REPORT NO: DOT-TSC-OST-76-24

TRANSPORTATION SAFETY ANALYSIS

Hans C. Joksch
THE CENTER FOR THE ENVIRONMENT & MAN, INC.
275 Windsor Street
Hartford, CT. 06120

November 1976
FINAL REPORT

Document is available to the U.S. public through the
National Technical Information Service,
Springfield, Virginia 22161

Prepared for

U. S. DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER
Kendall Square
Cambridge MA 02142

Technical Report Documentation Page

1. Report No.
DOT-TSC-OST-76-24

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
TRANSPORTATION SAFETY ANALYSIS

5. Report Date
November 1976

6. Performing Organization Code

7. Author(s)
Hans C. Joksch

8. Performing Organization Report No.
CEM Report 4191-548

9. Performing Organization Name and Address
The Center for the Environment and Man, Inc.*
275 Windsor Street
Hartford CT 06120

10. Work Unit No.
OS 643/R6546T

11. Contract or Grant No.
DOT-TSC-1089

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge MA 02142

13. Type of Report and Period Covered
Final Report
June 1975 - March 1976

14. Sponsoring Agency Code

15. Supplementory Notes
*Under contract to:
Special Studies Branch, Research Division
U.S. Dept. of Transportation, Transportation Systems Center
Kendall Square
Cambridge MA 02142

16. Abstract

A conceptual structure was developed for a model expressing transportation accident deaths as a function of transportation activity levels. The literature and data bases were reviewed. A first-level model was developed for the following modes: highway transport; air transport--scheduled and general aviation; and rail transport. The first-level model was used to project the number of transportation accident deaths, by mode, up to 1990, on the basis of transportation projections provided by TSC. An outline for a second-level model was developed.

17. Key Words
transportation safety
transportation fatalities
highway transport
air transport
rail transport

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC
THROUGH THE NATIONAL TECHNICAL
INFORMATION SERVICE, SPRINGFIELD,
VIRGINIA 22161

19. Security Classif.(of this report)
Unclassified

20. Security Classif.(of this page)
Unclassified

21. No. of Pages
150

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

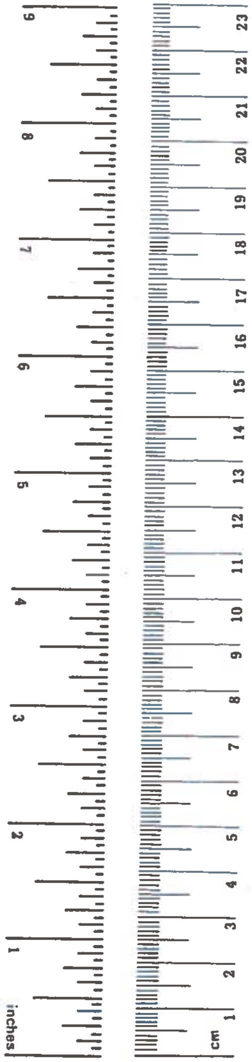
PREFACE

This study is based on previous work conducted by The Center for the Environment and Man and its predecessor organization. In addition to ideas and information obtained from published sources, many staff members of the Transportation Systems Center, other organizations of the U.S. Department of Transportation, and private organizations provided formal and informal information. CEM staff participating in the study were C. Costenoble, G. Haas and J. Reidy. J. Ball developed the computer program in addition to other contributions. T. Mayer and M. Wallace produced the report. Responsibility for the content and its accuracy rests with the author.

METRIC CONVERSION FACTORS

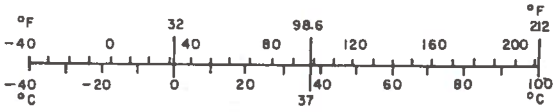
Approximate Conversions to Metric Measures

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



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



---

*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.

SUMMARY

The subject of this study is the relationship between transportation activities and transportation accidents. A conceptual structure was developed to study such relationships quantitatively. The literature was reviewed for relevant models but none were found. The quantitative analysis was restricted to transportation accident deaths, because of the reliability of the available data. Separate models were developed for highway transport, air transport, and rail transport. Data on water transport accidents were analyzed, but no model could be developed. Pipeline accidents would require a different conceptual structure and were, therefore, not studied further at this level.

The key variable in the highway transport model is vehicle miles of travel. Relations between vehicle miles of travel and highway accident deaths by highway class, were determined on the basis of cross-sectional analyses, using the states as sample points. The only other factor which could be incorporated was passenger car changes, in terms of average car size and safety improvements. The influence of a changing passenger car, truck, and bus mix could not be quantified with available data. Neither could the effect of travel speed be quantified.

The air transport model separates scheduled air transport and general aviation. For scheduled air transport, a model was developed with aircraft miles and the number of operations as variables. For general aviation the number of aircraft miles was considered.

For rail transport, a simple model using total rail train miles as independent variables was developed.

These models were used to project accident deaths for these three modes up to 1990, on the basis of traffic projections provided by the Transportation Systems Center.

The first level models developed were reviewed for simplifications, missing factors and limited scope, and an outline for developing a second level model given. The first level model can be improved under two aspects: 1) the accuracy and realism of relations used can be improved, and 2) its scope can be expanded to use transportation and not traffic data as inputs.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

Section | Page

LIST OF ILLUSTRATIONS

Figure No.

LIST OF ILLUSTRATIONS (CONT"D)

LIST OF ILLUSTRATIONS (CONT'D)

LIST OF TABLES

LIST OF TABLES (CONT'D)

1. INTRODUCTION

In 1973, 62,000 people died in transportation accidents:*

- 56,000 in highway accidents of which
  - 34,000 in automobiles
  - 6,000 in trucks
  - 3,000 on motorcycles
  - 170 in buses (including school buses)
  - 10,000 as pedestrians
- 2,000 in rail accidents, of which
  - 6 as passengers on trains
  - 170 as employees on duty
  - 600 as trespassers
  - 1200 in other roles, nearly all of them at railroad grade crossings**
- 1,500 in air accidents, of which
  - 140 on commercial airlines
  - 1,400 in general aviation
- 2,700 in water transport accidents, of which
  - 1,800 in pleasure boating accidents
  - 400 on passenger or cargo vessels, and
  - 200 on fishing vessels

The total numbers of deaths by mode show fairly smooth trends over time. Categories with small numbers, however, show great fluctuations from year to year. The number of deaths per year in scheduled domestic air transport accidents fluctuated between 0 and 258 during the years 1965 through 1974. During the same period, the annual number of railroad passenger deaths fluctuated between 6 and 48.

Deaths are the most reliably counted consequence of accidents. Numbers of injured persons can be estimated only with much less accuracy, partially because of different reporting requirements, partially because of the lack of a precise definition of what constitutes an injury for those of low severity. Even worse is the situation with the number of accidents. In rail, air, and certain water transport activities, precise definitions exist as to what constitutes a reportable accident, and for each mode one agency is charged with investigating these accidents. In highway

---

*These figures are compiled from References [1] and [2] ; 1973 is the last year for which reference 1 was available.

**This represents a double counting, because most of them are also counted as highway deaths.

transport, however, definitions of reportable accidents vary from state to state, actual reporting practices vary even within a state, and many agencies are responsible for investigating accidents and collecting accident information. Therefore, of the number of highway transport accidents, only the order of magnitude is known.

Many factors influence the expected number of accidents. Obviously, one expects that the volume of transport activities, as measured by the number of vehicle miles of travel, plane miles, train miles, etc. influences the number of accidents. Assuming a given volume of transport, one expects that improvements in the conveyances (such as those required by the Federal Motor Vehicle Safety Standards), whether cars, aircraft or others, will reduce the number of accidents, and that improved highways or air traffic control will do the same. On the other hand, one can expect that an increase in occupancy, e.g., due to the use of larger aircraft, or to carpooling, or an increased use of buses, will, for the same number of vehicle miles, result in a larger number of expected deaths.

In this study we attempt to develop a structure which will incorporate the various factors. We will develop, on the basis of known relations, and on the basis of analyses of historical data, a first level quantitative model. This first level model will allow, for given projections of transportation activity levels and of other critical parameters, the estimation of future transportation death rates by mode. We will also develop a plan for a second level model. This model will be more detailed and realistic. In addition to giving better estimates of future death trends, this model should be useful for exploring the potential consequences of alternative policy decisions.

The priorities and emphasis of this study are suggested by the figures given above: highway transport clearly deserves the highest priority. General aviation is second, rail and water transport third. On a purely numerical basis, commercial air transport would rank very low. However, we expect that actual interest in this mode might be greater than for rail or water transport, because of the large number of persons using commercial air transport.

2. OBJECTIVE AND SCOPE

2.1 OBJECTIVE

The objective of this study is to develop a methodology to assess the safety implications of projected future movements of passengers and freight. This objective was to be achieved in two steps:

1. To develop a first-level model which uses existing data and relationships, but which will not allow for major structural shifts in the relationship between vehicular and demographic patterns, nor for new modes of transport.
2. To outline a second-level model which will be improved to be more realistic and/or reliable and which will allow the incorporation of new modes of transport.

2.2 SCOPE OF WORK

Originally, the study was to be restricted to intercity transport. However, it soon became clear that "intercity" is not uniformly defined. Data on "intercity" transport can differ widely between different sources [7, 8, 9, 10, 11, 12, 13]. Also, there are strong interactions between intercity and local travel and transport on highways. Therefore, the limitation to intercity travel was abandoned, and all travel and transport within the United States was included, excepting streetcars and subways.

Though the methods developed are applicable to accidents of all degrees of severity, the study itself had to be restricted to accidental deaths. The main reason is that for highway transport, numbers of deaths are the only measures of accidents which are nationally valid. Also, deaths are the most serious consequences of accidents.

The study was limited to accidents occurring in the process of transportation and travel. Accidents indirectly related to transportation, such as in road construction, rail track construction, mining for materials used in vehicle manufacturing, producing fuels, etc. are not included, though they are a causal consequence of transportation activities.

The following modes were considered:

- Highway traffic
- Air traffic
- Rail traffic
- Water transport.

Transportation by pipelines was not considered in the first level model.

In water transport pleasure boating accidents were excluded, because they are clearly not related to a transportation function in the strict meaning of the word. Unfortunately, the same distinction could not be made for other modes. Some highway travel consists of joyrides, where the travel is its final objective and not the transport of persons from one place to another. Similarly, a considerable part of general aviation activities is for pleasure and not for transport. In the case of general aviation, a separation by purpose might be possible, but in the case of highway travel this is practically impossible, at least on a national basis.

3. THE CONCEPTUAL APPROACH

3.1 THE OVERALL STRUCTURE

3.1.1 The General Structure

Transportation accidents--and their consequences: deaths, personal injuries, and property damage--result ultimately from the demand for the transportation of persons and goods. In Figure 3.1-1 the causal chain is broken into its main elements: the demand for transportation is expressed by the number of people who want to go from one place to a certain other, or the quantity of a good to be shipped from one place to another. To satisfy this demand, a mode of transport--usually highway, air, rail or water--and a route are selected. The choice of the route is often left to the carrier, or sometimes results from the choice of a mode. Within each mode, usually a choice between conveyances of different types is possible--sometimes only for the carrier: between buses, large cars, small cars, different types of aircraft, etc. Choice of conveyance together with the load factor determine the number of conveyances moving on a "link"--each route being composed of "links" (of varying lengths) which are entered and left by the same number of conveyances. The traffic on a link and the characteristics of the conveyances moving on a link, including those of their operators, together with others, such as weather, which are stable in the long run, determine the frequency and kinds of accidents and their consequences: deaths, personal injuries, and property damage.

There are certain feedback processes: the choice--or availability--of conveyances and the characteristics of links influence the cost and time of satisfying a transport demand; the traffic on a link, resulting in congestion may do the same; and even the occurrences and cost of accidents may do so. Cost and time, in turn, influence the choice of mode and routes, and ultimately the demand for transportation. Another feedback loop is created by the demand to increase the capacity of a link if it becomes frequently congested by a high level of use.

