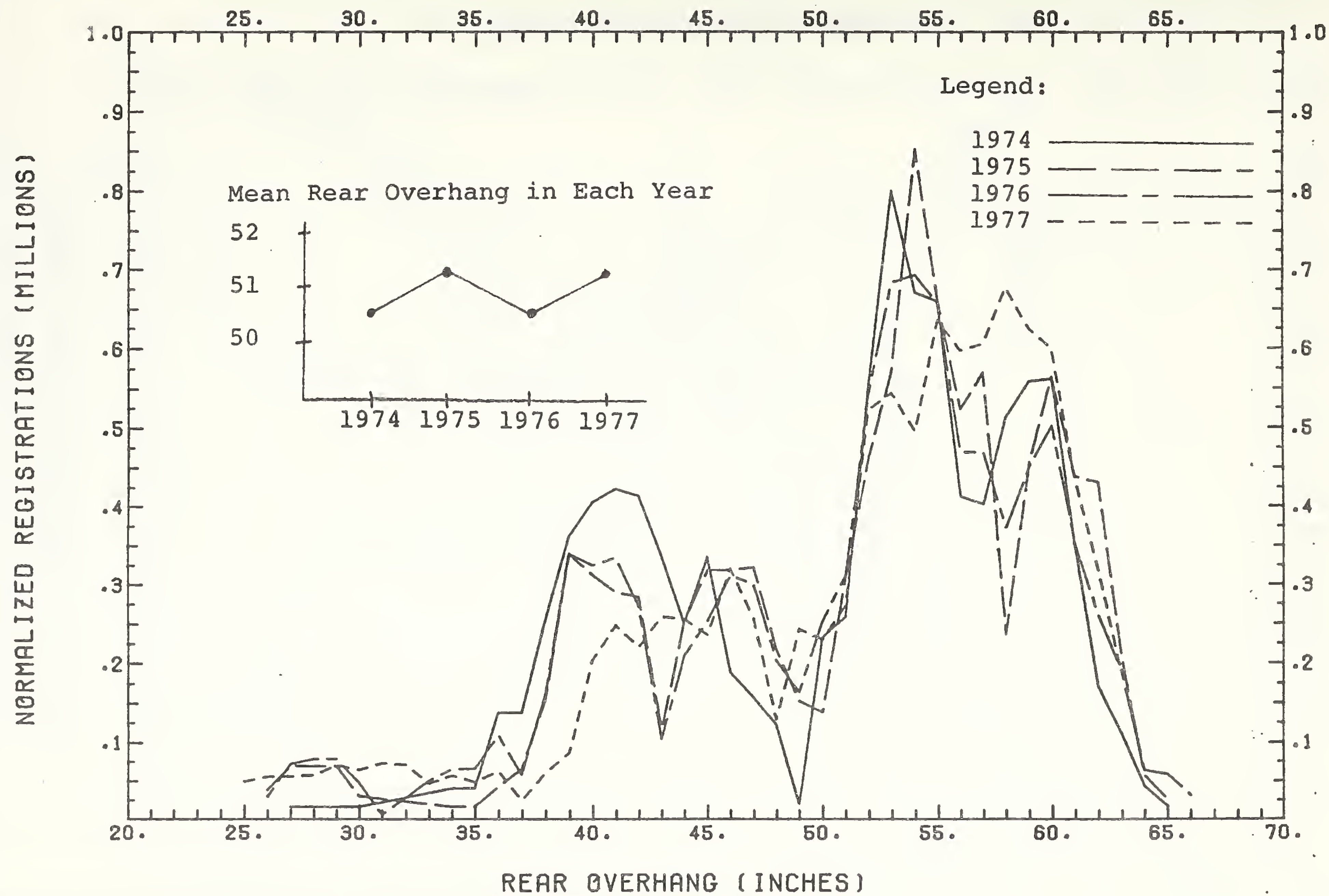

FIGURE 2-7. FREQUENCY DISTRIBUTION OVER REAR OVERHANG 1974-1977.

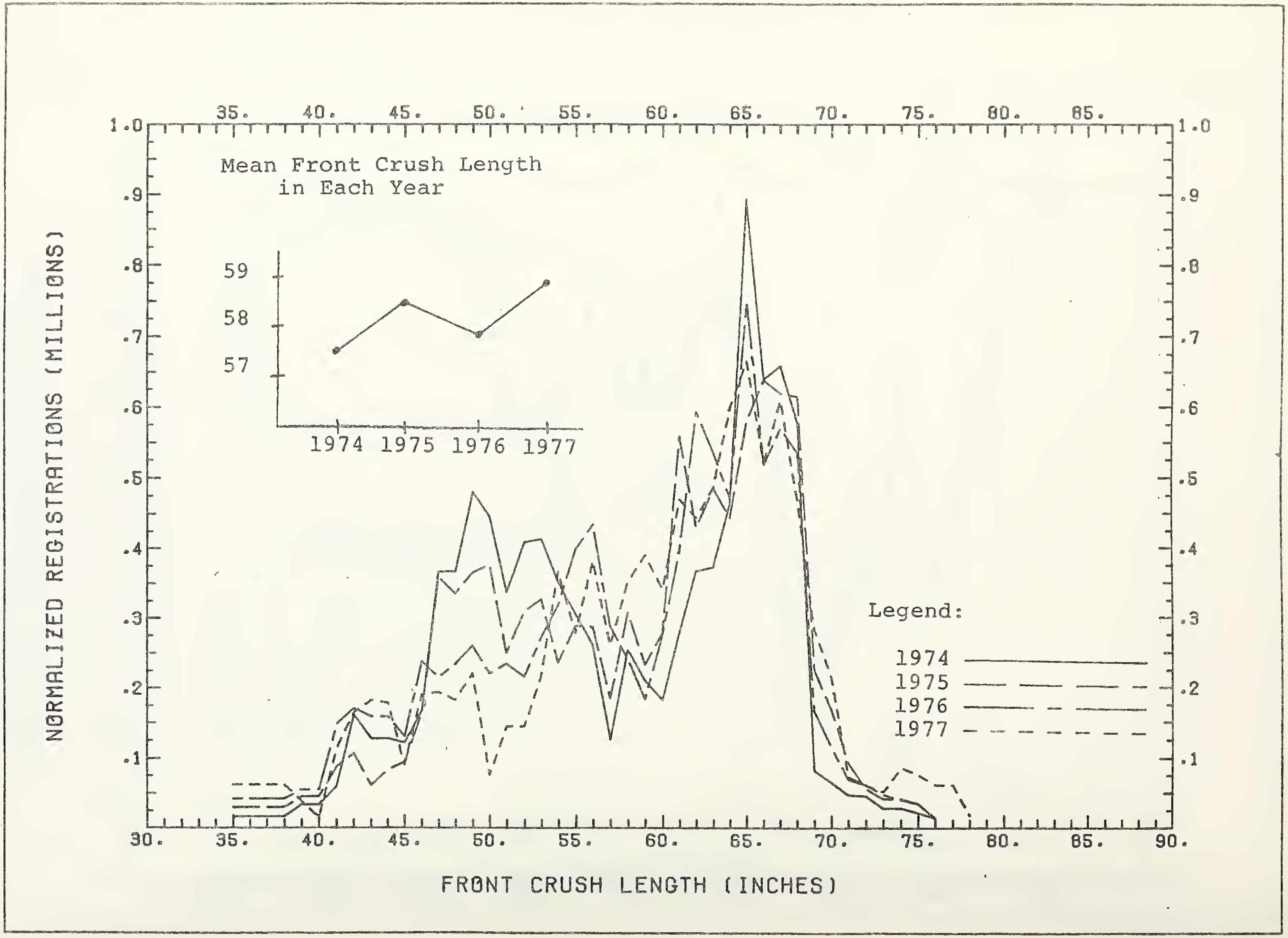

FIGURE 2-8. FREQUENCY DISTRIBUTION OVER
FRONT CRUSH LENGTH 1974-1977.

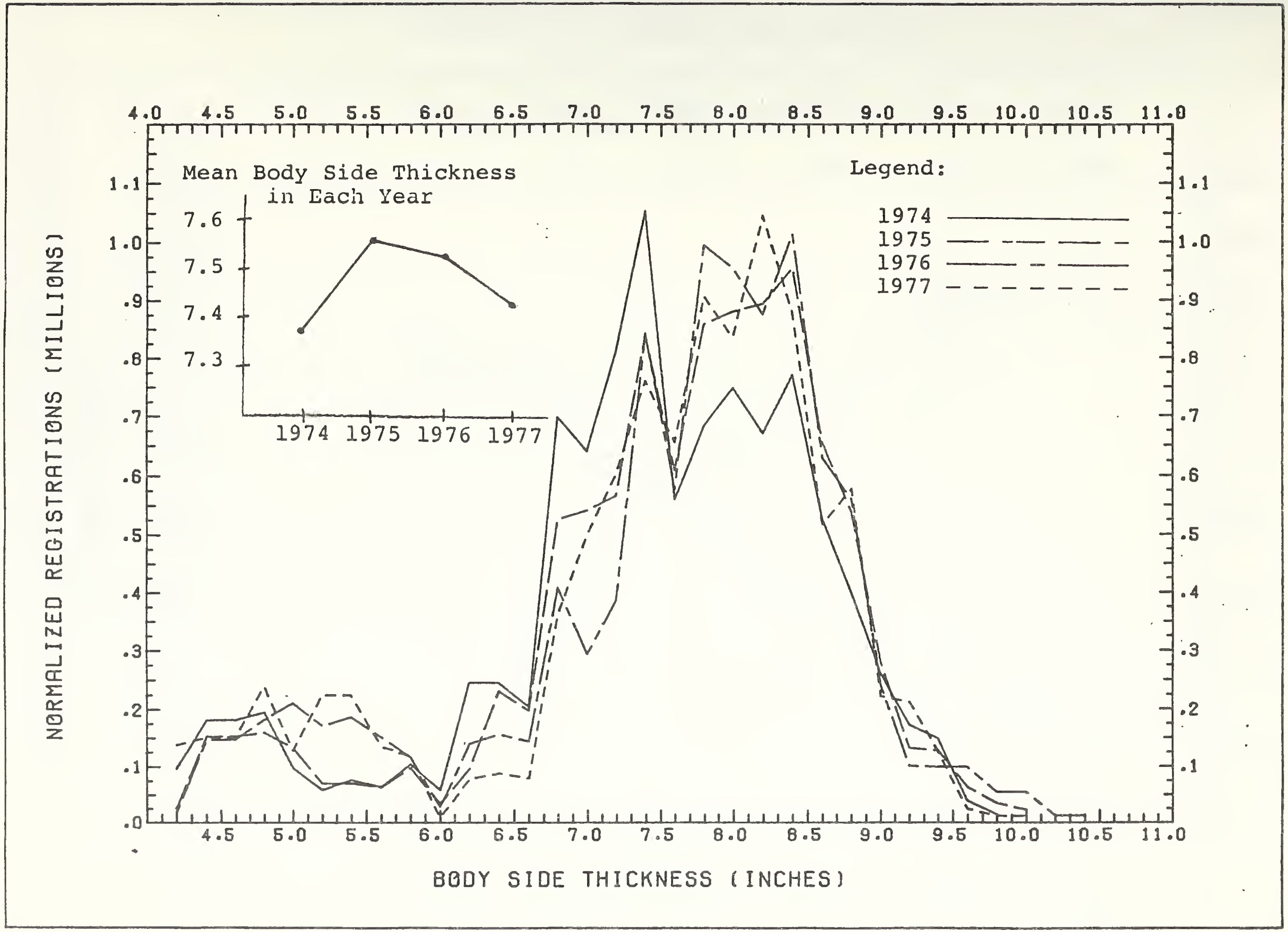

FIGURE 2-9. FREQUENCY DISTRIBUTION OVER BODY SIDE THICKNESS 1974-1977.

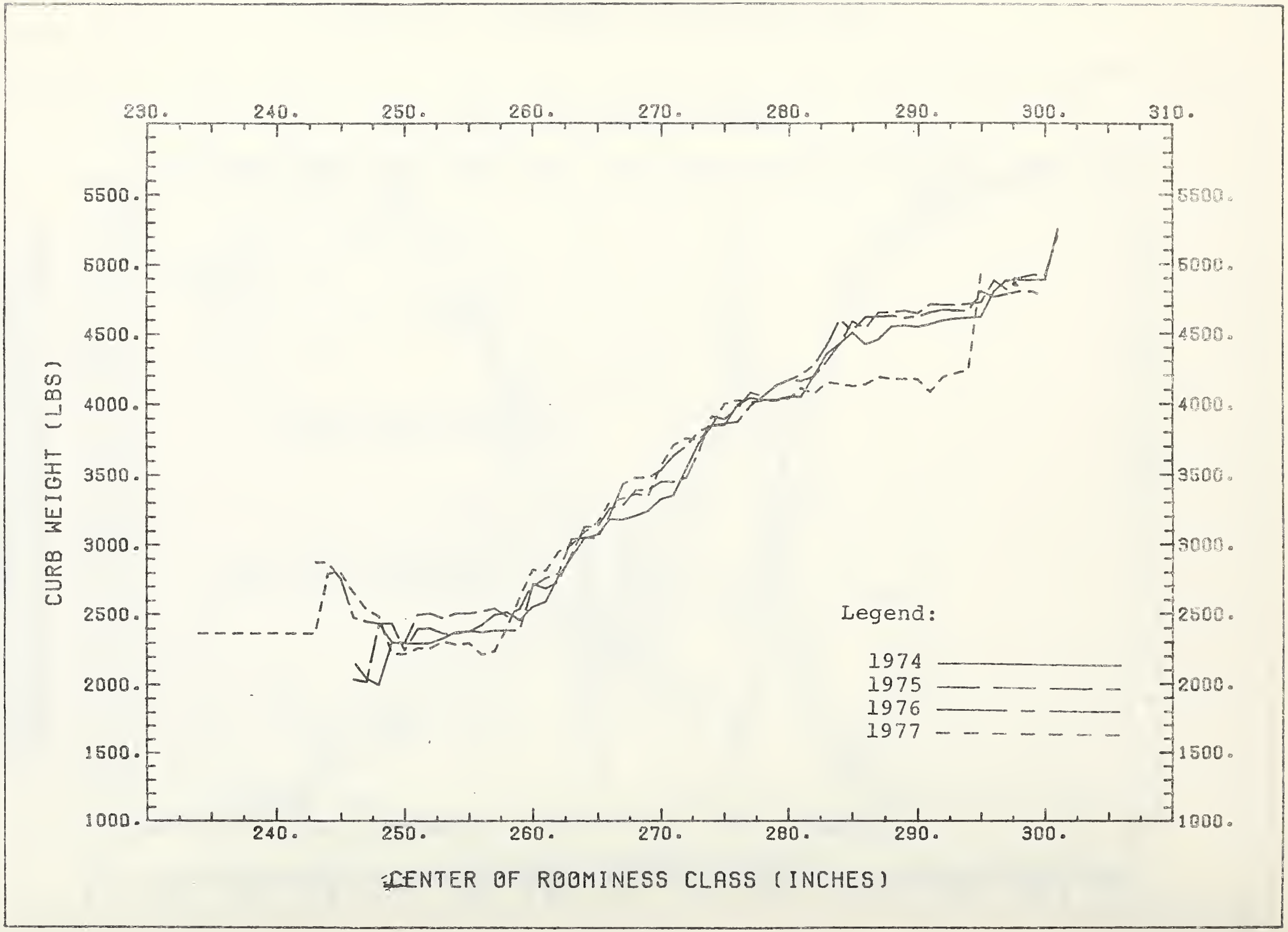

FIGURE 2-10. AVERAGE CURB WEIGHT IN ROOMINESS CLASS 1974-1977.

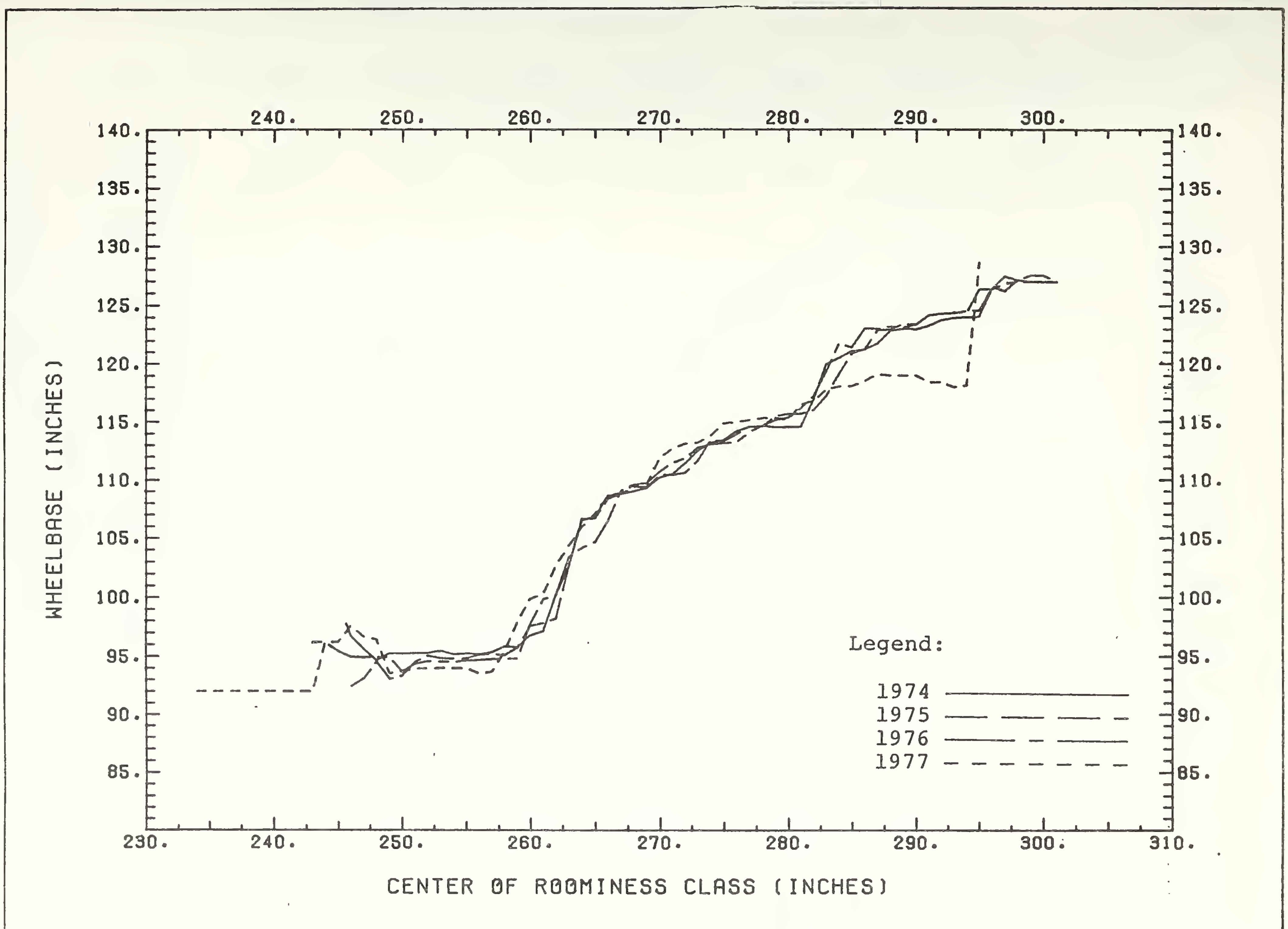

FIGURE 2-11. AVERAGE WHEELBASE IN ROOMINESS CLASS 1974-1977.

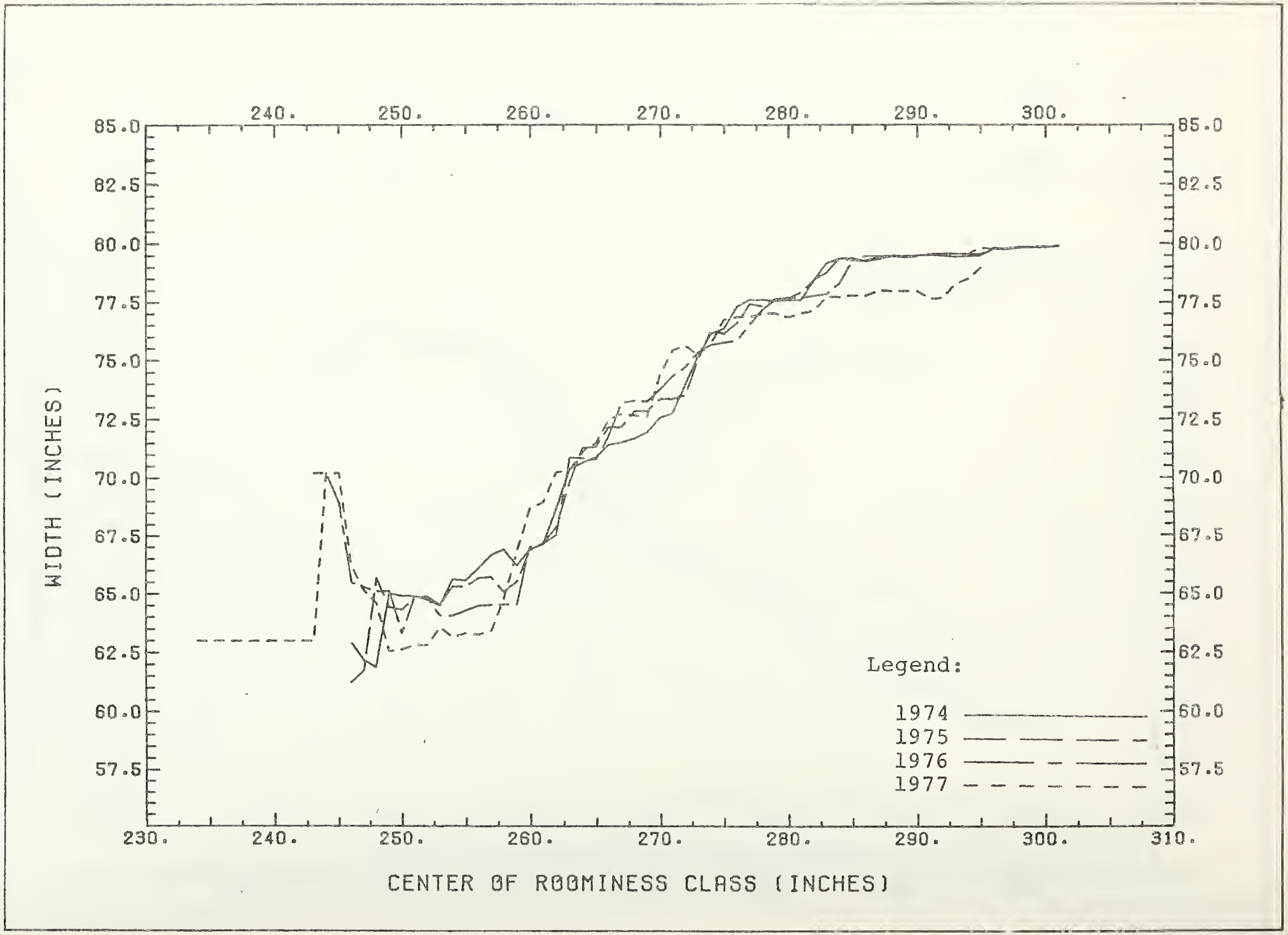

FIGURE 2-12. AVERAGE WIDTH IN ROOMINESS CLASS 1974-1977.

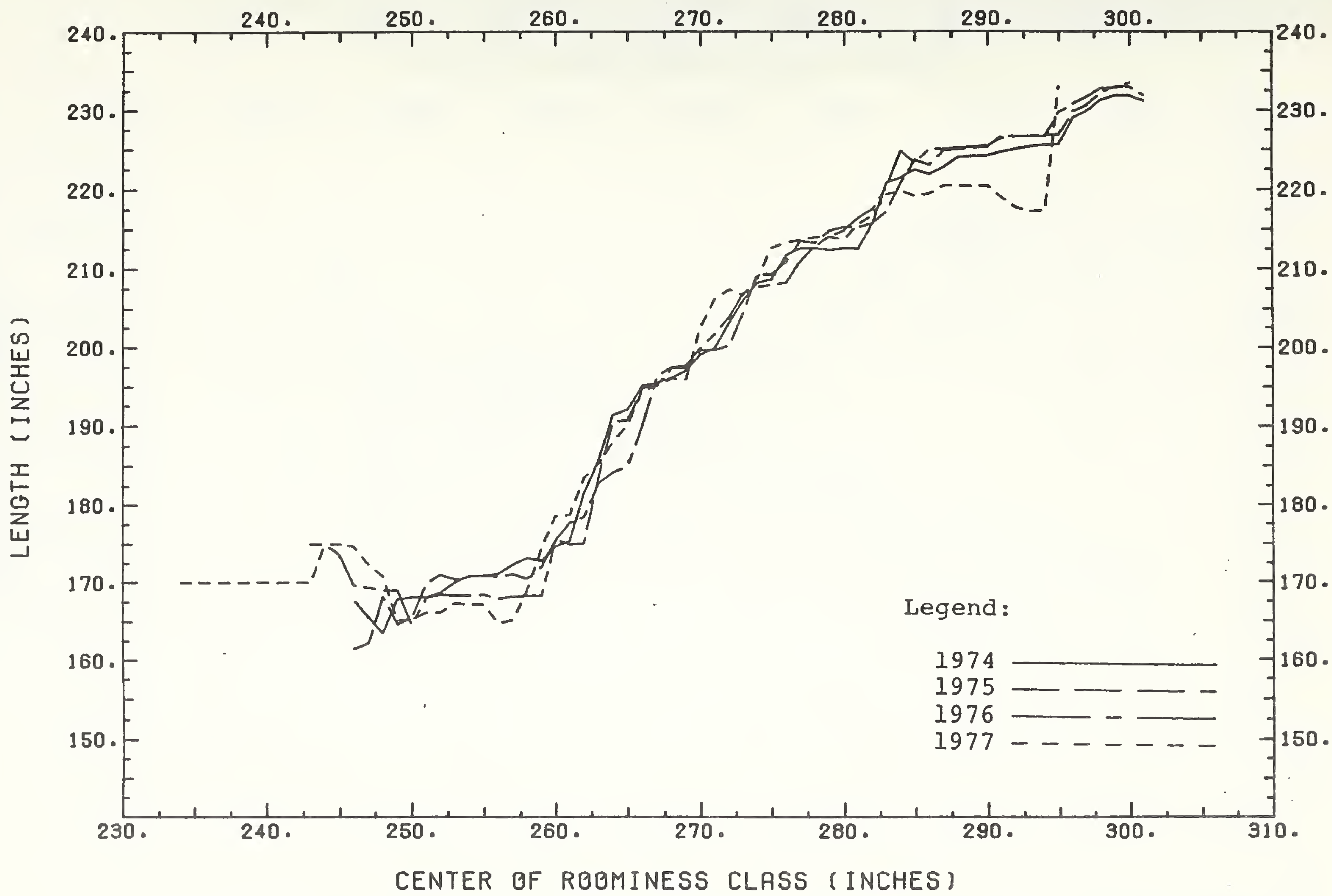

FIGURE 2-13. AVERAGE LENGTH IN ROOMINESS CLASS 1974-1977.

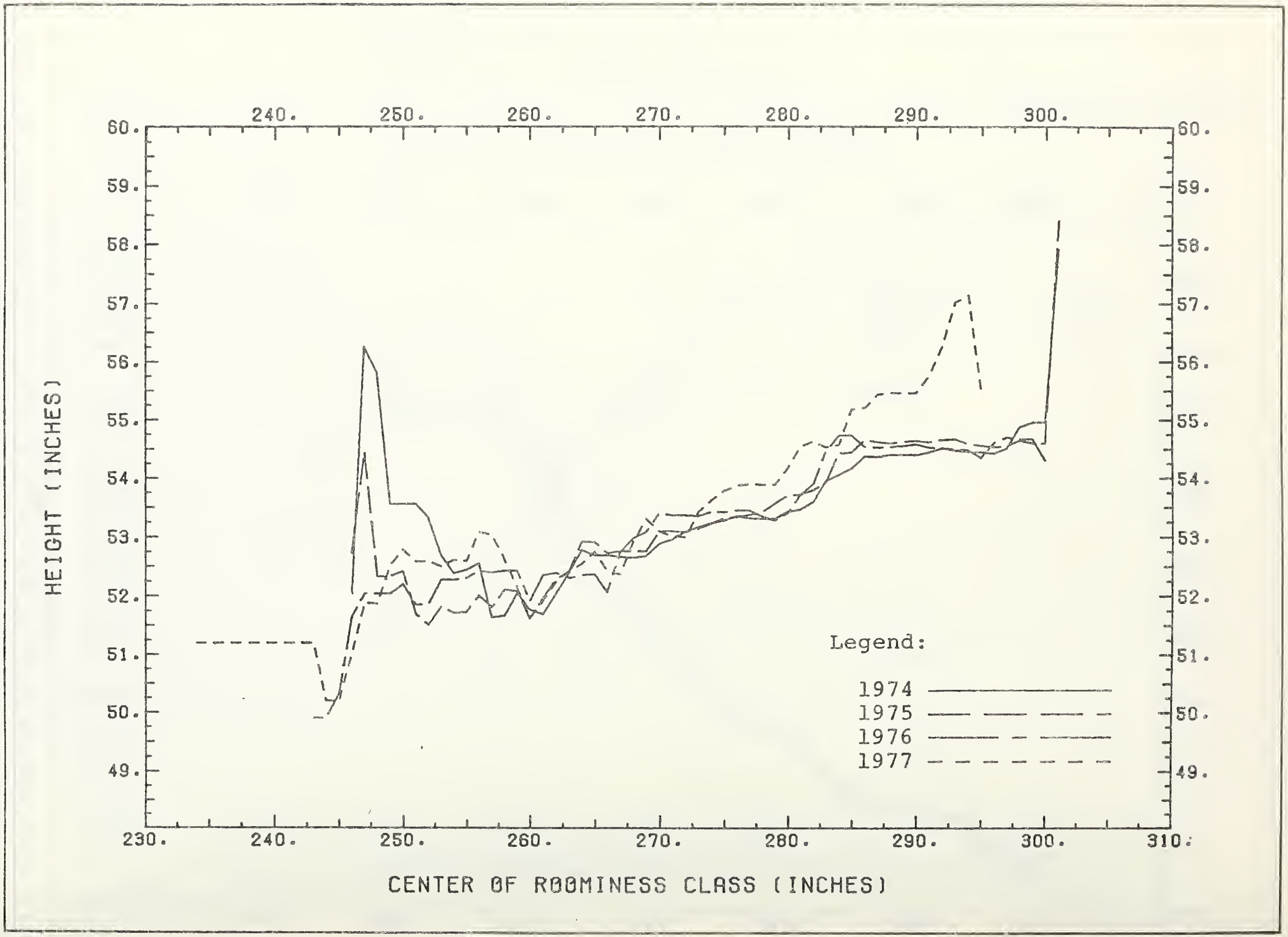

FIGURE 2-14. AVERAGE HEIGHT IN
ROOMINESS CLASS 1974-1977.

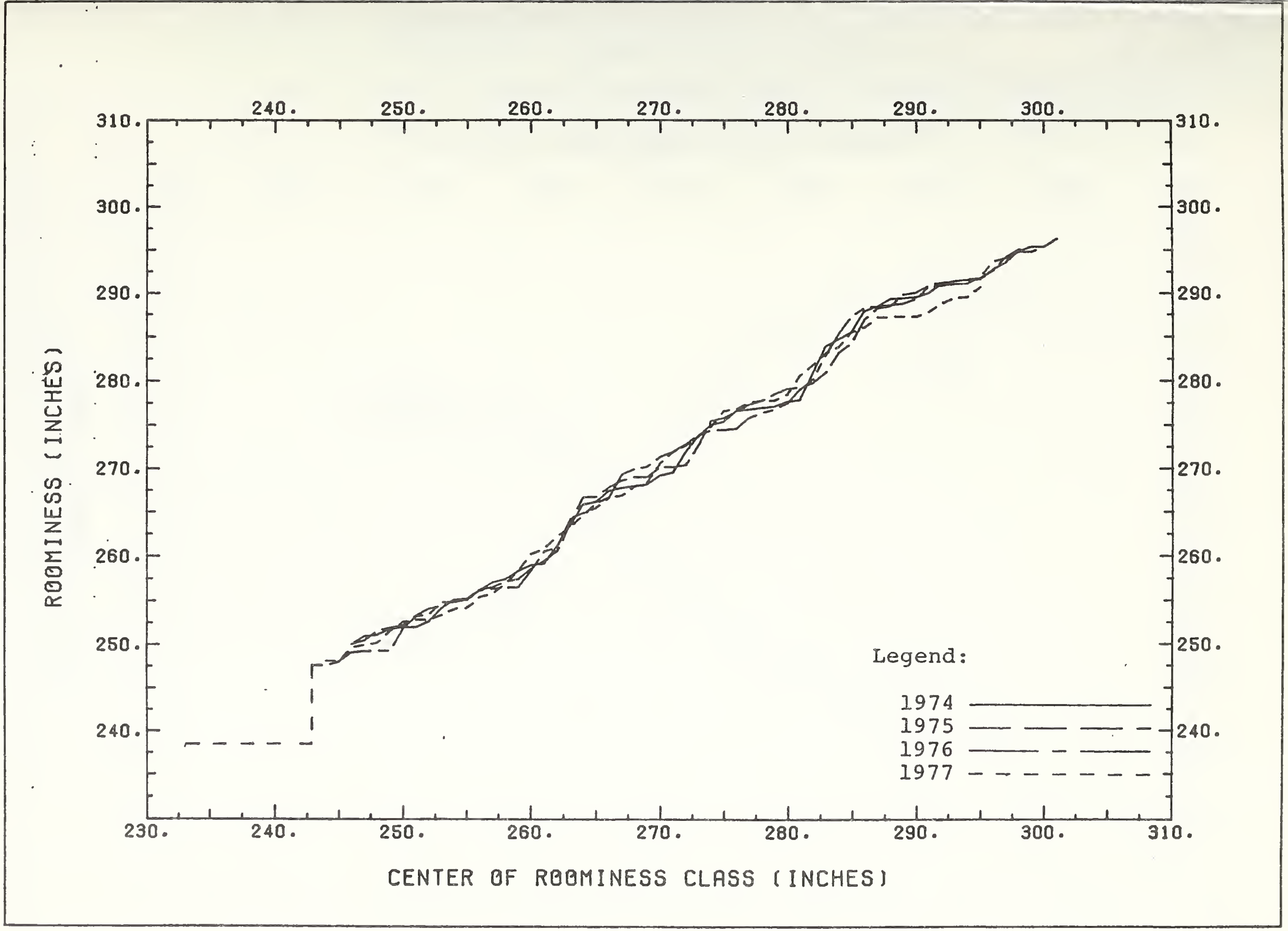

FIGURE 2-15. AVERAGE ROOMINESS IN
ROOMINESS CLASS 1974-1977.

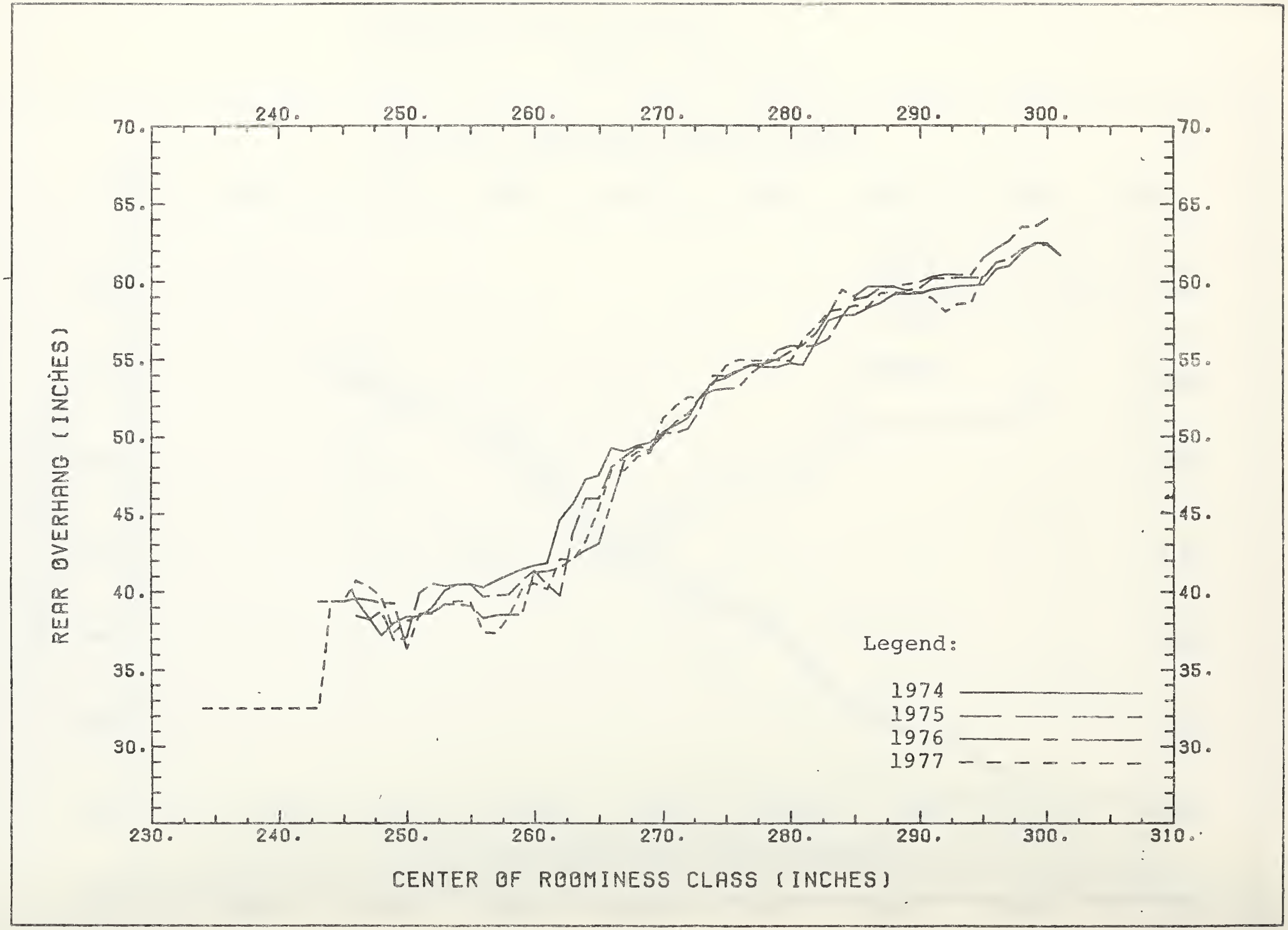

FIGURE 2-16. AVERAGE REAR OVERHANG IN ROOMINESS CLASS 1974-1977.

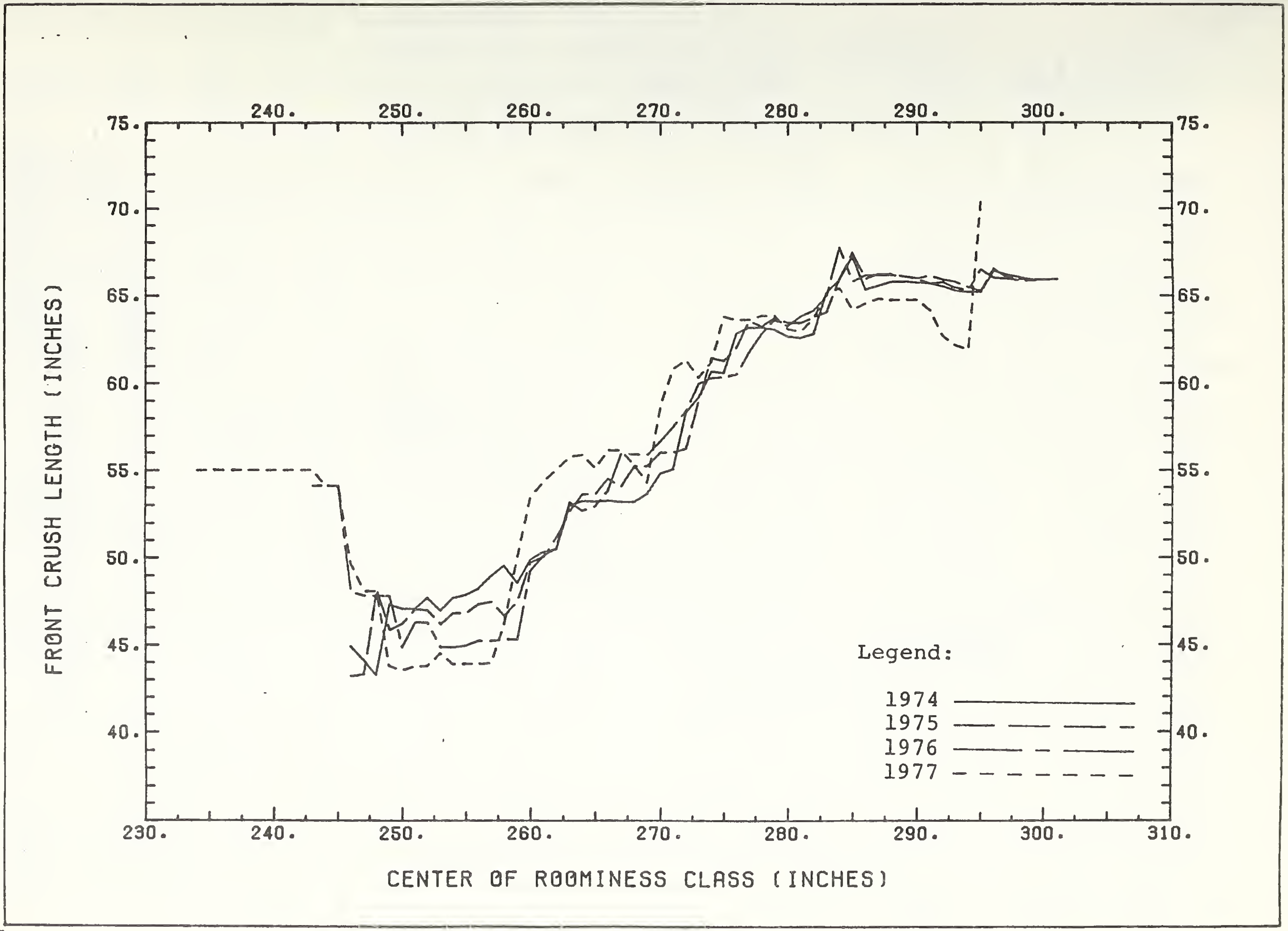

FIGURE 2-17. AVERAGE FRONT CRUSH LENGTH IN ROOMINESS CLASS 1974-1977.

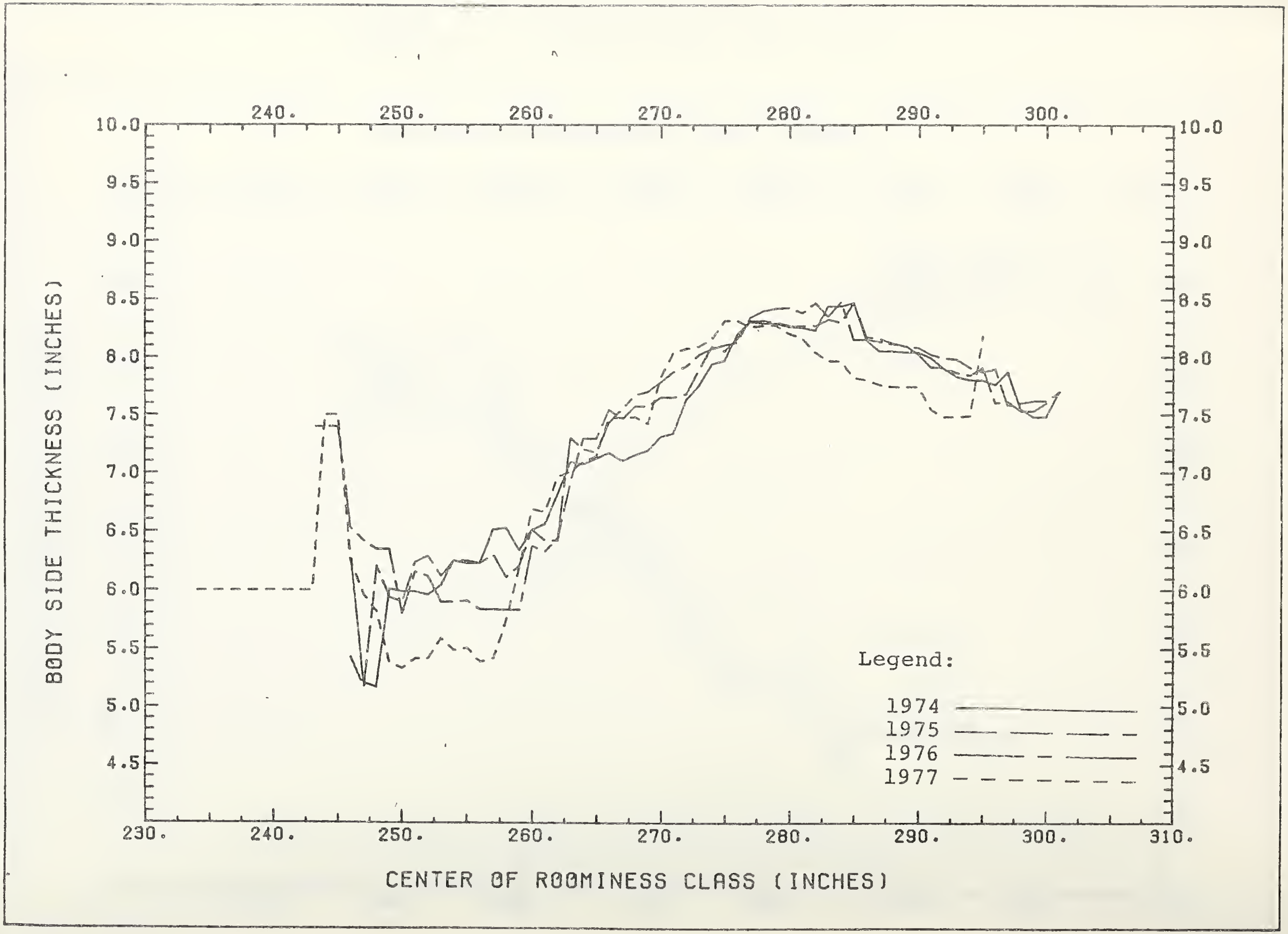

FIGURE 2-18. AVERAGE BODY SIDE THICKNESS
IN ROOMINESS CLASS 1974-1977.

applied over intervals corresponding to approximately ten percent of the range of each variable. Values are plotted at 49 points on each curve. Figures 2-10 through 2-18 are plots of the average values of each parameter over cars of given roominess in each model year. This data is the same as that used for the comparisons done in Section 2.2.

These graphs generally confirm the essential similarity of the model year fleets in the years 1974-1977 with the exceptions of the noticeable indentations caused by the downsizing of the 1977 General Motors full-size cars and the move from 1974 to 1975 away from compact cars (2400 - 2800 lb. weight class) to cars of the intermediate class.

Inset on the frequency distribution tables are plots of the trend in average values for each parameter as a function of model year. These values are also presented in Table 2-7. The smallness of the variation in these values is astonishing and would be even more noteworthy if one were to compare the net changes on either a year to year basis or on a 1974 to 1977 net change basis.

2.3.6 Regression Models to Predict Curb Weight

Given a characterization of vehicle design by several parameters, it may well be possible to simpligy the characterization if certain parameters can be shown to be good predictors of other parameters. This possibility anticipates the likely outcome that motor vehicle fatality rates observed in accident statistics are strongly dependent on vehicle weight and that, therefore, it will be useful to relate vehicle weight to the other design parameters under consideration.

Some preliminary stepwise multiple regressions have been performed for the 1974 model year vehicles.

When curb weight is regressed on wheelbase, width, length, height, roominess, rear overhang, front crush length, and body side thickenss the following stepwise regression results.

STEP	VARIABLE	MULTIPLE R	R^2	INCREASE IN R^2
1	Length (L)	.9748	.9503	.9503
2	Front Crush Length(FCL)	.9810	.9624	.0121
3	Width (W)	.9829	.9660	.0036
4	Wheelbase (WB)	.9845	.9692	.0032

TABLE 2-7 - AVERAGE VALUE OF EACH DESIGN PARAMETER BY MODEL YEAR 1974-1977

Parameter	1974	1975	1976	1977	Range As a Percent of Average
Curb weight	3468	3657	3608	3558	5.3%
Wheelbase	109.4	110.7	110.2	110.3	1.2%
Width	72.9	73.7	73.4	73.4	.7%
Length	198.7	201.8	200.2	201.7	1.6%
Height	53.2	53.2	53.2	53.8	1.1%
Roominess	272.2	273.5	272.6	273.5	.5%
Rear overhang	50.6	51.3	50.6	51.4	1.6%
Front crush length	57.5	58.4	57.9	58.9	2.4%
Body side thickness	7.38	7.57	7.54	7.44	2.5%

The regression equation is:

$$Weight=-5480.+(28.56 * WB)+(38.34 * W)+(8.15 * L)+(24.61*FCL)$$

A plot of the residuals shows, however, some curvature indicating that a linear model may not be the best fit.

A regression of curb weight on length^2 produced results which were just as good, namely the following model:

$$WT=-666.+(.1035 * L^2)$$
$$R = .9781$$
$$R^2= .9567$$

This time a plot of residuals indicated a suitable model. Since length alone is not a very useful parameter for purposes of safety performance analysis, an alternative model was developed. This model computed a regression of curb weight on the rear, front, and side crush lengths. The products of width with rear, front, and side crush parameters were also included. The results were:

STEP	VARIABLE	MULTIPLE R	R^2	INCREASE IN R^2
1	W x REAR	.9623	.9260	.9260
2	W x FRONT	.9819	.9640	.0381
3	REAR	.9834	.9670	.0029

The regression equation is:

$$Weight=745.-(49.8xREAR) + (1.183x(WxREAR) + (.0034x(W x FRONT^2)$$

The plot of residuals showed good fit except for weights above 4,800 lbs. where certain very large models (e.g. Lincoln, Mark IV) were underpredicted as much as 600 lbs.

A last variation of the regression calculation allowed the use of rear, front and side crush lengths plus the mid-length of the car which was total length minus front and rear crush spaces. The product of each of these with width were also considered. The results of this model were:

STEP	VARIABLE	MULTIPLE R	R^2	INCREASE IN R^2
1	W x REAR	.9623	.9260	.9260
2	W x FRONT	.9816	.9635	.0376
3	MID	.9850	.9701	.0066

The regression equation is:

Weight=-2069. + (.307x(W x REAR) + (.559x(W x FRONT) + (22.3xMID)

Again the fit is good except for very heavy cars such as Lincoln Continental which are underpredicted by as much as 600 lbs.

The indication is that curb weight is sufficiently well correlated with other design parameters, particularly suspected safety related dimensions, that it can be thought of as the primary parameter in characterizing make and model specific design distinctions in safety performance. This concept of course, is reinforced by the signigicant role played by weight in determining the ΔV experienced in vehicle to vehicle collisions. Other choices of the independent and dependent variables in the regression model could be developed if required.

One should note in closing that additional data such as stiffness has not been available on a thorough basis. This is certainly a variable we would expect to be important in occupant protection. Further work to obtain stiffness values is recommended.

2.3.7 Summary and Conclusions of the Automotive Design Change Analysis

The conclusions to be drawn from the data provided in this analysis depend in part on the philosophy and point of view of the analyst. One point of view is that one should consider design change on a model by model and version by version basis. A large part of the data presently developed is oriented to that point of view and presents a variety of comparisons between continuing, new, and discontinued models and themselves and other models both within years and across years. The other point of view is that true innovations in automotive design very seldom occur; that in fact most model changes and most model introductions are vehicles that are generally similar to vehicles that existed before under different names. This point of view looks for marketing changes, that is, changes in the number of cars of the different types which are sold each year or trends in the type of car which is competing in the various market classes.

Which of these two points of view predominates, if either, depends on both the motivation for doing the analysis and on the results. If one is interested in automotive design *per se*, one will primarily be concerned with model to model comparisons and particularly the new or anomalous design types. If one is interested in consequences of possible design changes in some other area, such as vehicle safety impacts of design change, the primary concern will be with aggregate characterization of the vehicle fleet and with trends in that characterization over time. Model by model comparisons will be useful to identify in more detail the nature of changes appearing in the aggregate characterization, and they are useful in identifying any new model which is a true innovation leading to a trend in design.

It happens that for the years 1974-1977 the plots provided in Section 2.5 which show the aggregate characteristics of the vehicle fleet provide the most direct and comprehensive display of the effects of recent design changes. The marked effect here is the 1977 G. M. downsizing which is also the predominating change detected in the analysis in Section 2.1. There is some debate concerning whether or not the 1977 G. M. full-size cars are really new designs, as discussed in Section 2.3, but there is no question concerning the existence of a market impact of these changes. One should note, however, that the effects on the average values of the design parameters over the model year fleet are quite small even for the large changes implied in the downsizing effort.

On the other hand, there are some model introductions which are selected as being relatively innovative deisgns. Chief among these is Rabbit which represents a great improvement in fuel economy and reduction in weight in the subcompact car roominess class. This design is undoubtedly a forerunner of new models to come in its own class and in the intermediate class (anticipating the front wheel drive 1980 G. M. intermediates and the Dodge Omni, Ford Fiesta, and other similar cars). Again, one can debate exactly how new this design really is, but one anticipates that as a marketing trend this type of car will be of significant impact on the characteristics of the future vehicle fleet. As of 1977, however, it would be difficult to see any market impact caused by Rabbit-like cars in the aggregate characteristics of the vehicle fleet.

There are assorted other design changes and/or new model introductions which have been documented. Some of these are simply ongoing modifications or shifts in model type as with Datsun 240Z/280Z or Opel. Others are truly innovative but isolated anomalies such as the Pacer. The remainder of the changes and model introductions may represent some significant shifts, notably the Monza/Skyhawk/Sunbird/Starfire/Mustang II class of cars, but are not in general accounted for as being responses to increasingly stringent fuel economy requirements.

SECTION 3

ANALYSIS OF OBSERVED FATALITY RATES BY MODEL YEAR AND BY MAKE AND MODEL

Evaluation of the safety impact of automotive design change requires an examination of automobile accident statistics by make and model. There are two objectives that can be met in such an analysis.

1. Examination of real world safety performance of models previously identified as significant design change vehicles compared to other vehicles. (See Section 2.)

2. Analysis of real world safety performance of all makes and models as a function of selected design parameters, in particular, curb weight.

One appropriate data file readily accessible for this analysis is the Fatal Accident Reporting System (FARS) file maintained at the National Center for Statistics and Analysis at NHTSA. This file contains information only on fatal accidents, but it is an exhaustive file--all fatal accidents are reported and tabulated. A sophisticated analysis would require investigation of injury and damage measures as well as fatalities, but the use of such data is more complex. Ambiguities concerning injury level classification, sampling problems, thresholds for inclusion in the file, etc., etc., cause a simple examination of fatality rate to be attractive for purposes of the work currently at hand.

The work in this section is discussed under the following headings:

1. Preparation of FARS Data (Section 3.1).

2. Make and Model Identification in the FARS Data (Section 3.2).

3. Annual Vehicle Mileages by Age of Vehicle (Section 3.3).

4. Observed Fatality Rates for all Vehicles by Model Year (Section 3.4).

5. Observed Fatality Rates by Make and Model for 1974-1977 Model Year Passenger Cars (Section 3.5).

6. Summary and Conclusions (Section 3.6).

3.1 PREPARATION OF FARS DATA

The FARS data file is a hierarchical data file based on an accident-vehicle-person hierarchy. Accidents are identified by a state code and a sequence number within each state. Each set of accident records consists of an accident record followed by one or more vehicle records, each of which is followed, in turn, by a driver record and one or more person records. Persons who are not vehicle occupants are provided with dummy vehicle cards identifying a mythical vehicle number "00". Details concerning the structure and coding of the FARS file may be found in Ref. 4. It should be noted that the FARS coding changes from year to year. The analysis reported here is based on 1977 versions of the FARS file for the 1976 and 1977 accident years.

Since the current work is concerned with make and model specific accident statistics, it was necessary to convert the FARS file from its hierarchical form to a rectangular form having a record for each vehicle in which a fatality occurred. This record contains information from the accident record, from person records associated with the case vehicle, and from the vehicle records of other vehicles in the accident.

First there were extracted from the original file certain data items from the accident, vehicle, and person level cards. No data items were needed from the driver cards, thus these records were discarded. Also discarded were a small number of records whose record type was not consistent with accident (A), vehicle (V), driver (D), or person (P), record types. Total record counts were

	1976 FARS	1977 FARS
Total Records	274,376	290,935
Illegal Type	261	322
Driver Cards	64,406	68,914
Remaining A,V,P Records	209,709	221,699

The data items which were selected for inclusion in the working vehicle level file were:

Accident Record	Card Type
	State Code
	Sequence Number Within State
	Number of Persons in Accident
	Hour of Day of Accident
	First Harmful Event
	Manner of Collision
	Speed Limit
Vehicle Record	Card Type
	State Code
	Sequence Number Within State
	Vehicle Number
	Make
	Model
	Body Type
	Model Year
	Odometer Reading
	Travel Speed
	Initial Impact Point
	Principle Impact Point
	Extent of Deformation
	Impacts
	Fire & Explosion
	VIN Make
	VIN Model
	VIN Body Type
Person Record	Card Type
	State Code
	Sequence Number
	Vehicle Number
	Person Number
	Age
	Sex
	Person Type (Driver, Passenger, Other, etc.)
	Seat Position
	Active Restraint System
	Passive Restraint System
	Ejection
	Drinking Involved

Person Record (Continued)

Alcohol Test Result
Injury Level
Death Year

The reduced file is then processed in a sequence of steps to produce a vehicle level file. These steps are as follows:

1. Records corresponding to persons number higher than six are removed.

2. Records having vehicle number "00" are removed.

3. Each remaining person record is combined with a copy of the vehicle and accident records with which it is associated.

4. The new record is reformatted to eliminate redundant data such as, card type, etc. A check is performed to verify that sequence numbers and vehicle numbers agree where expected.

5. Up to six accident/vehicle/$person_i$ (i=1,6) records are combined for each vehicle record.

6. The new record is reformatted to eliminate redundant data. A check is performed to ensure that all person records that were combined have the same sequence number.

7. All records for accidents having more than three vehicles are removed.

8. Up to three vehicles per accident are combined together into an accident record.

9. These new records are reformatted to eliminate redundant data. A check is performed to ensure that all the vehicles are in the same accident.

10. New records are created producing an accident/vehicles/ persons record for each of up to three vehicles in each accident.

11. Only those records are retained in which the subject vehicle in each record is a passenger car Body Type (FARS codes 1,2,3,6,8, and 9), the Make is appropriate to being a passenger

car (FARS codes 1-27, 61, 67, 97, and 99), the VIN Make is appropriate to being a passenger car (FARS codes 0-27, 61, 67, 97, and 99), and at least one person in the vehicle has an injury level code of "4" indicating a fatality.

Thus, the file now consists of records defined by individual vehicles which contain information on the accident, on each of up to three vehicles including a case vehicle, and on up to six persons who are occupants of the case vehicle.

The tabulation in Table 3-1 accounts for the total fatalities as they are distributed by the above manipulations.

3.2 MAKE AND MODEL IDENTIFICATION IN THE FARS FILE

The FARS file contains two separate items identifying make and model of vehicle. The first is identification provided by the FARS analyst from the police reports or other information. The second is identification derived from the Vehicle Identification Number which is decoded during file processing at NHTSA. Since a large amount of information concerning make and model information is missing or unknown, a program was written to crosscheck the police identified makes and models with the VIN derived designations in order to fill in missing data and to eliminate contradictory data.

The crosschecking program fills in the police report information with information from the VIN whenever the police data is coded other or unknown, and the VIN data is a valid known make and model code for a passenger car. If a police report make and model identification is invalid for passenger cars or if both that code and the VIN information are known but disagree, then the entry is reported as unknown model, unknown make, or both. The program also recodes the make and model indicators according to the modified scheme discussed in Section 2.2 concerning the recoding of the VW data base. These codes are listed in Appendix E. Table 3-2 is a summary of the missing, unknown, invalid, and inconsistent codes as well as counts of total vehicles for 1976 and 1977 FARS for case vehicles and for any second or third vehicles in the accident.

The statistics in Table 3-2 indicate that a substantial amount of make and model information is missing even after recovering about half of the missing data from the cross comparison

TABLE 3-1 - ACCOUNTING FOR FATALITIES IN 1976 & 1977 FARS DURING PROCESSING FOR THE PASSENGER CAR CASE VEHICLE FILE

	1976 FARS	1977 FARS
Total fatalities	45,509	47,715
Lost as person number greater than six	-136	-97
Lost as vehicle number equal zero (non-occupants)	-8,418	-8,688
Lost as accidents with more than three vehicles	-327	-441
Net fatalities	36,628	38,489
Fatalities in passenger cars	25,868	26,365
Remainder	10,760	12,124
Including (by body type):		
Passenger car miscodes	0	26
Off road vehicles	447	581
Motorcycles	3,297	4,050
Other vehicles	38	38
Special purpose vehicles	337	325
Light trucks	4,831	5,139
Heavy trucks	1,218	1,382
Unknown	592	583

TABLE 3-2 - ANALYSIS OF MAKE & MODE IDENTIFICATIONS
IN THE 1976 AND 1977 FARS FILES

	1976			1977		
	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 1	Vehicle 2	Vehicle 3
Total Vehicles	22,221	10,923	1,058	22,936	11,722	1,085
Total Passenger Cars	22,221	6,654	787	22,936	6,965	772
Other & Unknown Make - Police	505	89	15	491	86	16
Other & Unknown Make - VIN	7,541	1,941	265	6,716	1,731	192
Other & Unknown make - Police & VIN	204	44	7	162	41	4
Makes Disagree - Police & VIN	132	24	1	175	65	8
Other & Unknown Model - Police	9,123	2,751	370	8,793	2,645	348
Model Code = '0' - Police	505	88	15	428	81	16
Other & Unknown Model - VIN	8,151	2,063	283	8,551	2,001	234
Other & Unknown Model - Police & VIN	4,603	1,206	188	4,536	1,084	145
Models Disagree - Police & VIN	955	340	32	893	375	27
Invalid Code - Make	.0	0	0	0	15	1
Invalid Code - Model	0	0	0	2	2	0

of the police and the VIN codes. For 1976, make information is 98% complete, but model information is only 75% complete. For 1977, the proportions are 99% and 76% respectively. It should be noted as discussed in Ref. 2 that the foreign makes have a larger proportion of unknown model information than the domestic makes. For these makes, except Volkswagen, Toyota, and Datsun, the models have all been collapsed into one code. This reduces the missing model information by about 10 percentage points to approximately 15% missing. In addition to the collapsing of models for many import makes, a number of other models were combined together to reduce ambiguity (e.g. Impala and Caprice into Impala/Caprice). Certain other modifications were made for the cases of Dodge and Plymouth where certain ambiguities arise in the Satellite/Fury/Grand Fury and Coronet/Monaco/Royal Monaco lines, due to renaming of car lines during the period 1974-1977. This has been discussed in Section 2. The full list of make and model codes as used in the final analysis is found in Appendix E. Reference 4 details the original FARS coding scheme.

The final versions of the reformatted FARS data, stored as FARSMM76, and FARSMM77, can be used to compile fatality counts for any combination of specifications of make, model, model year, impact mode, or other variables.

3.3 ANNUAL VEHICLE MILEAGES BY AGE OF VEHICLE

3.3.1 Introduction

In an effort to obtain a measure of vehicle exposure to accident by model year, which could subsequently be utilized with the fatality counts developed in the previous sections, an estimate of miles of travel by vehicle age was necessary. This estimate could then be combined with vehicle registration figures by model year as the measure of vehicle exposure.

3.3.2 Estimates of Annual Miles of Travel by Vehicle Age

Three independent estimates of annual vehicle miles traveled as a function of vehicle age were obtained and appear in Table 3-3 and are plotted in Figure 3-1. The three plots are generally consistent with one another with the largest variability occurring for the most recently purchased automobiles. The estimate displaying the most rapid decrease in usage over age is the result of an April, 1972 report of the Federal Highway Administration (Ref 5). The range of vehicle age considered

TABLE 3-3 - DATA FOR FIGURE 3-1

Vehicle Age (Years)	FHA Annual Miles	NHTSA Annual Miles	HSRC Annual Miles	Average
1	15,900	18,000	13,200	15,700
2	15,000	15,100	12,800	14,300
3	14,000	13,400	12,200	13,200
4	13,100	12,200	11,600	12,300
5	12,200	11,300	11,100	11,500
6	11,300	10,500	10,700	10,800
7	10,300	9,900	10,200	10,100
8	9,400	9,300	9,700	9,500
9	8,500	8,800	9,300	8,900
10	7,600	8,400	8,900	8,300
11	6,700	8,000	8,400	7,700
12	6,700	7,600	7,900	7,400
13	6,700	7,300	7,500	7,200
14		7,000	7,000	7,000
15		6,700	6,400	6,600

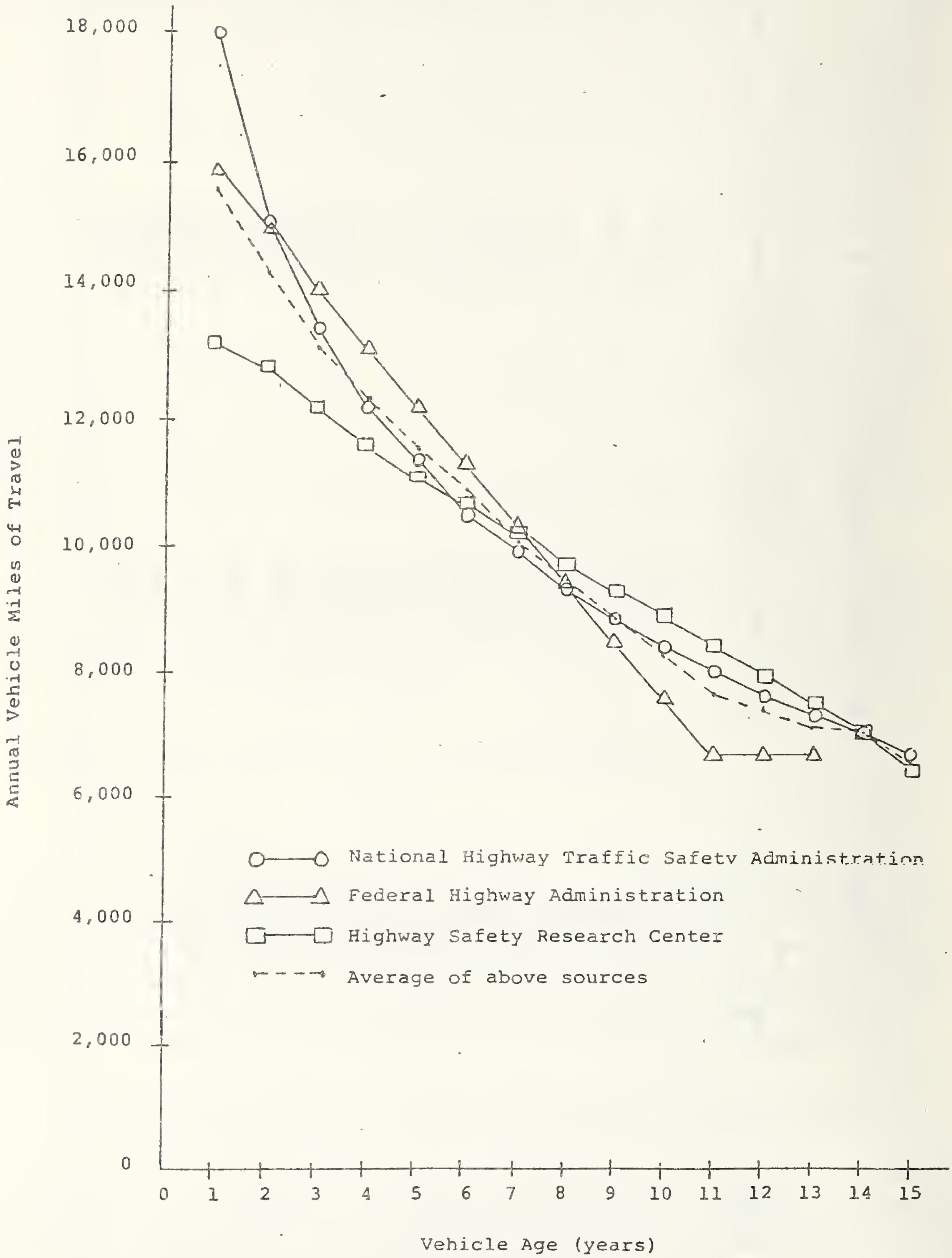

FIGURE 3-1. THREE ESTIMATES OF ANNUAL VEHICLE MILES TRAVELED AS A FUNCTION OF VEHICLE AGE.

in this study is only thirteen years as compared with the fifteen year range examined in the other two studies. The second estimate of annual miles traveled was part of a 1977 summary report of the National Highway Traffic Safety Adminsitration (Ref. 6). The final and most conservative estimate of vehicle miles by age was compiled by the University of North Carolina's Highway Safety Research Center in October, 1974 (Ref. 7).

No criteria existed initially for differentiating the quality of data among these three mileage sources, and an average estimate was computed among all three. However, further analysis (see Section 3.4.4.) indicated that the functional form of HSRC-based exposure figures most closely matched actual accident proportions derived from the National Crash Severity Study (NCSS) in 1977. In fact, a comparison between absolute HSRC and NCSS mileage data for five model years showed very close agreement. Thus, many of the subsequent application of the exposure measure present analyses based on both average and HSRC annual mileages.

Due to the variation in introduction data for any vehicle in a given model year sales period, it was necessary to adjust these mileage figures to reflect the appropriate observation period in calendar year 1977. To accomplish this, the yearly miles of travel were first converted to monthly miles by fitting the original data with parabolic curves and integrating for the desired units of time. The resulting monthly data for average and HSRC mileage appear in Table 3-4, with the corresponding fifteen year mileage plots shown in Figures 3-2 and 3-3. Assuming an expected vehicle introduction date of April 1 in each model year*, it is then possible to calculate the precise vehicle age in months at any point during 1977. Thus, the appropriate twelve months of vehicle travel can be summed for each model year. Table 3-5 presents the average and HSRC mileage reflecting this adjustment.

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*Midway within the car sales period from September 1 of the production year to September 1 of the following year.

TABLE 3-4 - MONTHLY MILEAGE AS A FUNCTION OF VEHICLE AGE
MONTHLY MILEAGE BY VEHICLE AGE -- AVERAGE
OF THREE SOURCES

	Months											
Age	J	F	M	A	M	J	J	A	S	O	N	D
Monthly Mileage by Vehicle Age - Average of Three Sources												
1	1362.	1352.	1342.	1333.	1323.	1313.	1303.	1294.	1284.	1274.	1265.	1255.
2	1244.	1233.	1222.	1212.	1202.	1193.	1184.	1176.	1168.	1161.	1155.	1149.
3	1141.	1133.	1124.	1116.	1109.	1101.	1095.	1088.	1082.	1076.	1070.	1065.
4	1059.	1052.	1045.	1039.	1033.	1027.	1021.	1015.	1010.	1005.	1000.	995.
5	990.	984.	979.	973.	968.	963.	958.	953.	948.	943.	939.	934.
6	929.	925.	920.	915.	910.	905.	900.	895.	891.	886.	881.	876.
7	871.	866.	861.	856.	851.	846.	842.	837.	832.	828.	823.	819.
8	814.	809.	804.	800.	795.	790.	786.	782.	778.	774.	770.	766.
9	762.	757.	753.	749.	745.	741.	737.	733.	729.	725.	721.	717.
10	713.	710.	706.	702.	698.	694.	690.	686.	682.	677.	673.	669.
11	664.	658.	653.	648.	644.	640.	637.	634.	632.	631.	630.	629.
12	628.	625.	623.	621.	619.	617.	615.	613.	612.	610.	609.	608.
13	606.	604.	602.	600.	599.	597.	596.	595.	593.	592.	591.	591.
14	591.	591.	591.	590.	589.	587.	585.	582.	579.	576.	572.	567.
15	563.	560.	557.	554.	551.	547.	544.	541.	538.	535.	532.	529.

TABLE 3-4 (CONTINUED)

	Months											
Age	J	F	M	A	M	J	J	A	S	O	N	D
Monthly Mileage by Vehicle Age - HSRC												
1	1115.	1113.	1110.	1107.	1104.	1101.	1099.	1096.	1093.	1090.	1088.	1085.
2	1083.	1081.	1079.	1076.	1074.	1070.	1067.	1063.	1059.	1054.	1050.	1044.
3	1040.	1035.	1031.	1027.	1023.	1019.	1015.	1010.	1006.	1002.	998.	994.
4	989.	985.	980.	976.	972.	968.	964.	960.	957.	953.	950.	947.
5	944.	940.	936.	932.	929.	926.	922.	919.	917.	914.	912.	909.
6	907.	905.	903.	900.	897.	894.	891.	888.	884.	881.	877.	873.
7	869.	866.	862.	859.	855.	852.	848.	845.	841.	838.	834.	831.
8	827.	823.	819.	816.	812.	809.	806.	803.	800.	797.	795.	793.
9	790.	788.	785.	782.	779.	776.	774.	771.	768.	765.	763.	760.
10	757.	755.	753.	750.	747.	744.	741.	738.	734.	731.	727.	723.
11	719.	716.	712.	709.	705.	702.	698.	695.	691.	688.	684.	681.
12	677.	673.	669.	666.	662.	659.	656.	653.	650.	647.	645.	643.
13	641.	638.	636.	633.	631.	628.	624.	621.	618.	614.	610.	606.
14	603.	600.	597.	593.	590.	586.	582.	578.	574.	570.	565.	561.
15	556.	552.	548.	544.	540.	535.	531.	527.	523.	519.	515.	510.

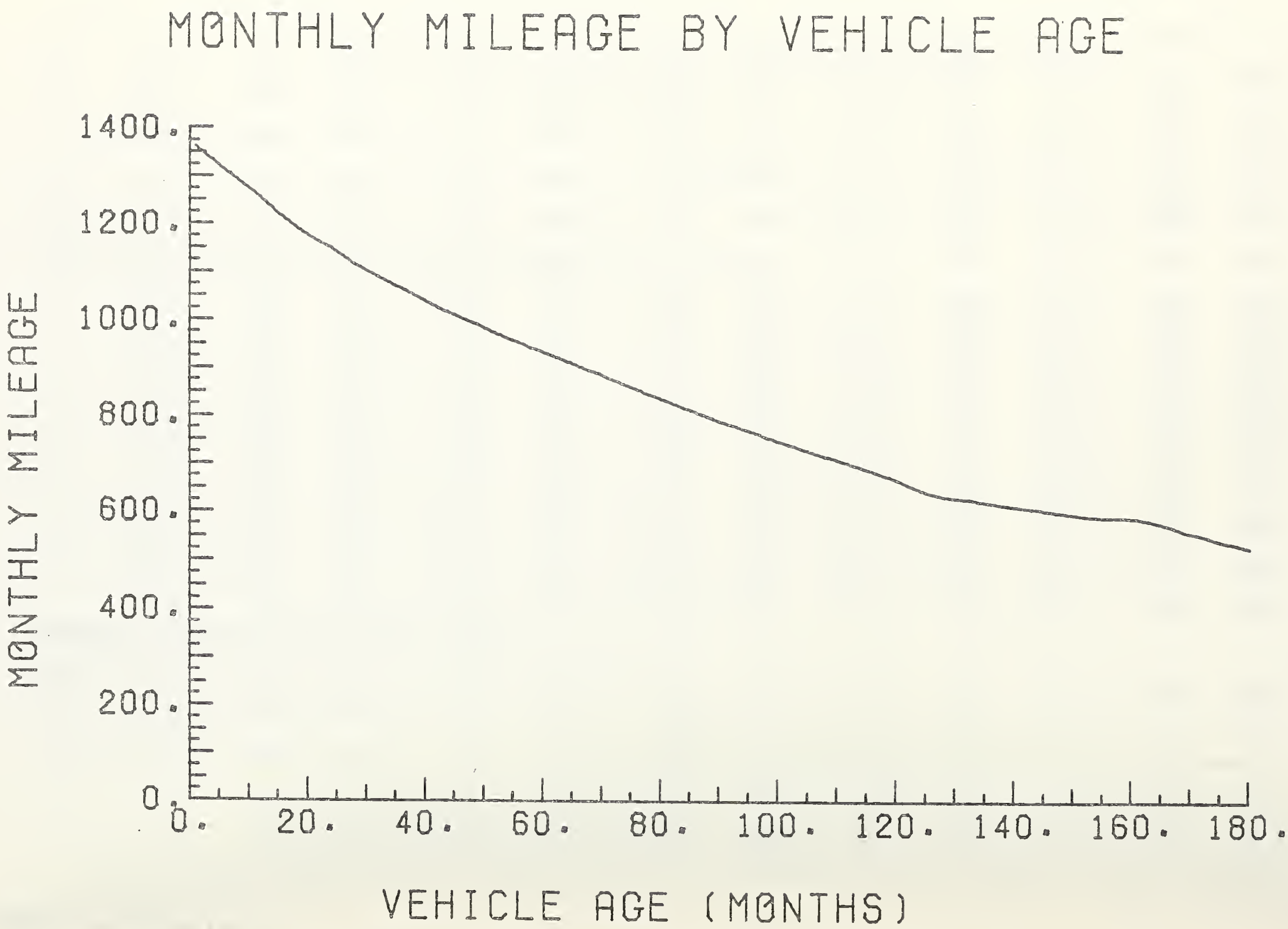

FIGURE 3-2. MONTHLY MILEAGE BY VEHICLE AGE (AVERAGE OF THREE SOURCES).