In addition to the accidents occurring within each mode, interactions between modes are possible. The most obvious interactions occur at railroad grade crossings where both the volumes of rail and of highway traffic influence the occurrence of accidents. Interactions between other modes are conceivable, but are extremely rare, e.g., a vessel knocking down a bridge support.

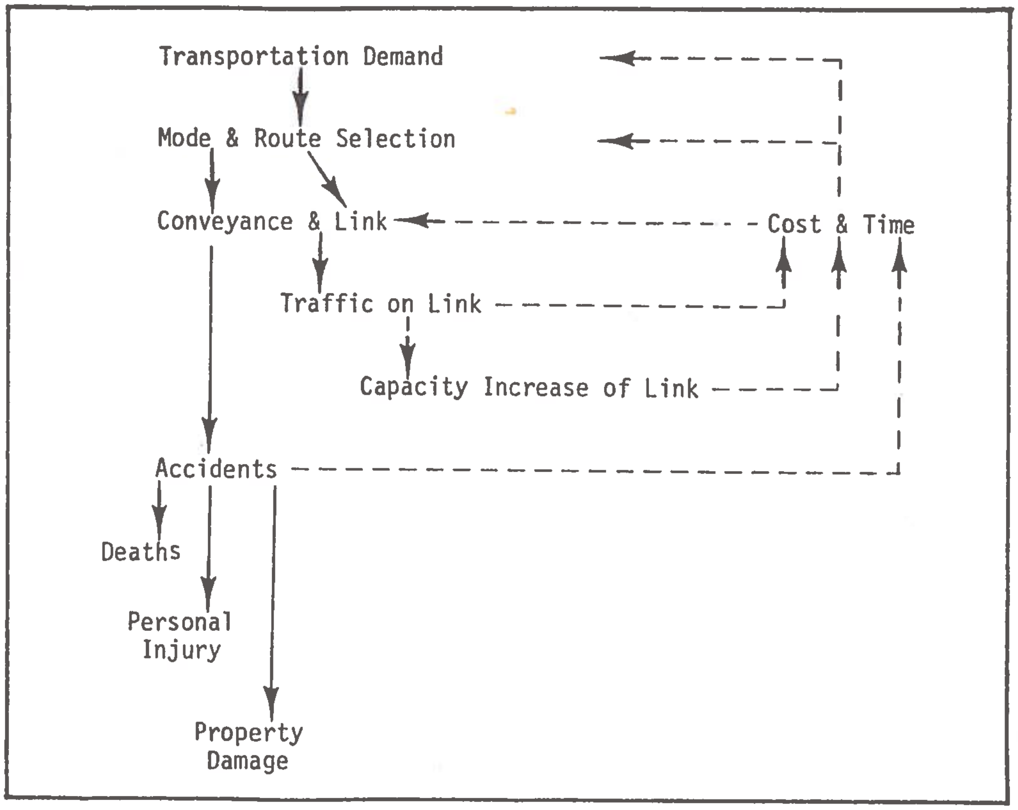


Figure 3.1-1. Outline of a structure relating transportation demand to accidents. Direct relations are indicated by solid arrows, feedback relations by broken arrows.

Besides interactions, there are also complementarities between modes. In most transport other than highway transport, highway transport is used for access to the other mode. This can noticeably change the door-to-door risk of travel by a certain mode.*

---

*Access is not a negligible risk associated with air travel. The average length of an air trip is 1000 miles, the death risk per passenger mile is 0.12×10^{-8}. Thus, the risk per average passenger air trip is 0.12×10^{-5}. If access at both ends amounts to 15 miles by car on Interstate and/or primary Federal Highways, for which the fatality rate is 5×10^{-8}, the total risk during access is 0.075×10^{-5}, about half the risk of the air travel itself.

With the exception of transport by pipeline or electric transmission lines, transport requires the movement of conveyances on links, be they physically constructed, such as highways or rail lines, or only defined by regulations, as in air transport. In water transport both possibilities exist.

In the narrowest meaning of the word, a transportation accident is one occurring as the result of moving a conveyance. There are, however, certain activities necessary for and closely related to the transport activity, such as loading and unloading, entering and leaving conveyances, and maintaining and repairing them. One step removed, there are accidents resulting in the construction,maintenance and repair of highways, tracks, bridges, airports, ports and canals. Ultimately,there are the accidents in manufacturing and distributing conveyances and their parts, fuels, and even in mining the basic minerals.

A comprehensive model would express all transportation-related accidents as functions of the transportation demand, incorporating economic submodels which describe how the demand will be satisfied. The expected number of accidents of varying severity would be described by empirical and physical models based on the movements of conveyances resulting from the economic models. It would also contain models describing the other activities necessary to support the transportation activities and the resulting accidents.

To develop such comprehensive models, however, would require extremely large efforts, and the results would probably not be very reliable, given the current state-of-the-art.

3.1.2 A Specific Structure

To have a framework for approaching the given problem, we express the structure described in the preceding paragraph in more specific terms. This way of specifying the structure is by no means the only one; however, it appears most natural against our background knowledge of the problem area.

The geographical structure is described by:

- Origin and destination points;
- Nodes;
- Links; and
- Modes.

Origin and destination "points" may represent an entire state, or an aggregation of several states, a Standard Metropolitan Statistical Area, or any other geographical area. The origin and destination points may be connected with each other, or with "nodes," by "links." "Links" are specific for each mode. A "link" may be a scheduled non-stop air connection, or it may be a highway of a certain type. There may be several links of the same type between any two origin or destination points, or nodes. Links can be "linked" into a route, leading from an origin to a destination.

The demand structure is described in terms of;

- Kind of demand,
- Quantity of demand,
- Origin and destination.

Kinds of demand are passenger and freight transport, which might be classified into finer categories, e.g., business travel, private business, and vacation or recreational travel. Freight might be classified in various ways, e.g., by the speed desired, or the acceptability of a slower mode, by the type of shipment, from small parcels to bulk shipments, which may be carried by the trainload or a barge, or by the type of good, defined possibly as precisely as by the 6-digit product code. The quantity of demand for passenger travel may be expressed by person trips, or passenger miles, but for some purposes perhaps better as "family miles." For freight, tons shipped or ton miles are natural measures. The definition of origins and destinations depends on the desired or feasible level of detail. The larger the regions are, which are represented by an origin or destination point, the more important the problem of intra-regional transport becomes. In this case, one has to use the same origin and destination, and assign it to a "dummy" link for each mode, which represents the typical intra-regional trip or shipment. In the extreme case, one can consider the entire U.S. one origin and destination point, then all trips and shipments are considered intra-regional.

To satisfy a given demand for transportation, modes and routes have to be assigned. Routes consist of a chain of links leading from origins to destinations. On routes and links

- Conveyances

are moving. Conveyances are described by the applicable mode, by their capacity, and other physical characteristics as desired. Together with a

- Load factor,

which may be an empirical description of past experience, or a deliberately set target for the future, the number of conveyances moving on a route is determined. The movement of conveyances over all routes determines the number of conveyances moving on each link.

The number of conveyances, by type, moving on a link is an idealized description of the physical transportation process. Together with the length of the link it gives Vehicle Miles of Travel (or aircraft miles, train miles, etc.) for each type of conveyance.

Given the number of vehicle miles of travel (or similar measures), by type of link and type of conveyance, empirical or *a priori* models are used to predict the expected number of accidents, deaths, persons injured, and resulting property damage.

Refinements of this structure can incorporate interactions, such as railroad grade crossing accidents as a function of highway and rail traffic on certain links, or indicate which intra-regional highway travel and corresponding accidents result from access to inter-regional air and rail travel.

To implement this specific structure is far beyond the scope of the first level model to be developed in this study, and even beyond the scope of the second level to be outlined; it is only intended to serve as an overall frame of reference.

3.2 STRUCTURE OF THE FIRST LEVEL MODEL

The first level model will assume the movements of conveyances as given; it will not deal with the economic processes leading from a given transportation demand to the physical movement of conveyances. It will deal separately with:

- Highway transport;
- Rail transport;
- Air transport; and
- Water

For air, rail and water transport, no geographical disaggregation will be considered. In highway transport, we consider the possibility of geographical disaggregation. However, due to the structure of the data, we could not disaggregate highway travel into "links," but only into travel by state. However, different highway types could be distinguished

For highway transport, cars, trucks and buses will be distinguished; in air transport,certificated carriers will be distinguished from general aviation.

As a measure of accidents, it will use only the number of deaths resulting from accidents.

The first level model aimed at will be a set of equations relating for each mode, the number of deaths to the number of conveyance miles. To some extent, the structure of these equations will be based on empirical knowledge or *a priori* arguments; to some extent it may be purely descriptive of the past trend in accidental deaths in relation to transport volume.

3.3 EXISTING MODEL OF TRANSPORTATION ACCIDENTS

One model is implicit in most discussions of transportation safety, especially in comparisons between different modes: proportionality of accidents, or deaths, to a measure of transport volume. It is this assumption which is implicitly made when comparing death rates per passenger mile or per vehicle mile, accident rates per vehicle mile, etc. This model is plausible if each mile of a trip carries the same risk.

This, however, is generally not the case. In air travel, most accidents occur during take-offs and landings; therefore, the expected number of accidents will not increase proportional to the length of a trip. Increasing the vehicle miles of travel on a highway increases the congestion and, thereby, changes the probability and type of accidents in a complicated manner.

These effects have been recognized in the literature; for air travel by Fromm [4], and for highway travel by several authors (a survey of earlier studies has been made by Slatterly and Cleveland [3], Joksch [6 , 14] analyzed published data further).

Simple empirical models relating the number of transportation deaths by mode to measures of transportation activity have been developed by Joksch and Wuerdemann [15] for passenger automobile travel, bus travel,truck travel, rail transport and air transport. They are,however, purely descriptive models based on a short time period. A more thorough analysis of the motor vehicle accident death trend was performed by Joksch [6]. Though the influence of several important factors could be quantified, the main component of the trend had to be described by empirical equations. A more ambitious attempt to explain the motor vehicle death trend as a function of several "determinants of accidents" has been made by Peltzman [16, 17]. This model, however, has been reviewed and criticized by Joksch [18,19] and Robertson [20]. We have concluded that it is without any validity.

A search of the literature on transportation accidents failed to find any more studies of overall relations between levels of transportation activities and related accidental deaths. Many studies, however, provide information used in the development of the first level model or useful for the development of a second level model.

4. THE FIRST LEVEL MODEL

4.1 SCOPE OF THE FIRST LEVEL MODEL

The most important limitation of the scope of the first level model is that it does not use the "product" of transportation activities as inputs, but only measures of movements of conveyances. Specifically, it does not use ton-miles of freight transported, passenger miles of travel or similar measures which express the demand for transportation activities, but uses measures such as vehicle miles of travel, train miles, aircraft miles, and the number of operations of aircraft. The reason for this limitation is that accidents have a more direct relation to these measures of activity than to the measures of transportation "output." Under the current state-of-the-art, even these relatively direct relations can be established only with very limited reliability.

4.2 HIGHWAY TRANSPORT

4.2.1 The Overall Structure

The commonly used measure of highway use is vehicle miles of travel (VMT). As an overall measure, no distinction is made between miles traveled by different types of vehicles and on different types of highway. Such disaggregated information is available in the annually published *Highway Statistics* [21]. Personal passenger vehicles (generally including motorcycles, which account for about 2% of the travel), commercial buses and school buses, single-unit trucks and truck combinations are distinguished. In addition, travel on main rural roads, local roads, and urban streets is distinguished. More detailed information on travel is given in the annually (since 1967) published *Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems* [22]. Here, VMT are given by state and highway type, distinguishing 15 different highway types (including the distinction urban/rural). However, vehicle types are not distinguished.