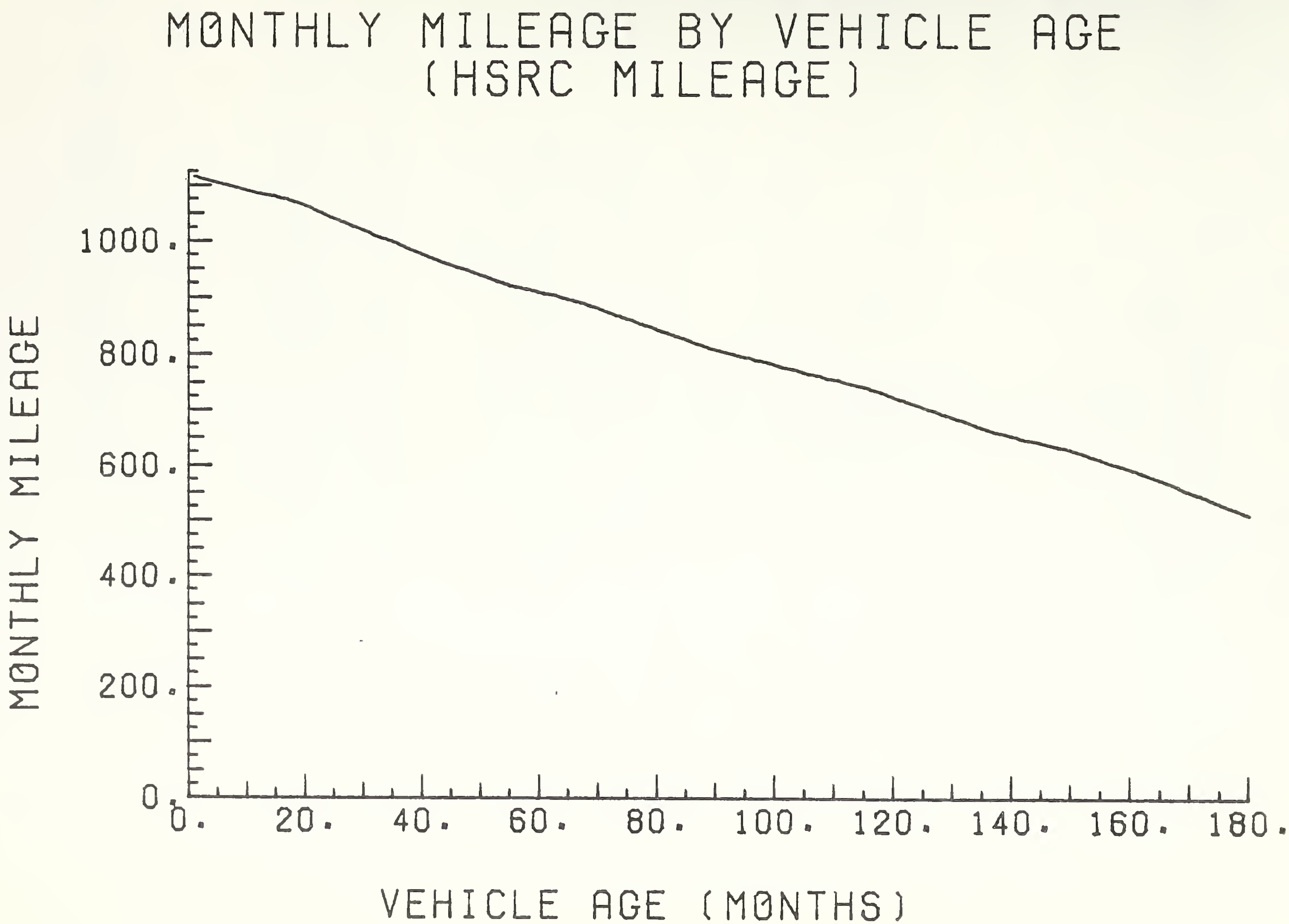

FIGURE 3-3. MONTHLY MILEAGE BY VEHICLE AGE (HSRC).

TABLE 3-5 - ADJUSTED ANNUAL MILEAGE FOR AVERAGE AND HSRC MILEAGE FIGURES

Model Year	Adjusted Average Mileage	Adjusted HSRC Mileage
77	11,906	9,937
76	14,629	12,914
75	13,454	12,355
74	12,511	11,743
73	11,717	11,216
72	11,006	10,805
71	10,306	10,327
70	9,628	9,818
69	9,013	9,398
68	8,443	9,007
67	7,830	8,527
66	7,463	8,018
65	7,219	7,605
64	7,060	7,134
63	6,669	6,552

3.4 OBSERVED FATALITY RATES FOR ALL VEHICLES BY MODEL YEAR

3.4.0 Introduction

This section describes the development of an observed fatality rate for each of fifteen automotive model years in calendar year 1977. Three necessary components comprise this estimate: first, the number of fatalities occurring for each model year during the reference year 1977; second, the number of cars registered for each model year in 1977; and third, an index of automobile exposure to accidents by vehicle age.

3.4.1 Fatalities

A breakdown of total passenger car* fatalities by vehicle model year was provided by a cross-tabulation of data from the 1977 Fatal Accident Reporting System (FARS) file. The distribution of fatality counts by model year is shown graphically in Figure 3-4. Data tables for figures 3-4, 3-9 and 3-10 presented in this report are contained in Table 3-6.

3.4.2 Registrations

Information concerning the second variable, the number of cars registered by model year in 1977, was obtained from the National Vehicle Population Profile (NVPP) of R. L. Polk & Co., and appears in Figure 3-5. Originally covering only model years to 1966, the data was extended to the remaining three years (to 1963) by extrapolating the present information by means of 1976 registration figures by Polk, found in Automotive News (April 26, 1978, p. 28).

Because the NVPP is only complete up to July 1 of the reference year 1977, the given registrations for 1977 model year vehicles had to be adjusted to reflect total year registrations. This was accomplished by comparing the July 1, 1976 NVPP with year end total registrations. The final estimated

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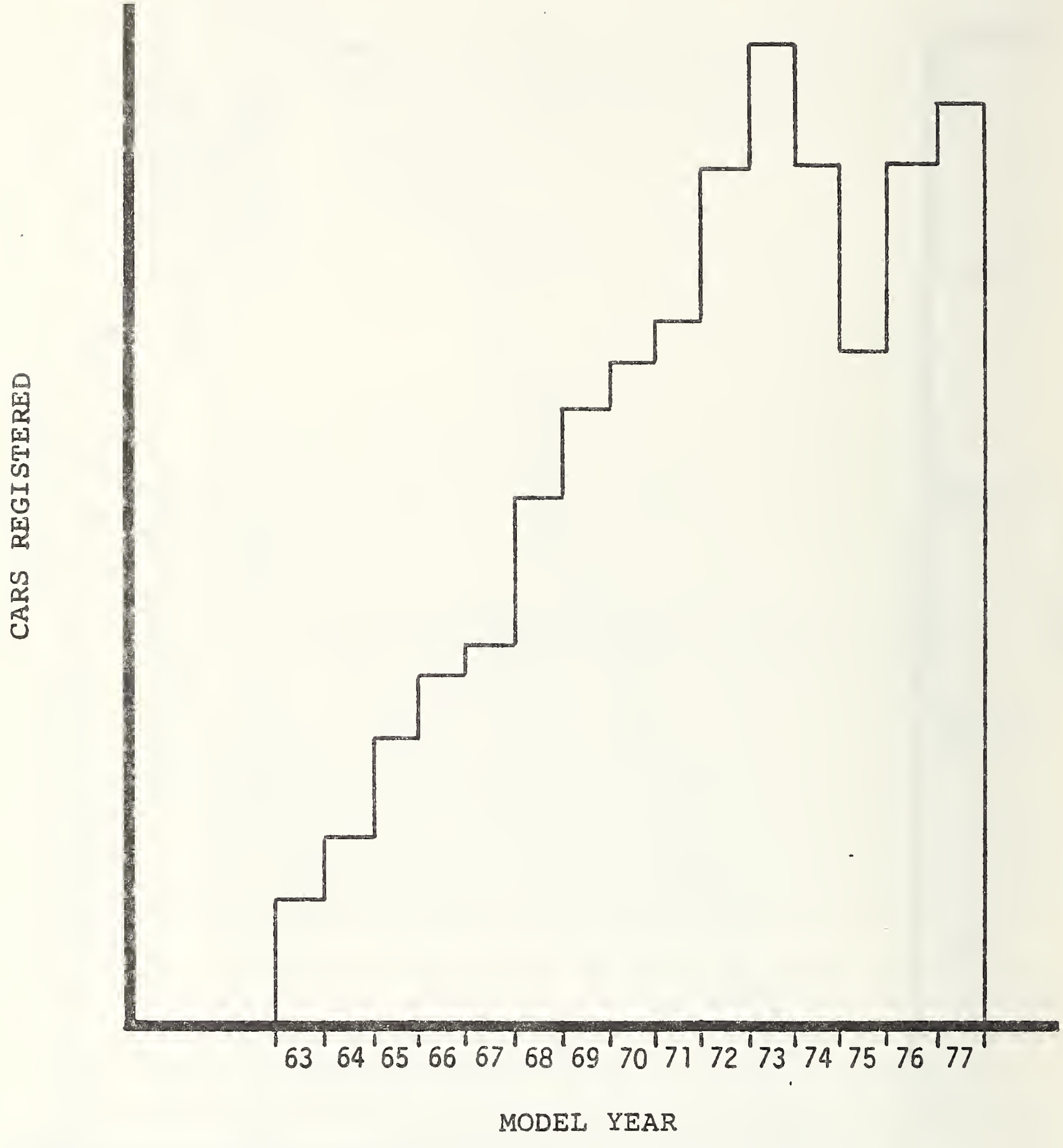
*These passenger cars represent FARS "body type" codes "01", "02", "03", "06", "08", and "09".

TABLE 3-6 - DATA FOR FIGURES 3-4, 3-9 and 3-10

Model Year	Fatalities	Observed Fatality Rate (1×10^{-8} Vehicle Miles) Using Adjusted Average Miles	Observed Fatality Rate (1×10^{-8} Vehicle Miles) Using Adjusted HSRC Miles
63	407	4.55	4.63
64	666	4.71	4.66
65	939	4.16	3.95
66	1,218	4.36	4.06
67	1,380	4.24	3.89
68	1,717	3.57	3.34
69	2,047	3.37	3.23
70	2,183	3.14	3.08
71	2,132	2.70	2.70
72	2,456	2.38	2.43
73	2,491	1.99	2.08
74	2,291	1.95	2.08
75	1,748	1.77	1.93
76	2,363	1.72	1.95
77	1,811	1.51	1.81

FIGURE 3-4. NUMBER OF FATALITIES IN 1977 BY MODEL YEAR.



*Due to restrictions regarding the use of R.L. Polk and Company data, the vertical scale is not shown.

FIGURE 3-5. NUMBER OF CARS REGISTERED IN 1977 BY MODEL YEAR.

figure of 70% total registrations by July 1 represents a weighted average among domestic manufacturers and imports, based on 1976 figures.

3.4.3 Exposure to Accident

The third necessary variable in deriving an observed fatality rate by model year is an index of automobile exposure to accidents by vehicle age. While there is no universally agreed upon index of exposure, the utilization of vehicle miles of travel is probably the most commonly accepted. The description of the mileage data used in this application appears in Section 3.3.2.

3.4.4 Validating the Exposure Index By Comparison to Accident Statistics

It is possible to verify the validity of the exposure measures used in the previous section by making comparisons to accident statistics. This analysis provides as a by-product an indirect demonstration of the effects of the 1972 bumper standard (FMVSS, Exterior Protection, Standard No. 215).

The exposure index considered is simply a product of vehicle miles of travel and number of registrations for each model year. To form this index, the average of three independent sources of miles of travel and the registration figures of R. L. Polk & Co. were used. To validate the exposure index, the proportion of exposure that each model year contributes to the total exposure can be compared with the actual proportions observed in a statistical sample of accidents.

One such statistical sample currently available is a sample of towaway accidents collected in the National Crash Severity Study (NCSS) program. From this data, the necessary proportional comparisons can be made for the fifteen model year from 1973 through 1977.

However, the available NCSS data was only complete from January 1, 1977 to approximately the middle of November, 1977. Therefore, it was first necessary to adjust our mileage figures to reflect the proper NCSS observation period. This was accomplished by fitting the yearly mileage figures with parabolic curves and integrating for monthly mileage as described in

Section 3.3.2. The final comparison between the proportions of NCSS accidents and our adjusted exposure index for each model year appears in Figure 3-6. NCSS data appear as a dotted line while the solid line indicates the exposure proportions using average annual mileage figures of Figure 3-1. Vertical sensitivity bars indicate the extent of deviation resulting from use of the three mileage sources independently.

While both plots reflect very similar patterns of change, the overall fit was initially unsatisfactory. The adequacy of the registration component of the exposure index was assumed, leaving the mileage component as the suspect factor. Thus a comparison was initiated between our adjusted model year mileage figures and NCSS mileage figures obtained through odometer readings of accident vehicles. A major limitation in this procedure, however, is that odometer turn-overs begin to occur in some NCSS sample vehicles relatively early in vehicle age, causing a significant underestimation of total mileage at least by the time a vehicle is six years old. Thus the comparison appearing in Figure 3-7 shows cumulative mileage for only the five model years from 1973 to 1977. Given that NCSS mileage totals will increasingly underestimate actual mileage with vehicle age, the fit between data sources seems very good, especially for the HSRC mileage.

Our exposure index thus appeared satisfactory with respect to both the registration and miles of travel components, yet the data did not compare well with NCSS accident proportions in Figure 3-6. In fact, regardless of which of the three mileage sources utilized, the exposure index consistently underestimates the NCSS data from 1972 and earlier, and consistently overestimates NCSS data from 1973 and later. And when the two above time periods are analyzed separately as in Figure 3-8, by finding the proportion of accidents or exposure for each model year data within its respective time period, the results are nearly overlapping. This suggests that the time periods are separated by a distinct event occurring just prior to the 1973 model year production.

The nature of this event seems apparent with the realization that NCSS data represents towaway accidents only. Figure 3-6 suggests that the proportion of towaway accidents for model years 1973 and later decreased relative to the experience of previous model year vehicles. It is precisely the former group

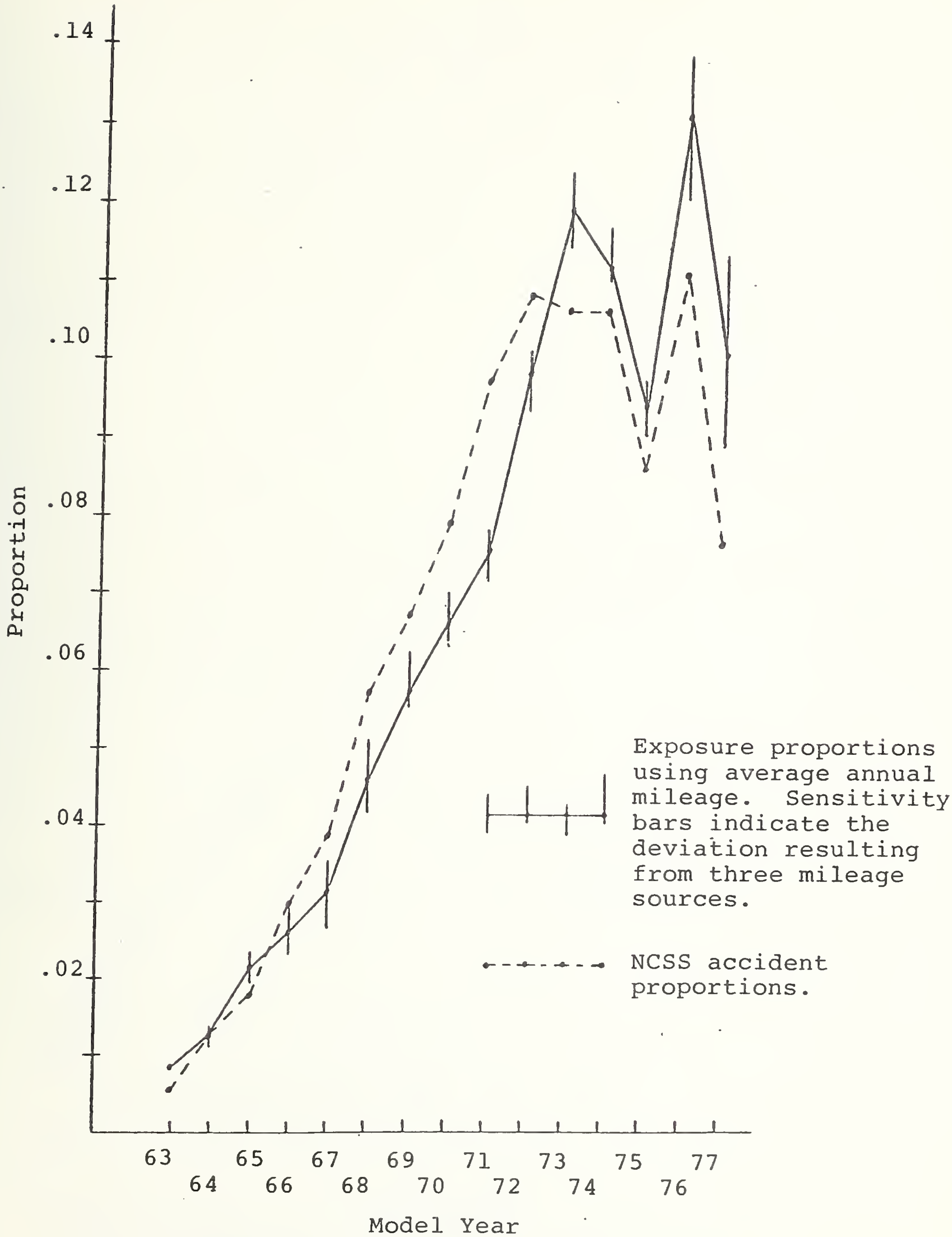


FIGURE 3-6. A COMPARISON BETWEEN THE PROPORTIONS OF NCSS ACCIDENTS AND THE ADJUSTED EXPOSURE INDEX FOR FIFTEEN MODEL YEARS.

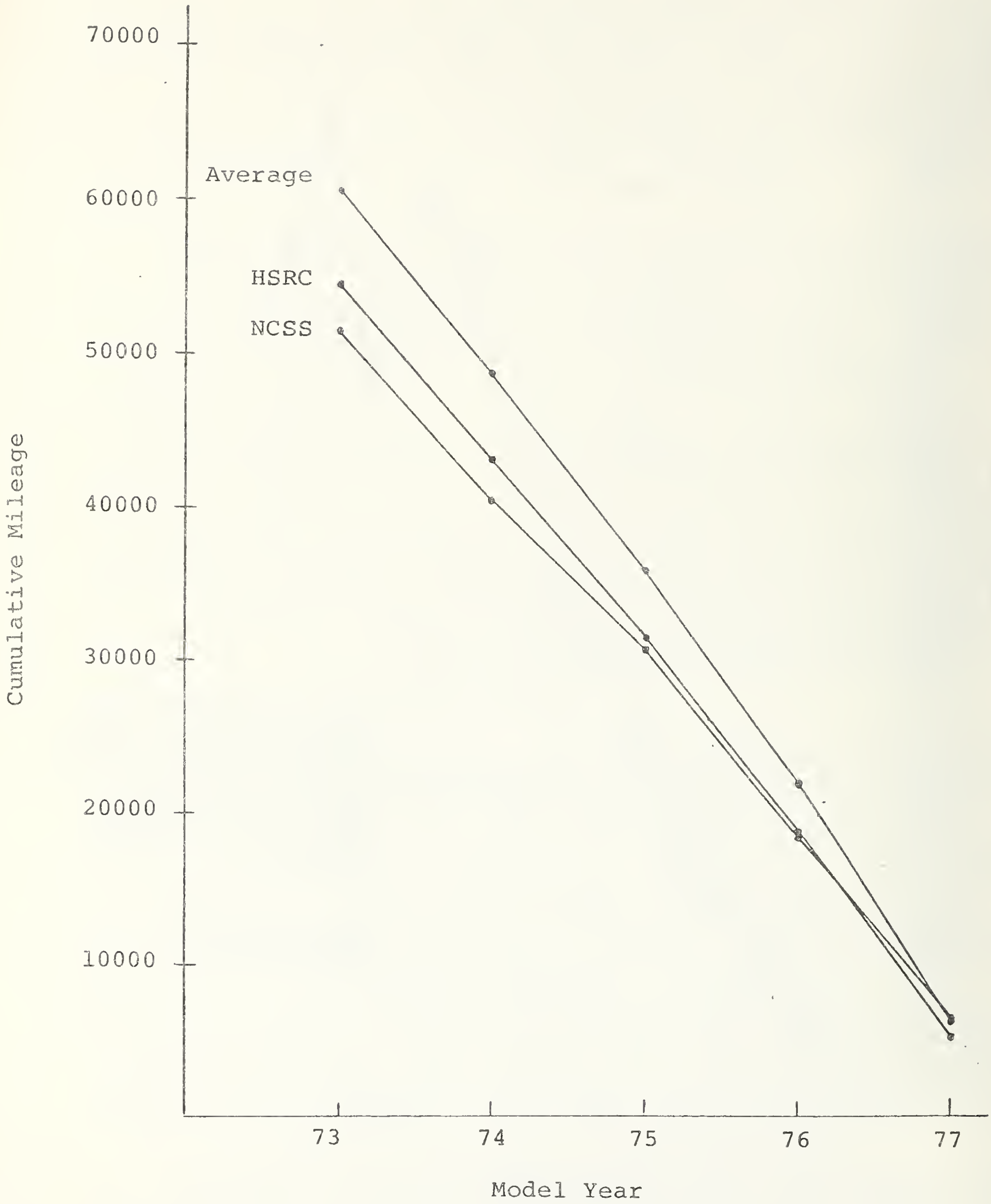


FIGURE 3-7. A COMPARISON BETWEEN NCSS MILEAGE FIGURES AND THE MILEAGE DATA UNUSED IN THE EXPOSURE INDEX.

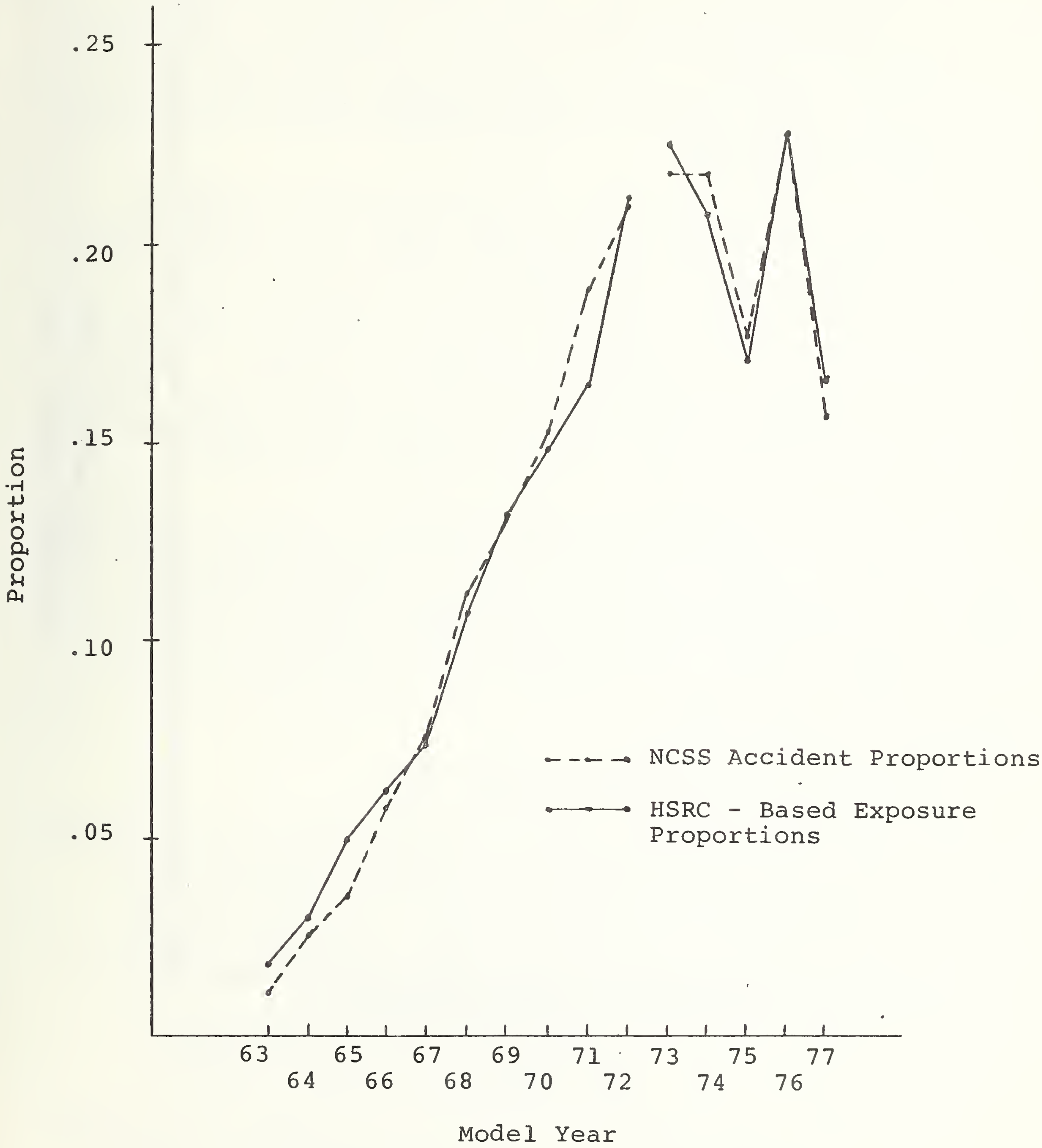


FIGURE 3-8. A COMPARISON BETWEEN NCSS ACCIDENT PROPORTIONS AND HSRC - BASED EXPOSURE PROPORTIONS FOR THE TWO MODEL YEAR PERIODS SEPARATED BY FMVSS #215.

to which the federal bumper standard (FMVSS, #215) applies. This standard was intended to reduce property damage losses in low crash severity collisions. The additional exterior protection and the structural modifications required to accommodate the standard are likely to be influential in reducing towaways as well, as the data clearly suggests. No other known event at that point in time seems to account for the distinction between those model year groups.

So although the proportions predicted by our exposure measure do not match the accident data used, the difference can be explained very well by recognizing that the comparison is affected by limiting the data collection process to towaway accidents only. Once the towaway nature of the data is taken into account, there is excellent agreement as shown in Figure 3-8. Thus, it can be expected that the exposure measure would predict proportions involving all accidents very well since it so clearly accounts for the towaway nature of the NCSS.

In summary, the above analysis appears to show an important effect of the federal bumper standard in towaway accidents. In addition, it provides validation of the exposure measure utilized in the development of an observed fatality rate by vehicle year. Further investigation will hopefully clarify which causative factors are operative in the downward trend observed for that rate.

3.4.5 <u>Observed Fatality Rate By Model Year</u>

The derivation of an observed fatality rate for the fifteen model years between 1963 and 1977 is simply a matter of combining the three variables defined above. This is done by examining the quantity of fatalities for each model year as a function of vehicle usage, where usage is merely a factor of miles of travel and number of registrations:

$$\text{observed fatality rate} = \frac{\text{observed number of fatalities}}{\text{cars registered x miles traveled}}$$

The plot of the observed fatality rate appears in Figures 3-9 and 3-10, utilizing respectively, the average and HSRC adjusted mileage found in Table 3-6. The four model years, 1963-65 and 1977 appear as broken lines to indicate their derivation through estimated registration figures. The registrations for model years 1963-65 were obtained by extrapolation

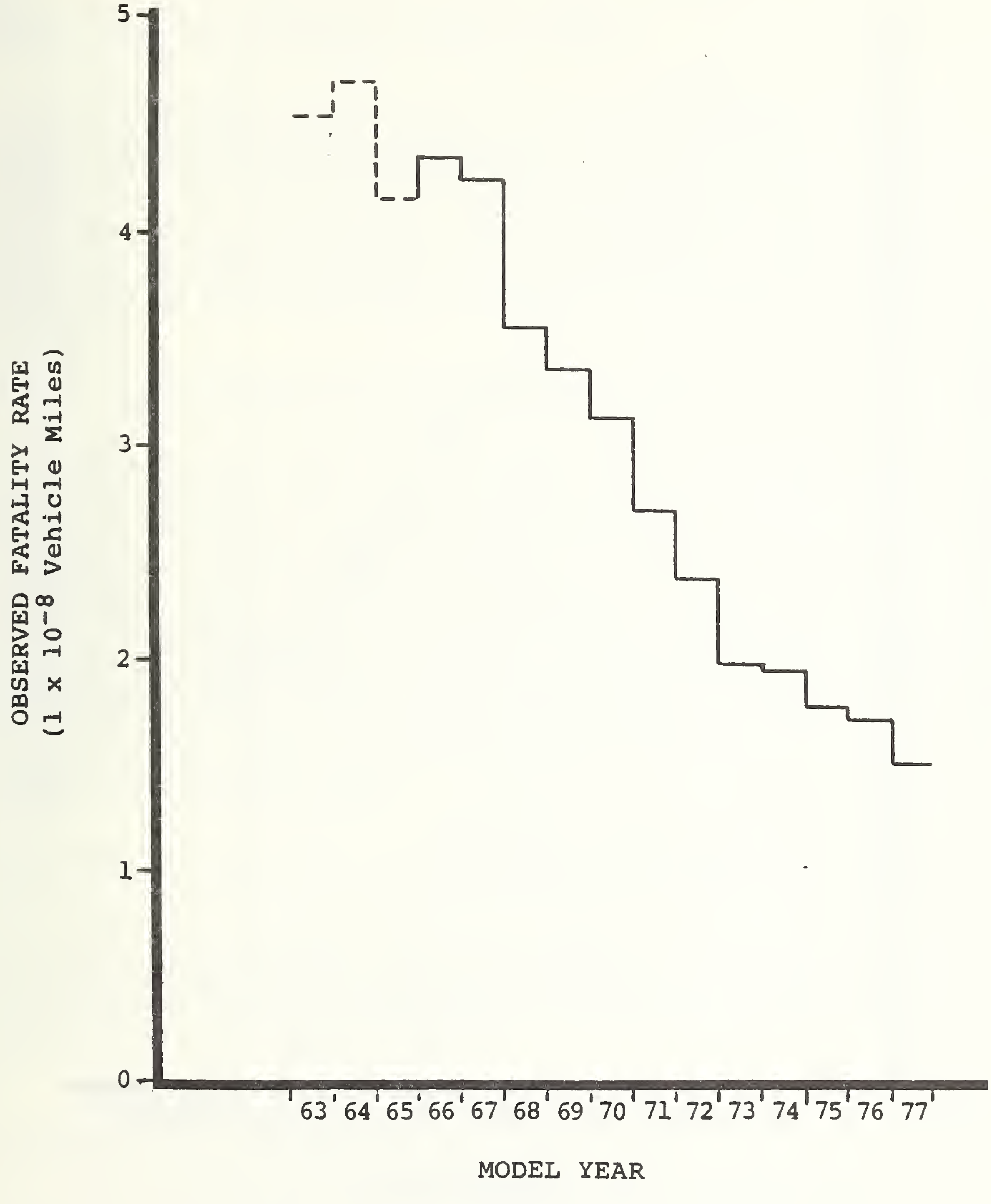


FIGURE 3-9. OBSERVED FATALITY RATE USING AVERAGE MILEAGE DATA.

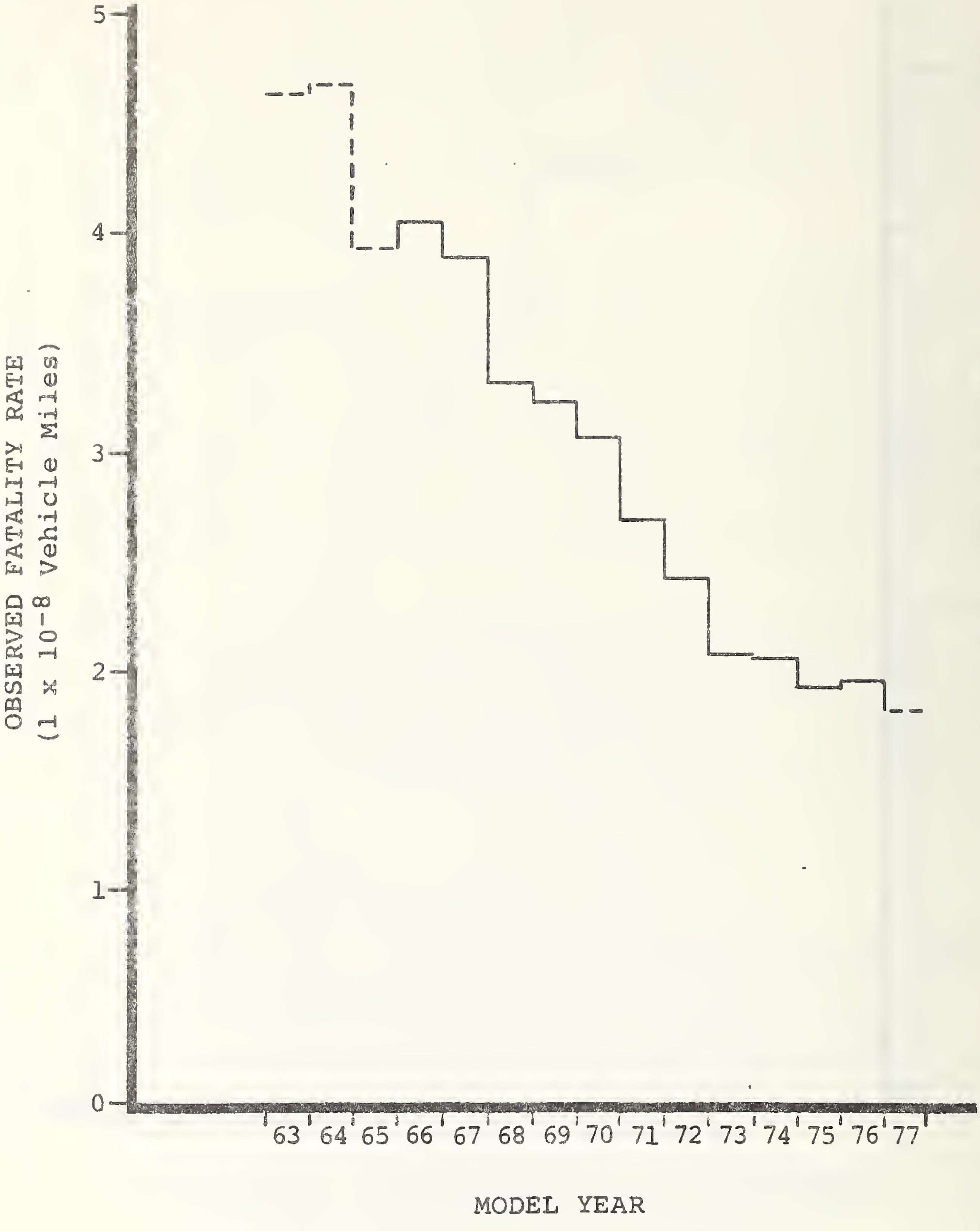


FIGURE 3-10. OBSERVED FATALITY RATE USING HSRC MILEAGE DATA.

while the 1977 registrations resulted from adjusting mid-year Polk figures to represent the full year.

A comparison of Figures 3-9 and 3-10 indicates that a very similar downward trend exists in the observed fatality rate regardless of the particular mileage data selected. The overall pattern of the two plots is nearly equivalent with a slight increase in slope resulting from use of average mileage figures. Thus the obtained fatality rate is not highly sensitive to minor fluctuations in mileage data, the least accurately known input variable.

3.4.6 Observed Fatality Rate by Impact Mode

Sections 3.4.1 to 3.4.5 present the development of an observed fatality rate for fifteen automotive model years based on statistics for calendar year 1977. Three necessary components comprise this estimate: first, the number of fatalities occurring for each model year during the reference year 1977; second, the number of cars registered for each model year in 1977; and third, an index of automobile exposure to accidents by vehicle age. The observed fatality rate is the quantity of fatalities for each model year as a function of vehicle usage, where usage is a factor of miles of travel and number of registrations:

$$\text{observed fatality rate} = \frac{\text{Observed number of fatalities}}{\text{cars registered x miles traveled}}$$

For the fifteen model years from 1963 to 1977 the observed fatality rate exhibits a general downward trend, not highly sensitive to minor fluctuations in mileage data, the least accurately known input variable.

The purpose of this section is to present a breakdown of this observed fatality rate by impact mode. This is accomplished by distributing passenger car[1] fatality data from the 1977 Fatal Accident Reporting System (FARS) by vehicel model year and by FARS Principal Impact Point. The FARS Principal Impact Point

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[1] These passenger cars represent FARS 'Body Type' codes of 01, 02, 03, 06, 08, and 09.

element is coded either by vehicle clock position, 'top', 'undercarriage', 'unknown', or 'not applicable'. For the present analysis, the frontal impact mode is defined as clock positions 11, 12, and 1 while the side impact mode is defined as clock positions 2-4 and 8-10. Figure 3-11 shows the number of passenger car fatalities for each of fifteen model years distributed by frontal, side, other, and all impact modes.