The only meaningful nationally representative measure of traffic accidents is the number of persons killed in traffic accidents. The number of injured persons (even if only serious injuries are considered) is of questionable relevance, because the reporting and classifying of injuries vary widely between states. Even less certain are estimates of total accident numbers, because definitions and reporting practices differ even more widely between the states [14]; for analytical purposes, total accident figures are generally useless.

There are many different kinds of motor vehicle accidents: accidents involving a single vehicle, collisions between two motor vehicles, those involving more than two motor vehicles, collisions between a motor vehicle and a railroad train, collisions between a motor vehicle and a pedestrian, and several other infrequent types of accidents. Many states publish annual summaries of the numbers of accidents, injury accidents, fatal accidents, and persons killed by type of accident. National estimates are compiled by the National Safety Council. Such summaries, however, are quite aggregated, and they do not indicate the involvements of the various kinds of vehicles in the different types of accidents; nor do they differentiate by the type of highway. The tables in *Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems* give fatal accidents and deaths by state and highway system, but they show no differentiation by vehicle type or accident type.

One can expect that the number of accidents increases with the number of VMT, though this increase does not necessarily have to be proportional, as is often implicitly assumed. The severity of accidents--measured by the risk of death once a crash has happened--increases very strongly with speed; also the frequency of accidents appears to depend, in a more complicated way, upon speed. The economic situation, as expressed, e.g., by the Federal Reserve Board Index of Industrial Production, influences the number of fatal accidents in a highly obvious, but not yet understood way. One can expect that the size of the population, and perhaps its age distribution, has some influence on the number of pedestrian deaths, and that the number of train miles has some influence on the number of railroad grade crossing deaths.

Currently, the influence of none of these factors is sufficiently understood to incorporate it into a model which can be used with confidence for predictions. Therefore, we concentrate upon developing a model which uses only the most obvious--and within our context, most important--factor: vehicle miles of travel.

Our previous work [6, 14] has shown that the relations between vehicle miles of travel and fatal accidents or fatalities varies widely between different highway types. Therefore, we studied such relations for five highway types into which the 15 highway types mentioned above were aggregated on the basis of similar accident rates.* We did this by treating each state as a "sample point," having a certain density of VMT per highway mile, which is the key variable in the model we use. Having established such a relation, we used it to estimate the number of deaths by highway system and state using projections of vehicle miles of travel by highway system and by state.

In addition, we studied two factors which could change as a result of changes in transportation patterns; the vehicle mix, and the occupancy. For the first, we could develop a conceptual model which considers changes in the frequency of interactions of different vehicles, e.g., passenger cars and trucks. The numerical coefficients we found, however, are too uncertain to currently allow a meaningful application. Regarding

---

*The 5 groups used in our analyses were aggregated from those used in [22] as follows:
Rural Interstate: Interstate-Final, Rural
Urban Interstate: Interstate-Final, Urban
Main Rural Roads: Interstate, Traveled Way, Rural
Other Federal-Aid, Primary, Rural
Other Rural Roads: Federal-Aid Secondary, State, Rural
Federal-Aid Secondary, Local, Rural
Other State, Rural
Local Roads and Streets, Rural
Urban Highways and Streets: Interstate, Traveled Way, Urban
Other Federal-Aid, Primary, Urban
Federal-Aid, Secondary, State, Urban
Federal-Aid, Secondary, Local, Urban
Federal-Aid, Urban
Other State, Urban
Local Roads and Streets, Urban

the influence of occupancy on fatalities and fatal accidents, however, a considerable conceptual question remains.[*]

Thus, the model we are developing has the following structure:

Basic relation:
$$\frac{\text{deaths}}{\text{highway mile}} = f_{\substack{\text{highway}\\ \text{system}}}\left[\frac{\text{VMT}}{\text{HM}}\right] \tag{4.2-1}$$

Overall model:
$$\text{Total deaths} = \sum_{\substack{\text{highway}\\ \text{system}}} \sum_{\text{states}} f_{\substack{\text{highway}\\ \text{system}}}\left[\frac{\text{VMT}}{\text{HM}}\,\middle|\,\text{state}\right] \text{HM}_{\substack{\text{State,}\\ \text{highway}\\ \text{system}}} \tag{4.2-2}$$

4.2.2 Effects of Vehicle Miles of Travel

4.2.2.1 Relation Between Traffic Deaths and Traffic Density

To illustrate our approach to establishing a relation between vehicle miles of travel and traffic deaths, let us consider several stretches of road, of different lengths. If the stretches are homogeneous in terms of other physical characteristics and traffic, then the number of traffic accidents on each of them can plausibly be expected to be proportional to its length. Also, the number of vehicle miles of travel will, *ceteris paribus* be proportional to this length. On the other hand, traffic density will change if the number of vehicle miles of travel per highway mile increases, and accident frequency, the type of accident, and the number of traffic deaths may change in a non-proportional manner. If a highway system were divided into homogeneous segments, and if we

---

[*] At first glance, "fatal accident" appears to be a more appropriate measure than "fatality," because it is directly related to the number of vehicles which crash, and not the number of persons killed. However, if the probability of an occupant's death in an accident is small, then the probability of an accident's being fatal is approximately proportional to the number of occupants. Thus, in a first approximation, one might use fatalities since their numbers are ultimately desired, though this is conceptually unsatisfactory. The ratio of fatalities to fatal accidents differs noticeably between different highway types, presumably because of differences in the relative frequencies of single- and multi-vehicle accidents, and differences in average vehicle occupancy.

knew the deaths and VMT on each segment, then we could use each segment as a "sample point" and determine an empirical relation between deaths per highway mile and vehicle miles per highway mile. Knowing such a relation, we can use it to predict the total number of deaths on a highway system, if we know the VMT on each segment.

We do not have such a breakdown of the highway system. However, we do have a breakdown by highway type, and by state, as described in Paragraph 4.2.1. All highways of a certain type in one state are far from being one homogeneous segment of highway. Also, the same type of highway may have considerably different physical characteristics in New England, if compared with states in the Middle West. Though highly imperfect, this is the best disaggregation of highways available.

In a previous study [14] CEM has illustrated how the number of highway fatalities do not vary with vehicle miles of travel in a strictly proportional manner. How a change in total VMT affects the number of fatalities depends critically upon which highway segment (in terms of highway type and traffic density) the change occurs. We have used VMT per highway mile (HM) as a measure of the average traffic density on a particular highway type in a given state. To eliminate the influence of the different sizes of states, deaths per highway mile were used instead of deaths per VMT. Rates per HM have the advantage of being standardized physical quantities, e.g., an average rural interstate highway mile will not generally differ from state to state, though for other highway types the differences are likely to be much greater.

We conducted exploratory studies with both fatal accidents per highway mile and fatalities per highway mile, but later used fatality numbers only. For each road type and each year a scatter diagram was constructed of 48 states (Alaska and Hawaii were excluded) with fatal accidents per highway mile (FA/HM) as the dependent variable and VMT per highway mile (VMT/HM) as the independent variable. Figures 4.2-1a through 4.2-1e show these diagrams for 1973. Also shown are least squares fitted lines, giving each state the same weight. In all cases there is a quite strong relationship between fatal accidents per highway mile and VMT per highway mile. With the exception of urban highways and streets, the relations are not a simple proportionality, but have a positive intercept. In the case of "other rural roads" there is a strong suggestion of non-linearity. Therefore, polynomial regressions

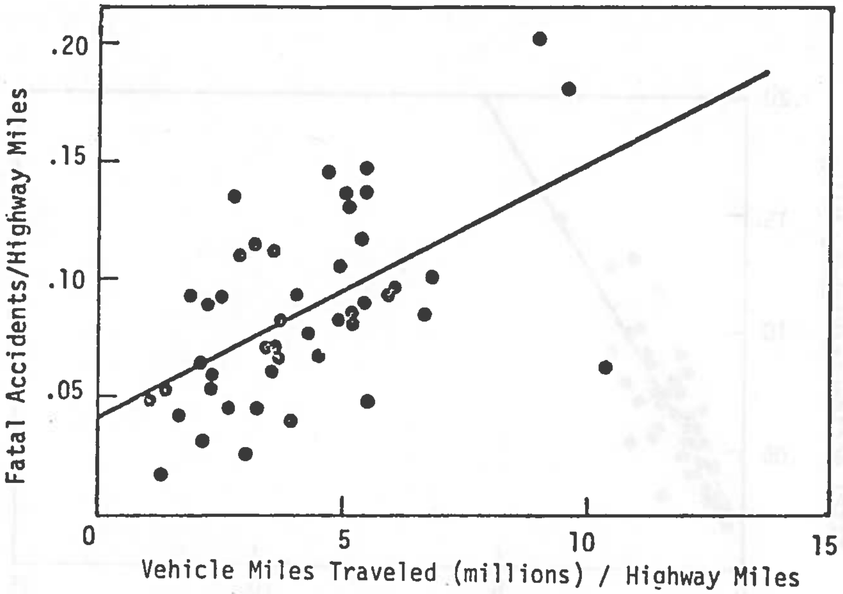


Figure 4.2-1a. Fatal accident density versus traffic density. Rural interstate highways, 1973. Each dot represents one state.

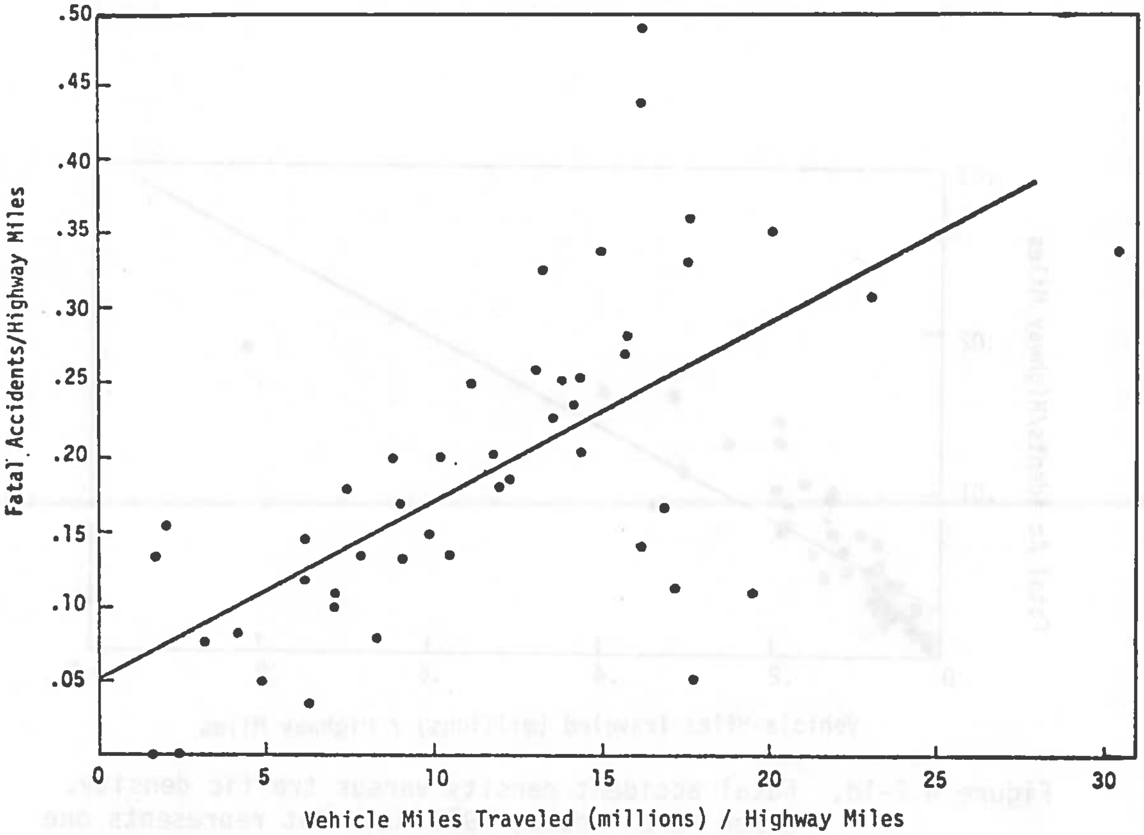


Figure 4.2-1b. Fatal accident density versus traffic density. Urban interstate highways, 1973. Each dot represents one state.

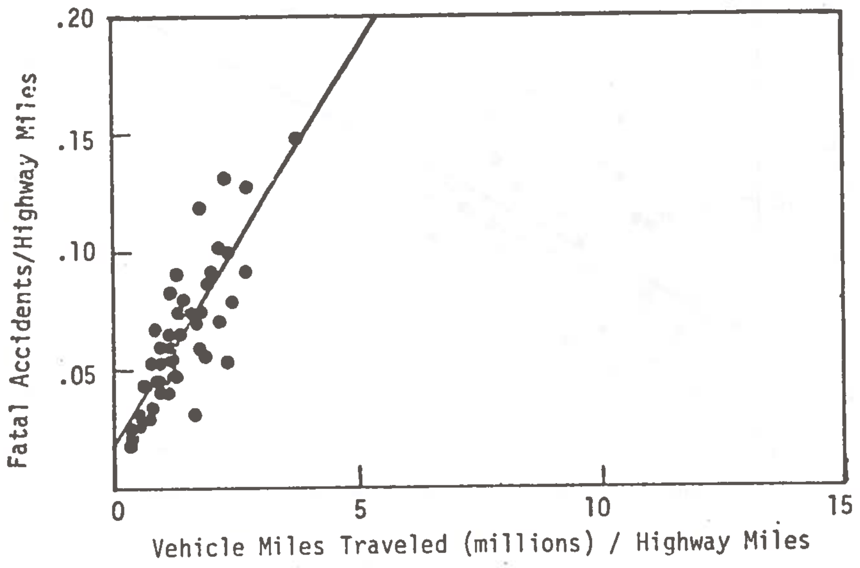


Figure 4.2-1c. Fatal accident density versus traffic density. Main rural roads, 1973. Each dot represents one state.

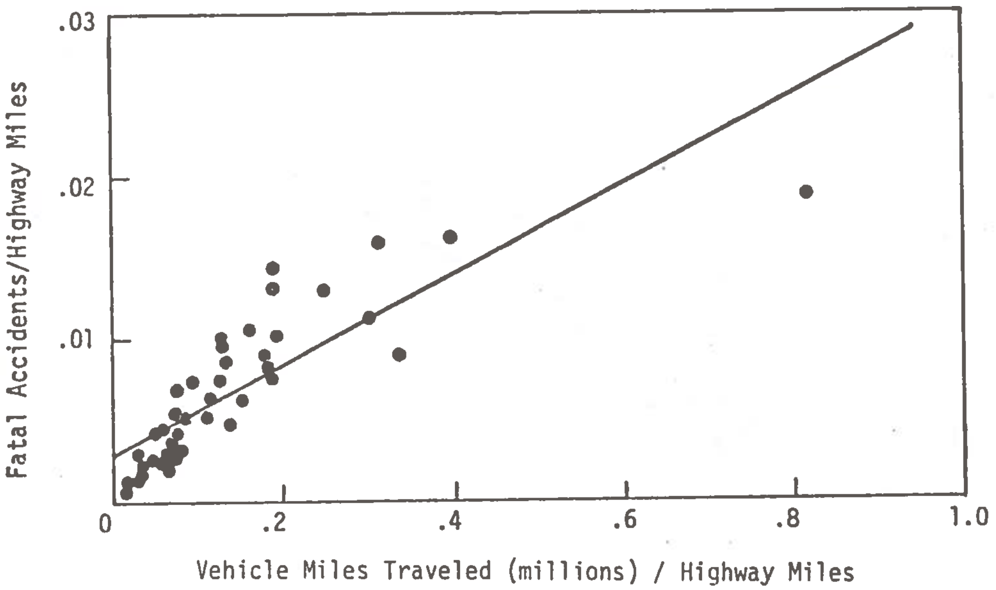


Figure 4.2-1d. Fatal accident density versus traffic density. Other rural roads, 1973. Each dot represents one state.

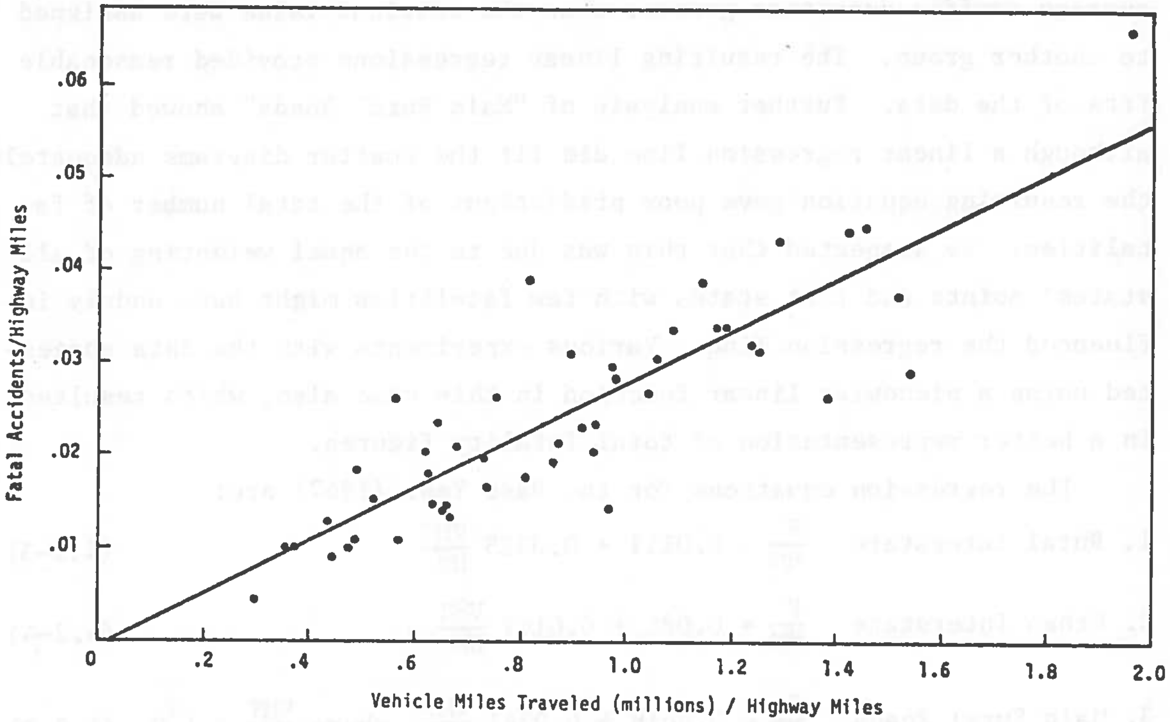


Figure 4.2-1e. Fatal accident density versus traffic density. Urban highways and streets, 1973. Each point represents one state.

were calculated up to the fourth degree. It was found that for three road classes (Rural Interstate, Urban Interstate, and Urban Highways and Streets) the linear fit was adequate and the higher order terms did not explain significant additional error. It is noteworthy that for Urban Interstate Highways the points scattered widely around the regression line, but in the aggregate, the fit was quite good.

For "Other Rural Roads" the polynomial regressions did yield a significant quadratic term. Further analysis showed that this term resulted from fitting the curve to a few extreme points. When extrapolated just beyond the range of the data points, the regression line curved downward and reached zero very soon. Using this regression equation for projections into the future when traffic densities will be higher would give very poor and even unacceptable results. Therefore, the quadratic term was dropped and a different approach was used. The scatter diagram suggested that a piecewise linear function might adequately fit the data. A critical value of traffic density was experimentally chosen and those states with average traffic densities less than or equal to the critical value were assigned to one group while those with average traffic densities greater than the critical value were assigned to another group. The resulting linear regressions provided reasonable fits of the data. Further analysis of "Main Rural Roads" showed that although a linear regression line did fit the scatter diagrams adequately the resulting equation gave poor predictions of the total number of fatalities. We suspected that this was due to the equal weighting of all states' points and that states with few fatalities might have unduly influenced the regression line. Various experiments with the data suggested using a piecewise linear function in this case also, which resulted in a better representation of total fatality figures.

The regression equations for the Base Year (1967) are:

1. Rural Interstate

$$\frac{F}{HM} = 0.0111 + 0.0325\,\frac{VMT}{HM} \qquad (4.2\text{-}3)$$

2. Urban Interstate

$$\frac{F}{HM} = 0.085 + 0.0167\,\frac{VMT}{HM} \qquad (4.2\text{-}4)$$

3. Main Rural Roads

$$\frac{F}{HM} = 0.0018 + 0.0741\,\frac{VMT}{HM}, \text{ where } \frac{VMT}{HM} \leq 1.0 \qquad (4.2\text{-}5)$$

$$\frac{F}{HM} = 0.0546 + 0.0399\,\frac{VMT}{HM}, \text{ where } \frac{VMT}{HM} > 1.0 \qquad (4.2\text{-}6)$$

4. Other Rural Roads

$$\frac{F}{HM} = 0.0 + 0.0806\,\frac{VMT}{HM}, \text{ where } \frac{VMT}{HM} \leq 0.15 \qquad (4.2\text{-}7)$$

$$\frac{F}{HM} = 0.0095 + 0.0181\,\frac{VMT}{HM}, \text{ where } \frac{VMT}{HM} > 0.15 \qquad (4.2\text{-}8)$$

5. Urban Highways & Streets

$$\frac{F}{HM} = 0.0004 + 0.0387\,\frac{VMT}{HM} \qquad (4.2\text{-}9)$$

where F is the number of fatalities, HM the number of highway miles, and VMT the vehicle miles of travel in millions.

We also studied briefly whether the scatter of the points could be explained by other factors. In general, for each road type, states with extreme values in one year tended to retain extreme values in succeeding years which belies a purely random fluctuation. Classifying states into those being above and those being below the regression line did not suggest any influence of obvious factors such as average travel speed, or geographical or socio-economic characteristics.

4.2.2.2 Time Trends

The coefficients of the relations derived in Subparagraph 4.2.2.1 showed, besides the year-to-year fluctuations to be expected, definite time trends.

As will be discussed in Paragraph 4.2.3, a change in vehicle mix, in vehicle characteristics, and in vehicle occupancy will result in a change in the number of deaths, even if the number of accidents remains the same. Therefore, before attempting to formally represent the time trend in the regression coefficients, which is due to various factors not currently quantifiable, we try to eliminate the change due to known factors. We have insufficient data about vehicle occupancy during the years 1967 through 1972, though some indication that there was little, if any change (see Subparagraph 4.2.3.3). Also the change in vehicle mix was small (see Subparagraph 4.2.3.2). There was, however, a noticeable reduction of the fatality risk in a crash for passenger car occupants from 1967 on (see Paragraph 5.1.1). Passenger car occupants account for approximately two-thirds of all deaths. The greatest part of the remainder are pedestrians, followed by truck occupants. Since the representation of passenger car occupants, pedestrians and truck occupants among the fatalities varies between highway systems; one would have to develop different overall risk factors for each highway system. However, the mix of victims for the various highway systems is not adequately known. Also, pedestrian and truck occupant deaths had a different trend than passenger car occupant deaths, from the 1950's on. It is not predictable how these trends will behave in the future. Therefore, we used the relative risk factor, as described in Paragraph 5.1.1 for all traffic deaths, fully realizing that this is only a very crude approximation. The justification is that we could project the relative risk factor affecting the largest group of fatalities with a relatively high degree of confidence.

Having adjusted the 1967 through 1973 values of the regression coefficient for the change in the risk factor, the regression coefficients for each road type were tested for linear time trends. Figures 4.2-2a through 4.2-2e show these trends. A is the intercept, B the coefficient of travel density (slope).