The number of fatalities for each impact mode, shown in Figure 3-11 may be used in the calculation of the observed fatality rate to determine a rate for any give mode. This is done in Figures 3-12 and 3-13 for frontal, side, other, and all impact modes. Figure 3-12 uses mileage data from the Highway Safety Research Center (Ref. 7) while Figure 3-13 uses an average of this mileage and mileage from two other sources(see Section 3.4.3). These mileage data are first adjusted to account for the variation in vehicle introduction date for a given model year sales period.

Both plots indicate that regardless of the impact mode examined, the observed fatality rate exhibits a downward trend across the model year period. The slope of the trend, however, does differ slightly by mode. For instance, the frontal mode fatality rate appears to be decreasing more sharply throughout the period than the side fatality rate, expecially using average mileages.

Further work is being undertaken to examine the factors causing the downward trend. It may be possible to determine which of these factors are mode-specific in effect. For example, the federal bumper standard (FMVSS, #215) should differentially affect the frontal vs. side mode fatality rate. In addition, similar fatality rates for other combinations of modes, such as front and rear together, could also be examined.

3.4.7 Validating the Exposure Index By Comparison to Accident Statistics By Impact Mode

Previous investigation described in Sections 3.4.5 and 3.4.6 has shown that the observed fatality rate within calendar

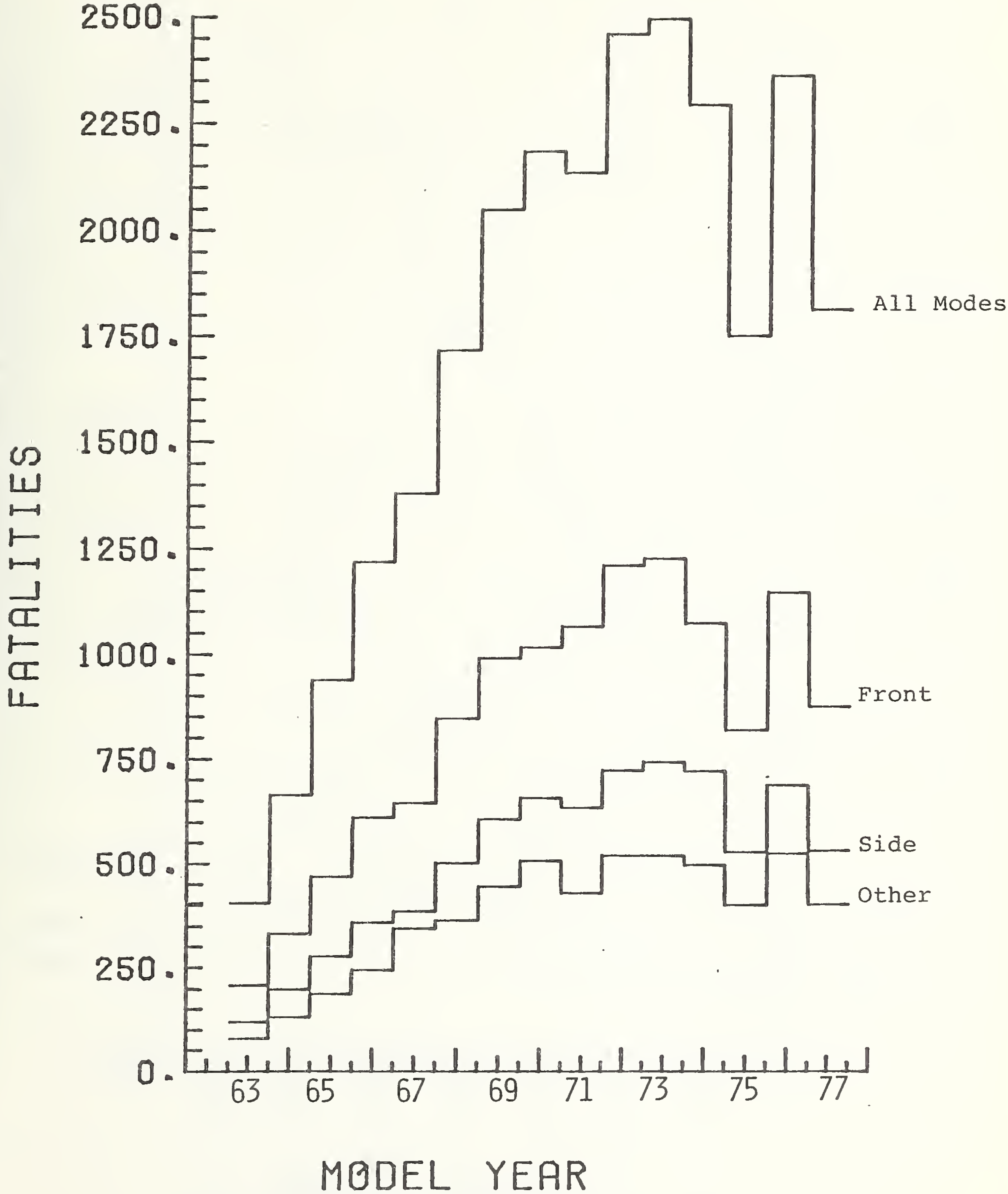

FIGURE 3-11. NUMBER OF 1977 PASSENGER CAR FATALITIES BY IMPACT MODE.

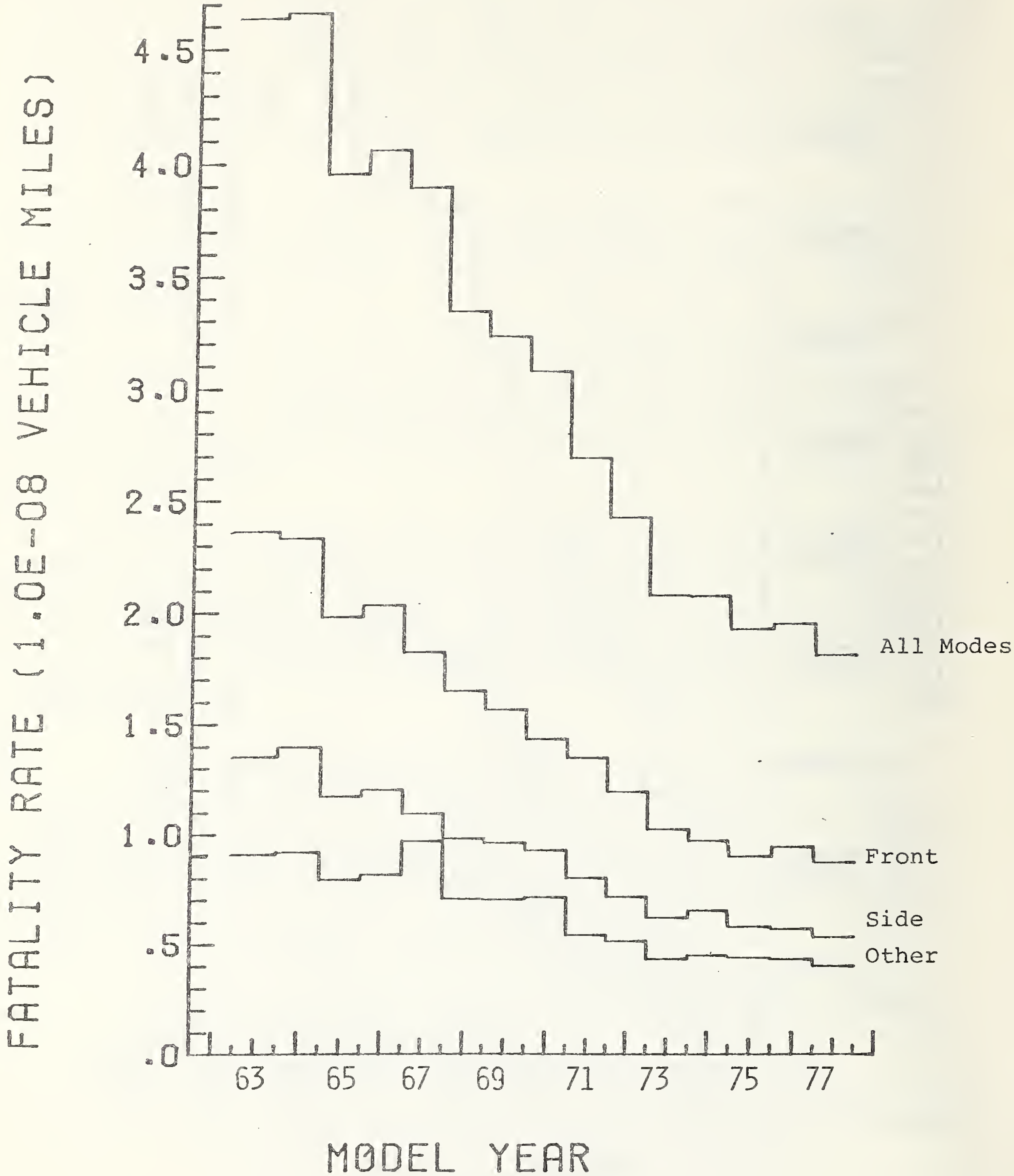

FIGURE 3-12. OBSERVED FATALITY RATE BY IMPACT MODE USING HSRC MILEAGE.

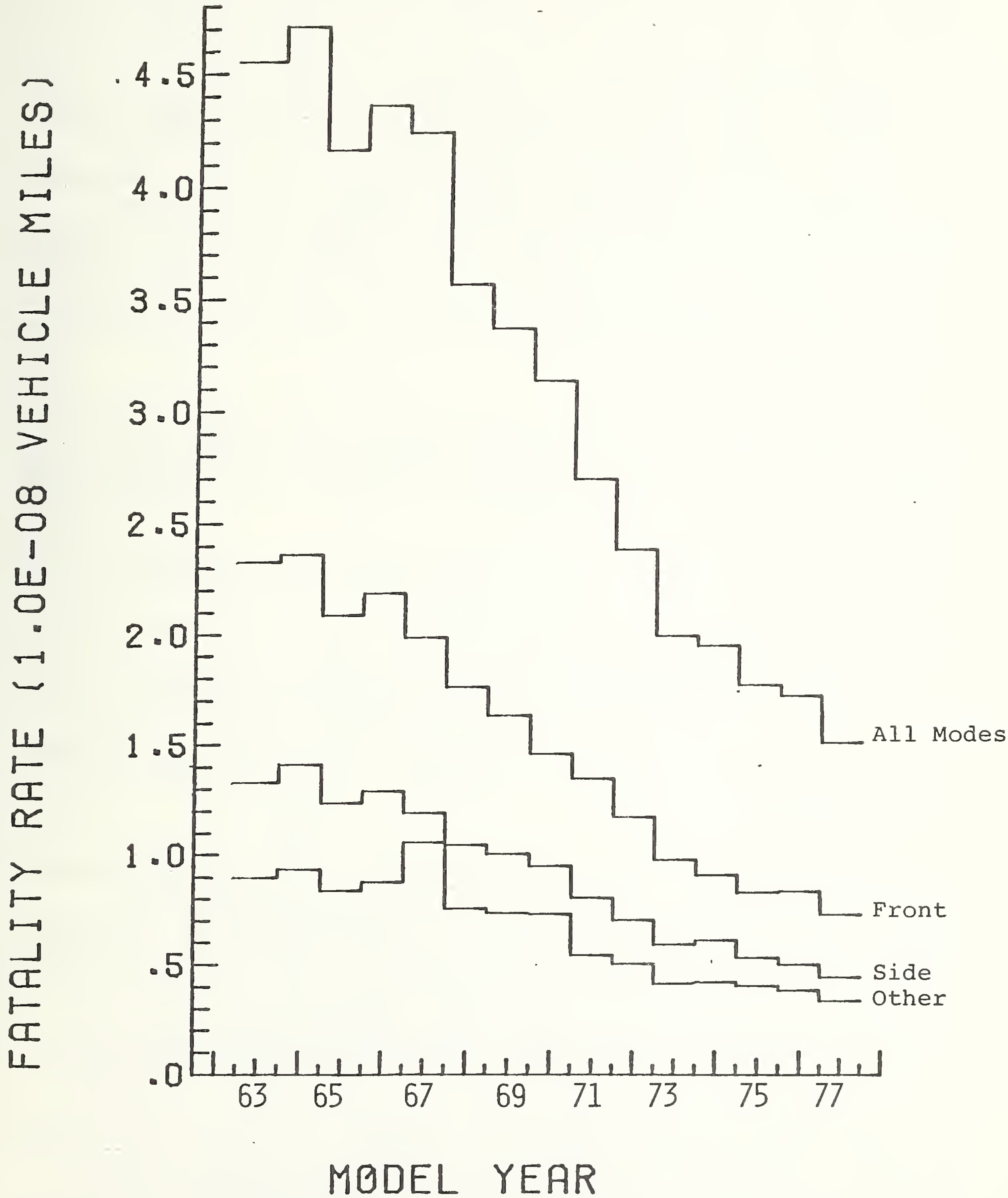

FIGURE 3-13. OBSERVED FATALITY RATE BY IMPACT MODE USING AVERAGE MILEAGE.

year 1977, defined as the quantity of annual fatalities over annual vehicle exposure, has steadily decreased for model year vehicles from 1963 to 1977. The measure of vehicle exposure used in this application is a factor of annual vehicle miles of travel and the total number of registrations for the year. A comparison of this exposure measure with actual accident counts from the National Crash Severity Study (NCSS) has provided validation for the measure (See Section 3.4.5). This comparison also suggests that the federal bumper standard (FMVSS, #215), effective on 1973 and later model year vehicles may have reduced the likelihood of towaway accidents. The purpose of this section is to enchance the comparison between NCSS accident proportions and the exposure measure defined above by analyzing the NCSS data by impact mode.

The NCSS data utilized in this analysis considered the time period from January 1, 1977 to approximately the middle of November, 1977. The accidents in this sample were divided into five principal impact categories:

1. front, defined as clock positions 11, 12 and 1;
2. side, defined as clock positions 2-4 and 8-10;
3. rear, defined as clock positions 5, 6, and 7;
4. other, including top, undercarriage, and rollovers; and
5. unknown.

Figure 3-14 shows the proportions of NCSS accidents within each of fifteen model years distributed by the five impact modes. There is a general decrease in the proportion of frontal accidents relative to side accidents across the model year period.

Figure 3-15 shows the proportion of the total number of accidents for each vehicle model year, where the contributions are shown by impact mode. Front and side accidents comprise about 86% of the total sample, with frontal impacts numbering more than twice the amount of side impacts. Although the overall patterns of front and side accidents are very similar, minor differences do exist following the implementation of the federal bumper standard. For 1973, the model year in which the standard

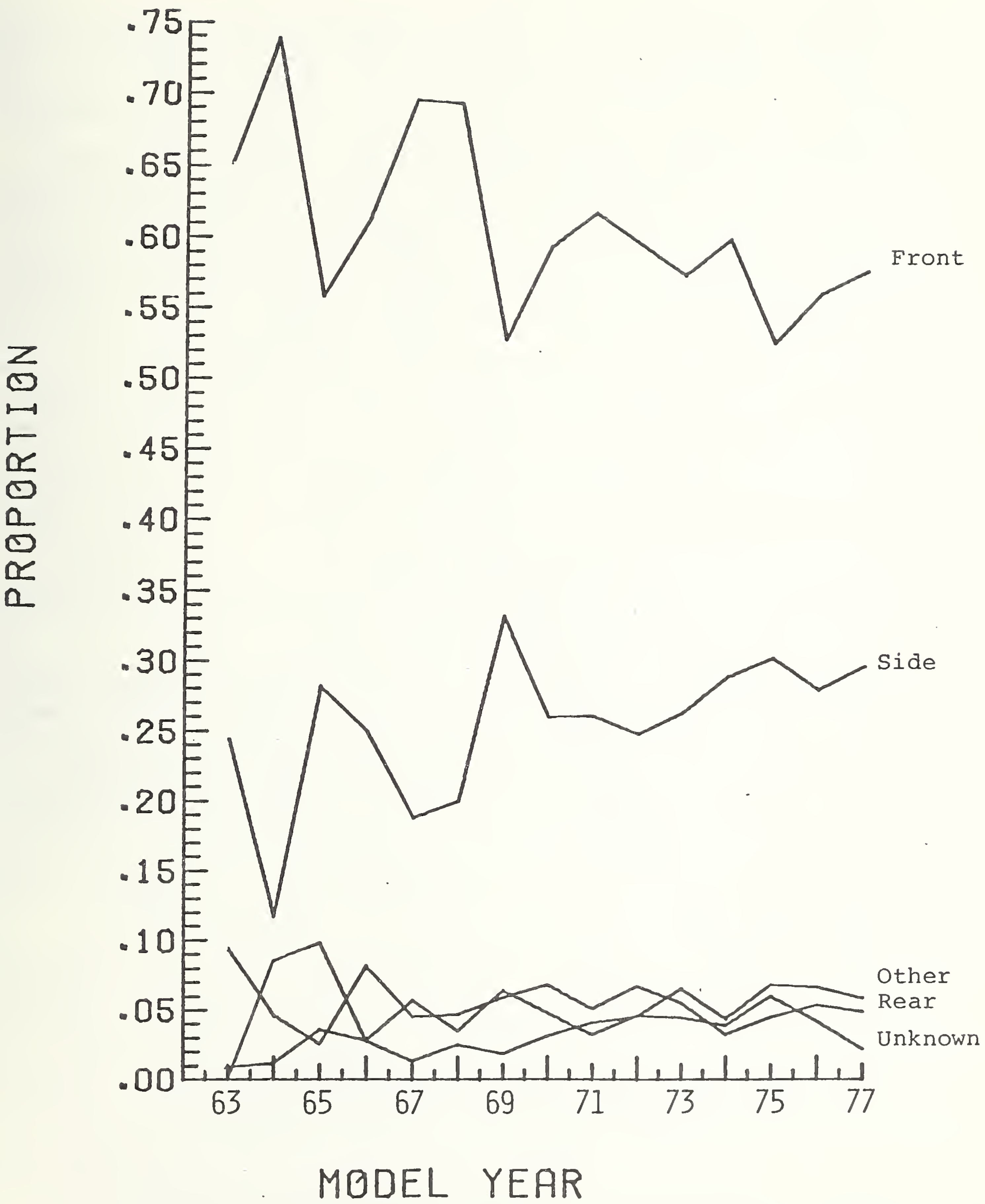

FIGURE 3-14. THE PROPORTION OF NCSS ACCIDENTS WITHIN EACH OF FIFTEEN MODEL YEARS DISTRIBUTED BY FIVE IMPACT MODES.

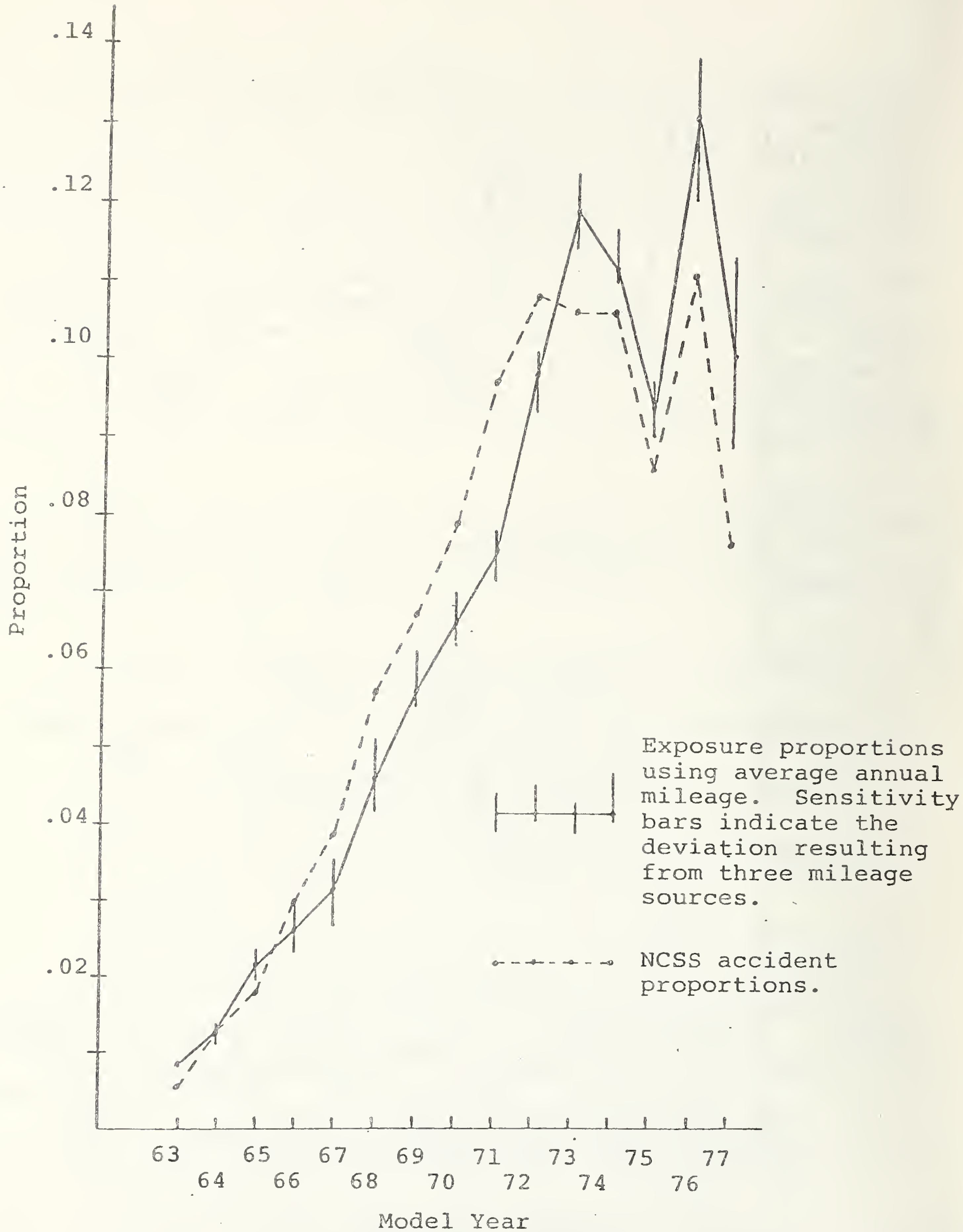

FIGURE 3-15. A COMPARISON BETWEEN THE PROPORTIONS OF NCSS ACCIDENTS AND THE ADJUSTED EXPOSURE INDEX FOR FIFTEEN MODEL YEARS.

became effective, the proportion of frontal accidents decreased while side impacts continued to rise. It may also be the case that the relative proportion of frontal accidents to side accidents is changing toward a higher fraction of side towaways.

With the breakdown of NCSS accidents by impact mode, it is now possible to make a model comparison with the exposure measure defined above. To accomplish this, the proportion of exposure that each model year contributes to the total exposure can be compared with the actual accident proportions observed in the NCSS data. When this comparison is made without regard to impact mode, the exposure index consistently underestimates the NCSS data for 1972 model years and earlier, and consistently overestimates NCSS data for 1973 and new vehicles (Figure 3-15). When the two above time periods are analyzed separately by finding the proportion of accidents or exposure for each model year data within its respective time period, the results are nearly overlapping (Figure 3-16).

Figure 3-17 is a display of the model year contributions to total NCSS accidents broken down by impact mode. Figures 3-18 and 3-19 present the above two comparisons utilizing NCSS front and rear accidents combined. In both plots, the solid line represents exposure proportions using HSRC annual mileage (Ref. 7) adjusted for the proper NCSS data collection period and the dashed line represents proportions of NCSS front and rear accidents. The NCSS accident proportions in Figure 3-18, much like those proportions without regard to mode, are consistently less than the exposure proportions following the 1972 model year. And when the two time periods are analyzed separately in Figure 3-19, a much better overall fit is observed.

Figures 3-20 and 3-21 present the same two comparisons utilizing only NCSS side accidents. Again, the solid line represents exposure proportions and the dashed line represents proportions of NCSS accidents. Figure 3-20 does not exhibit the post-1972 relative decrease in accident proportions which is evident in the analysis of both front and rear accidents and accidents regardless of mode. In fact, when the two time periods are analyzed separately in Figure 3-21, virtually no change appears in the pattern of the plot.

Figures 3-22 to 3-25 show the two comparisons with NCSS front-only and rear-only impact modes. These comparisons behave much like front and rear modes examined together.

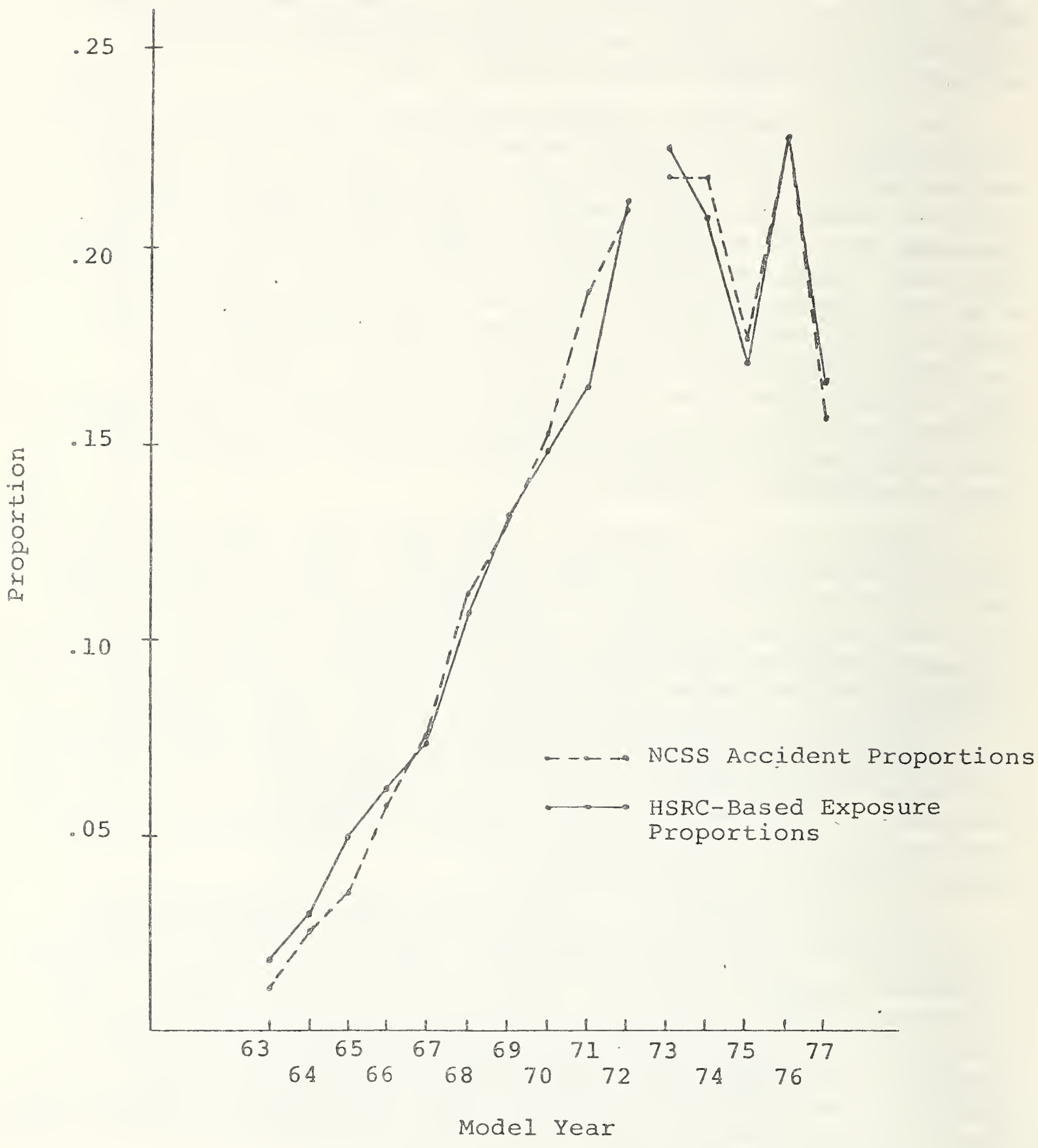

FIGURE 3-16. A COMPARISON BETWEEN NCSS ACCIDENT PROPORTIONS AND HSRC-BASED EXPOSURE PROPORTIONS FOR THE TWO MODEL YEAR PERIODS SEPARATED BY FMVSS #215.

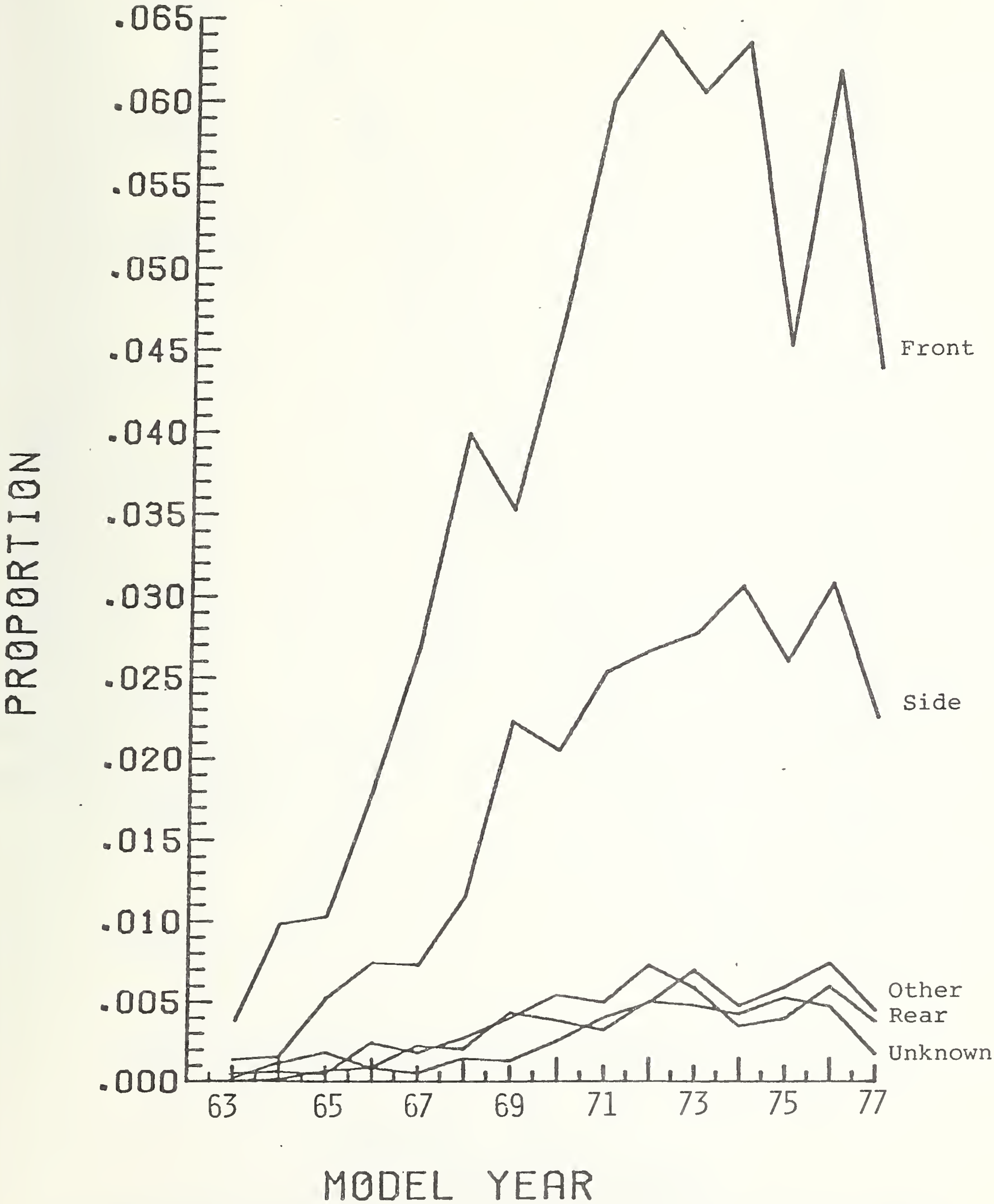

FIGURE 3-17. THE PROPORTION OF THE TOTAL NCSS ACCIDENTS FOR EACH MODEL YEAR, WITH CONTRIBUTIONS BY IMPACT MODE.

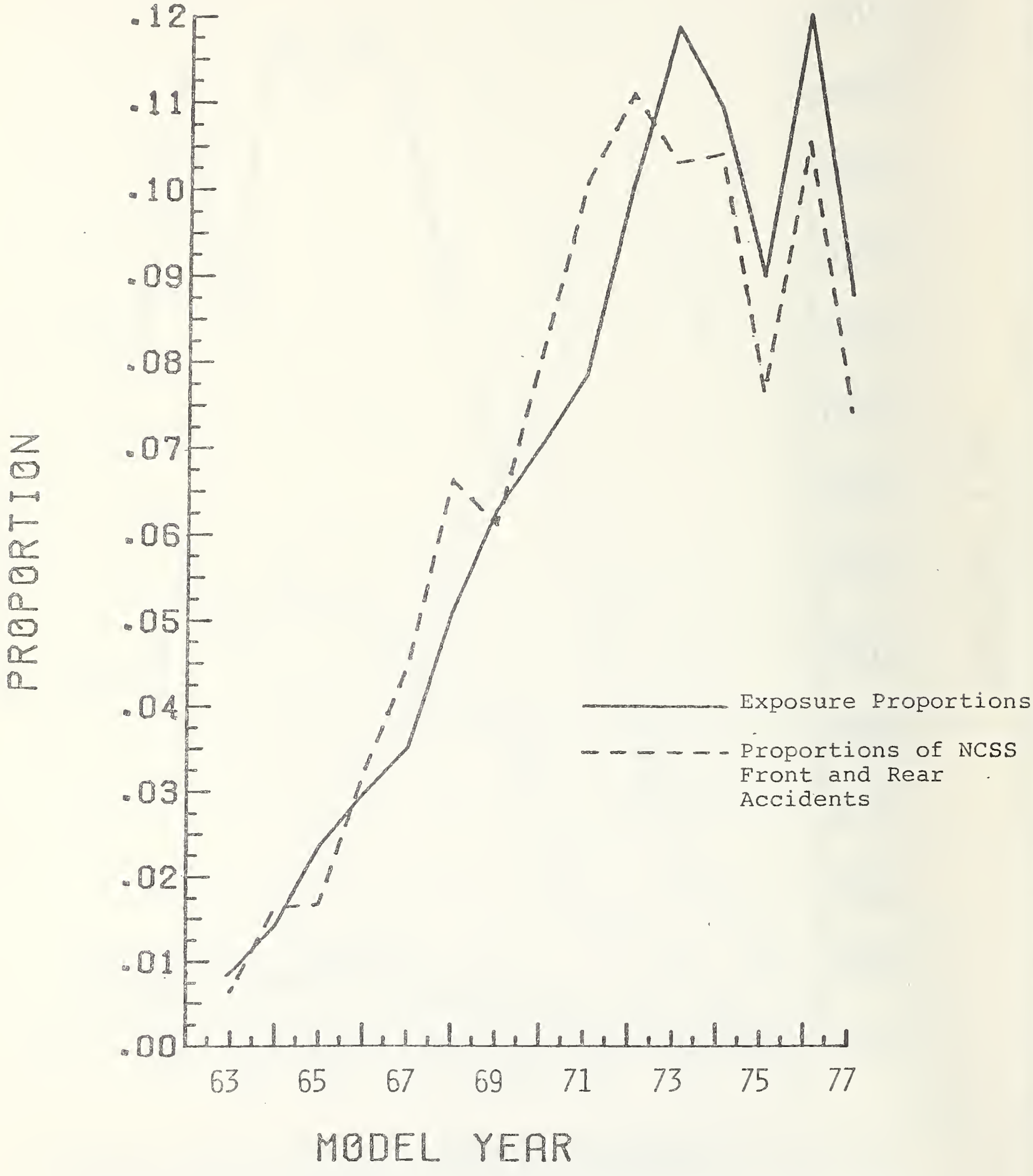

FIGURE 3-18. COMPARISON BETWEEN PROPORTIONS OF NCSS FRONT AND REAR ACCIDENTS AND EXPOSURE PROPORTIONS.

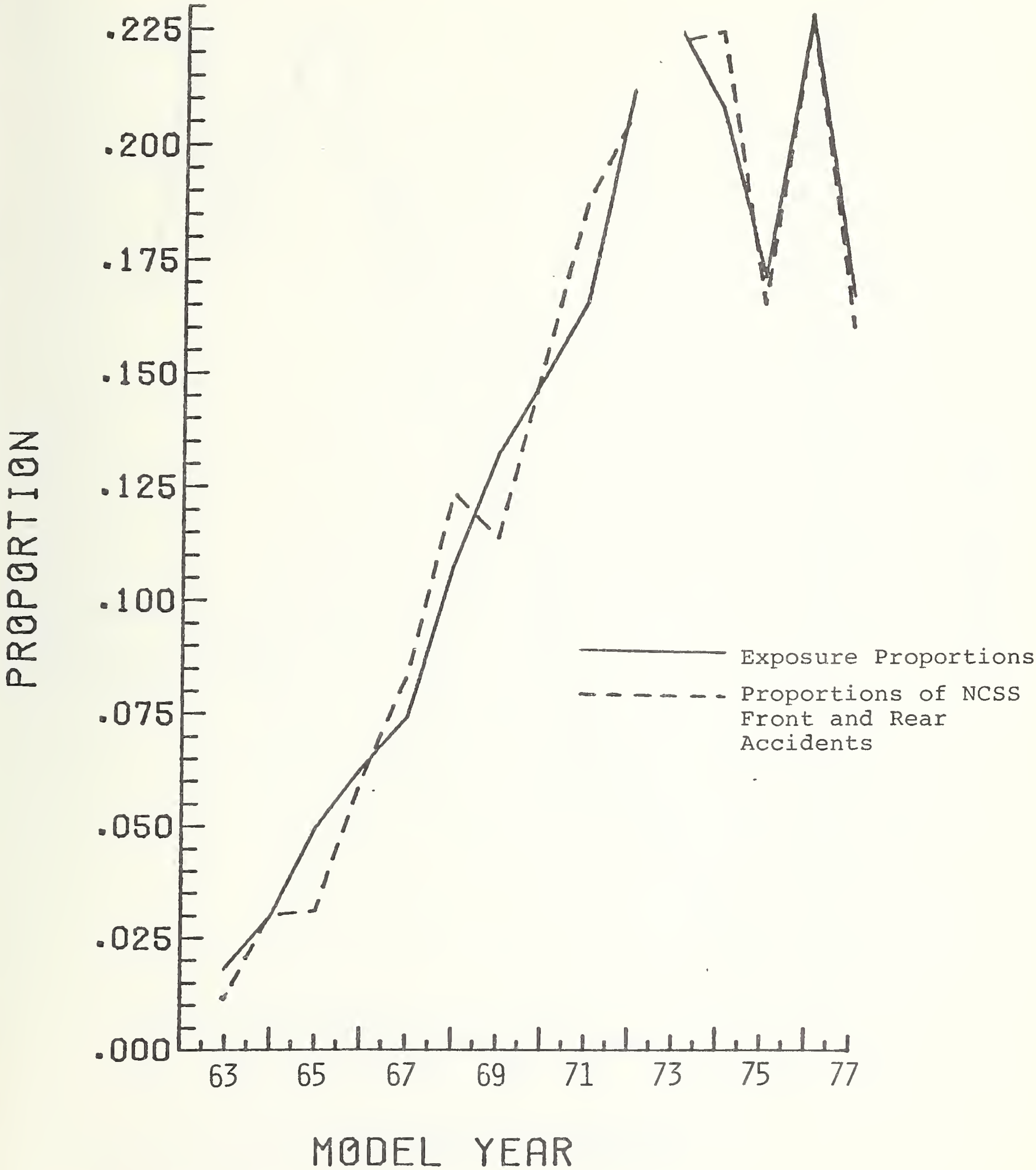

FIGURE 3-19. COMPARISON BETWEEN PROPORTIONS OF NCSS FRONT AND REAR ACCIDENTS AND EXPOSURE PROPORTIONS FOR THE TWO MODEL YEAR PERIODS SEPARATED BY FMVSS #215.

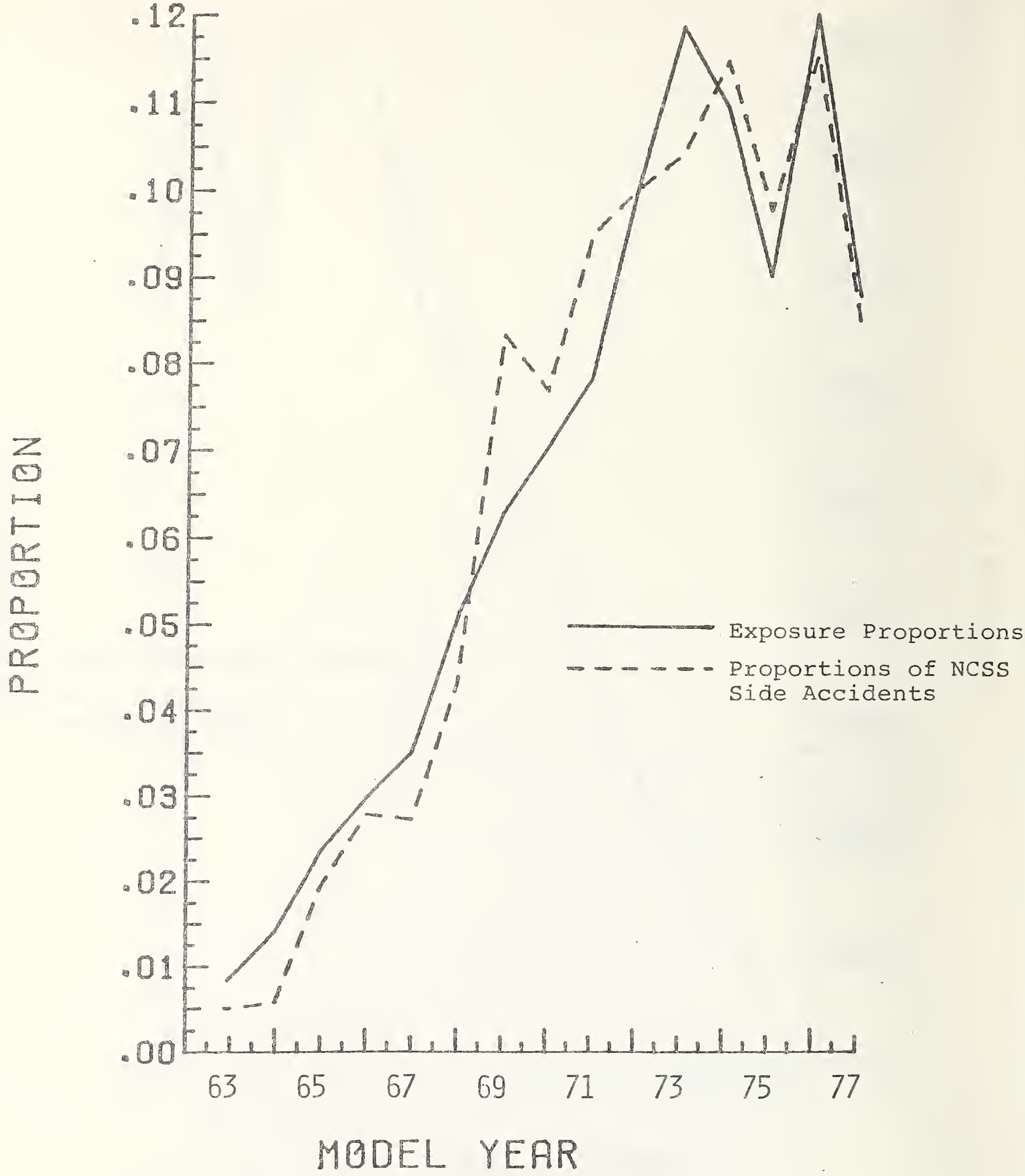

FIGURE 3-20. COMPARISON BETWEEN PROPORTIONS OF NCSS SIDE ACCIDENTS AND EXPOSURE PROPORTIONS.

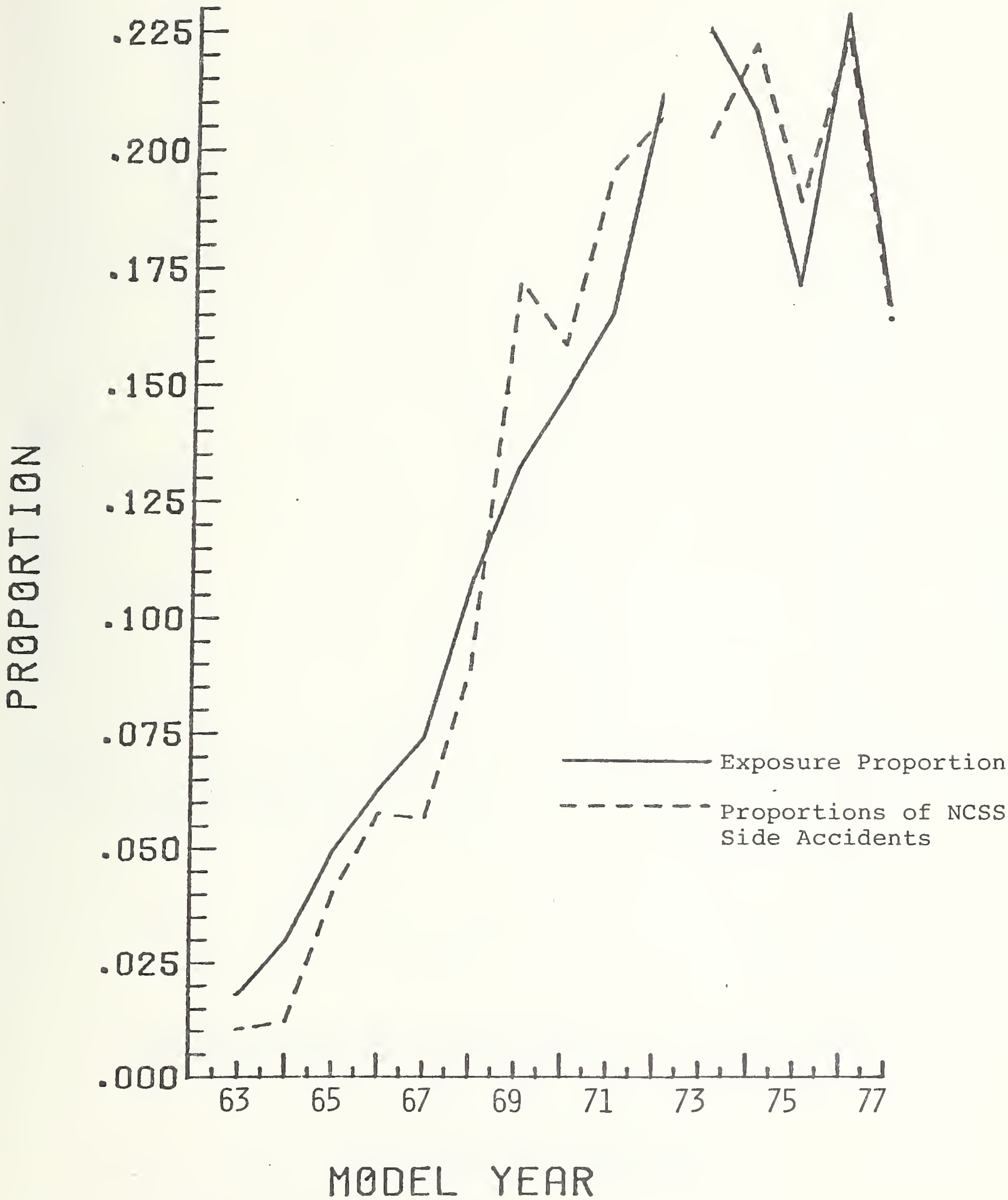

FIGURE 3-21. COMPARISON BETWEEN PROPORTIONS OF NCSS SIDE ACCIDENTS AND EXPOSURE PROPORTIONS FOR THE TWO MODEL YEAR PERIODS SEPARATED BY FMVSS #215.

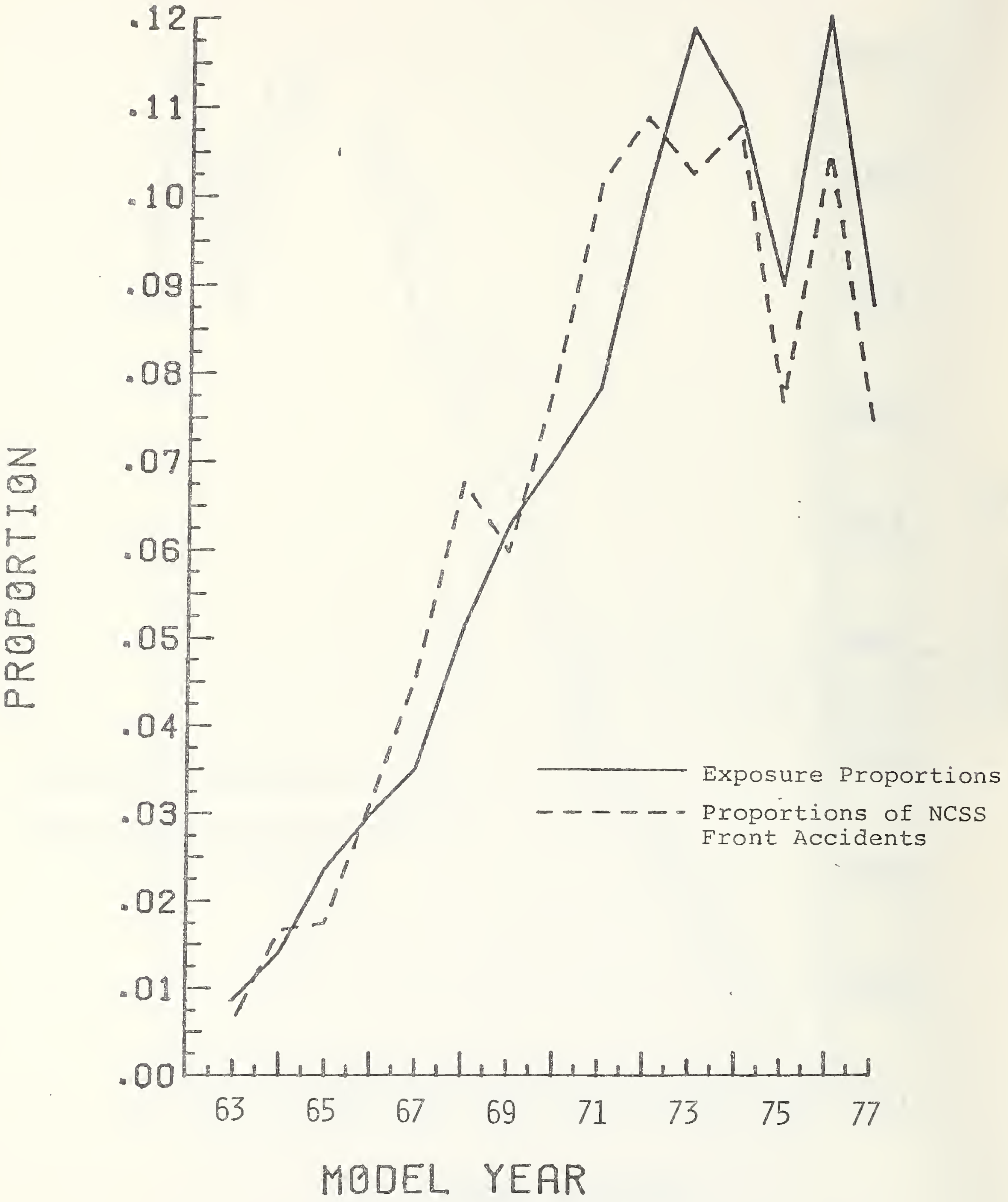

FIGURE 3-22. COMPARISON BETWEEN PROPORTIONS OF NCSS FRONTAL ACCIDENTS AND EXPOSURE PROPORTIONS.

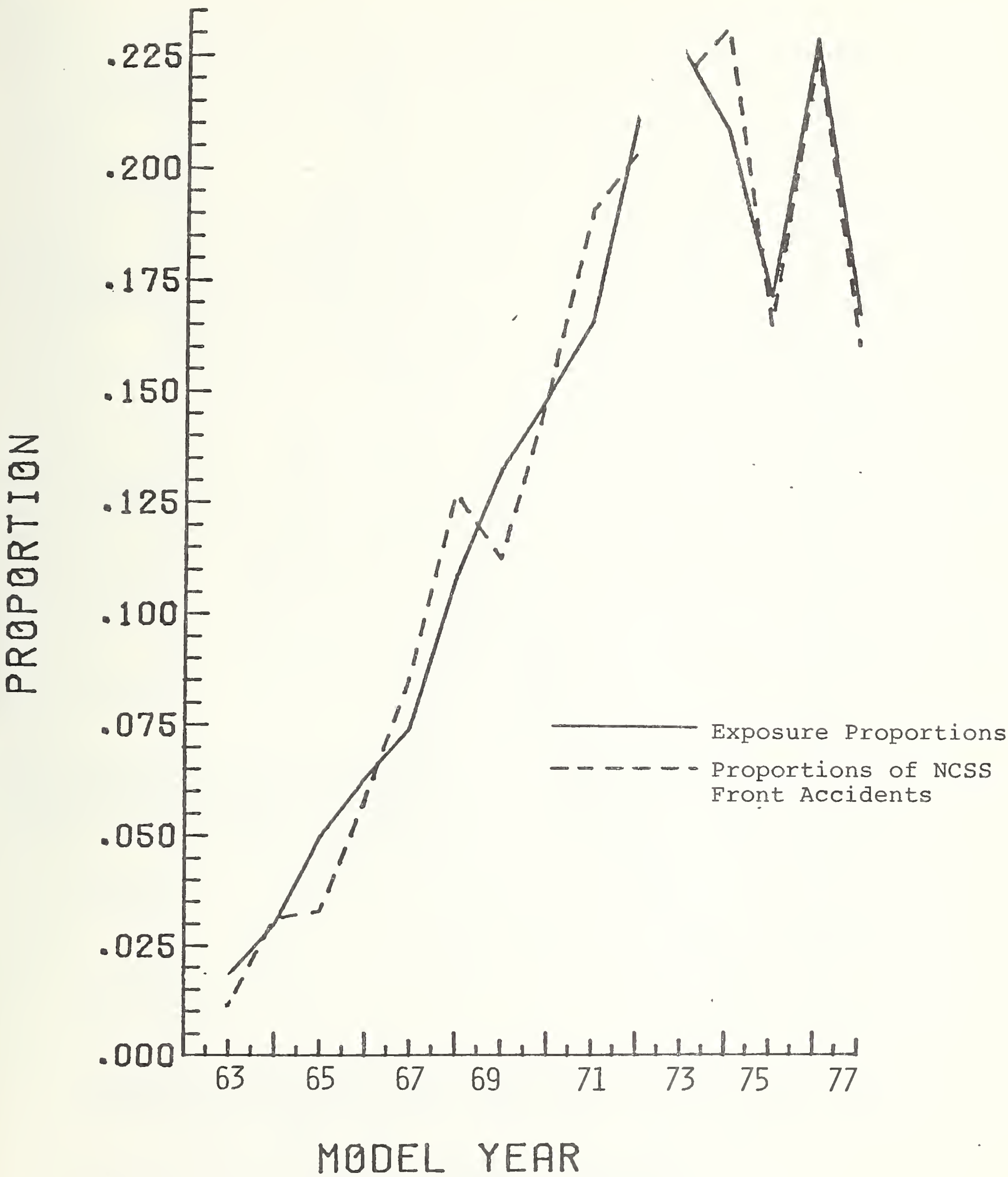

FIGURE 3-23. COMPARISON BETWEEN PROPORTIONS OF NCSS FRONTAL ACCIDENTS AND EXPOSURE PROPORTIONS FOR THE TWO MODEL YEAR PERIODS SEPARATED BY FMVSS #215.

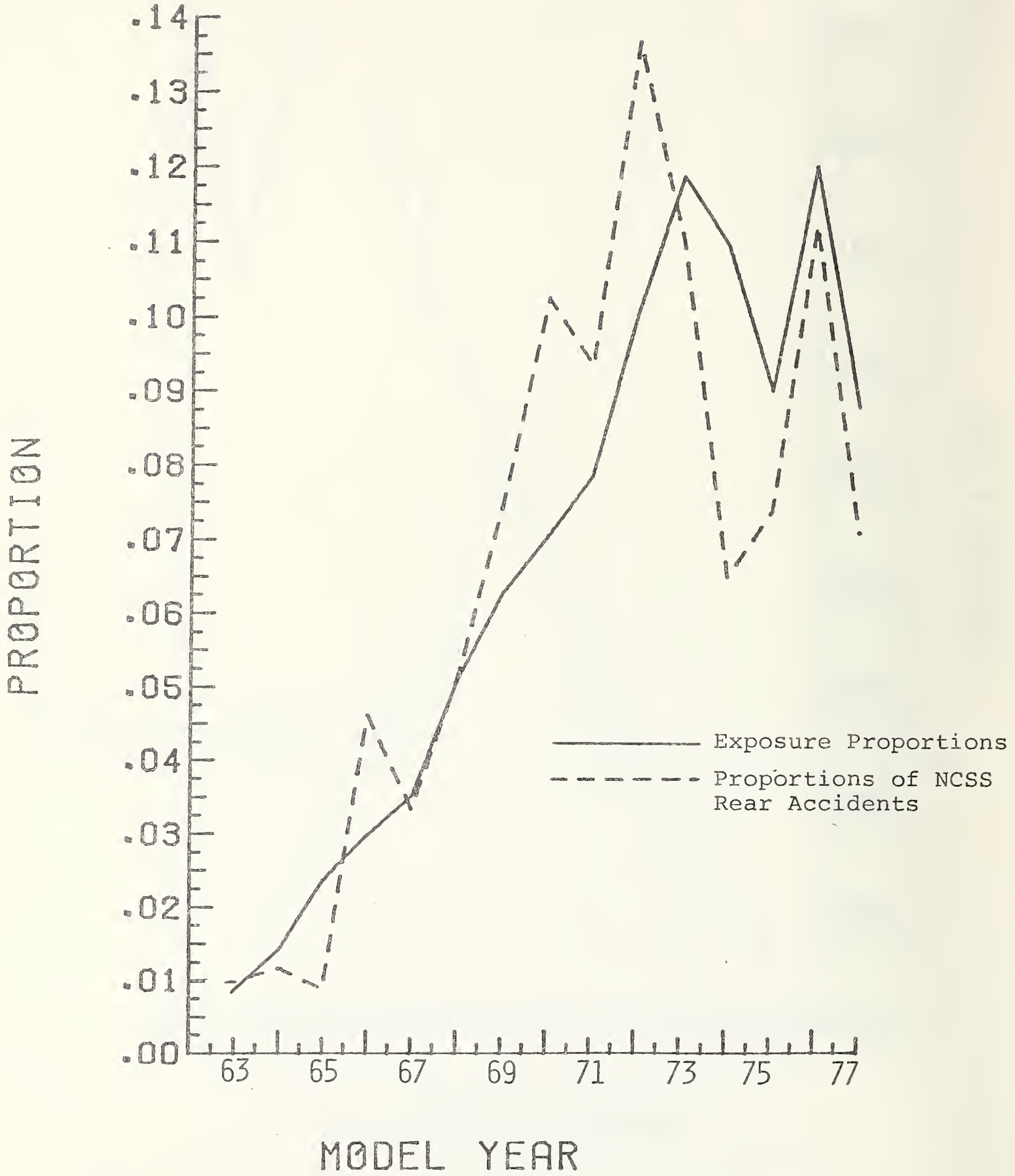

FIGURE 3-24. COMPARISON BETWEEN PROPORTIONS OF NCSS REAR ACCIDENTS AND EXPOSURE PROPORTIONS.

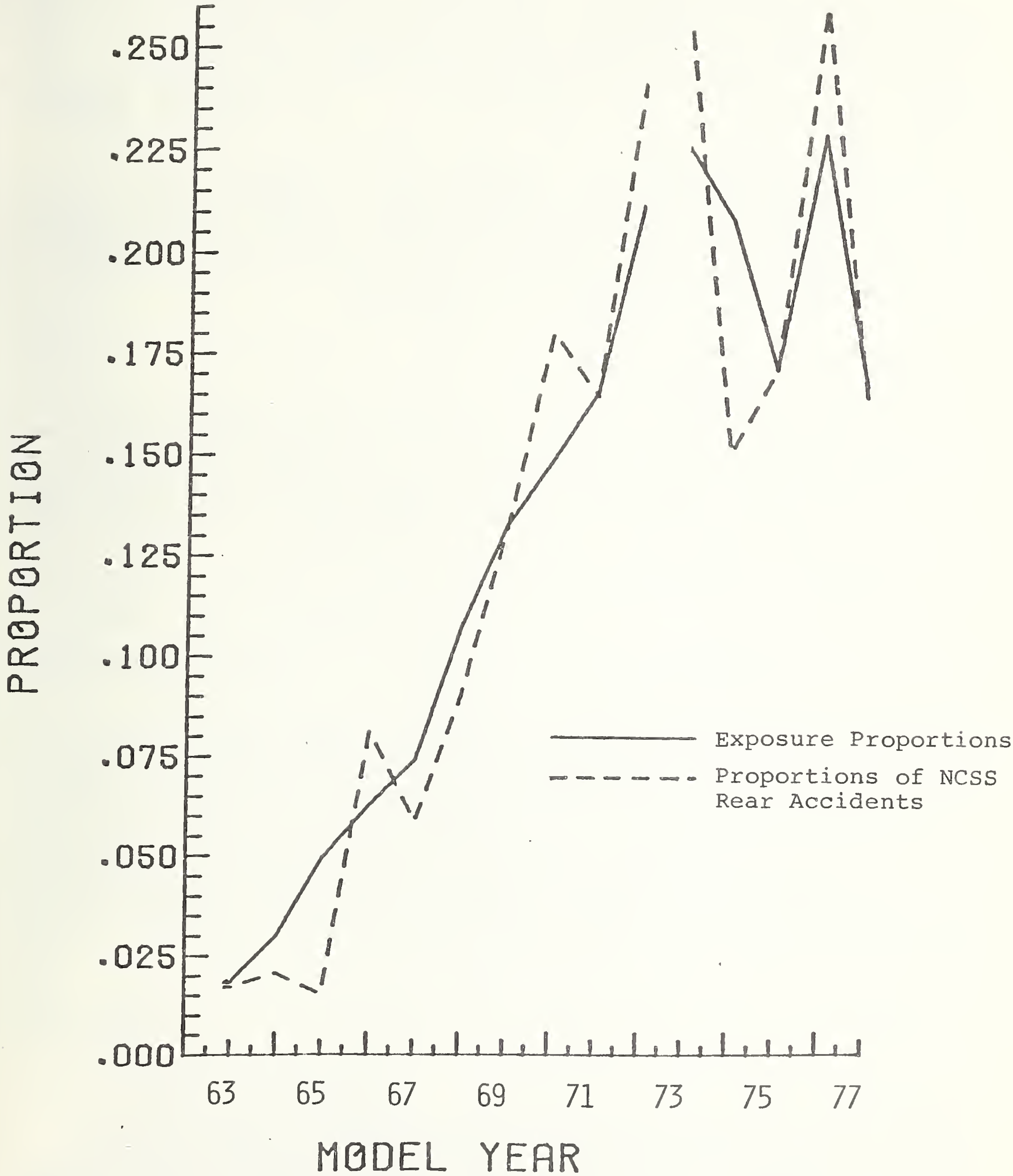

FIGURE 3-25. COMPARISON BETWEEN PROPORTIONS OF NCSS REAR ACCIDENTS AND EXPOSURE PROPORTIONS FOR THE TWO MODEL YEAR PERIOD SEPARATED BY FMVSS #215.

This analysis appears to lend support to the suggestion that the federal bumper standard is effective in the reduction of damage severity. As expected, front and rear accident proportions for towaways behave differently than side accident proportions following the implementation of the standard. Front and rear accidents for 1973 and newer model year vehicles occur with less frequency than would be predicted by their exposure, while side accident for these vehicles occur closer to the expected frequencies. Further investigation could validate this finding using alternative accident samples and could also provide a more quantitative estimate of the effect. In particular, the effect of vehicle age should be assessed.

3.4.8 Remarks On Observed Fatality Rate By Model Year

The observed fatality rate developed in this section and displayed in Figures 3-9 and 3-10 probably reflects a number of causative factors. The downward trend clearly indicates that given the vehicle exposure definition employed, the fatality rate for recent model year vehicles is less than for earlier models; yet the reasons for this trend are less clear.

One factor likely to influence the downward trend is the legislation of Federal Motor Vehicle Safety Standards occurring since the passage of the National Traffic and Motor Vehicle Safety Act in September of 1966. This would include such standards as collapsible steering columns, seat belt assembly anchorages, interior impact protection, and windsheild shatter protection--all effective in January of 1968, the model year in which the largest drop in the observed fatality rate is noted. Additionally, those regulations most clearly designed to reduce fatalities were made effective between 1968 and 1972, the model year period showing the most rapid decrease in Figures 3-9 and 3-10.

However, other factors may be influencing the observed trend as well. The deterioration of the physical and mechanical condition of automobiles with age may increase the likelihood of defects leading to fatal accidents. (In fact, the decline of accident avoidance capability with vehicle age may actually affect the exposure of older cars to accidents, affecting the observed fatality rate itself.) The possible over representation of young drivers in older vehicles may suggest a higher risk class for those vehicles. Even the changing average weight of automobiles in the model years under consideration may influence the trend. However, neither the magnitude of these effects nor their relative contribution to the variability are precisely known at this time.

Future investigation may lead to a better understanding of the causative factors. More detailed data concerning average vehicle weights, driver age, and effects of vehicle age on proneness to accident could be analyzed in light of the observed trend. It may also be worthwhile to run the entire analysis utilizing a reference year other than 1977 and make a detailed comparison. Certainly the effects of vehicle age could begin to be assessed in this way. The procedure discussed may have the added benefit of providing a mechanism by which to asses the effectiveness of Federal Motor Vehicle Safety Standards for the model years examined. Future work could, for example, break-down the contribution to the overall fatality by imapct mode, vehicle class, and seat position.

3.5 OBSERVED FATALITY RATES BY MAKE AND MODEL FOR 1974-1977 MODEL YEAR PASSENGER CARS

3.5.1 Definitions

The Observed Fatality Rate for a given model automobile is defined to be the number of fatalities counted in that model in a given period of time divided by the exposure in vehicle miles traveled during the same period of time. The fatality rate calculations presented here are average rates for specific makes and models combined over 1974-1977 model years based on fatality counts from the 1976 and 1977 FARS file. Naturally, models which are introduced after 1974 or discontinued between 1974 and 1977 will not be averaged over all the years 1974-1977. Also, the 1977 General Motors full-sized cars have been analyzed separately.

3.5.2 Counts of Fatalities

The calculation is performed by searching the files FARSMM76 and FARSMM77 for all fatalities which correspond to a make and model automobile which is coded in the file of registrations and design parameters (74VW, 75VW, 76VW, 77VW). Thus we are tabulating 1976 and 1977 calendar year fatalities in 1974-1977 model year automobiles by make, model, and model year. A count is also kept of fatalities having known make, but "other" or "unknown" model, and of fatalities for which both make and model are "unknown" or "other". The counts are broken down by impact mode (front, side, rear, etc.) for all but "unknown" of "other" make. Counts are also tabulated for fatalities which are totally ejected, for number of fatal accidents by make and model, and for number of fatal accidents involving fire/explosion. These data are also broken down by impact mode. These breakdowns are based on values of FARS coding elements as follows (See Ref 4).

Impact Mode Based on Prinicple Impact Point

Front	"11", "12", "1" Clock Positions
Side	"8"- "10", "2"- "4" Clock Positions
Rear	"5"- "7" Clock Positions
*Rollover	"13" or First Harmful Event = "01"(Overturn)
Other	"0", "14", "99", "Blank"
Total	Sum of the Above

*When First Harmful Event is "01" (overturn), the case is classed as a Rollover, regardless of the value of Principle Impact Point.

A person is considered to be a fatality if the Injury Severity is coded "4". A fatality is considered an ejection if ejection is coded "1" (totally ejected). The accident is considered to involve fire if Fire/Explosion is coded "1" (fire/explosion occurred in vehicle during accident).

It should be noted that there are some inconsistencies in the FARS file between the coding of Principle Impact Point and First Harmful Event. Ongoing work under another contract is dealing with questions such as this. Due to coding errors in the FARS file, some fatalities coded as being in 1974 to 1977 model year automobiles cannot be assigned to a legitimate model name (e.g. 1976 Corvair?!). There were 83 such cases in the 1977 FARS of a total 1974 through 1977 model year fatality count of 8,070. In the 1976 FARS there were 35 cases of 5,516. These 118 cases were deleted. Also deleted from the computations were counts of 1977 model year cars having accidents in 1976. There were 62 fatalities in that category.

Since a substantial portion of the fatalities were of known make, but "unknown" or "other" model designation, it was decided to distribute these fatalities over known models in each make in proportion to the fatalities already present. This distribution is computed separately in each category of impact mode and for ejections and fires. Prior to this distribution, the number of "other" and "unknown" in each make is augmented by distribution of fatalities in "unknown" or "other" make among all the makes in proportion to the fatalities already counted in each make.

The total fatalities considered in each model year have been crosschecked with totals known to be in the original FARS file by model year and agree, excepting the inconsistent codes mentioned above concerning invalid model names.

3.5.3 Exposure Measure and Calculation of OFR

The Observed Fatality Rate can now be calculated for each impact mode and category of ejection or fire by dividing the total fatality count for the model years 1974-1977 and accident years 1976-1977 by a suitable exposure measure. We have chosen to measure exposure as estimated vehicle miles of travel for the period corresponding to the observation time over which fatalities were counted. This exposure measure is computed for a given model vehicle by adding together the vehicle miles traveled by each model year version of that model in 1976 and 1977. For this purpose, R. L. Polk National Motor Vehicle Population Profile data giving mid-year registrations in 1976 and 1977 were used. Annual vehicle mileages as a function of vehicle age were derived as discussed in Section 3.3. The mileage numbers used here are:

Model	Accident Year	
Year	1976	1977
1974	12,355	11,743
1975	12,914	12,355
1976	9,937	12,914
1977	0	9,937

The mileages for 1976 cars in 1976 and 1977 cars in 1977 reflect the fact that those cars where being intorduced as new cars in those years. One can not, in addition, use mid-year registration figures for those cases as this would doubly compensate for the process of new model phase-in. Therefore, the mid-year registration figures must be corrected to reflect full-year figures for those years. For 1977, this has been done as discussed in Section 2, by multiplying domestic registrations by 1.402 and import registrations by 2.024. For 1976, the mid-year 1977 registrations are used.

The Observed Fatality Rate is now computed by dividing fatality counts by the exposure, and the result is expressed as fatalities per 100 million vehicle miles. These results together with the design parameters, registration data, and exposure meausres are retained in the file NEW*FATALS.

3.5.4 Results of the OFR Calculation

Figures 3-26 to 3-31 show the Observed Fatality Rates as a function of curb weight for:

- -Overall Fatalities
- -Fatalities in the Front Impact Mode
- -Fatalities in the Side Impact Mode
- -Fatalities in the Rear Impact Mode
- -Fatalities in Rollover Accidents
- -Fatalities in Which the Victim Was Totally Ejected

Opel and Mazda are excluded on account of suspicions concerning the validity of the registration data (See Section 3.5.6).

The evident relationship between vehicle weight and the Observed Fatality Rate is quite striking. A discussion of possible regression models for the OFR as a function of vehicle engineering parameters is presented in Section 4. Qualitative aspects of the OFR results are discussed here.

A characteristic of the fatality rates in all modes except rollover is that the high fatality rates are concentrated at weights below 3,200 lbs., while the lower fatality rates are concentrated at weights above 3,200 lbs. Figure 3-32 shows the overall Observed Fatality Rate as a function of curb weight. The solid lines divide the plot into quadrants which provide a definite separation of the various models of cars into light weight, high fatality cars and heavy weight, low fatality cars. Within each quadrant it is not absolutely evident that there is any dependence of fatality rate on curb weight at all.

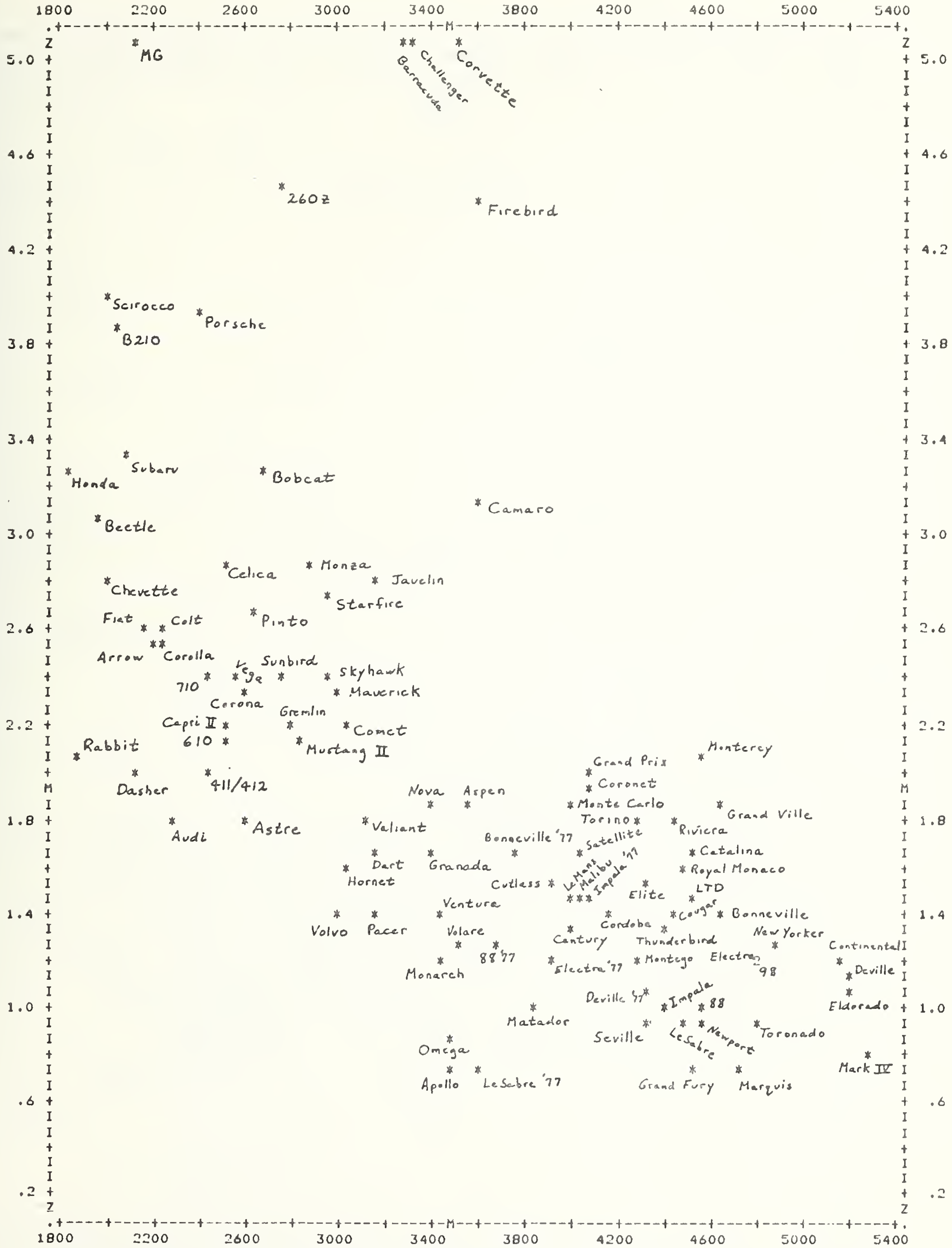

FIGURE 3-26. OBSERVED FATALITY RATE IN ALL IMPACT MODES 1974-1977 PASSENGER CARS IN 1976 and 1977 FARS.