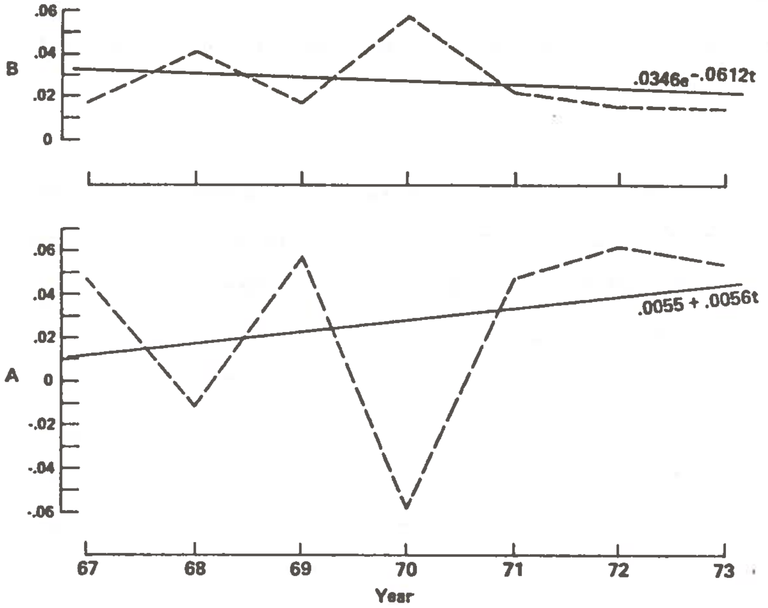


Figure 4.2-2a. Time trends of the regression coefficients for Rural Interstate Highways (broken lines) and representation by linear and negative exponential trends. t = 0 corresponds to 1966.

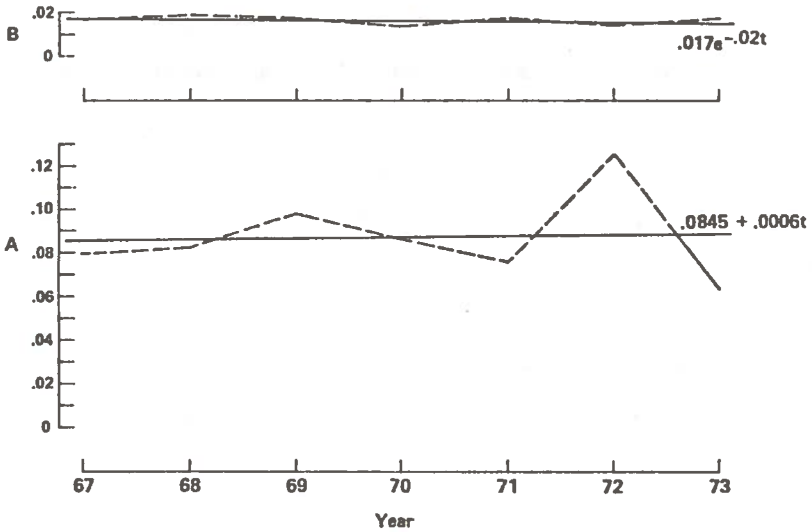


Figure 4.2-2b. Time trends of the regression coefficients for Urban Interstate Highways (broken lines) and representation by linear and negative exponential trends. t = 0 corresponds to 1966.

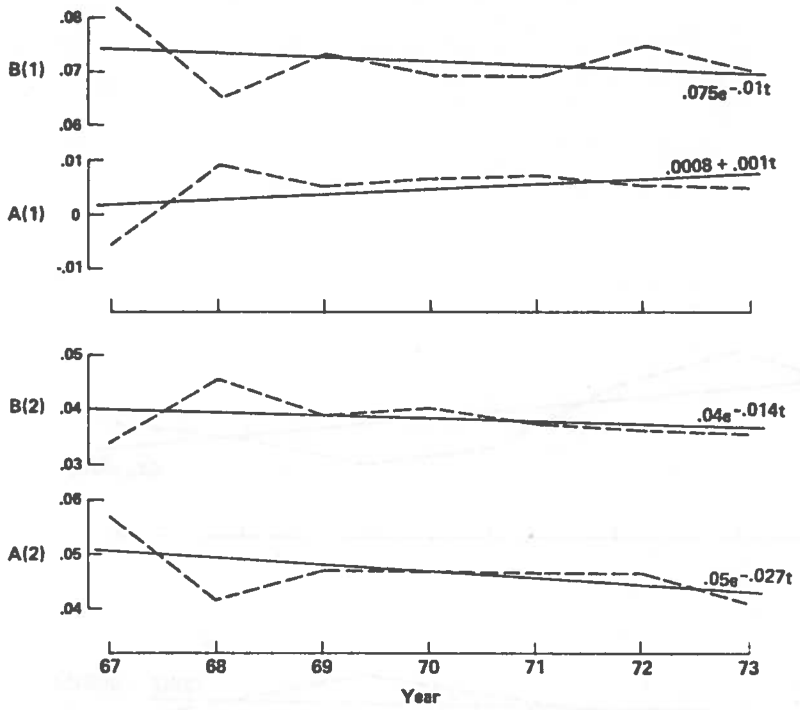


Figure 4.2-2c. Time trends of the regression coefficients for Main Rural Roads (broken lines) and representation by linear and negative exponential trends. t = 0 corresponds to 1966.

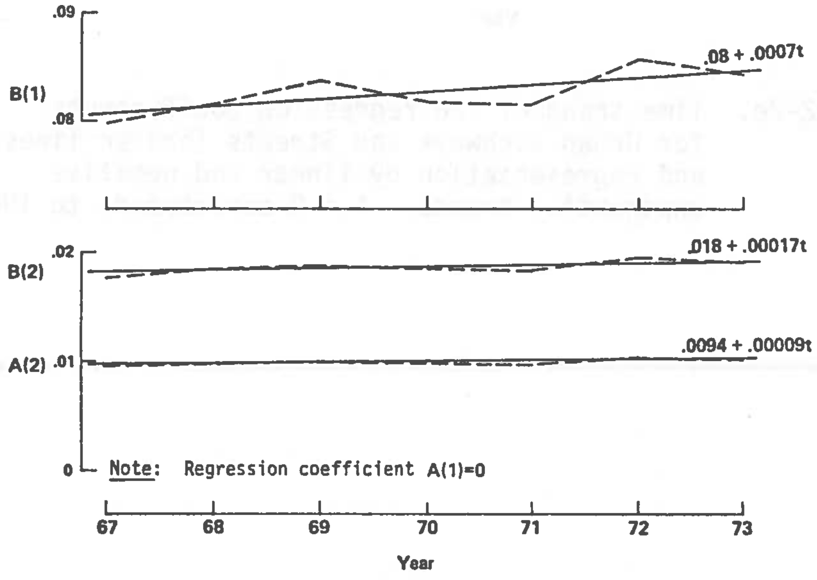


Figure 4.2-2d. Time trends of the regression coefficients for Other Rural Roads (broken lines) and representation by linear time trends. t = 0 corresponds to 1966.

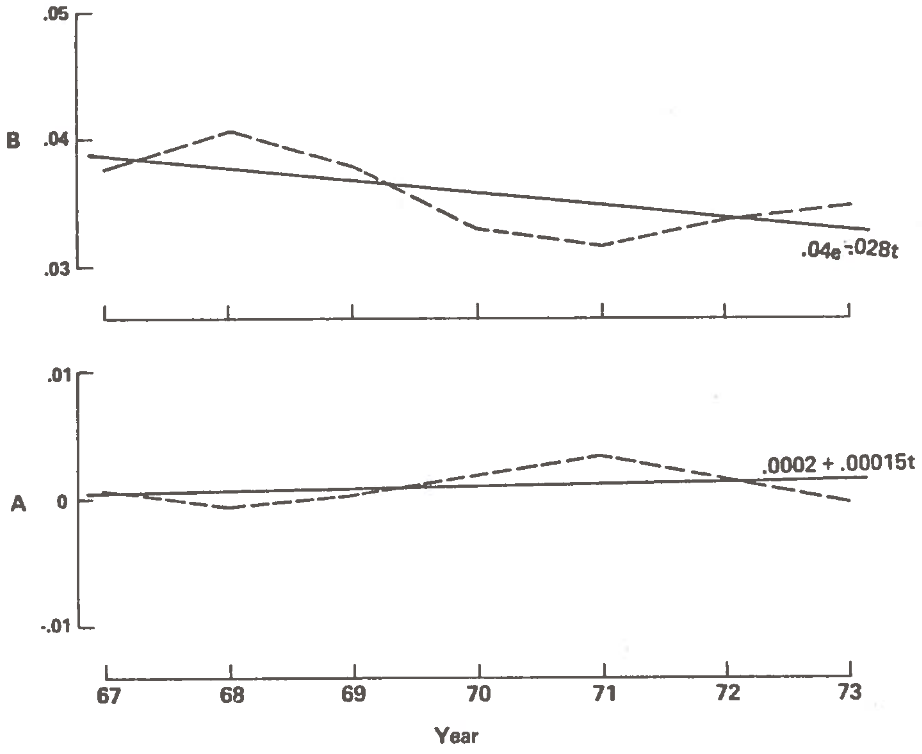


Figure 4.2-2e. Time trend of the regression coefficients for Urban Highways and Streets (broken lines) and representation by linear and negative exponential trends. t = 0 corresponds to 1966.

There exists significant variation in the time trend of the coefficients among the five road types. There also exists significant variation between the time trend of the slope and the time trend of the intercept for each road type. This suggests a fundamental difference in the effect of changing VMT on fatalities over time. Only two categories--"Rural Interstate" and "Urban Highways and Streets"--exhibited similar trends. This was a relatively small intercept increasing significantly over time coupled with a relatively large slope decreasing significantly over time. "Urban Interstate" had a large intercept increasing slightly and a small slope decreasing considerably. "Main Rural Roads" exhibited different time trends for each of its two equations. The first had a small intercept increasing significantly with a large slope decreasing slightly while the second had a large intercept and slope, both decreasing considerably. "Other Rural Roads" had no significant time trend.

All road types except "Other Rural Roads" had a significantly decreasing slope over time. Since the trends were to be extrapolated into the future, the possibility existed to project a negative regression coefficient from a certain year on,which might result in a forecast of fatalities decreasing with sufficiently high traffic density. To avoid this possibility, the negative linear trends were replaced by negative exponential trends, which for the years 1969 through 1973 were essentially indistinguishable from straight lines, as can be seen in Figure 4.2-2. They are, however, curved slightly upward so that their projections will always remain positive. Figure 4.2-3 shows how the actual fatality numbers for the years 1967 through 1973 were represented by the regression equations (4.2-3) through (4.2-9) together with the time trends of the regression coefficient shown in Figure 4.2-2. Two calculations were made: one using the current mileage of the applicable highway class for each year; the other using the highway mileage of 1970 for all years. With one exception--Main Rural Roads--the model represented the actual values satisfactorily. No reason could be found for the

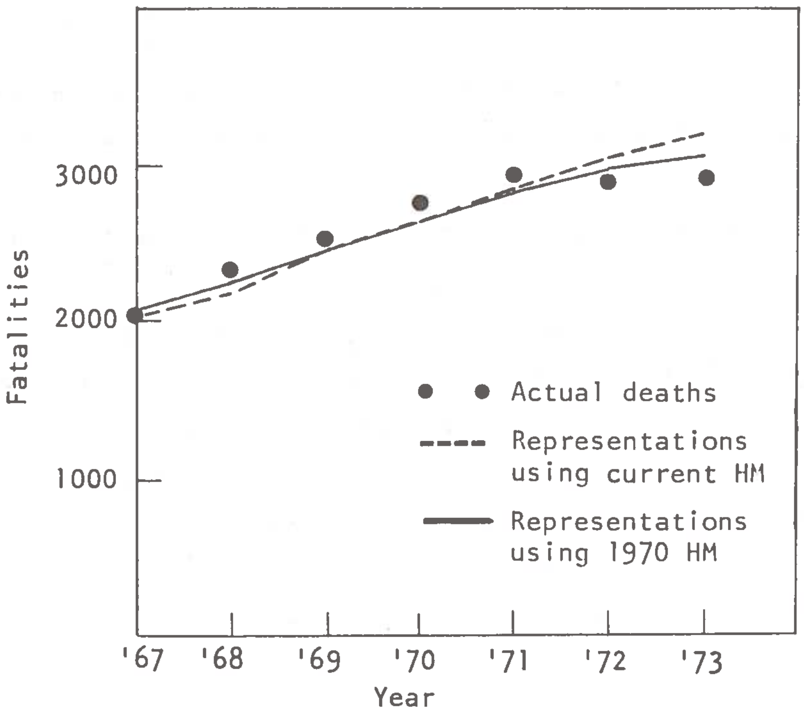


Figure 4.2-3a. Time trend of fatalities on Rural Interstate Highways as represented by equations 4.2-3 and 4.2-10,11. The dots give the actual values.

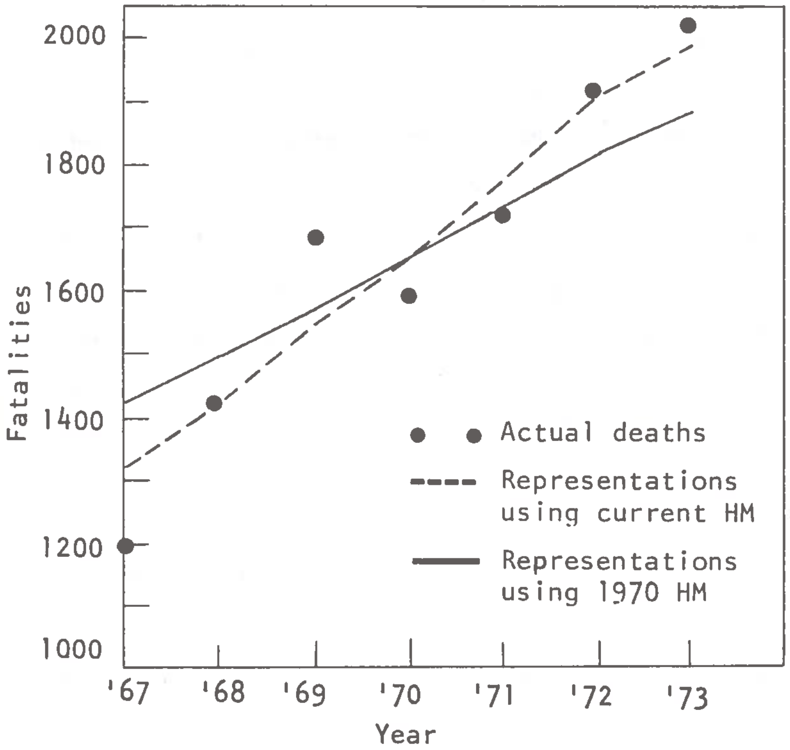


Figure 4.2-3b. Time trend of fatalities on Urban Interstate Highways as represented by equations 4.2-4 and 4.2-12,13. The dots give the actual values.

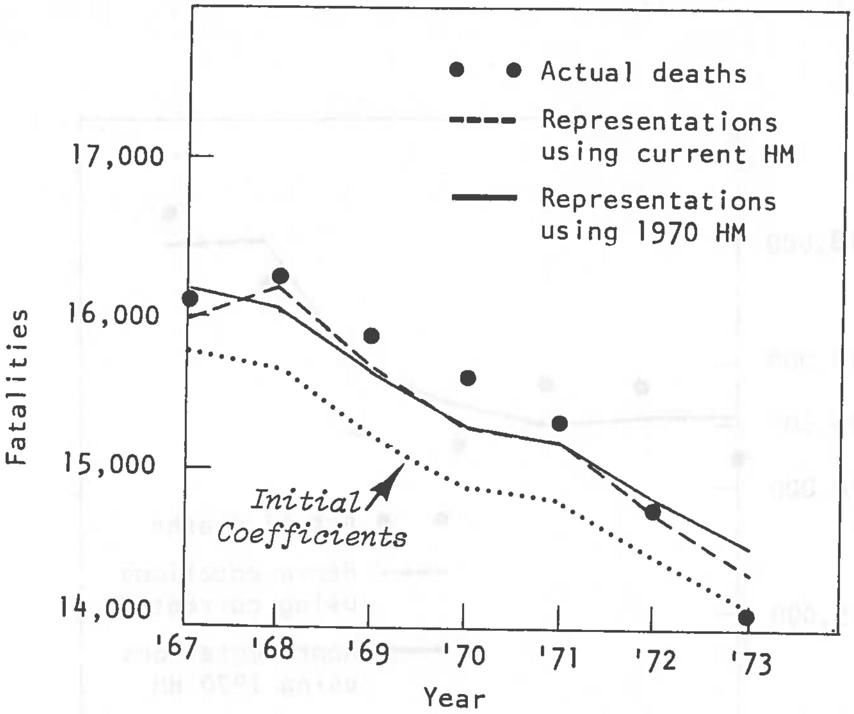


Figure 4.2-3c. Time trend of fatalities on Main Rural Roads as represented by equations 4.2-5,6 and 4.2-14,15. The dotted lines give the representation by the coefficients shown in Figure 4.2-2c. The dots give the actual values.

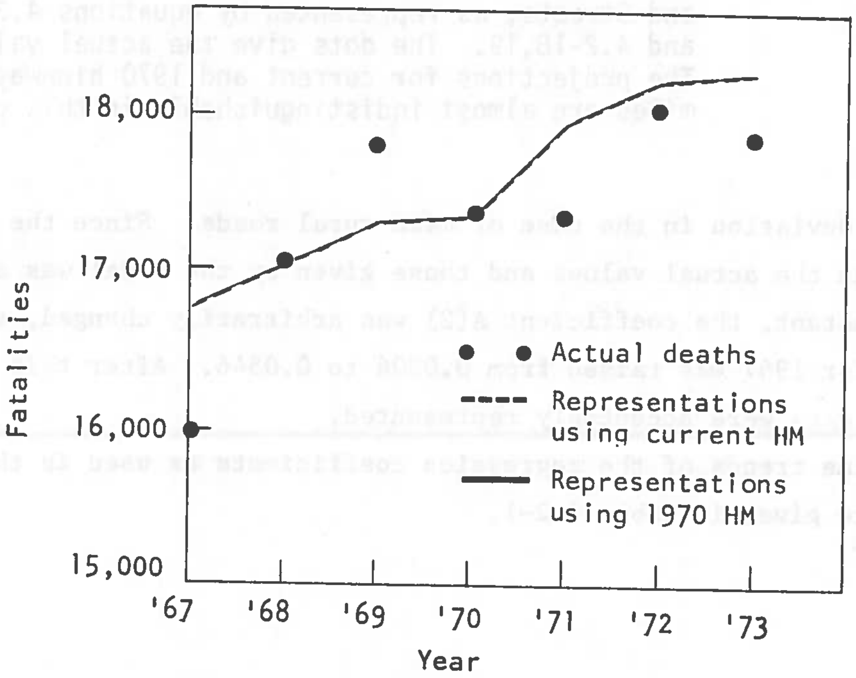


Figure 4.2-3d. Time trend of fatalities on Other Rural Roads as represented by equations 4.2-7,8 and 4.2-16,17. The dots give the actual values. The projections for current and 1970 highway miles are almost indistinguishable in this graph.

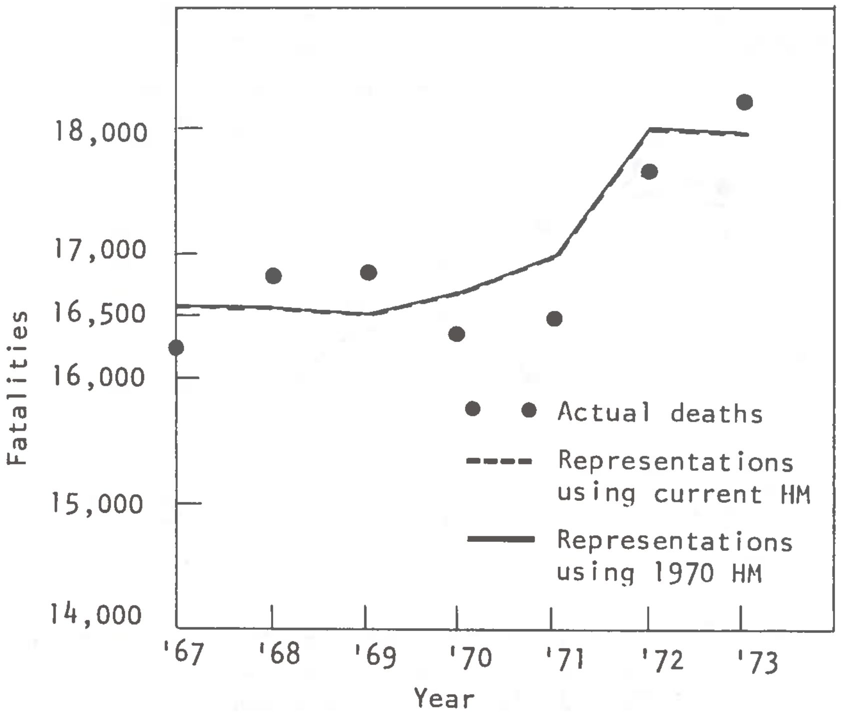


Figure 4.2-3e. Time trend of fatalities on Other Urban Highways and Streets, as represented by equations 4.2-9 and 4.2-18,19. The dots give the actual values. The projections for current and 1970 highway miles are almost indistinguishable in this graph.

systematic deviation in the case of main rural roads. Since the difference between the actual values and those given by the model was approximately constant, the coefficient A(2) was arbitrarily changed, so that its value for 1967 was raised from 0.0506 to 0.0546. After this change, the actual data were acceptably represented.

The time trends of the regression coefficients as used in the projections are given in Table 4.2-1.

TABLE 4.2-1. TIME FACTOR FOR THE REGRESSION COEFFICIENTS USED FOR PREDICTIONS (t = year-1966)

Rural Interstate

$$A(1) = 0.00551 + 0.0055t \tag{4.2-10}$$

$$B(1) = 0.0346\ e^{-0.061t} \tag{4.2-11}$$

Urban Interstate

$$A(1) = 0.0845 + 0.00061t \tag{4.2-12}$$

$$B(1) = 0.017\ e^{-0.02t} \tag{4.2-13}$$

Main Rural Roads

$$A(1) = 0.00077 + 0.00097t \tag{4.2-14a}$$

$$B(1) = 0.0748\ e^{-0.01t} \tag{4.2-15a}$$

$$A(2) = 0.056\ e^{-0.027t\,*} \tag{4.2-14b}$$

$$B(2) = 0.0404\ e^{-0.014t} \tag{4.2-15b}$$

Other Rural Roads

$$A(1) = 0 \tag{4.2-16a}$$

$$B(1) = 0.0800 + 0.00067t \tag{4.2-17a}$$

$$A(2) = 0.00944 + 0.00009t \tag{4.2-16b}$$

$$B(2) = 0.0179 + 0.00017t \tag{4.2-17b}$$

Urban Highways & Streets

$$A(1) = 0.0002 + 0.00015t \tag{4.2-18}$$

$$B(1) = 0.0398\ e^{-0.028t} \tag{4.2-19}$$

*The coefficient has been raised to 0.056, as discussed in the text.