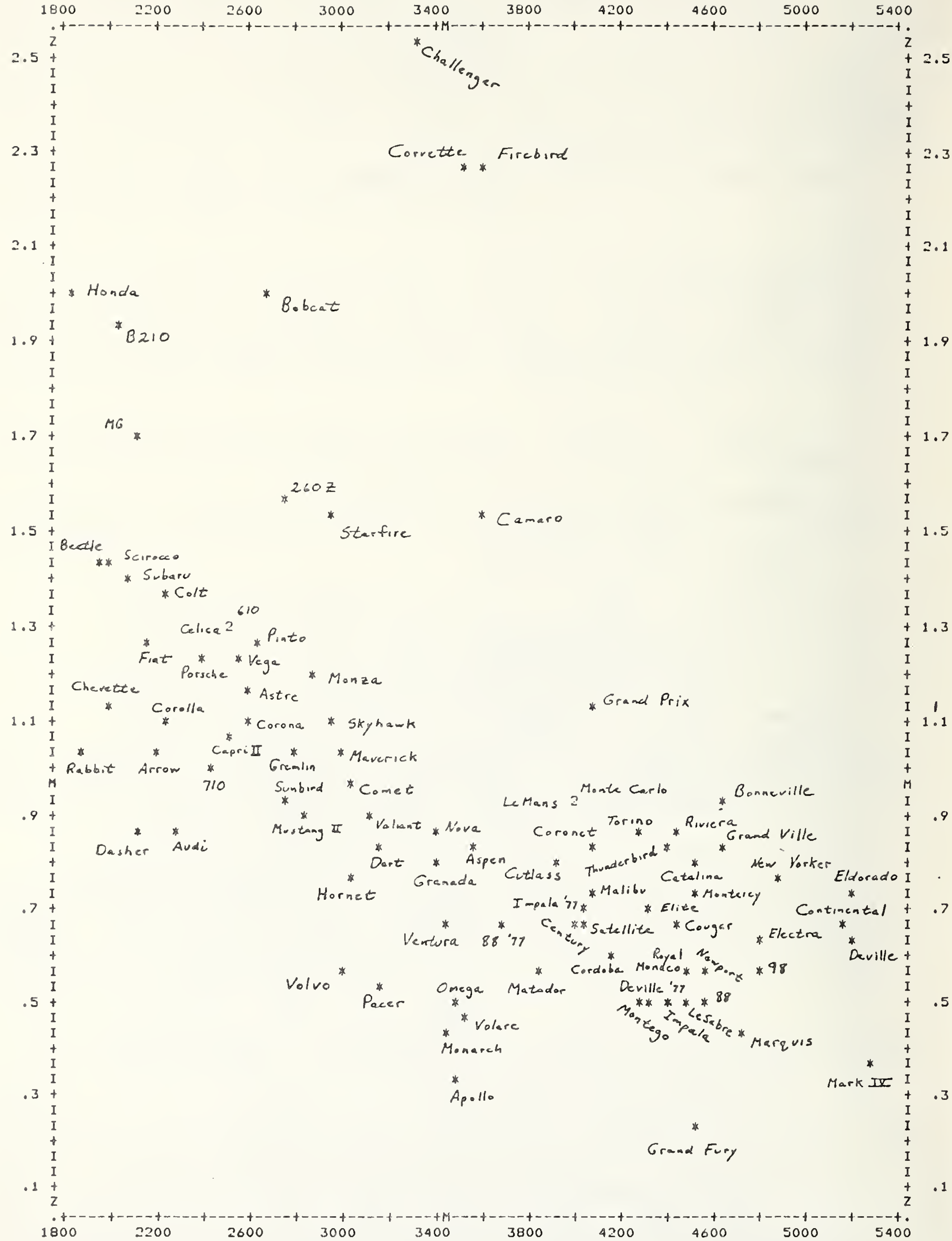

FIGURE 3-27. OBSERVED FATALITY RATE IN FRONT IMPACT MODE 1974-1977 PASSENGER CARS IN 1976 AND 1977 FARS.

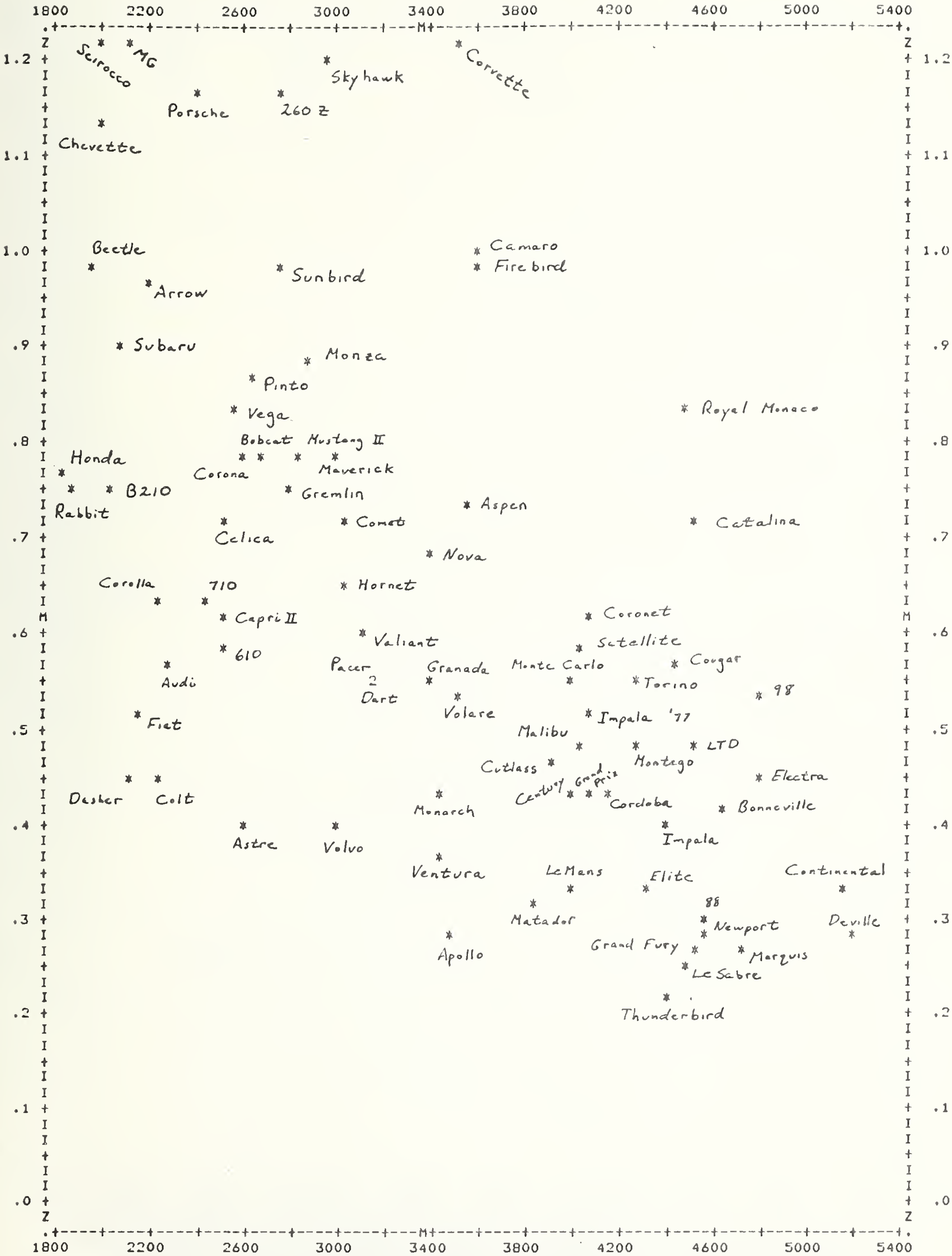

FIGURE 3-28. OBSERVED FATALITY RATE IN SIDE IMPACT MODE 1974-1977 PASSENGER CARS IN 1976 AND 1977 FARS.

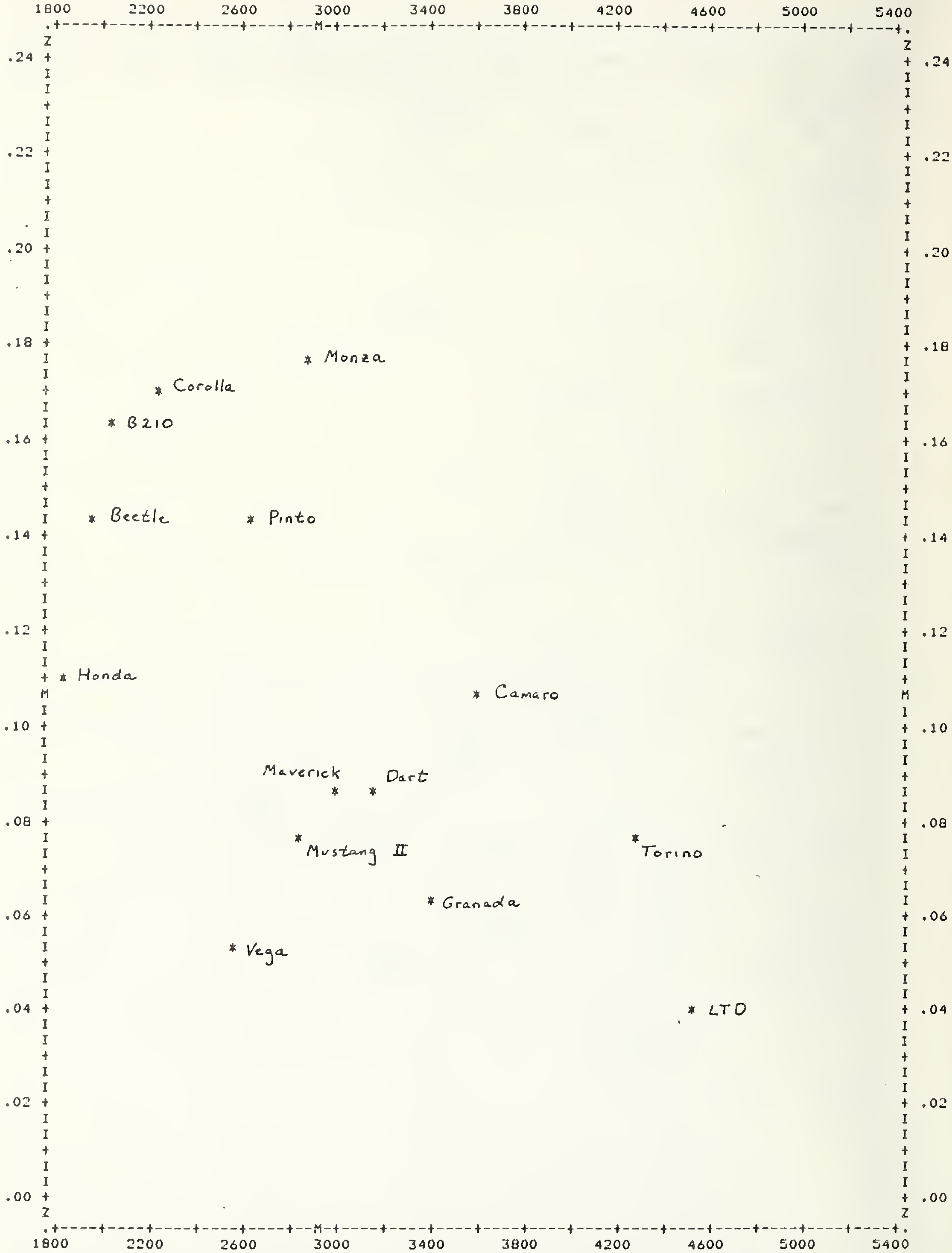

FIGURE 3-29. OBSERVED FATALITY RATE IN REAR IMPACT MODE 1974-1977 PASSENGER CARS IN 1976 AND 1977 FARS.

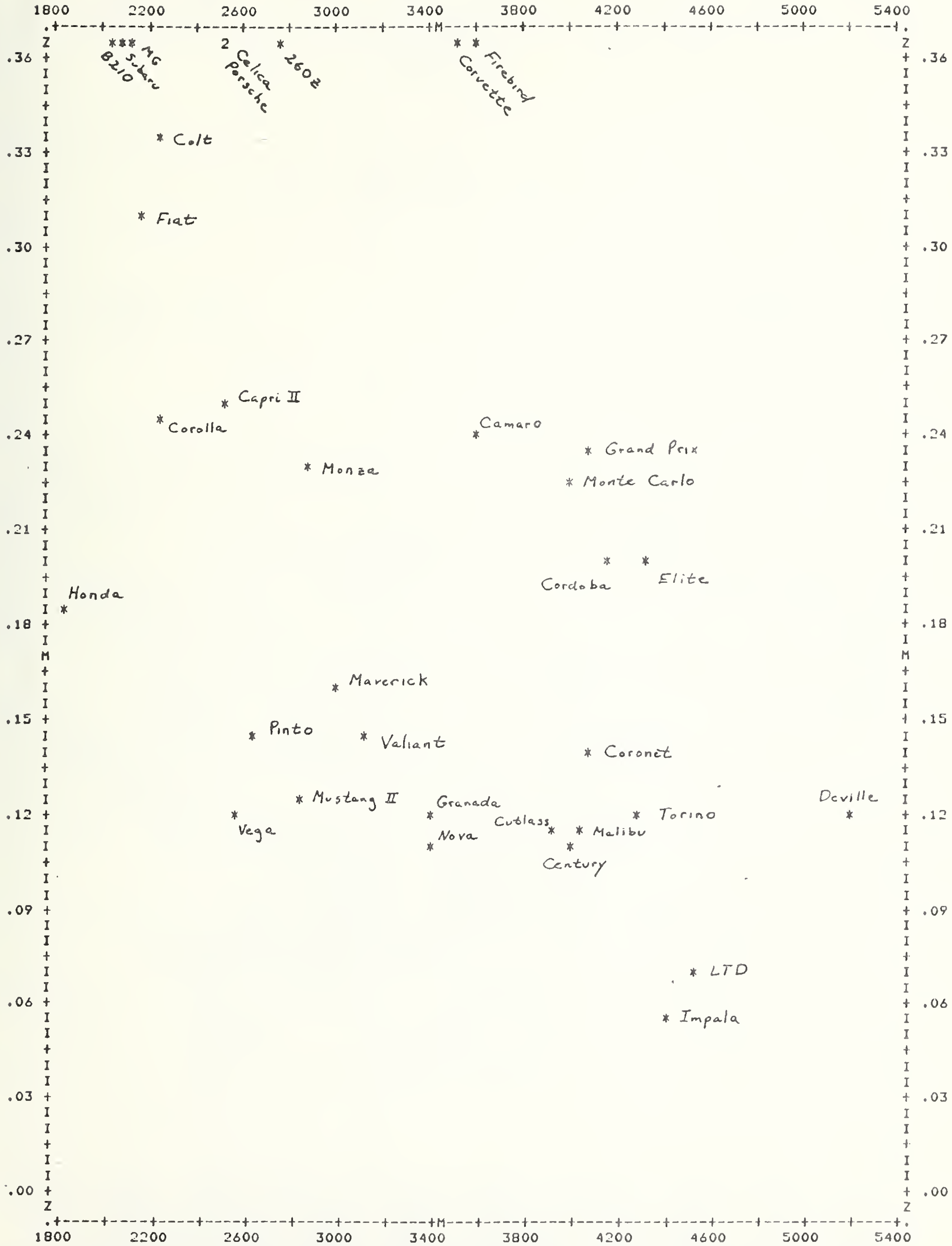

FIGURE 3-30. OBSERVED FATALITY RATE IN ROLLOVER ACCIDENTS 1974-1977 PASSENGER CARS IN 1976 AND 1977 FARS.

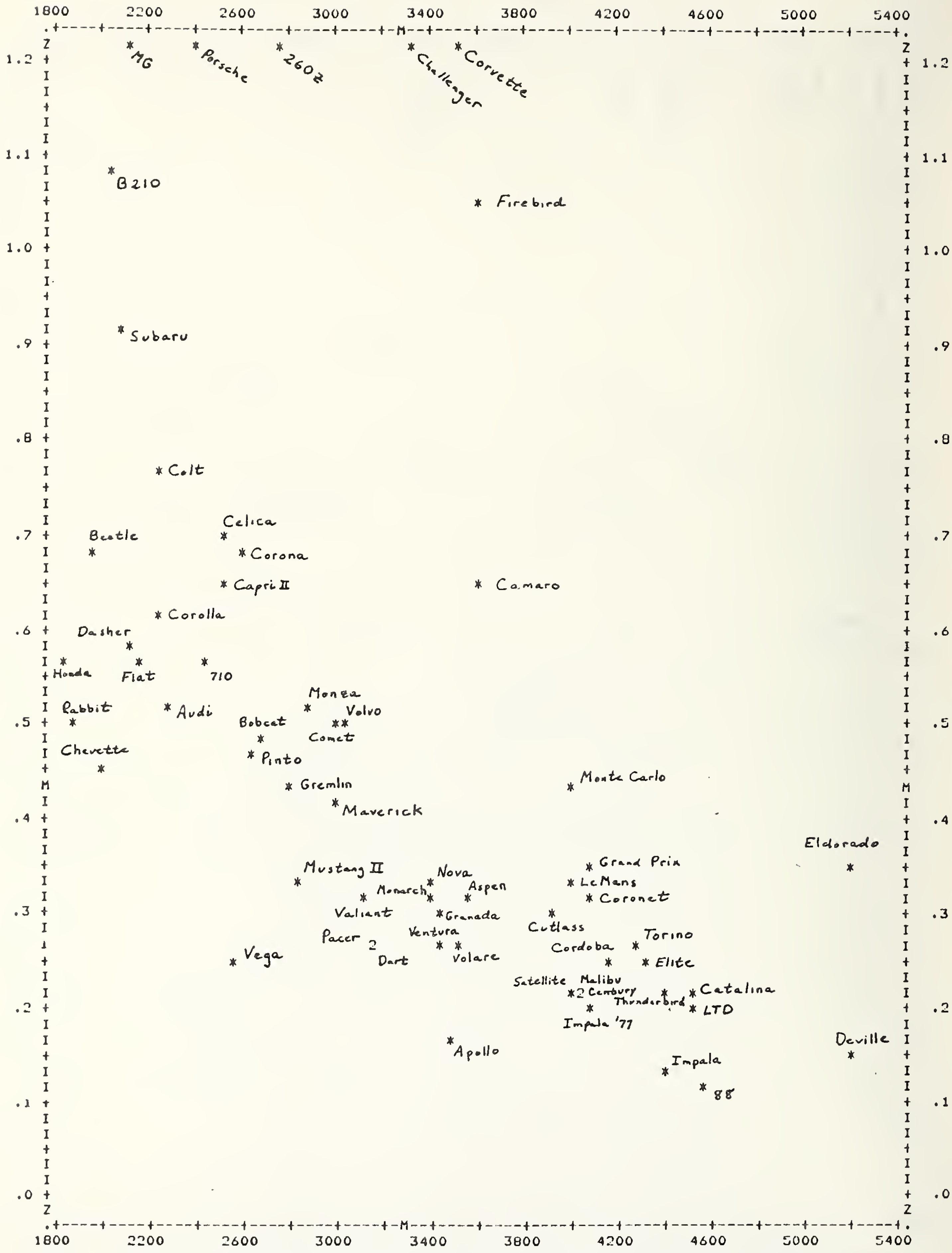

FIGURE 3-31. OBSERVED FATALITY RATE WHERE THE VICTIM IS TOTALLY EJECTED 1974-1977 PASSENGER CARS in 1976 AND 1977 FARS.

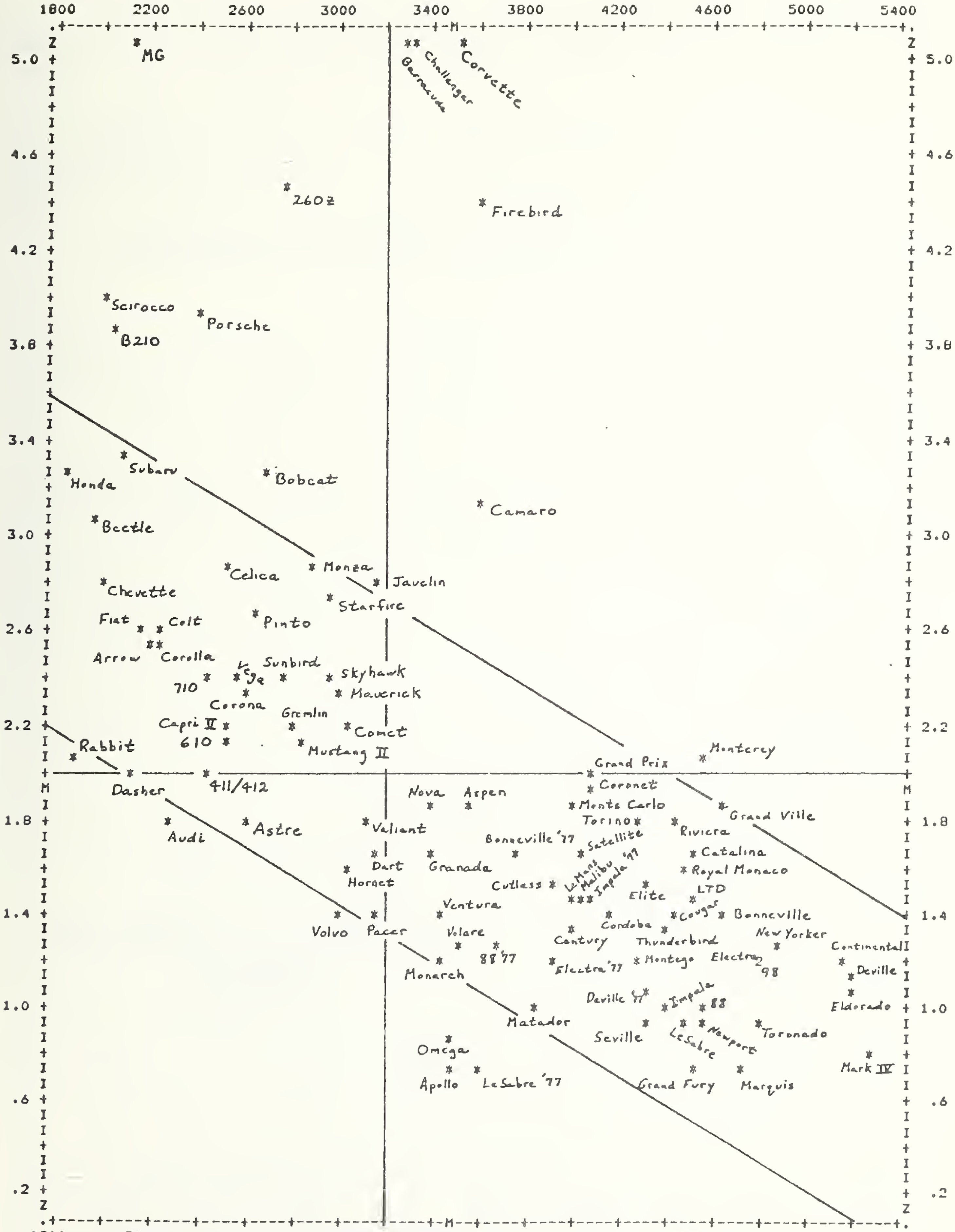

FIGURE 3-32. OBSERVED FATALITY RATE IN ALL IMPACT MODES 1974-1977 PASSENGER CARS IN 1976 AND 1977 FARS.

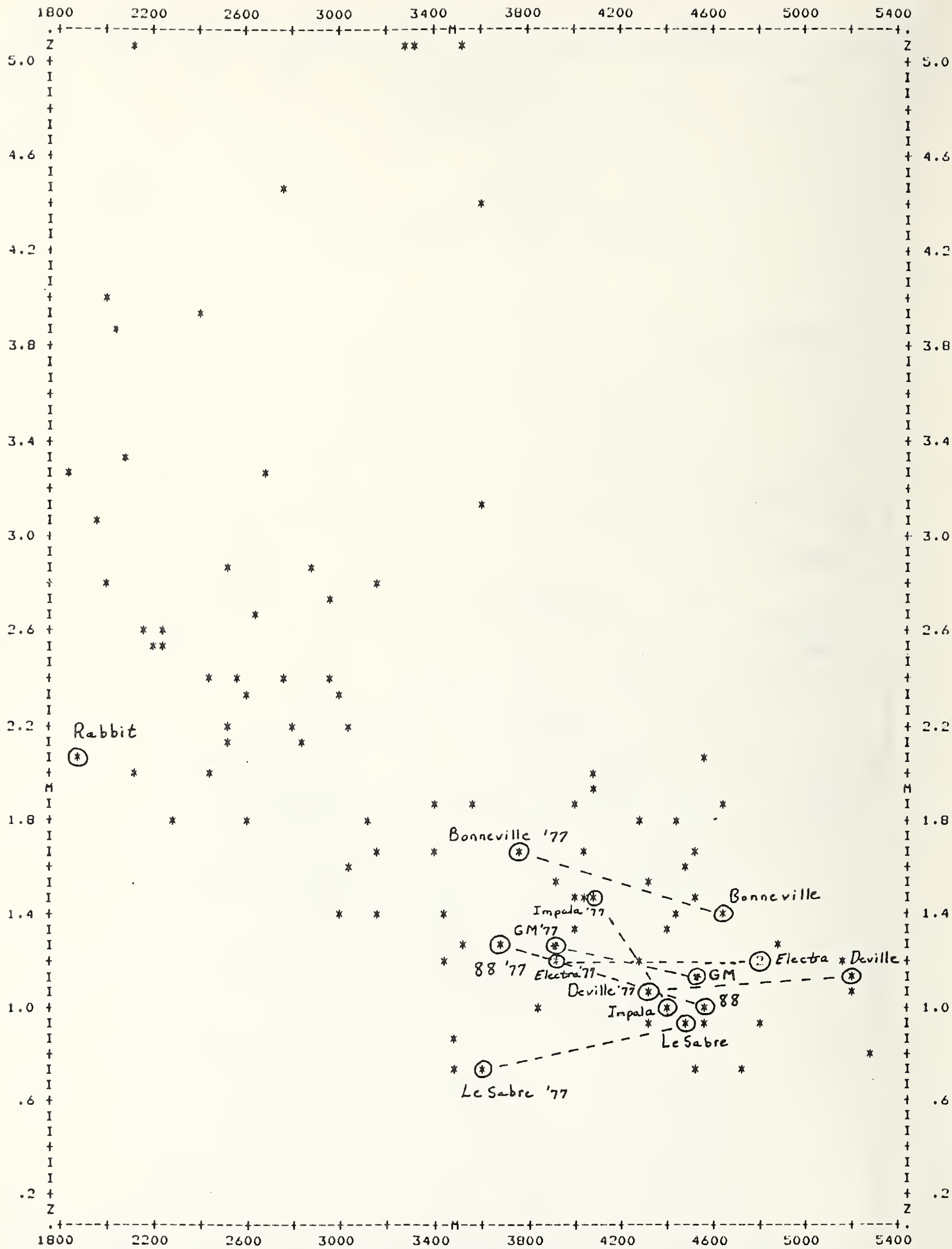

FIGURE 3-33. OBSERVED FATALITY RATE IN ALL IMPACT MODES 1974-1977 PASSENGER CARS IN 1976 AND 1977 FARS.

The diagonal lines provide an alternative interpretation wherein the dependence on weight is taken to be a linear decrease with increased weight.

Further consideration of the structure of this data is presented in Section 4.

3.5.5 Examination of Observed Fatality Rates for Significant Design Change Vehicles

Figure 3-33 is a reproduction of Figure 3-26, "Overall Observed Fatality Rate as a Function of Curb Weight", which now locates Rabbit and the old and new General Motors full-size cars. Also on this plot is a point for the combined fatality rate of the 1974-1976 and the 1977 Impala, Catalina, Bonneville, LeSabre, Electra, 88, and 98. The overall impression of this figure is that the new GM cars fall essentially where they would be expected to fall given the new weights they have. In fact, Impala is now located very nearly where LeMans and Malibu are, two GM intermediates, and the Electra and 88 are now comparable to Century, the Buick intermediate. These results are not inconsistent with the observations concerning the similarity of the 1977 GM downsized models to previous intermediates. (Section 2.3 and Appendix F.) The overall fatality rate for the full-size GM cars (indicated "GM" in Figure 3-33) follows almost exactly the trend that would be expected for these cars if one were to think of the downsizing as nothing more than a marketing shift away from existing 4,500 lb. car designs to existing 3,900 lb. car design. Table 3-7 is a compilation of the fatality rates and margin of Poisson variability for the GM cars. Of these examples Impala and GM combined show differences which exceed the ranges of the estimated variability. For Impala, the difference is a significant increase in fatality rate, for GM combined, there is a marginally significant increase in fatality rate. The other GM models of 1977 do not show meaningful changes relative to the 1974-1976 versions. However, the variability in the data for these models is sufficiently large that changes consistent with the overall pattern of fatality rate as a function of weight would probably not be detected.

The Volkswagen Rabbit, the other significant design change vehicle identified in Section 2, is also marked on Figure 3-33

TABLE 3-7 - FATALITY RATES FOR 1974-1976 and 1977 GENERAL MOTORS FULL-SIZE CARS

Model	1974-1976 Model Year Observed Fatality Rate (Fatalities per 100 Million Vehicle Miles)	1977 Model Year Observed Fatality Rate (Fatalities per 100 Million Vehicle Miles
Impala/Caprice	1.03 ± 0.05	1.47 ± 0.16
Catalina	1.68 ± 0.17	Fewer than 10 cases
Bonneville	1.41 ± 0.23	Fewer than 10 cases
Le Sabre	0.94 ± 0.11	0.73 ± 0.21
Electra	1.23 ± 0.13	1.20 ± 0.30
88	1.01 ± 0.10	1.28 ± 0.24
98	1.19 ± 0.15	Fewer than 10 cases
Combination of the above	1.12 ± 0.04	1.27 ± 0.09
DeVille	1.11 ± 0.14	1.09 ± 0.22

and on Figure 3-26. Rabbit demonstrates a lower than typical fatality rate for cars of its weight class and also a lower than typical fatality rate for cars of its roominess class (Pinto, Vega, Gremlin). Table 3-8 compares Rabbit to certain other vehicles. Rabbit is seen to have a significantly reduced fatality rate compared to Beetle, Chevette, Honda, and Pinto, but is not significantly different from Vega or Gremlin. If one averages together the data for Pinto, Vega, and Gremlin to produce a representative sample of the fatality rate of that car class one gets a number which is significantly higher than the data for Rabbit. It is worth noting in Figure 3-26 that the relative position of Rabbit in the OFR plot is consistent with certain other Volkswagen products, notably Dasher, 411/412, and Audi. The older style VW Beetle is, however, significantly higher in fatality experience.

A final evaluation of the meaningfulness of the differences in the Observed Fatality Rates requires consideration of the sources of error in the data. As will be seen, considerable caution should be used when considering Observed Fatality Rates for any specific model.

3.5.6 Observed Fatality Rates for Sister Models

Since the auto manufacturers often produce in the different divisions "sister" models which are very similar in design, it might be expected that these sister models would have similar Observed Fatality Rates. Table 3-9 is a list of such models with their fatality rates bounded by the Poisson variability in the data. Those models which differ significantly from their analogs are indicated with an asterisk. In fifteen sets of models, nine offer pairings or groupings into significantly separated groups. Six of these are significant even beyond an error estimate given by $2\sqrt{N}$ rather than the usual estimate of $\sqrt{N}$. It would be difficult to believe that all these differences are strictly due to statistical uncertainties and error sources. The evidence is that there are real differences between some sister models.

The nature of the Observed Fatality Rate is that differences between cars will depend not just on the design of the car, but on variabilities such as driver characteristics, usage habits, demographic features, etc. Generally speaking, one would not

TABLE 3-8 - OBSERVED FATALITY RATE FOR 1975-1977 RABBIT COMPARED TO CERTAIN OTHER VEHICLES

Model	Curb Weight (pounds)	Roominess (inches)	Observed Fatality Rate (Fatalities per 100 Million Vehicle miles)
Rabbit	1,887	261	2.09 ± 0.18
Beetle	1,976	252	3.07 ± 0.18
Chevette	1,992	255	2.80 ± 0.24
Honda	1,831	254	3.30 ± 0.19
Pinto	2,643	257	2.66 ± 0.11
Vega	2,570	257	2.42 ± 0.11
Gremlin	2,802	260	2.18 ± 0.19
Average of Vega, Gremlin, and Pinto	2,637	257.6	2.51 ± 0.07

TABLE 3-9 - ANALYSIS OF OBSERVED FATALITY RATE FOR SISTER MODELS

Model	Observed Fatality Rate		
	Overall	Front+	Side+
Monza	2.85 ± 0.23		
Starfire	2.71 ± 0.42		
Sunbird	2.43 ± 0.38		
Skyhawk	2.39 ± 0.38		
Maverick	2.33 ± 0.13		
Comet	2.23 ± 0.23		
Valiant	1.81 ± 0.10		
Dart	1.70 ± 0.12		
Firebird	4.41 ± 0.26		
Camaro	3.14 ± 0.16*		
Granada	1.64 ± 0.09		
Monarch	1.23 ± 0.14*		
Nova	1.88 ± 0.07*		
Ventura	1.39 ± 0.17		
Omega	0.86 ± 0.16*		
Apollo	0.71 ± 0.11*		
Aspen	1.87 ± 0.17		
Volare	1.25 ± 0.13*		

*Indicates differences exceeding the range of Poisson variability.

+These numbers are deleted when less than 10 cases are available for analysis in the given mode.

TABLE 3-9 (CONTINUED)

Model	Observed Fatality Rate Overall	Front+	Side+
Cutlass	1.53 ± 0.07		
LeMans	1.48 ± 0.14		
Century	1.36 ± 0.10		
Malibu	1.48 ± 0.08		
Coronet	1.92 ± 0.15		
Satellite	1.64 ± 0.14		
Torino	1.78 ± 0.10		
Montego	1.23 ± 0.17*		
Royal Monaco	1.60 ± 0.21		
Grand Fury	0.72 ± 0.12*		
Impala	1.03 ± 0.05		
88	1.01 ± 0.10		
98	1.19 ± 0.15		
Electra	1.23 ± 0.13		
LeSabre	0.94 ± 0.11		
Catalina	1.68 ± 0.17*		
Bonneville	1.41 ± 0.23*		
Grand Prix	2.02 ± 0.13		
Monte Carlo	1.88 ± 0.09		
Vega	2.42 ± 0.10		
Astre	1.80 ± 0.27*		
Bobcat	3.29 ± 0.41		
Pinto	2.66 ± 0.11*		

*Indicates differences exceeding the range of Poisson variability.

+These numbers are deleted when less than 10 cases are available for analysis in the given mode.

expect that great differences would exist in those factors between models of similar design and market class, any more than that there would be differences in design having significant effect.

Nevertheless, certain design differences may exist which do indeed account for significant differences between apparently similar models. For example, it has been reported to us that Firebird has certain front end structural characteristics which result in more rearward displacement of the steering column into the passenger compartment than is the case for Camaro, at least in high velocity impacts. Curiously the significant differences between Camaro and Firebird in the fatality rate are especially great in the front impact mode but disappear completely in the side impact mode, which is consistent with the possibility that the front crush effects contributed to the Firebird-Camaro differences at least in part.

It also happens to be the case that there are some significant differences between the Nova/Venture/Omega/Apollo series regarding engine types installed in the various models. This is outlined in Table 3-10. There is a considerable difference in engine length between the 250 in^3 in-line 6 (L6) and the 231 in^3 V6 (V6) which are very differently distributed among the 4 cars. Likewise the various V-8 options are differently distributed among these cars. Notably, the cars which are at the extremes of the V6/L6 distribution, Nova and Apollo, are also the ones at the extremes of the fatality rate span. One would not, however, want to assert without further investigation that any observed differences in fatality rate are necessarily explained by these engine differences. The assertion to be made is that the "sister" models are not necessarily "exactly" the same.

Analysis at this level of detail is difficult to carry out for all makes and models but can be proposed for selected models. In particular, we are in the process of investigating steering box location, steering wheel characterisitics and other factors which may help explain some differences.

TABLE 3-10 - ENGINE OPTIONS INSTALLED IN 1974-1977
NOVA, VENTURA, OMEGA AND,
APOLLO SERIES AUTOMOBILES

Model Year	250 in^3 L-6	231 in^3 V-6	260 in^3 V-8	305 in^3 V-8	350 in^3 V-8	151 in^3 L-4
Omega						
1974	20,472				21,583	
1975	12,075		18,913		4,513	
1976	14,898		31,521		4,138	
1977		23,860	3,296	10,453	2,030	
Total	47,445	23,860	53,730	10,453	36,402	
Ventura						
1974	24,214				38,552	
1975	17,009		20,042		13,347	
1976	17,853		33,943		5,957	
1977		30,476		14,660	1,303	1,981
Total	59,076	30,476	53,985	14,660	59,159	1,981
Apollo						
1974	14,729				33,863	
1975	2,658	8,576	5,332		3,836	
1976		85,698	13,177		3,672	
1977		56,279		13,537	1,478	
Total	17,387	150,553	18,509	13,537	42,849	
Nova						
1974	143,211				189,442	
1975	120,050		54,884		60,916	
1976	178,974			99,279	11,193	
1977	126,216			88,928	5,384	
Total	568,451		54,884	188,207	266,935	

3.5.7 Discussion of Sources of Error in the Observed Fatality Rate

Uncertainties can be propagated into the calculation of the OFR. Each of the three quantities fatality count, annual mileage, and registrations is subject to uncertainty.

The basic uncertainties in fatality count arise from two sources.

In the first place, reported compilations of counts of a rare event occurring in a large population may be though of as samples from a set of events which follows a Poisson distribution. The mean of the Poisson distribution would be an accurate measure of the fatality count, but any actual observation would be expected to differ from that mean by an amount estimated on average by $\sqrt{N_o}$ if N_o is the mean count expected. (i.e. $\sqrt{N_o}$ is the standard deviation of a Poisson distribution with mean N_o). This in turn can be approximated by $\sqrt{N}$ if N is the number of counts observed. For example, if 100 fatalities are found for a certain model, this number may be considered statistically uncertain by ± 10 or $\pm 10\%$. For 10 cases, the estimate of error can be taken to be ± 3 of $\pm 30\%$.

The second significant source of error in fatality counts is the problem of "unknown" or "other" model identification codes in the FARS, which constitutes about 15% of the total file as was discussed in Section 3.5.2. These fatalities are distributed in an average way across the known makes and models. There is no way to know if this is in fact correct inasmuch as some models may be more frequently coded "unknown" or "other" than others. This effect is currently being studied under another project.