4.2.3 Effects of Vehicle Characteristics and Mix

4.2.3.1 Accident Classification

The same number of vehicle miles of travel per highway mile may result in quite different numbers of deaths depending on the mix of vehicles generating these VMT. Different vehicle types may have different accident rates per mile of travel (though empirical evidence to support this hypothesis is insufficient) and they have different probabilities of death or injury, once an accident has happened. Also, a collision between two vehicles has quite different consequences in terms of death or injury, depending on the types of vehicles colliding. A review of our knowledge about this can be found in [6] and [14].

To study these effects we consider the structure shown in Figure 4.2-4. The left margin classifies the primary vehicle--the vehicle in which injuries and deaths are counted--(or pedestrian), the upper margin classifies the secondary vehicle, with which the primary vehicle was colliding (including "none" in the case of single-vehicle crashes). This scheme allows us to classify all motor vehicle accidents with the exception of rare ones, e.g., collisions with an animal, or collisions with a pedestrian where the driver was injured too.. In a collision between two vehicles, both vehicles appear once as primary and once as secondary vehicles, and in a collision involving several vehicles, each appears once as a primary vehicle.

This scheme can be expanded, e.g., passenger cars can be disaggregated into size classes, which have quite different experiences in accident severity. However, we found that the available data are insufficient to provide more than a guess of the distribution of deaths over this scheme.

Very little data are available in the form necessary to complete the matrix. Much of the data available do not distinguish the fatal vehicle in a multi-vehicle fatal accident. Other data provide only "drivers killed" as distinct from occupants killed. Some data were from limited samples. Definitions are not necessarily compatible. And often partial results derived from different data sources disagree widely. In addition to information from [2, 14, 23, 24, 25, 26, 27, 28, 29] we used

Secondary Vehicle Colliding with the Primary / Primary Vehicle (Where Injuries or Deaths are Counted)	Passenger Car 1	Single Unit Truck 2	Combination Truck 3	Bus 4	Other Motor Vehicle 5	Other Vehicle or More than Two Motor Vehicles 6	None (Single Vehicle Accidents) 7
Passenger Car 1							
Single Unit Truck 2							
Combination Truck 3							
Bus 4							
Other Motor Vehicle 5							
Pedestrian 0							

Figure 4.2-4. Structure for organizing vehicle interactions.

unpublished information from the University of North Carolina Highway Safety Research Center provided by L. S. Lohman and L. S. Robertson of the Insurance Institute for Highway Safety, unpublished data available at CEM, and various states' annual motor vehicle accident summary statistics. After extensive attempts to reconcile them in a formal manner, we had to give this up and arrive by trial, error, and conjecture at the "guesses" presented in Tables 4.2-2 and 4.2-3. They cannot be considered as more than illustrations of the order of magnitude of the various crash type frequencies.

To determine how a change in vehicle mix, in vehicle occupancy, and in vehicle crashworthiness affects total deaths, we developed the following conceptual model.

TABLE 4.2-2 CEM'S ESTIMATES OF DISTRIBUTION OF MOTOR VEHICLE DRIVERS KILLED BY ACCIDENT TYPE
(Percent)

Primary Vehicle (where fatality occurs)	Secondary Vehicle						
	1 Passenger Car	2 Single-unit Truck	3 Combination Truck	4 Bus	5 Other Motor Vehicle	6 Other	7 Single Vehicle
Passenger Car 1	23 (19-27)	4.6 (3.3-8)	4.2 (4-16)	0.65 (0-2)	0.75 (0-3)	2.2 (0-7)	37 (31-37)
Single-unit Truck 2	1.8 (1.6-1.8)	0.77 (0.01-0.84)	0.41 (0.4-2.5)	0.14 (0-0.4)	0.14 (0-0.5)	0.36 (0-0.8)	4.4 (3-5)
Combination Truck 3	1.1 (0.7-1.3)	0.34 (0.25-0.5)	1.1 (0.7-1.5)	0.10 (0-0.2)	0.14 (0-0.2)	0.20 (0-4)	2.7 (2.6-3.7)
Bus 4	0 (0-0.1)	0.007 (0-0.1)	0 (0-0.2)	0 (0-0.01)	0 (0-0.02)	0.007 (0-0.02)	0.007 (0.00-0.13)
Other Motor Vehicle 5	4.3 (4-6)	1.1 (1-1.5)	0.85 (0.8-1.2)	0.04 (0-0.2)	0.18 (0-0.2)	0.72 (0.1-0.8)	5.4 (5-6)

NOTE: The numbers in parentheses indicate the range within which the estimate may be, considering the discrepancies between the various data sources.

TABLE 4.2-3 CEM'S ESTIMATES OF DISTRIBUTION OF FATALITIES BY ACCIDENT TYPE
(Percent)

Primary Vehicle (where fatality occurs)	Secondary Vehicle						
	1 Passenger Car	2 Single-unit Truck	3 Combination Truck	4 Bus	5 Other Motor Vehicle	6 Other	7 Single Vehicle
Passenger Car	25.5 (19-27)	5.5 (2-8)	4.8 (4.6-16)	0.69 (0-2)	0.89 (0-3)	3.7 (0-7)	36.4 (31-43)
Single-unit Truck	2.0 (1-2)	0.87 (0.4-1.2)	0.54 (0.5-2.4)	0.067 (0-0.4)	0.16 (0-0.5)	0.37 (0-0.8)	4.1 (2.4-4.1)
Combination Truck	0.71 (0.4-0.9)	0.22 (0.2-0.4)	0.95 (0.9-1.3)	0.067 (0-0.2)	0.089 (0-0.2)	0.18 (0-0.4)	2.2 (2.0-2.5)
Bus	0.055 (0-0.1)	0.055 (0-0.1)	0.007 (0-0.02)	0.004 (0-0.01)	0.01 (0-0.02)	0.044 (0-0.09)	0.089 (0.05-0.13)
Other Motor Vehicle	3.3 (2.0-5.0)	1.3 (0.5-2.5)	0.67 (0.1-1.0)	0.02 (0-0.2)	0.12 (0-0.2)	0.55 (0.1-0.8)	4.0 (3.0-5.0)
	PEDESTRIANS KILLED (%)						
	Vehicle Involved						
	82 (75-90)	13 (8-17)	3.5 (1.0-5.0)	1.4 (0.1-2.0)	0.6 (0.2-0.8)		

Note: The numbers in parentheses indicate the range within which the estimate may be, considering the discrepancies between the various data sources.

Let A^{7}* be the measure of "exposure" of vehicles to single-vehicle accidents--measured, e.g., by the total number of high risk locations passed by vehicles, etc.-- and m_i the function of total VMT driven by vehicles of Class i. Then $A^7 m_i$ is the exposure for vehicles of Class i. Let a_i^7 be the risk per exposure unit for vehicle Class i to get into an accident, then $A^7 m_i a_i^7$ is the expected number of single-vehicle accidents. If there are on the average $\bar{n}_i$ occupants in vehicles of Class i, and the fatality risk for any occupant is p_i^7, then the expected number of deaths in single-vehicle crashes for vehicle Class i is:

$$D_i^7 = \bar{n}_i p_i^7 A^7 a_i^7 m_i \qquad i = 1, 2 \ldots\ldots 5 \qquad (4.2\text{-}20)$$

We do not know enough of the quantities entering this equation. However, if we knew the D_i^7, we could estimate how the change of certain factors would influence the number of single-vehicle deaths. If $\bar{n}_{io}$ would change to $\bar{n}_i$, p_{io}^7 to p_i^7, m_{io} to m_i, then D_{io}^7 would change to D_i^7 according to

$$\frac{D_i^7}{D_{io}^7} = \frac{\bar{n}_i}{\bar{n}_{io}} \; \frac{p_i^7}{p_{io}^7} \; \frac{m_i}{m_{io}} \qquad (4.2\text{-}21)$$

For the case of two-vehicle collisions (superscripts j = 1....5), we assume A to be the total number of "encounter" situations where two vehicles are so close that they may collide. We further assume that the mix of vehicles is random, so that the number of collisions between vehicles of Type i and j is $Am_i m_j$. If the probability of an accident, given an encounter, is a_i^j, the expected number of collisions is $Aa_i^j m_i m_j$. With $\bar{n}_i$ as above, and p_i^j the probability of an occupant's death (if in Vehicle i) if in collision with Vehicle j, the expected number of deaths in Vehicles i colliding with Vehicles j is

$$D_i^j = \bar{n}_i p_i^j A a_i^j m_i m_j \qquad \begin{matrix} i = 1, 2, \ldots 5 \\ j = 1, 2, \ldots 5 \end{matrix} \qquad (4.2\text{-}22)$$

---

*The superscripts refer to the columns in Figure 4.2-4; in this case the seventh, referring to deaths in single-vehicle accidents.

Again, we do not know enough of the factors to use this formula directly, but analogously to (4.2-21) we can use

$$\frac{D_i^j}{D_{io}^j} = \frac{\bar{n}_i}{\bar{n}_{io}} \frac{p_i^j}{p_{io}^j} \frac{m_i}{m_{io}} \frac{m_j}{m_{jo}} \tag{4.2-23}$$

Collisions between more than two vehicles are relatively rare, and the large number of possible vehicle type combinations would leave only very small numbers for each combination. Therefore, we will rather treat these analogously to single-vehicle crashes, defining

$$D_i^6 = \bar{n}_i p_i^6 A^6 a_i^6 m_i \qquad i = 1, 2.....5 \tag{4.2-24}$$

The total number of occupant deaths is

$$D = \sum_j \sum_i D_i^j + \sum_i D_i^6 + \sum_i D_i^7 \qquad \begin{array}{l} i = 1,2....5 \\ j = 1,2....7 \end{array} \tag{4.2-25}$$

For a change in the number of occupant deaths resulting from a change of $\bar{n}_{io}$ to $\bar{n}_i$, from m_{io} to m_i, and p_{io}^j to p_i^j, we obtain

$$\frac{D}{D_o} = \frac{\sum\limits_i \frac{\bar{n}_i}{\bar{n}_{io}} \frac{m_i}{m_{io}} \left\{ \sum\limits_{j=1}^{5} \frac{m_j}{m_{jo}} \frac{p_i^j}{p_{io}} D_{io}^j + \sum\limits_{j=6}^{7} \frac{p_i^j}{p_{io}^j} D_{io}^j \right\}}{\sum\limits_i \sum\limits_j D_{io}^j} \tag{4.2-26}$$

Due to the lack of credible values for the D_{io}^j, this conceptual model was not programmed for the first level model.

4.2.3.2 Changes in Vehicle Mix

The fraction of total VMT traveled by the different kinds of vehicles remained practically constant over the years 1960-1973 (Appendix B):

• Passenger cars	0.775
• Single unit trucks	0.17
• Combination trucks	0.035
• Buses	0.005
• Motorcycles	0.015

Therefore, it was not necessary to consider changes in vehicle mix in the analysis of the historic trend. Neither is it possible to use the past trend to judge how realistically the model can represent the effect of a changing vehicle mix.

To illustrate the potential effect of a future change in vehicle mix, we assumed a relative drop in the share of passenger car VMT to 0.7, an increase of single unit and combination trucks to 0.22 and 0.063, respectively, and a decrease in the shares of motorcycles to 0.014. Even this drastic increase in the trucks' share of VMT would only result in a 1.5% increase of the total number of deaths, using Formula (3.2-27) and the D^j_{io} from Table 4.2-3. However, using different D^j_{io}, still being in the range shown in Table 4.2-3 would result in a change of 6.6% due to the same change in VMT shares as above. Thus, we have to conclude that the basic data are not sufficiently known to allow a credible prediction of the effects of a change in vehicle mix.

4.2.3.3 Changes in Vehicle Occupancy

With the encouragement of carpooling, changes in vehicle occupancy may occur in the future, at least on certain types of highways. There are only a few scattered historical data on occupancy available. However, we have studied the number of deaths per fatal crash* in a previous study [6]. From 1953 through 1971, the ratios for single-vehicle and multiple-vehicle accidents showed no clear trend, although there was suggestion of a declining trend for multiple-vehicle accidents from 1965 on. The change, however, is so small that we did not adjust for it.