A final difficulty in the counting of fatalities is that the model year specification of the case vehicle can be uncertain by one year in the FARS file. This comes about due to the practice in some states of registering cars with a model year designation corresponding to the year of registration rather than the actual manufacturer's model year series. This problem could be corrected in the FARS file is NHTSA wished to do so.

The calculation of annual mileages is discussed in Section 3.3. Aside from the various concerns mentioned there concerning the appropriateness of the data used and its validation, there is the fact that the mileage estimates have been applied across all models uniformly. There has been some analysis of mileage differences across vehicle market classes (Ref. 7) but there does not seem to be any available data which is sufficiently detailed and up-to-date to justify a departure from the use of the average data we have utilized. Field studies to improve the information known in this area are recommended.

The last area of concern is with the registration figures. Two problems are evident here. The first is in the application of mid-year 1976 and 1977 figures to what should be an estimate of the average registrations of each model year vehicle in the subject years 1976 and 1977. The problem arises primarily in the treatment of 1976 model year cars in 1976 where the mid-year 1977 registrations are used and in the treatment of 1977 model year cars in 1977 where estimated original registration are used. These latter figures are estimated by an average correction for domestic and foreign cars separately based on a comparison of 1977 and 1976 mid-year figures for 1976 model year cars. A make by make calculation of this estimating factor might produce some changes. In the case of Volkswagen, for example, the correct factor is 1.73 not 2.04, which is the average correction for 1976 mid-year to 1977 mid-year registrations for all imports. Use of the correct factor for Volkswagen would result in an Observed Fatality Rate for Rabbit of 2.18 rather than 2.09. There may, however, be enough fluctuation in this factor from year to year for any one manufacturer that it is indeed still the wiser choice to consider the average correction rather than a manufacturer by manufacturer correction. It would be possible to improve the quality of the data with regard to these factors by obtaining month by month sales figures for the various models. This would also serve as a check on the registration data itself, which is the last problem area to be discussed.

It is not a simple problem to detect errors in registration figures since the sources of data for make and model specific figures are confined to the R. L. Polk materials. It has already been mentioned that there are two forms of the R. L. Polk data, a set of yearly registrations used by Volkswagen and the National Motor Vehicle Population Porfile figures for 1976 and 1977. These sets of data are not completely consistent with each other for all models. For example, one finds by model year the following numbers of models for which there are discrepancies of more than 10% between respective data sets:

Model Year	1976 NMVPP Vs. VW	1977 NMVPP Vs. VW	1976 NMVPP Vs. 1977 NMVPP
1974	1 of 60 domestic 22 of 23 foreign	2 of 60 domestic 22 of 23 foreign	none of 83
1975	8 of 68 domestic 19 of 23 foreign	7 of 68 domestic 20 of 23 foreign	1 of 68 domestic 11 of 23 foreign
1976	----------------	1 of 68 domestic 13 of 24 foreign	---------------
1977	----------------	-----------------	---------------

One cannot, of course, make comparisons for 1977 since VW and 1976 NMVPP have no data for the 1977 model year, nor for two columns of 1976, since the 1976 NMVPP are only partial year figures.

If one projects the 1976 figures for 1976 to total year registrations and combines the registrations for the years 1974-1976 one finds the following numbers of models with greater than 10% discrepancies among the VW and NMVPP sources:

1976 NMVPP Vs. VW	1977 NMVPP Vs. VW	1976 NMVPP Vs. 1977 NMVPP
6 of 75 domestic	2 of 75 domestic	9 of 75 domestic
7 of 25 foreign	10 of 25 foreign	8 of 25 foreign

This is a slight worsening of the situation for domestic models due mainly to the inaccuracy in projecting 1976 figures to full year figures. On the other hand, there is a great improvement in consistency for foreign makes, suggesting that there are some problems with model year identification for those models.

There are specific instances of clearly erroneous data. One example is 1975 Rabbit, which has 100,564 registrations July 1, 1976 and 91,373 registrations July 1, 1977. It does not seem reasonable that 10% of all 1975 Rabbits would disappear in one year. 1975 Mazda reports registrations of 22,727 in 1977. 1976 Opel has 2,527 registrations in 1976 and 20,727 in 1977. This situation may be confused by the change from the German to the Japanese version of the Buick captive import. Mazda lists the following registrations in 1977:

Model	Registrations
1974	79,269
1975	11,399
1976	38,740

The figure of 11,399 is evidently in error. Based on data in the original VW source, this figure should be closer to 62,000. Strangely enough, the 1976 NMVPP lists only 22,974 registrations for 1976 Mazda. Thus, NMVPP is inconsistent in consecutive years and is clearly erroneous overall. A recalculation of the data for Mazda would reduce the Observed Fatality Rate from 3.988 to 2.997. Mazda and Opel have not been included in Figures 3-26 - 3-33 on account of these problems. In several instances there are more registrations reported for 1974 and 1975 model year cars in 1977 than in 1976, although generally the differences are small.

The reader is also reminded at this point that the registration data discussed here does not include registrations in the state of Oklahoma. No correction has been applied for this omission.

The overall impact of these sources of error is to introduce a certain amount of scatter into the data. Only one of these, the Poisson sampling variability, can be readily evaluated. It is this variation which has been quoted in the various tables. A more refined analysis of automobile mileages and registration figures should be pursued in future work. For present purposes, the reader should exercise due caution in interpreting fatality rate comparisons between specific individual models.

SECTION 4

RELATIONSHIP OF OBSERVED FATALITY RATE TO DESIGN PARAMETERS

4.1 GENERAL CONSIDERATIONS

It is evident from the work discussed in Section 3 that there is a significant dependence of the Observed Fatality Rate on vehicle design characteristics, notably curb weight. It does not seem unreasonable that one should attempt a formal analysis (in this case regression analysis) of the dependence of the fatality rate on the vehicle design parameters used in this study, together with combinations or transformations of these parameters. There are, however, several general comments pertaining to this sort of analysis.

First, there is an intrinsic scatter in the values of the dependent variable arising from random fluctuations, from error sources, and from factors not considered in the analysis. One will not, therefore, expect to fully explain all the variation in the data. It may be pointed out that there are a number of potential parameters that could be taken into account in this problem which are currently being investigated for use. These include frontal stiffness characteristics, steering box location, steering wheel characteristics, restraint system, and investigation of the relationship between stiffness and mass.

At the same time, one must recognize that fatality rates affected by special problems in particular cars (as may be suspected of Firebird, for example) or in the source data for particular cars, (e.g. Mazda, Opel) cannot be brought in line by a regression analysis. These cases must be excluded from the problem or corrected as appropriate information becomes available.

Secondly, the data demonstrate, at least for dependence of fatality rate on curb weight, that the outcome may not depend on the weight in a smooth manner. It is possible that the dependence of fatality rate on certain design parameters is quite different within different ranges of values of the independent variable. If a regression analysis is performed, it may be useful to consider separate subsets of the total vehicle population.

Other methods of analysis may be appropriate to this situation. A notable possibility is discriminant analysis, wherein different design parameters can be tested for their ability to predict observed fatality rate groups (e.g. cars with fatality rates above and below 2.0 fatalities per 100 million vehicle miles). We recommend exploring this possibility in future work.

Thirdly, there is a high degree of correlation among the various design parameters. A consequence of this is that a stepwise regression analysis which is allowed to fit the data to a wide choice of design parameters may find the best fit is produced by selection of variables whose role is not easy to interpret from an engineering point of view. Such variables can be picked because they include the effects of a more easily interpreted variable and at the same time account for additional factors.

4.2 RESULTS OF STEPWISE LINEAR REGRESSION ANALYSIS

The Observed Fatality Rate data has been subjected to stepwise linear regression analysis in an attempt to relate Observed Fatality Rate to design parameters of the vehicles. There are a number of choices concerning how such an analysis is to be conducted. The methodology used was to analyze observed fatalities in the front and side modes separately. Fatalities in other modes were not considered to be present in sufficiently large numbers to justify analysis. Stepwise regressions were performed both unweighted and using the number of fatalities in each model line as a weighting factor. Using Figure 3-27 as a guide, it seemed useful to distinguish between cars less than 3,900 lbs. curb weight and all cars for frontal mode fatality rate. Separate regressions were performed considering only vehicles under 3,900 lbs. curb weight in the frontal mode. The separation by weight is not so evident in side mode impacts, and no separate set of analyses was run.

The nine original design parameters were allowed to enter. In addition to these, three new parameters were defined. These were the mid-length of the car, which was the overall length minus the front and rear crush lengths, the product of width by height by front crush length, and size which is the product of width x length x height. Also entered were all of the old and new parameters both multiplied and divided by weight. Finally, the logarithms of the possible parameters were allowed to enter. Regressions were run using the program BMDP.P2R.

The results of these analyses are summarized in Table 4-1 wherein the various sets of possible conditions are indicated together with the regression equation produced and a summary of the stepwise procedure showing the variables picked and the amount of variation explained (R^2). Variables are entered and/or removed from the problem according to values of their F-ratio in each step. In these runs, the minimum F-to-enter is 4.00 and the maximum F-to-remove is 3.90. Vehicles having less than 10 fatalities in the mode in question are not considered in the analysis. Also not considered are models for which there are unknown values in any parameter entering the problem. This resulted in the use of 64 models of a possible 119 in the side impact mode, 74 of 119 in the frontal impact mode, and 39 of 119 cases in the frontal impact mode for cars weighing less than 3,900 lbs. These seemingly small numbers of cases do, however, account for the vast majority of overall fatalities and overall vehicle registrations.

In three of the six regression models size (width x length x height) or roominess are the preferred variables and produce values of R^2 ranging from .18 to .51. In one case, front crush length is picked in addition to size as an effective contributor. In this case, front crush length enters with a positive coefficient indicating a higher fatality rate in larger cars. This is evidently a correction to the initial predictions based on vehicle size. In the remaining three of the six problems, not easily interpreted combinations of variables do the best job of fitting the response.

The usefulness of size or roominess as predictors of fatality rate is not unreasonable, considering that both variables are highly correlated with weight and that they are, in addition, indicative of protective affects having to do with good energy management in collisions and immunity to intrusion. Size and roominess are themselves highly correlated, and in most of the regressions either variable could have been entered at the first step with roughly equal effect. Interestingly, if these variables are not permitted to enter the mid-length of the car is the next variable to select for a good fit.

In the case of side mode unweighted regression, where log (REAR OVERHANG) is used, the next possible choices that could be entered would be REAR OVERHANG, SIZE, LENGTH, log(LENGTH), log(ROOMINESS), log(SIZE, log(REAR OVERHANG x WEIGHT), log (HEIGHT x WEIGHT), log (SIZE x WEIGHT) and others all at roughly

TABLE 4-1 - RESULTS OF STEPWISE REGRESSION ANALYSIS OF OBSERVED FATALITY RATE 1974-1977 MODELS IN 1976 AND 1977 FARS

Conditions	Model	R^2	ΔR^2
Front Impact Mode			
Vehicles of all weights - weighted regression	OFR = 11.13 - 2.79*log(SIZE/10000) + .348*(FRONT/10)	.46	
	Step 1 log(SIZE/10000)		.39
	Step 2 FRONT/10		.07
Vehicles of all weights - unweighted regression	OFR = -1.2235 + 1.0304*(1000*SIDE/WT)	.24	
Vehicles under 3,900 pounds - weighted regression	OFR = 9.08 - 3.00*(ROOM/100)	.18	
Vehicles under 3,900 pounds - unweighted regression	OFR = -1.84 + 3.57*log(1000*SIDE/WT)	.16	
Side Impact Mode			
Vehicles of all weights - weighted regression	OFR = .763 - .017*(SIZE/10000) + .697*log(FRONT/10)	.56	
	Step 1 SIZE/10000		.51
	Step 2 log(FRONT/10)		.05
Vehicles of all weights - unweighted regression	OFR = 4.97 - .854*log(REAR/10) - 1.80*log(H/10)	.48	
	Step 1 log(REAR/10)		.45
	Step 2 log(H/10)		.04

Legend:

OFR - Observed Fatality Rate
ROOM - Roominess
SIZE - Length x Width x Height of Vehicle
SIDE - Body Side Thickness
FRONT - Front Crush Length
REAR - Rear Overhang
WT - Curb Weight
H - Height

equivalent F-ratios. In the case of frontal mode unweighted regression, for all curb weights instead of SIDE/WT one could have used log (SIDE/WT), ROOM, log (ROOM), log (HT x WT), REAR x WT, HT x WT, and others although SIDE/WT or log (SIDE/WT) have substantially higher F-ratios than anything else.

4.3 CONCLUSIONS

The results of the preliminary regression efforts completed to date are evidently reflecting the consequences of the severe confounding of the different parameters describing vehicle design and may be additionally complicated by the other factors mentioned in Section 4.1. The results that are obtained suggest the following observations:

1. The Observed Fatality Rate for individual makes and models of passenger cars in generally dependent on the overall size as reflected by total volume (width x length x height) or by roominess, or by combinations of crush lengths, heights, width, weights, and other size factors.

2. Curb weight, although it is correlated with parameters of size, it is not generally a strong competitor by itself in the stepwise regression problem.

It is probably premature to suggest that the safety performance of passenger cars can be modeled with much precision by design parameters which bear specific and direct relationships to the safety outcome in each impact mode. The most evidently needed additions to the problem are specifications of vehicle stiffness and an examination of special properties affecting the crash response of certain vehicles. Progress has been made in compiling this type of data, but one needs to have it on a more comprehensive basis.

SECTION 5

ASSESSMENT OF FUTURE IMPACT

5.1 KINETIC RESEARCH ACCIDENT ENVIRONMENT SIMULATION AND PROJECTION MODEL

Efforts to identify the future impacts of 1974-1977 design changes have been initiated using the Kinetic Research Accident Environment Simulation and Projection (KRAESP) model (Ref. 1). The KRAESP model was developed to provide a tool with which to describe the future automobile accident environment as well as to evaluate the safety impact of various automobile subsystems in that environment.

The model has a number of characteristics which are summarized:

1. Considerations of fleet composition by vehicle class, manufacurer and model year from 1952 through 1990.

2. Specification of the restraint-structure system for each seat position and general impact mode, property damage system, accident avoidance system, and weight for each vehicle class, manufacturer and model year 1977 through 1990 with baseline specifications for existing vehicles 1952-1976.

3. Consideration of occupancy rates by seat position as a function of time 1977-1990.

4. Consideration of vehicle exposure probabilities based on initial sales, scrappage rates and vehicle mileage.

5. Consideration of the accident environment by damage area clock position, impact mode and crash severity.

6. Consideration of restraint-structure performance characteristics by system type, vehicle class, seat position, damage area impact mode, and anthropometric size (optional).

7. Consideration of restraint system usage by restraint type and seat position.

8. Consideration of the effects of advanced accident avoidance systems on the relative impact velocity distribution.

9. Consideration of the exposure as a function of relative velocity by damage area and impact mode, used in conjunction with the crash severity calculation.

10. Consideration of the effects of advanced property damage systems on property damage losses.

11. Specification of occupant injury level probabilities based on restraint structure performance and best known injury measure to injury level relations.

12. Determination of injury level distributions as well as injury costs by year, mode, crash severity, etc.

13. Identification of benefit cost ratios for various implementation schemes based on subsystem costs.

14. Assessment of implementation scenario benefits for future years.

The KRAESP model consists of a number of computer programs which are designed to address various aspects of the accident picture. The outputs of each are appropriately integrated to provide the most advanced picture of the future accident environment currently available. Further, the model contains many features which will allow it to consider and utilize the more sophisticated information which will be forthcoming from the research of the coming decade.

As shown in Figure 5-1, the model can be considered as consisting of sections each of which may contain several components. Section A is the main body of the model which includes the implementation logarithm, the restraint-structure performance algorithm and the accident environment algorithm. Sections B, C. D. And E include the braking, property damage, system cost, and benefit-cost algorithms, respectively. At this point in the project, only Section A of the model has been used. Its characteristics are described briefly below.

The factors addressed by the implementation, restraint-structure performance, and accident environment algorithm are provided below, together with associated outputs.

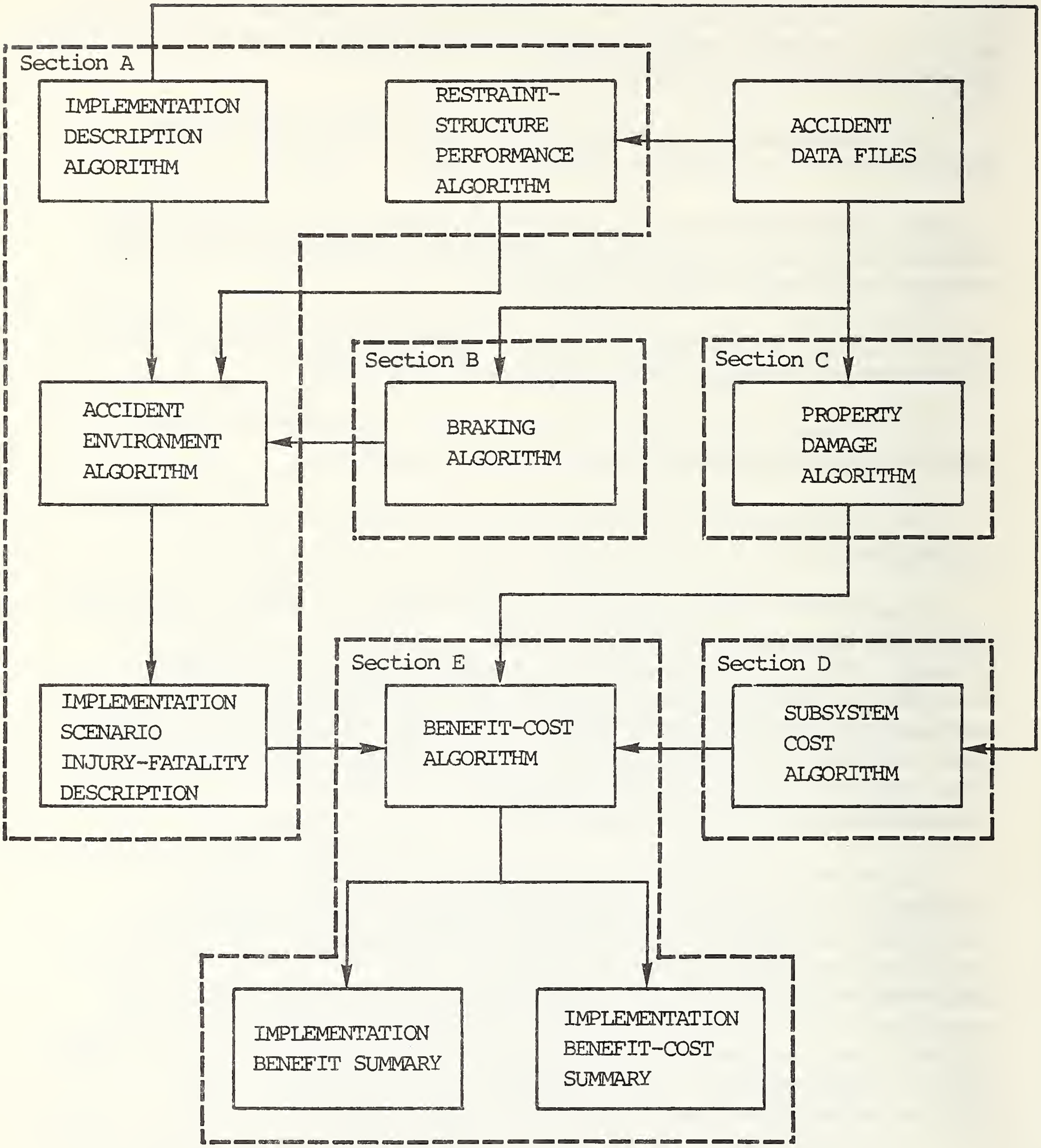

FIGURE 5-1. OVERVIEW OF THE KRAESP MODEL.

Vehicle Population Characteristics

- Market share by manufacturer, vehicle class, and model year 1952-1990
- Scrappage rate by age of vehicle
- Mileage by age of vehicle
- Weight of each vehicle class by model year and manufacturer
- Restraint/structure type for each vehicle class, seat position, manufacturer, model and model year
- Property damage system for each vehicle class, manufacturer, model and model year
- Brake system for each vehicle class, manufacturer, mode and model year

Output:
- Exposure probabilities for each restraint-structure type
- Brake system combination for each manufacturer, vehicle class, seat position, model year by impact year for each implementation scenario
- Case vehicle weights for each manufacturer, vehicle class and model year
- Mean other vehicle weights by vehicle class by impact year
- Exposure probabilities for property damage systems by vehicle class, manufacturer, model year and mode by year

Usage Characteristics

Factors considered:
- The usage of each restraint system type by seat position and vehicle class

Output:
- When combined with the restraint-structure characteristics identifies the probability of being unrestrained for each vehicle class, model year, manufacturer in any particular year and allows an adjustment in the exposure probabilities for other restraint system types

Impact Probabilities by Year and Model

Factors considered:
- The Vrel distribution by damage area and impact type for the conventional and advanced braking systems by impact year

Crash Severity Probability Distributions by Restraint-Structure Type and Mode

Factors considered:
- The exposure probability for each case vehicle model year, vehicle class and manufacturer, and the other impact exposure probability and the weight for each combination;
- The mean other vehicle weight
- The Vrel distribution appropriate for each case vehicle defined above for each damage area and impact type

Output:
- For each system characterization, the probability of impact as a function of crash severity by damage area and impact mode

Occupancy Characteristics

Factors considered:
- The probability of a particular age (and optionally weight) group given a particular vehicle class and seat position
- The probability of occupancy by seat position and year

AIS to Injury Measure Relationships

Factors considered:
- The AIS probability distribution as a function of ΔV for each seat position, damage area, vehicle class, body region, and age
- The injury measure versus crash severity relationship by seat position, damage area, vehicle class, body region and age

Output:
- An AIS probability distribution as a function of injury measure for each seat position, damage area and age

Restraint Performance Characteristics

Factors considered:
- Injury measure versus crash severity characteristics for each combination of seat position, vehicle class, damage area, impact type, restraint structure type and body region.

5.2 APPROACH

It is clear from the foregoing discussion that one needs to consider a number of features of a particular vehicle when assessing its impact on the number of injuries and fatalities in the future if vehicle characteristics are implemented on a large scale. Our efforts to date have focused on the design change vehicles (DCV) identified in Section 2, namely the VW Rabbit and the "downsized" G.M. full-size vehicles.

In particular, we have focused on two general areas which can affect the safety picture. The first area considers whether the design parameters, which are significantly different from others in the relevant roominess class, will have an effect on the crash severity distribution the DCV will experience. The second area we have been considering is whether the design change vehicle provides restraint-structure performance as a function of crash severity which is significantly different from other vehicles typical of its roominess class. These two areas of investigation are discussed in the following two sections.

5.2.1 Probability Distribution Over Crash Severity

5.2.1.1 Effects of Weight on the Crash Severity Distribution

The probability distribution over crash severity to which a vehicle will be exposed will be affected by its weight and the general impact velocity distribution. For purposes of the analysis to date, the impact velocity distribution has been assessed to be constant for all cars for a particular impact mode and damage area.

In both cases under consideration at the moment, i.e. the Rabbit and the downsized G.M. full-size cars, the weights are perhaps 500-700 pounds less than other cars typical of their roominess class. This difference represents a 15-25% reduction from the weights of previous cars typical of the respective roominess classes and hence, can be expected to affect the distribution of crash severities experienced by these DCVs relative to vehicles which previously existed. It is interesting to note the ways in which this will affect the future safety picture.

At least two effects should be recognized. First, there are in a sense three relevant impact situations which a passenger car may encounter: an impact with a truck; an impact with another passenger car; and an impact with a fixed object. Since weight reductions are not currently projected for trucks, a weight reduction in a passenger car class will generally result in a positive shift* in the crash severity distribution for that passenger car class. For an impact with a passenger car, the effect of a weight reduction will depend on what happens to other cars and in what year the situation is examined. If other cars remain the same then a positive shift in the crash severity distribution for the passenger car class with a weight reduction can be expected. If the other cars in the vehicle mix are also changing, then in the short term a positive shift may be expected as a result of older cars still in the vehicle mix; in the long term, the crash severity distribution experienced due to car to car impacts can return to the original distribution if a number of conditions are met. Some of the caveats are that the shape of the vehicle weight distribution is maintained and that the only change is a shift in the mean weight of new vehicles which stabilizes after some period of time. For the fixed object impact, the crash severity as quantized by ΔV will not change since the vehicle will still have a velocity change equal to its impact velocity. The second point to recognize is that if the crash severity distribution for a particular DCV does suffer a positive shift from vehicle to vehicle impacts the other vehicles will experience a negative shift**. Thus, the net effect of a weight change in a particular vehicle will be the sum of the effects on occupants of the DCV as well as the effects on the occupants of the other vehicles which interact with that vehicle. Further, this effect must be integrated over time to assess the true long term effects. It should be pointed out, however, that assessment of the effects on the occupants of any vehicle due to design changes is non-trivial since, in particular, the injury and fatality probabilities are non-linear functions of crash severity and other parameters.

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* Where a positive shift is intended to reflect an increased probability of high crash severity impacts.

** A negative shift is intended to reflect a reduction in the probability of a high crash severity impact.

5.2.1.2 Effects of Stiffness on the Crash Severity Distribution

To this point in the analysis we have made a number of assumptions which are clearly stated in Sections 5.4-5.6. Each of the assumptions should be assessed in the future to assure that the KRAESP corroborates the Observed Fatality Rates for various class cars. In particular, one set of parameters which we have not assessed to this point, but which is recommended for further work is the vehicle stiffness. Stiffness does enter into the equations which describe the crash severity. However, its effect is masked due to an accepted engineering judgement which is explained below.

Specifically, the crash severity in a two car impact is estimated on the basis of:

$$\Delta V_1 = \frac{M_2}{M_1 + M_2} \, \text{Vrel} \qquad (1)$$

where Vrel can be a complex and M_1 and M_2 represent the case and other vehicle weights respectively, Vrel represents a complex impact velocity relationship (Ref. 8) and ΔV_1 represents the velocity change of the case vehicle.

Equation 1 however, was derived on the basis of:

$$\Delta V_1 = \frac{\text{Vrel}}{\sqrt{\left(\frac{M_1 + M_2}{M_2}\right)\left(\frac{K_1 + K_2}{K_2}\right)}} \qquad (2)$$

where Vrel, M_1, and M_2 are as in equation 1 but K_1 and K_2 represent the effective stiffness of the case and other vehicles respectively for the impact configuration of interest. The accepted engineering judgement has been that M is directly proportional to K and hence the appropriate substitution is made to derive equation 1.

As will be discussed in Section 5.5, it's certainly possible that this is not the case - particularly in high crash severity impacts involving certain portions of the vehicle population which may be newly introduced. Further, it may be the case that the assumption is valid over some limited portion of the crush region, but not over all regions (e.g. at high and low crush). This area of investigation is strongly recommende- for further analysis, since it can affect the crash severity distribution experienced by particular cars.

5.2.2 <u>Restraint-Structure Performance</u>

A second area which has been considered in the assessment of design change vehicles is the restraint-structure performance. The restraint-structure performance (RSP) is defined as a dummy injury measure versus crash severity relation for a particular impact mode and damage area. The performance can be defined for various body regions, seat positions, and vehicle classes, etc. (more detail on this aspect of the model is provided in Ref. 1). For the purposes of this project to date, the Thorax injury measure is used as an indicator of the crash severity which the occupant is exposed to. A particular RSP system type is specified for each vehicle for each general damage area (e.g. front). A usage rate is recognized for that RSP system type in each seat position and model year. For those occupants not using the full capabilities of the RSP system type available, a default condition is specified, usually the unrestrained condition.

There are at least two issues related to restraint-structure performance which have been addressed to date, although further work can and should be done.

The first issue is whether there are RSP differences between the design change vehicle and vehicles representative of its roominess class. The second is whether there are differences in the RSP between various vehicle classes in general. These two issues are discussed separately below.

5.2.2.1 Differences in Restraint-Structure Performance

Three methods were applied to assess whether restraint-structure performance differences existed between design change vehicles and vehicles representative of the respective DCV .

roominess classes. The first method was to compare the Observed Fatality Rates for the vehicles of interest. The second approach was to simulate the dynamic response characteristics, which an occupant would experience as a function of crash severity. The third approach was to compare crash tests results for the vehicles of interest. It should be pointed out that recent data and results have become available which would warrant continued analysis of these areas. The results to date in these areas are discussed below.

An indepth study of the effects of the transverse front engine configuration versus the standard longitudinal engine/ drivetrain has been initiated. This effort consists of a five mass, eleven spring lumped mass model of the front end. The evaluation has used as the baseline the Pinto for which validation runs have been performed. It is planned that the engine-drivetrain will be replaced in the model with a transverse Lancia-Beta drivetrain. The model will be rerun and the effects of implementation assessed. It may also be advisable to simulate the effects of the rear-end shortening.

5.2.2.2 Implications of Observed Fatality Rates on Restraint-Structure Performance

As discussed in Section 3, the results of the OFR analysis indicate that when controlling for roominess class that neither the V.W. Rabbit nor the G.M. downsized vehicles show sufficient deviations from their roominess class averages to suspect that the variation could not be explained by statistical variability and the modified crash severity distributions resulting from the reduction in weight. This topic has been discussed in Section 3. However, we should reiterate here that simple calculations of expected crash severity numbers based on mass relationships are not sufficient due in part to the non-linear nature of the injury probabilities as a function of crash severity by mode, etc., etc. and also in part due to other effects such as restraint usage induced by vehicle design. Certainly, the review in Section 3 indicates that if nothing else, the data doesn't suggest that the restraint-structure performance for the design change vehicles is significantly worse than the previous vehicles representative of their respective roominess groups.

5.2.2.3 Implications of Dynamic Crash Simulation

An effort has been made to model the dynamic response characteristics of the V.W. Rabbit in the frontal mode. Data which would allow simulations for the Rabbit side mode and for the Impala frontal mode has recently become available and should be pursued. The results for the Rabbit frontal mode and results based on estimates for the Impala are discussed below.

For the purposes of comparing a V.W. Rabbit to a vehicle representative of its roominess group, a set of computer simulations were conducted. A Ford Pinto was selected for the purposes of this comparison primarily due to the availability of data on its structural characteristics. A simple two mass model was used in the preliminary comparisons. The simulations were conducted assessing the response on a mass representing the unrestrained driver in frontal barrier impacts up to 50 mph. While these simulations were crude at best, they were of interest in that they showed essentially no differences in the expected occupant response for unrestrained drivers except in the region of 50 mph. Using estimated force deflection characteristics for the downsized G.M. full-size cars, we found very little difference in the response as a function of crash severity between the downsized and original versions of the full-size vehicle.

However, we did note that features which would affect the unrestrained occupant response include the crush lengths and stiffness characteristics of vehicles. The degree to which this is the case for unrestrained occupants in the real world is difficult to assess due to the almost total lack of unrestrained dummy crash tests at high crash severities. This is an important point, however, since most occupants are currently unrestrained in an impact although with the advent of passive restraints in a few years, its significance will diminish. The point is that the uniform assumption to date has been that the unrestrained occupant response as a function of crash severity is the same for each vehicle class controlling, of course, for the appropriate set of conditions - (e.g. impact mode, damage area, seat position, etc.). The simulations suggest that this is true up up to a certain point in crash severity but that after a certain crash severity the unrestrained response characteristics diverge.

The simulations conducted to date, suggest the divergence for unrestrained occupants in the frontal mode begins at about 40 mph ΔV as hoswn in Figure 5-2. Intuitively one might find this bothersome, but a brief examination of restrained tests at 40 mph did not support the notion of a divergence below 40. This should certainly be followed up in more depth in subsequent work since the effects of the specific form of the assumption are very important.

One further point of interest with regard to vehicle class differences is that preliminary side impact simulations also fail to show substantial differences in near side unrestrained occupant responses as measured by peak Thorax g's. However, our previous and current work using injury probability models controlling for numerous factors do not generally show any difference in injury probability at the vehicle class level for crash severity and other factors. These analyses, however, necessarily rely on data which is heavily weighted toward the low end of the crash severity scale and hence could not hope to show significant differences at high crash severities where there was no data. However, with the availability of the NCSS file an examination of this type focusing on crashes at high severities may be possible and should be considered.

The conclusion of the restraint-structure analysis for the two DCV's to date is that we have not found any substantial evidence to support the notion of reduced restraint-structure performance characteristics relative to vehicles representative of the respective DCV roominess class. However, we have found some inferences that for the unrestrained occupant in the frontal mode that the earlier assumption of equivalent occupant response as a function of crash severity, independent of vehicle class, may only be valid up to a point in crash severity and that after this crash severity the assumption is no longer valid. An indepth assessment of the dynamic response in the side mode has yet to be made, but the data and model for doing such a study is now available and this should be pursued, particularly to assess the validity of the assumption in the side mode.

5.3 ASSESSMENT OF SAFETY IMPACT OF DESIGN CHANGE VEHICLES

In the assessment of the safety impact to date, we have been directed to impose a number of important constraints. First, it has been explicitly defined that we not consider effects

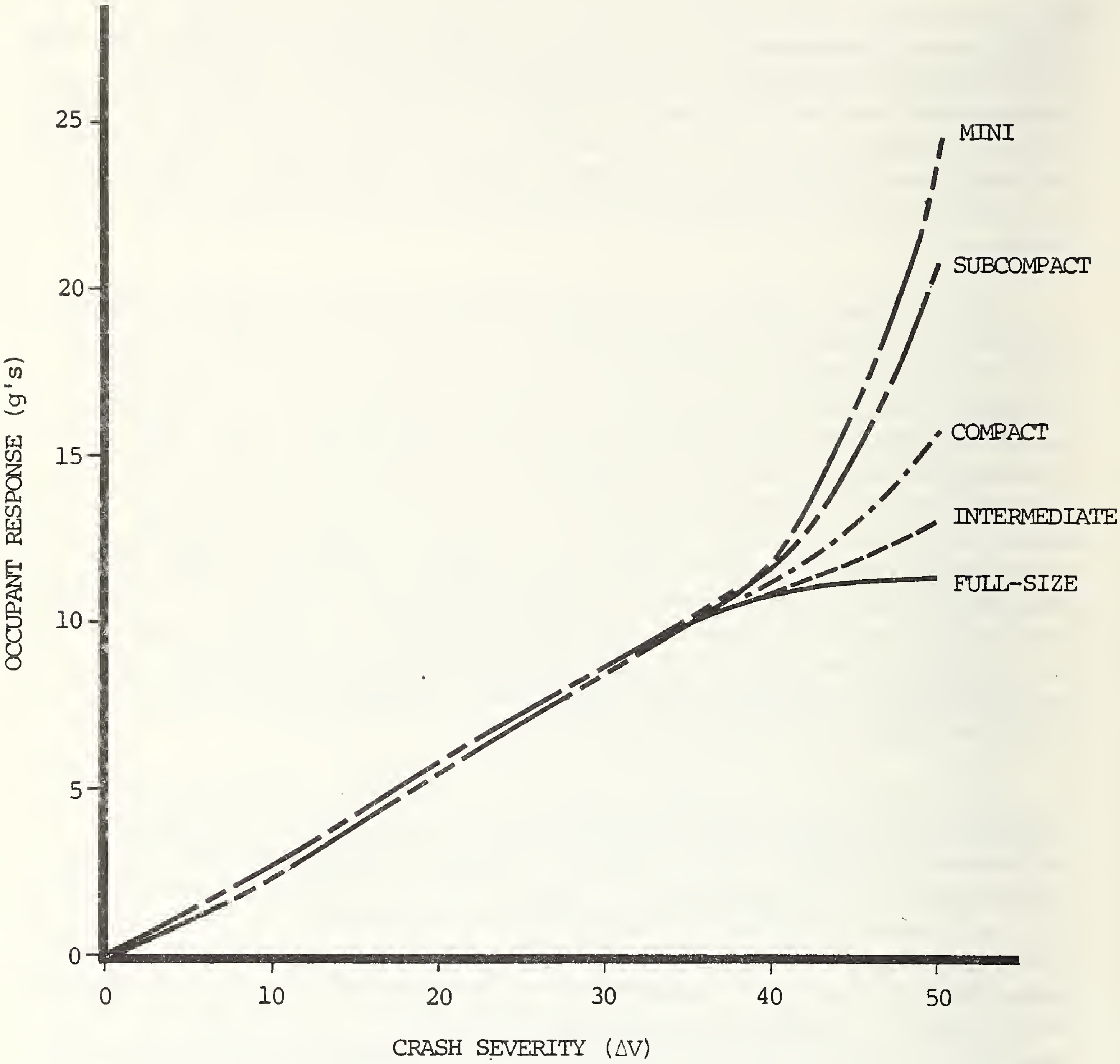

FIGURE 5-2. RESULTS OF SIMULATIONS EVALUATING OCCUPANT RESPONSE AS A FUNCTION OF CRASH SEVERITY FOR OCCUPANTS OF VARIOUS VEHICLE CLASSES.

resulting from changes induced by Federal Motor Vehicle Safety Standards. Hence, consideration of the impact of passive restraint introduction has been specifically excluded. Second, it has been explicitly stated that effects due to the marketing shifts not be considered. The analyses conducted to date have been done with these constraints in mind.

The KRAESP model has as input data the projected sales by vehicle class and manufacturer from 1977 through the year 1990. These sales projections basically reflect a trend towards small cars which attempt to be consistent with the CAGE requirements for 1985. In addition to the sales input data, the weight characteristics by vehicle class and model year are also projected.

The problem presented in the current project is what are the effects on the safety picture which will result from the observed design changes without consideration for chagnes due to FMVSS's or marketing shifts. Thus the question can be raised as to the context in which the design change is to be assessed (Where by context is meant the conditions under which the assessment is to be made). Clearly, the context in which the design change is to be assessed will influence the perceived effect of the design change.

Perhaps most importantly we would wish the analysis to be realistic within the framework of what we would expect to be representative of future conditions.

However, since we expect design changes to be characteristic of future conditions, a dilemma is presented. The dilemma is further complicated by the fact that marketing shifts are anticipated in conjunction with future design change. Hence, one must be prepared to sort through these issues and decide what is the right question to ask of the model. At this point, we have identified at least eight scenarios which can be considered. Of there, two have been analyzed to date. Pending feedback from the CTM, the remaining scenarios can be considered if desired and/or additional previously unspecified scenarios may be analyzed.

The development of possible scenarios has considered the findings to date. In particular, we have not found substantial evidence of restraint-structure performance degradation in the design change vehicles compared with vehicles representative of the respective roominess groups. As a result, the scenarios developed to date have considered only the effects of changing vehicle weights. However, as was mentioned previously, how this change is introduced into the vehicle population, and under what conditions the effects should be assessed are examples of conditional scenarios which can be considered in the KRAESP model.

The eight scenarios we have identified to date are shown in Table 5-1. As can be seen there, the first four (a) through (d) assume that the anticipated marketing shifts will occur as expected. The last four (e) through (h) assume that the new car market share distribution by vehicle class remains as it was in 1976. However, it should be noted that in 1976 a substantial market shift had already occurred with respect to 1973 sales.

Following the distinction with regard to the characterization of future market shares, scenarios have been identified in which the vehicle class weights by model year change as they have been projected (e.g. scenario a and e). A second scenario type assumes that the vehicle class weights for the model years 1977 through 1990 remain as they were in 1976 (e.g. scenario b and f).

A third alternative is to assume that as of the 1977 model year, a stepwise change in vehicle class weights occurs for those classes in which a design change has been observed. Introductions of 1977 and later model year vehicle classes, in which no design change has been observed, would have vehicle class weights as they were in 1976. This scenario type is indicated in (e) and (f).

A fourth scenario would force a stepwise change in the design change vehicle class weights for the 1977 and later model years. The vehicles without significant design changes would be allowed to change weights as they have been projected to in the future. This fourth scenario is reflected in (d) and (h).

Having identified some scenarios, one can decide which scenarios, when compared, will address the question of interest. At this point, only scenarios (a) and (b) have been evaluated although discussions with the CTM may identify other combinations to be of more interest.

TABLE 5-1. - EIGHT POSSIBLE SCENARIOS FOR CONSIDERATION

	Model Year Vehicle Class Market Shares	Model Year Vehicle Class Weights	Vehicle Class Restraint-Structure Performance
a)	P.C.	P.C.	No change
b)	P.C.	1976	No change
c)	P.C.	D.C.[1]	No change
d)	P.C.	D.C.[2]	No change
e)	1976	P.C.	No change
f)	1976	1976	No change
g)	1976	D.C.[1]	No change
h)	1976	D.C.[2]	No change

Legend:

P.C. Use of projected changes

D.C.[1] Stepwise changes for design change vehicle classes starting with the 1977 model year allowing other classes to remain as in 1976.

D.C.[2] Use projections for design change vehicle classes while allowing other classes to remain as in 1976.

Scenarios (a) and (b) were selected for comparison on the basis that they controlled for market share shifts which will occur in the future while not allowing the changes to affect the relative comparison. Alternatives would be to keep the market shares as they were in 1976, as in scenarios (e) and (f), but it would seem that this alternative would be getting further from reality in the sense that we know that the market shifts will occur if only because of fuel economy considerations. It does appear to us that an evaluation of potentially greater interest is what changes in the safety picture will result from the combination of marketing and design change shifts by 1990. In particular, it is likely to be of great interest to assess the impact on the safety picture due to all fuel economy effects. To do this, one would compare scenarios (a) and (f) with exception of using the market shares of 1973 instead of 1976 in scenario (f). We, however, have not done this to date pending agreement with the CTM. One could, of course, then go further and ask what the effects of FMVSS 208 will be etc., etc.

Because of the uncertainty we have as to the scenario of most interest to NHTSA at this time, we have limited the simulation of future years to 1980, 1985 and 1990, since the model is not inexpensive to run. As a result, only estimated cumulative effects are provided for the scenarios studied up to this point. More comprehensive analyses can be conducted following discussion with the CTM to identify the scenarios currently of interest.

As was mentioned previously in this section, the KRAESP is a complex model. As with any complex model, the conditions under which it is exercised should be understood by the user. The runs conducted to date are conservative in their assumptions. Since the runs conducted represent early runs on the KRAESP model, the effects of several assumptions have not been explored. The assumptions of interest, which are discussed in the next section, are conservative in that reasonable alternatives to them will increase the expected number of injuries and fatalities in the future. It is strongly recommended that the effect of these assumptions be fully explored in further work. The details presented for the runs conducted simply focus on the unique features of the analysis relative to normal conditions imposed in the model. For Run 1 which utilized scenario (a), no changes were made in basic model assumptions. Run 2 imposed the condition that while the market shares would change, as in Run 1, the vehicle class weights by model year subsequent to 1976 would remain at the 1976 values through model year 1990. Thus, the change in vehicle weights can be shown conceptually as in Figure 5-3.

It should be noted that the effect of this is only to affect the weights of the larger vehicle classes. However, in this configuration of the model, the market shares for the full-size vehicle decrease substantially by 1990 and hence, the effect of the differences in the two scenarios is somewhat mitigated.

The results of the two scenarios using the conservative assumptions are summarized in Tables 5-2 and 5-3 while the actual output is shown in Appendix G. Although only four years were evaluated (all years could have been run) we can make an estimate of the differences in the two scenarios by interpolating. On this basis, the overall difference which accrues from 1977 through 1990 is estimated at 2,000 fatalities and approximately 60,000 injuries in towaway accidents. The changes in fatalities appears to be equally divided between the front and side damage areas although percentagewise the effect is greater in the side. This is also the case when injuries are considered. However, it should be noted that two effects should be examined here. First, an examination of the fatalities by vehicle classes with and without weight changes and market share shifts is extremely important and will be accomplished pending resolution of the scenarios of interest. The second point of interest is that the mean crash severity for the fatalities in the smaller vehicle classes is likely to be higher than that observed in the larger vehicle classes. This latter point can also be assessed and should be very important to rulemaking considerations.

5.4 FURTHER ANALYSIS CONSIDERATIONS

A number of factors considered by the KRAESP model need to be understood by the reader. Further work is strongly recommended to assess whether sufficient information exists to warrant use of alternative factors.

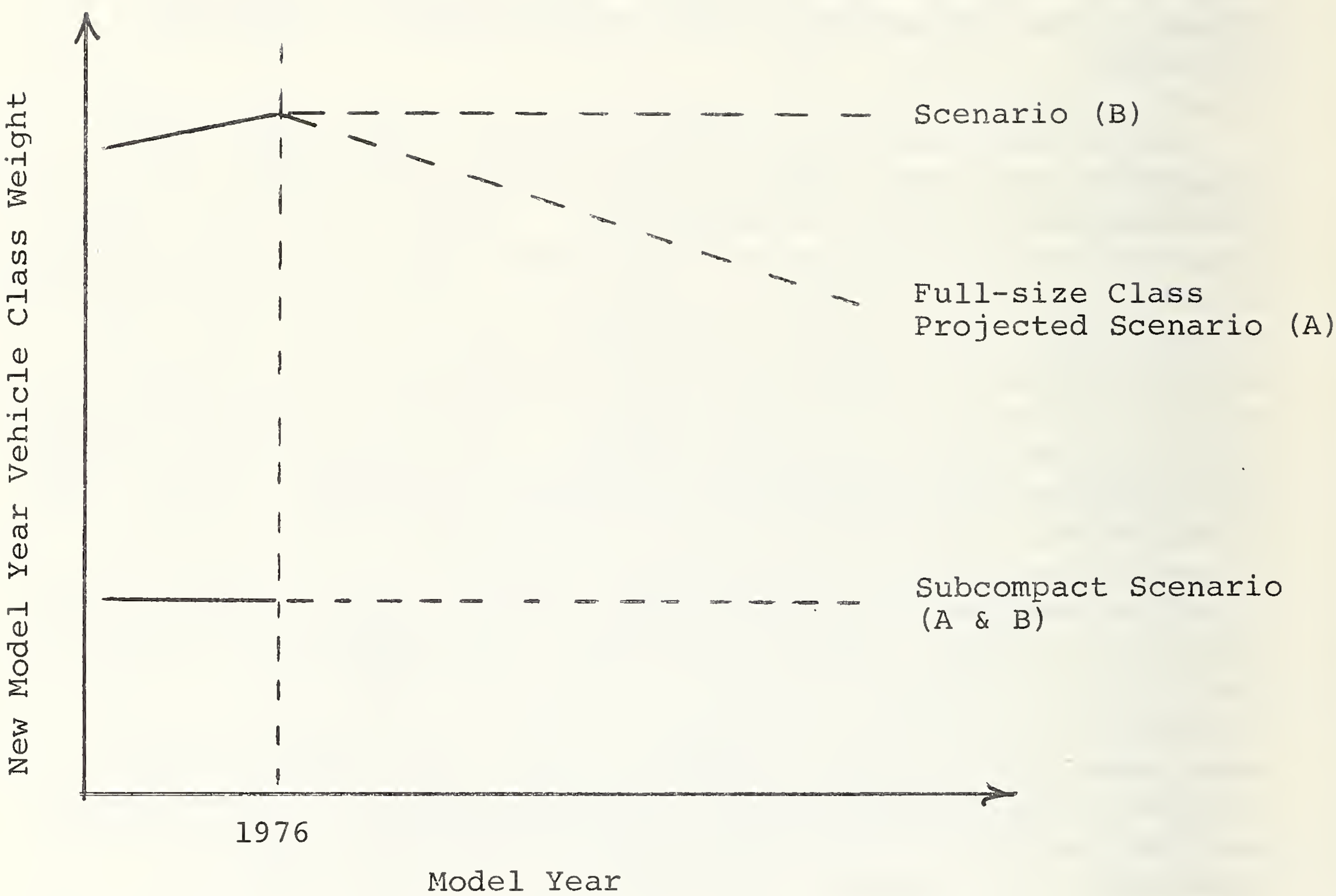

FIGURE 5-3. CONCEPTUAL DEMONSTRATION OF WEIGHT CHANGE BETWEEN SCENARIOS.

TABLE 5-2 - SUMMARY OF RUN 1 RESULTS

Impact Configuration	Accident Year 1977	1980	1985	1990	
V.V. Front	8,931	9,534	10,710	11,880	(A)
	899,173	933,312	1,009,296	1,104,436	(B)
F.O. Front	4,420	4,600	4,991	5,469	(A)
	265,792	276,365	299,618	328,189	(B)
Total Front	13,351	14,134	15,701	17,349	(A)
	1,164,965	1,209,677	1,308,914	1,432,625	(B)
V.V. Side	6,650	7,079	7,928	8,788	(Z)
	393,824	408,677	441,685	483,203	(B)
F.O. Side	3,309	3,442	3,732	4,088	(A)
	73,853	76,807	83,287	91,238	(B)
Total Side	9,959	10,521	11,660	12,876	(A)
	467,677	485,484	524,972	574,441	(B)
Rear V.V.	193	208	235	260	(A)
	79,888	83,082	90,112	98,737	(B)
Roll	3,193	3,320	3,600	3,944	(A)
	63,550	66,092	71,668	78,510	(B)
Total	26,696	28,183	31,196	34,429	
Number uninjured occupants	1,776,080	1,844,335	1,995,666	2,184,313	
No. accident towaways	1,725,977	1,795,011	1,946,446	2,132,269	
Total number of occupants	2,761,563	2,872,017	3,114,313	3,411,630	

Legend:

(A) - Predicted fatalities

(B) - Predicted uninjured in towaway accidents

TABLE 5-3 - SUMMARY OF RUN 2 RESULTS

Impact Configuration	Accident Year				
	1977	1980	1985	1990	
V.V. Front	8,976	9,548	10,562	11,675	(A)
	899,271	934,391	1,012,746	1,109,431	(B)
F.O. Front	4,420	4,600	4,991	5,469	(A)
	265,792	276,365	299,618	328,189	(B)
Total Front	13,396	14,148	15,553	17,144	(A)
	1,165,063	1,210,756	1,312,364	1,437,620	(B)
V.V. Side	6,675	7,076	7,790	8,589	(A)
	393,925	409,435	443,971	486,518	(B)
F.O. Side	3,309	3,442	3,732	4,088	(A)
	73,853	76,807	83,287	91,238	(B)
Total Side	9,984	10,518	11,522	12,677	(A)
	467,778	486,242	527,258	577,756	(B)
Rear V.V.	194	208	230	254	(A)
	79,871	83,030	89,992	98,551	(B)
Roll	3,193	3,320	3,600	3,944	(A)
	63,550	66,092	71,668	78,510	(B)
Total Fatalities	26,767	28,194	30,905	34,019	
Number uninjured occupants	1,776,262	1,846,120	2,001,282	2,192,437	
No. accident towaways	1,725,977	1,795,011	1,946,446	2,132,269	
Total number of occupants	2,761,563	2,872,017	3,114,313	3,411,630	

Legend: (A) - Predicted Fatalities

(B) - Predicted Uninjured in Towaway Accidents

The factors used in the analysis to date for which further study is warranted and which are discussed in the remainder of this section are listed below:

1. The assumption that the crush stiffness (k) is proportional to the vehicle mass (m).

2. The assumption that the occupant response characterized as dummy g's versus crash severity (ΔV) is independent of vehicle class.

Additional considerations, which are concerned more with the issue of what analysis is done, are also discussed and are listed below:

1. The effects of differences in the future vehicle sales used as input by the KRAESP model as opposed to data projected by the Wharton model.

2. Scenarios developed have used as a baseline the market shares as in 1976.

3. The changes in injuries and fatalities have to date, been projected for the overall fleet.

4. The effects of the implementation of passive restraints.

5. The effects of differing restraint usage and occupancy for specific vehicles.

5.5 FACTOR CONSIDERATIONS

One of the parameters which may play an important role and for which sufficient data is now becoming available, is the vehicle crush stiffness. The assumption that the vehicle crush stiffness is proportional to the vehicle mass may not be appropriate especially for very light cars. In particular, since one recognizes that stiffness varies as a function of crush the effect at large crush distances may also be significant. The relationships between k and m may be of the form suggested in Figure 5-4 or something else. The relationships in different crush regions may be very important. Preliminary assessment of the effects of the

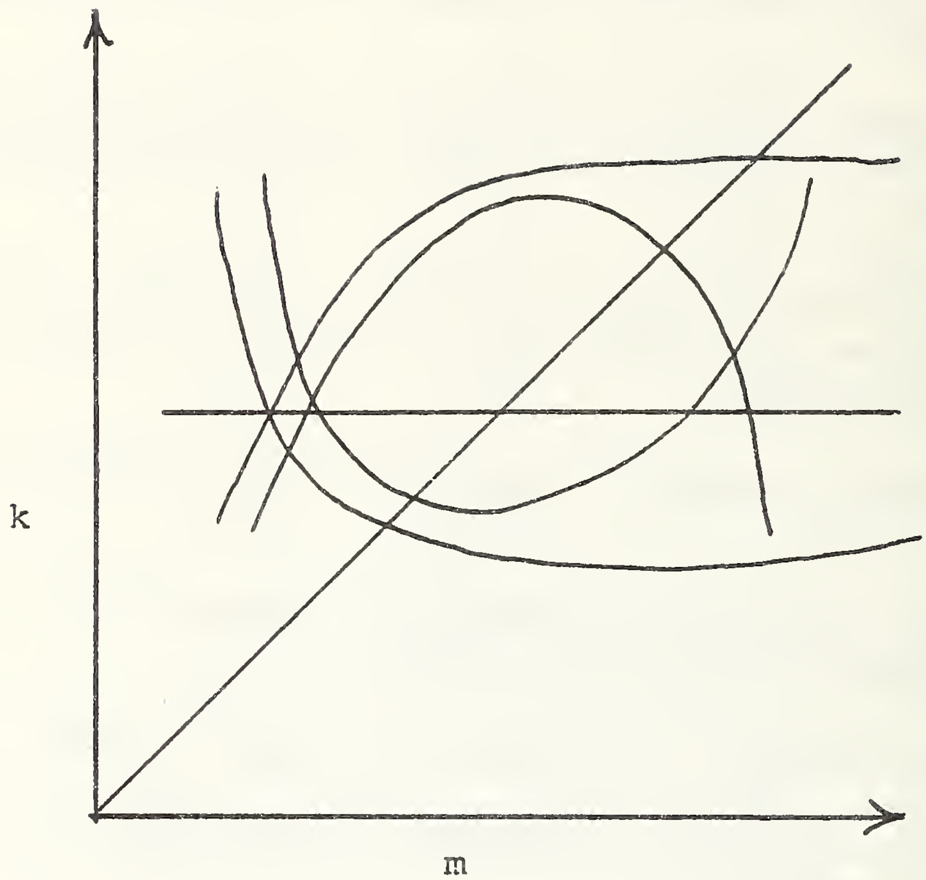

FIGURE 5-4. EXAMPLES OF POSSIBLE FUNCTIONAL FORMS RELATING k AND m.

relationships being $k \alpha m^{3/2}$ have been notable. A thorough study of this relationship is recommended.

Another assumption which requires further study is whether the occupant response as a function of crash severity is independent of vehicle class. While we have at this point shown this not to be the case with accident data, we have shown it with crash simulations. However, substantial differences have not appeared except at high crash severities as discussed in Section 5.2.2.3. Preliminary results using the occupant response as a function of crash severity predicted by simulations for small and large cars in the frontal mode have shown this effect to be important.

Some crash simulations in side impacts have not shown significant differences in occupant response by vehicle class. However, it is highly recommended that this factor be further investigated.

The resolution of the above two issues can be resolved by showing that the fatalities by vehicle class match those observed in the FARS file.

5.6 ADDITIONAL CONSIDERATIONS

1. A recent study has shown that substantial differences in the projections of new vehicle sales characteristics exist between the input data used in the KRAESP and the data projected by the Wharton model. The differences shown in this study, contained in Appendix H, should be resolved with the resulting data being used in the final analyses.

2. It should be noted that in 1976 a substantial market shift had already occurred with respect ot 1973 sales. In fact, if one simply uses the market share of 1976 out to 1990, there is a substantial change in the vehicle mix with respect to its composition in 1976. This is because in 1976 many small cars were already being sold, but since the sales change had only recently taken place (i.e. starting in 1974) its effect on the total vehicle mix had only just begun. Thus, it may be appropriate to constrain the market shares to those which existed in 1973 to keep from seeing the effects of marketing shifts.

To summarize the above comment: As a result of reviewing the KRAESP model it has been found that even assuming the market shares remain as they were in 1976, the vehicle mix will be substantially changed by 1990. Thus, if market shifts are not to be considered, one must accept as a basis for new car sales the market share distribution which existed in 1973 or earlier in order that the 1990 vehicle mix not reflect the market shifts brought on by fuel economy concerns. It also suggests that while in this study we looked at 1974 through 1977 new vehicle sales and saw little shift in the market distribution, if we had examined 1973 in addition, that there may well have been a shift in the market distribution. It is suggested that this point be examined in further work.

Further, a change in the scenarios identified should be made so that rather than 1976 market shares being used out until 1990, the 1973 market shares should be used to properly eliminate the effect of changing market shares.

3. The changes in injuries and fatalities which have been projected are for the overall vehicle fleet. However, this can and should be done for each vehicle class, pending resolution of the scenarios of interest ot the CTM.

4. Since it is known that passive restraints will be implemented in the 1980's, it may be of interest to assess the effects including consideration for the impact of these restraints. Effects associated with passive restraints have been ignored since they are perceived as changes due to FMVSS's.

5. Differences associated with differing restraint usage and occupancy rates have not been addressed. This may or may not be of interest to NHTSA, but if it is, the effects could be considered.

SECTION 6

SUMMARY

This section is a general summary of the work discussed in this report. Subsection 6.1 offers some general observations concerning the objectives of the analysis. The remaining subsections summarize results obtained in Sections 2 through 5 respectively.

6.1 GENERAL OBSERVATIONS

The work reported in this paper is concerned with the identification of automobile design change in the time period 1974-1977, together with evaluation of the projected safety impact of identified design changes.

The number of injuries and fatalities that will occur among occupants of passenger cars as a function of time, depends on many factors, including at least:

1. Number of vehicle miles travelled and the nature of the vehicle population.

2. Driving characteristics such as travel speed, distribution of travel by class of roadway, improvements (or deterioration) in roadway design, relative incidence of unsafe driving habits (driving while intoxicated) which may be affected by enforcement programs, shifts in occupant age and sex distributions, restraint system usage, and so on.

3. Vehicle characteristics including weight, crashworthiness, restraint system technology and other factors.

The analysis undertaken here is intended by the Statement of Work to examine primarily the effects of design changes which are a consequence of increasingly stringent fuel economy standards. At the same time, by the Statement of Work, it is intended not to consider the effects of Federal Motor Vehicle Safety Standards, particularly passive restraint requirements or any other standards affecting occupant protection and crashworthiness. The primary focus then becomes an examination of weight reduction and structural changes associated with weight reduction, as manufacturers attempt to produce vehicles which will meet the fuel economy requirements.

A characteristic of these requirements is that they are based on a Corporate Average Fuel Economy measure and not on absolute requirements for each and every vehicle produced by a company. As a consequence, manufacturers have open the alternative of not so much altering vehicle designs, as simply changing the sales mix of vehicles already available. In a similar way, a consumer desiring a car with better fuel economy can simply choose a smaller and more efficient model from the selection offered and does not have to seek out an innovative design vehicle. In fact, of course, both design changes and vehicle sales mix changes will occur. It will be seen in the results of the current work that a downsized vehicle in a given vehicle class may very well not be drastically different in design characteristics or safety performance from previously existing vehicles similar to the new version in size and/or weight. The downsizing effort appears, at least from a safety impact point of view, as simply a marketing shift of sales from the larger to the next smaller vehicle class.

That marketing shifts are an important factor to consider in evaluating the safety consequences of design change is additionally motivated by the fact that the accident experience of any given type of vehicle is very much affected by the nature of the vehicles with which it impacts. Given a distribution of relative velocities among different vehicles on the road, the accelerations suffered by a subject vehicle are a function of both the striking and struck vehicle weights, structural stiffness characteristics, and impact angles. The injury and fatality experience of occupants of the subject vehicle is then a function of these accelerations and of factors concerning methods of restraint, incidence of intrusion or ejection, details of the collision of the occupant with the interior of the car, and so on. Single vehicle accidents are, of course, subject to similar considerations except that the "other" vehicle is replaced by a variety of possible objects including "infinite" masses (e.g. bridge abutments), poles, collapsible guard rails, hillsides, or whatever. The characteristics of other vehicles on the road will not be of consequence in such accidents.

6.2 IDENTIFICATION OF DESIGN CHANGES

The analysis of design changes presented in Section 2 consists of a methodology for comparing individual model lines in any model year to the same models in a baseline year (specifically 1974). This comparison is based on the relative difference in values of nine parameters describing the weight and linear dimensions of each model. Analogous comparisons can be constructed for mewly introduced models relative to similar models previously existing.

In general, the design changes surveyed for the period 1974 through 1977 are dominated by the 1977 downsizing of the General Motors full-sized lines and by the introduction of the Volkswagen Rabbit in 1975. These two changes are, however, quite different in character. The 1977 downsizing is characterized by major reductions in weight, wheelbase, overall length, and body side thickness together with increases in overall height. Interior roominess is only slightly reduced. The Rabbit, alternatively, effectively represents an upgrading of roominess while retaining the weight, body side thickness, and general dimensions of the typical minicompact car. Certain innovations are required, however. These include the front transversely mounted engine, front wheel drive layout, shortened or "boxy" rear end design, and generally square body shape.

It is noted that General Motors 1977 and Rabbit are not the only vehicles which represent design changes or innovations in the 1974-1977 period. Pacer, for example, is clearly an anomalous entry given its shorter overall length, shorter rear end, greater width and extreme body side thickness. It does not, however, accomplish significant improvement in fuel economy or in roominess to weight ratio over other designs, nor has Pacer typified a design approach that seems likely to be a future trend. A second significant exception is the 1975-1977 General Motors sporty subcompact line, Monza, Starfire, Sunbird, and Skyhawk. These cars are variants on the basic Vega and are characterized by heavier than average weight to roominess ratio and no particular improvement in fuel economy performance. It is fairly evident that this design type will be replaced by more weight and fuel efficient versions of the subcompact sports style.

We suggest that neither the 1977 GM full-size lines or the Rabbit are necessarily drastically different from certain other cars existing previously (e.g. Lemans and Matador in the first instance, and Fiat 128 in the second). It is clear that the new cars are significantly different from the cars they may be imagined to be replacing (old full-size cars in the first instance, subcompacts such as Pinto, Vega, and Gremlin in the second).

The dependence of ultimate safety effects on the entire mix of models on the road, together with other comments offered above on the meaning of design change as compared to sales shifts motivates the presentation of frequency distributions of vehicles over values of design parameters. The impact of the 1977 GM downsizing is evident in these distributions but is also seen to be quite small in the initial year of implementation. Effects of the introduction of Rabbit are not evident as such, but certain other shifts can be observed, such as the decline in compact/subcompact class registrations after 1974.

The overall impression of the design change analysis is that there is very little change in the time period 1974-1977 and that what real world change there is is confined to the 1977 downsizing at GM. This is not surprising since it is the case that manufacturer responses to the fuel economy standards have been scheduled to be implemented in 1978 and later model years. The 1977 changes at GM are really only the precursor of this massive modification in vehicle design. This leads immediately to the recommendation that the analysis applied to the 1974 through 1977 model years should be extended to 1978 and 1979 model year designs.

6.3 CALCULATIONS OF OBSERVED FATALITY RATE

Observed Fatality Rates for 1974 through 1977 model year passenger cars were calculated by dividing total fatalities for each model in the 1976 and 1977 calendar years by the total vehicle miles of travel in those years. Fatality counts were obtained from the Fatal Accident Reporting System by make and model. Adjustments were made for missing and unknown make and model coding. Vehicle miles of travel were derived from vehicle registrations adjusted for scrappage and model introduction sequences. Mileages were based on a study of mileage by vehicle age. This study did not attempt mileage estimates by make and model.

The Observed Fatality Rate analysis methodology is intended to identify relative differences between particular makes and models. Such comparisons can be used to measure the real world differences between significant design change vehicles and other vehicles previously existing. At the same time the results of such analysis when displayed for all models allow insight into the general pattern of fatality experience as a function of make and model specific characteristics.

Our analysis of fatality rates does not attempt to control for driver factors, crash conditions other than impact mode, or other non-design-related influences. On the other hand this analysis does reflect the actual direct experience of various makes and models in the real world. It can be argued that many factors concerning driver age variations, usage habits and so on are a reflection of design characteristics in the sense that the vehicle characteristics influence buying decisions and driving behavior. That is, the design characteristics encourage the vehicle to be used in a particular fashion and hence induce particular driver behaviors.

The results obtained do not indicate that either Rabbit or the 1977 General Motors full-size lines have a fatality experience significantly different from the average of other cars of similar roominess. At the same time it is clear that there are cars that do have disporportionately high fatality rates. These cars are typically 2- seater sports types or sports coupes like Camaro and Firebird. There are no cars that are obviously better than most other cars at least when controlling for roominess or weight.

It is the case that "sister" models of apparently similar design sometimes have fatality rates which differ by amounts exceeding the bounds of statistical variation. At the same time we have cited evidence that suggests so called "sister" models may not be identical in design and that the differing fatality rates cannot be assumed to have no basis in engineering differences.

An overall view of the fatality rates for all models indicates a generally decreasing observed fatality rate with increasing vehicle weight. This dependence is fairly drastic. Observed Fatality Rate dependence on weight is not necessarily smooth. Indeed the marked impression of figures 3-26 through 3-31 is that vehicles divide themselves into two classes; large, low fatality rate vehicles and small, high fatality rate vehicles. Within each group dependence on vehicle weight is not marked, especially in the large car group. This structure in the data should be kept in mind when considering the influences of relatively small changes in vehicles size and weight on fatality experience.

The analysis of Observed Fatality Rates is concluded with discussion of error sources in the analysis. The reader is warned that sufficient statistical variation and other uncertainties exist that reasonable caution should be exercised in making particular model to model comparisons. Confidence limits based on random statistical fluctuations are quoted in some of the results, but no definite estimates are attempted for other error sources.

The Observed Fatality Rates were aggregated by model year. These statistics demonstrate a strong declining trend in fatality rates over the model years in which various Federal Motor Vehicle Safety Standards were introduced. These results are not controlled for vehicle age, however. A useful extension of this work will be to investigate the effects of vehicle age on safety performance and to verify more precisely the effects of safety standard implementation on reduction of fatalities and injuries.

A useful byproduct of the work to develop vehicle annual mileage estimates as a function of vehicle age is a statistical indication of the effects of the 1973 bumper standard (FMVSS 215-Experior Protection). This result came about in a comparison of predicted and observed accident frequency in the NCSS file which was performed in order to validate the vehicle annual mileage estimates used in the Observed Fatality Rate. It was found that good correspondence was obtained only if one imposed a change in the frequency of towaway accidents in the NCSS data beginning with 1973 model year vehicles. This suggests that the new bumpers were effective in reducing collision damage below towaway thresholds in a significant number of cases.

6.4 RELATIONSHIP OF OBSERVED FATALITY RATE TO DESIGN PARAMETERS

It was found in the analysis of Observed Fatality Rates that a substantial dependence of fatality rate on vehicle curb weight is qualitatively evident. The possibility that the fatality rate could be related more explicitly to design characteristics of the individual models was investigated on a preliminary basis. The technique used was to perform stepwise linear regression analysis of the fatality rate on the various vehicle dimensions available in our data. Certain combinations of these dimensions and the logarithms of each dimensional parameter or combination of parameters were included in the problem.

The problem is characterized in general by a high degree of correlation among the various parameters used. This correlation is a consequence of the fact that all the dimensional parameters of a vehicle are closely related to its overall size and weight. The results of the regression problem when run separately for the frontal impact mode and side impact mode fatalities were that vehicle size (width x length x height) or vehicle roominess are the best predictors of Observed Fatality Rate when individual models are weighted by the number of fatalities occurring in that model. Values of R^2 on the order of 50% were obtained. When an unweighted regression is performed the frontal impact mode fatality rate was best predicted by body side thickness divided by curb weight and the side impact mode fatality rate was best predicted by the logarithm of rear overhang and the logarithm of vehicle height. Results of this sort are indicative of a situation where the various independent parameters are highly cross-correlated. One should note, however, that the "obvious" parameters such as curb weight, front crush length, etc. are not strong competitors for entry in the stepwise regression.

The nature of the Observed Fatality Rate data, particularly the large car/small car dichotomy discussed previously, suggests that linear or transformed linear regression may not be a suitable tool for analysis of fatality rate dependence on design parameters. Discriminant analysis is a possible alternative analysis method. In discriminant analysis independent variables are picked based on their ability to predict inclusion of a case in one of a set of groups, such as fatality rate greater than two deaths per 100 million vehicle miles or fatality rate less than two deaths per 100 million vehicle miles (which is the approximate dividing line between the large and small car fatality rates).

Another characteristic of the problem as presently formulated is that it does not account for structural stiffness variations from vehicle to vehicle in an explicit manner. This is an area that deserves further work.

The general conclusion to be drawn at this time from analysis of the dependence of fatality rate on vehicle design parameters is that is is very much an open question whether or not a reasonable understanding in detail of the influence of vehicle dimensional and stiffness parameters on safety performance can be obtained directly from empirical data.

6.5 ASSESSMENT OF FUTURE IMPACT

The Kinetic Research Accident Environment Simulation and Projection (KRAESP) model has been used to project injury and fatality counts as a function of time up to 1990. The model has a number of characteristics which are summarized:

1. Consideration of fleet composition by vehicle class, manufacturer and model year from 1952 through 1990.

2. Specification of the restraint-structure system for each seat position and general impact mode, property damage system, accident avoidance system, and weight for each vehicle class, manufacturer and model year 1977 through 1990 with baseline specifications for existing vehicles 1952-1976.

3. Consideration of occupancy rates by seat position as a function of time 1977-1990.

4. Consideration of vehicle exposure probabilities based on initial sales, scrappage rates and vehicle mileage.

5. Consideration of the accident environment by damage area clock position, impact mode and crash severity.

6. Consideration of restraint-structure performance characteristics by system type, vehicle class, seat position, damage area impact mode, and anthropometric size (optional).

7. Consideration of restraint system usage by restraint type and seat position.

8. Consideration of the effects of advanced accident avoidance systems on the relative impact velocity distribution.

9. Consideration of the exposure as a function of relative velocity by damage area and impact mode, used in conjunction with the crash severity calculation.

10. Consideration of the effects of advanced property damage systems on property damage losses.

11. Specifications of occupant injury level probabilities based on restraint structure performance and best known injury measure to injury level relations.

12. Determination of injury level distributions as well as injury costs by year, mode, crash severity, etc.

13. Identification of benefit cost ratios for various implementation schemes based on subsystem costs.

14. Assessment of implementation scenario benefits for future years.

There are two general mechanisms by which design changes can operate to affect the overall safety outcome as predicted in the KRAESP model. The first mechanism concerns the crash severities over the vehicle population at any time, which is a function of the weight and stiffness of the vehicles among other things (e.g. Vrel). The second mechanism concerns the restraint-structure performance (or crashworthiness) of each vehicle as a function of crash severity.

It is clear that downsizing efforts, such as for the 1977 G.M. full-size line, will have a significant effect on the distribution of vehicle weights. The KRAESP model already contains projections of weight by vehicle class which are generally in line with trends now being observed. Since the vehicle weight trends are input data to the model appropriate evaluation of design change effects involving vehicle weight can be made according to any choice of scenario which NHTSA finds of interest.

Knowledge of the detailed stiffness characteristics of various vehicles is difficult to obtain, but if these are known the model will allow an evaluation of the effects of stiffness on the crash severity distribution. The standard assumption, the one currently used, is that stiffness is proportional to weight so that the dependence of crash severity on vehicle design characteristics reduces to a dependence on weight alone. Preliminary investigations of variations in this assumption show that it is important to know what the relationship of stiffness to mass is and to identify whether this relationship will change with new vehicles. Further work is recommended in this area.

Restraint-structure performance is considered in the KRAESP model with regard to differences in performance of significant design change vehicles compared to vehicles of similar size and with regard to variations in performance across vehicle classes.

The Observed Fatality Rate results do not suggest that there is a difference in crash performance between Rabbit or the 1977 G.M. full-size lines and other cars of similar size and weight. This result is substantiated by very simplified two mass model simulations in which the V.W. Rabbit and the Ford Pinto show essentially no difference in the expected occupant response for unrestrained drivers except in the region of 50 mph ΔV. The same is true in comparisons between the downsized G.M. cars and original versions of the same.

There are some indications that previous assumptions concerning the constancy across vehicle classes of occupant response as a function of ΔV may not be valid at least in high crash severity frontal impacts. Further research is suggested.

We have suggested a number of scenarios which can be used to evaluate the impact of the introduction of cars like Rabbit or 1977 Impala into the vehicle mix.

A sample comparison between scenarios in which vehicle weights and sales follow the base input projections of the KRAESP model and one in which vehicle weights by market class are fixed at 1976 values in all successive model years shows a cumulative difference of 2,000 fatalities and 60,000 injuries between 1977 and 1990. The benefit goes to the scenario maintaining the higher vehicle weights. These results show some complex dependencies on time into the future and also incorporate a number of assumptions which deserve further investigation.

SECTION 7

CONCLUSIONS

1. A method for the identification of automotive design changes has been implemented. This method considers both changes and innovations in individual models and aggregate changes in vehicle mix.

2. Volkswagen Rabbit and the 1977 General Motors full-size cars were found to be significant design change vehicles based on measurement of degree of change in selected dimension parameters and by comparison to previous vehicles of similar roominess.

3. Very little change is observed in aggregate fleet characteristics by model year in the years 1974-1977. The effects of the 1977 downsizing are evident but small.

4. A method for the calculation of observed fatality rates for specific makes and models has been implemented. Results of these calculations may be useful for rulemaking and consumer information purposes.

5. The observed fatality rate statistics aggregated by model year demonstrate a decreasing trend in fatality experience which parallels the implementation of Federal Motor Vehicle Safety Standards. These statistics further demonstrate a decline in the incidence of towaway accidents in the National Crash Severity Study which is coincident with the implementation of the bumper standard (FMVSS 215-Exterior Protection) in 1973.

6. Based on the observed fatality rate and on engineering simulations the Rabbit and the 1977 General Motors full-size cars were not found to have safety performance significantly different from other cars of similar roominess.

7. The problem of relating safety performance in detail to design characteristics of individual models is complex.

Consideration of variables not readily available in the past may be useful. In particular, stiffness characteristics of individual vehicle models may be of importance. Preliminary regression models relating observed fatality rate to vehicle design parameters indicate that variables related to overall vehicle size and weight are the best predictors of safety performance.

8. The Kinetic Research Accident Environment Simulation and Projection (KRAESP) model is capable of evaluating the future impact of current and projected design changes. The KRAESP model can and should be exercised using future vehicle implementation scenarios of interest to NHTSA.

SECTION 8

RECOMMENDATIONS

1. The study of automotive design changes should be extended to include 1978 and 1979 model year passenger cars and 1974-1979 model year light trucks and vans.

2. The Observed Fatality Rate analysis methodology should be applied to 1978 and 1979 model year passenger and 1974-1979 model year light trucks and vans. This type of analysis can be extended to include injury as well as fatality experience. There should be further refinement of make and model identification in accident data and of registration, mileage, and driver characteristic data by make and model.

3. There should be at least a preliminary investigation of the relationship of vehicle stiffness to mass. If significant deviations are found from the relationship assumed the effects on the crash severity experience of particular cars should be reassessed. An extensive crush test program would be desirable to supplement currently available data.

4. The KRAESP model can be implemented using a variety of possible scenarios for the characteristics of future vehicle designs and vehicle populations. Scenarios should be chosen in order to elucidate the dependence of future fatality and injury experience on specific trends of interest in either vehicle design or vehicle population mix.

5. Automotive design change and fatality/injury rate analysis should be used as an approach to rating the safety of individual makes and models of vehicles for consumer information purposes. Results should be displayed both with and without control for crash severity.

6. The preliminary work on the dependence of fatality rate on model year should be continued. In particular it is imperiative to understand the dependence of fatality and injury rate on vehicle age.

7. The results of design change and fatality/injury rate analysis will indicate specific vehicles whose engineering characteristics should be investigated in more detail. These investigations should incorporate study of design details, in depth crash simulation studies, and crash tests. Particular attention should be paid to steering box location and steering column design features. The goal would be to provide engineering based explanations of observed and injury rate differences between specific makes and models of vehicles.

8. The dynamics of side impact collisions should be studied in detail. A combination of simulation, crash test, and accident analysis work should be used.

9. There should be an analysis of the role played by trucks as striking vehicles. Of particular concern is the issue of incompatibility between trucks and passenger cars, especially for small cars.

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