Again, this did not allow us to validate the occupancy aspect of the model. Therefore, though conceptually plausible, its use for prediction is speculative.

4.2.3.4 Vehicle Crashworthiness Improvements

The requirements of the Federal Motor Vehicle Safety Standards (FMVSS) have considerably reduced the fatality and injury risk in cars manufactured since 1967 [30, 31, 32]. To what extent they have reduced the frequency of accidents per exposure measure, is still an open question. A model which combines the effect of the FMVSS death and injury frequency reductions with those of a changing vehicle population--in

---

* As discussed in 6.2.1.3, the number of deaths per fatal accident is not a simple function of occupancy and the fatality risk;however, it is a first approximation.

terms of age and in terms of vehicle size--has been previously developed by CEM [6, 14]. The product of this model is a "relative risk" factor which expresses the risk of death (or injury) to a car occupant in a crash, averaged over the entire automobile population, relative to the corresponding risk of the automobile population in a base year. The purpose of introducing the relative risk factor is to separate "scale" effects due to increased exposure such as an increasing number of cars or an increasing number of VMT per car per year, or both, from effects of vehicle crashworthiness changes.

Figure 5.1-2 shows the relative risk factor for the period 1967 through 1990--projected into the future under two alternative assumptions (described in detail in Paragraph 5.1.1): A, assuming the future market shares of car classes to be as in 1972, and D, assuming essentially a doubling of compacts' and subcompacts' market shares and a corresponding reduction of larger cars' shares.

Some of the crash injury-reducing FMVSS apply to trucks, and one (FMVSS 211) prohibiting wing nuts on automobile wheels is intended to protect pedestrians. The effects of this standard, however, have not yet been quantified.

4.2.4 Effects of Other Factors

There are two factors which are well-known to have a relation to traffic deaths: 1) speed, and 2) the level of economic activity.

Impact speed in a crash--and, therefore, indirectly travel speed--has a strong direct influence on the probability of death and injury. The relation between speed and accident frequency, however, is more complex. It appears that the dispersion of travel speeds has a stronger influence than absolute speed levels. Our current quantitative knowledge of these effects, however, is inadequate to model them [6].

There has been a stable trend of increasing travel speeds on straight level sections of main rural roads (the only ones for which such data are available over longer periods) over the last decades, though it had essentially flattened out since 1971 . The 55 mph speed limit completely interrupted this trend. We have previously studied the potential effect of this speed reduction [14] but could estimate it only with great uncertainty. Currently, other studies are ongoing. Once their results are available, better estimates may be possible.

The level of economic activity, as measured, e.g., by the Federal Reserve Board's *Index of Industrial Production*, parallels in a striking manner the number of traffic deaths (as shown in figures in various issues of the annual report of the National Highway Traffic Safety Administration). The nature of this relation is not understood. However, we have developed [6] purely descriptive quantitative models of this.

Figures 4.2-3a through 4.2-3e show an interesting pattern: Other Rural Roads, Urban Interstate Highways and Urban Streets and Highways have a "dip" in the fatality trend in the recession year 1970. Fatalities on Rural Interstate Highways and Main Rural Roads do not show this dip. The first group of highways service largely local travel; the second long distance travel. This invites various speculative hypotheses, but the evidence is too weak to justify any further exploration within the scope of this study.

There are, however, two important aspects to be considered for an improved model: 1) if predictions of economic cycles are given, more precise predictions of death by highway class might be possible, and 2) if alternative economic development trends are considered for the future, different fatality trends might be predictable for the two highway groups.

4.2.5 The First Level Model

The following is a summary of the first level model for highway transportation deaths:

$$\frac{\text{Deaths}}{\text{HM}}_{h,s,t} = VIO_t \left[TFA(I)_{h,t} \times A(I)_h + \left(TFB(I)_{h,t} \times B(I)_h \times \frac{VMT_{h,s,t}}{HM_{h,s,t}} \right) \right]$$

where the parameters are defined as follows:

VIO_t = Vehicle Interaction Factor for Year t

$A(I)_h$ = Regression Intercept for Highway Type (h) in Traffic Density Range I

$B(I)_h$ = Regression Slope for Highway Type (h) in Traffic Density Range I.

$TFA(I)_{h,t}$ = Time Factor for $A(I)_h$ in Year t

$TFB(I)_{h,t}$ = Time Factor for $B(I)_h$ in Year t

$VMT_{h,s,t}$ = Vehicle Miles Traveled (in millions) for Highway Type (h) in State(s) in Year t

$HM_{h,s,t}$ = Highway Mileage for Highway Type (h) in State(s) in Year t

VMT and HM projections are required inputs (though unchanged HM may be assumed). TFA and TFB are based on formulas given in Table 4.2-1. For VIO a conceptual model has been developed but no numerical coefficients and no computer programs.

Though the VMT data are needed as $VMT_{h,s,t}$, the model is able to accept non-aggregated data which it distributes over highway types and states according to an assumed pattern, as described in Appendix C.

4.3 AIR TRANSPORT

4.3.1 Scheduled Service of Certificated Route Air Carriers

4.3.1.1 The Basic Relations

In the analyses described in this section, the following fatal accidents are excluded: (1) international and territorial operations, (2) training flights, (3) supplemental air carriers and (4) accidents involving fatalities outside the certificated route air carrier aircraft with no fatalities aboard the aircraft.

Almost two-thirds of the fatal accidents involving scheduled service aircraft occur during takeoff and landing operations; the other third are in flight--though in recent years the proportions have shifted to about 3 to 1. Assuming that there are no congestion effects increasing the risk, when the number of operations at an airport increases, one would expect the number of accidents during takeoffs and landings to increase proportional to the number of such operations. The number of inflight accidents can be expected to depend either on the hours of flight or the miles flown. For the first analysis, we used the number of revenue miles flown, because they have a more direct relationship to revenue passenger miles, the product of the activity. A tabulation of data for all fatal accidents in the period 1962 - 1973, which forms the basis for analyses in this section, is given in Appendix D. Sources for the data were [34, 35, 36, 37, 38, 39].

In Figure 4.3-1, the ratios of fatal accidents during takeoffs and landings to the number of revenue departures (passenger or cargo) of domestic service of certificated route air carriers, and the corresponding ratio of fatal accidents inflight to the number of revenue aircraft miles is shown. In both cases, the ratios show a declining trend, but there is a great scatter of the points. One can think of several reasons for a decline in the fatal accident rates: improved air traffic control, better navigational and landing aids, and more reliable equipment. Very detailed studies would be required to determine the contributions of these factors. A purely formal description is, therefore, used. A linear trend would suffice to fit the widely scattered points adequately; however, its extrapolation would soon give negative fatal accident rates.

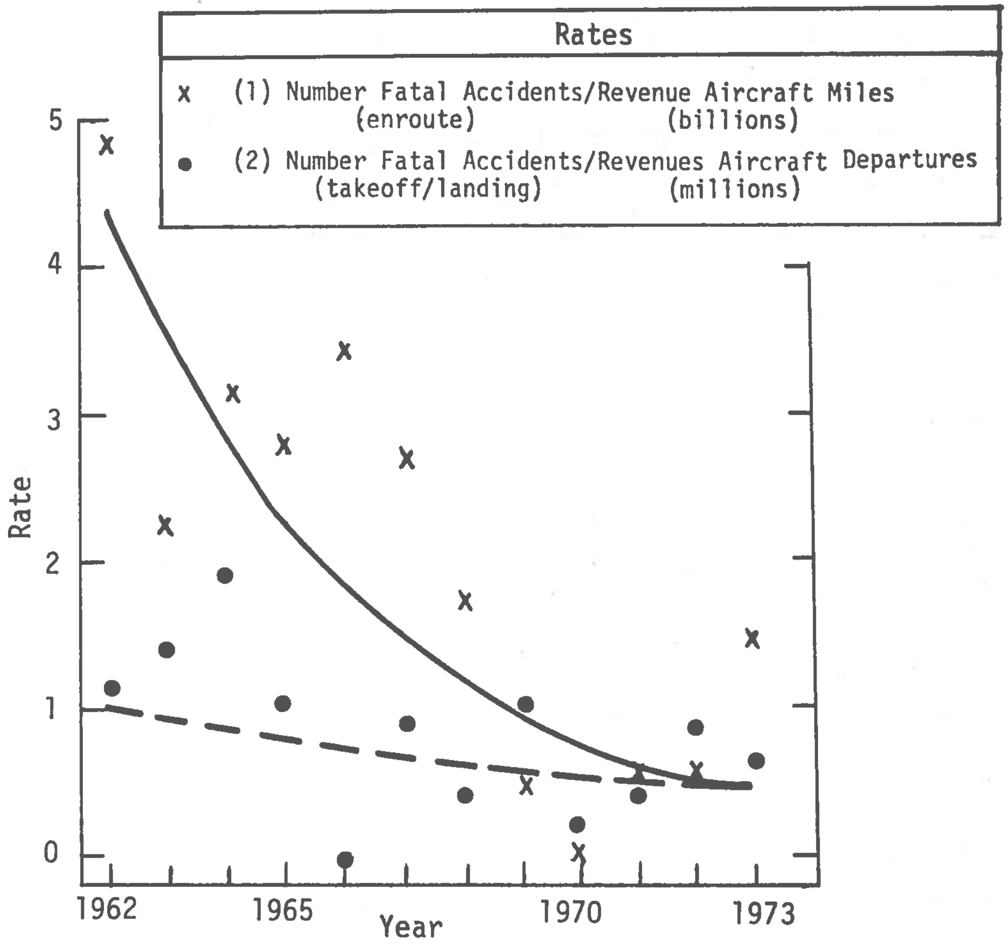


Figure 4.3-1. Accident fatality rates for U.S. Certificated Route Air Carriers domestic passenger/cargo service.

Therefore, an exponentially declining trend was assumed which guarantees that the projected number of fatal accidents can never be negative.

The curves shown in the figure are exponentially declining trends, obtained by least squares fits to the logarithms of the accident rates. They are represented by:

$$\text{Takeoff and landing accident rate} = e^{0.0126-0.0818\,(\text{year}-1962)} \qquad (4.3\text{-}1)$$

$$\text{Enroute accident rate} = e^{1.4713-0.2169\,(\text{year}-1962)} \qquad (4.3\text{-}2)$$

where the takeoff and landing rate is per million departures, the enroute accident rate per billion revenue aircraft miles.

We did explore two potential reasons for the decline in the fatal accident rate; (1) a shift to airports with better landing aids, and (2) a shift to safer aircraft. For the first analysis, we used the classifications of airports into large, medium, and small Air Traffic Hubs as given in the FAA Handbook on aviation [33]. In Table 4.3-1, the absolute number of such accidents is shown for two time periods. Except for the decrease in fatal accidents at medium airports, there appears to be no shift between the airport classes. To put this into perspective, the number of operations of the different airport classes should be considered. They are available only for the period 1968 - 1973. The fatal accident rates appear to vary widely, suggesting no obvious relation; however, if one combines medium and small airports and compares them with large airports, there appears to be no difference.

TABLE 4.3-1. FATAL ACCIDENTS AT TAKEOFF AND LANDING BY AIRPORT SIZE

Period	Number of Fatal Accidents		
	Large Airports	Medium Airports	Small Airports
1962 - 67	13	5	7
1968 - 73	12	1	9
Fatal Accidents per Million Departures			
1968 - 73	0.84	0.2	2.1
		$\underbrace{}_{0.99}$	

Therefore, one has to conclude that if there is an effect of airport size, it can be determined only on a case-by-case study of accidents and their causes.

It is difficult to determine whether improvements in aircraft did reduce the accident rate over time, because there are few, if any, fatal accidents for many aircraft types. Therefore, some aggregation had to be made. We used two classifications in Tables 4.3-2 and 4.3-3. Data on flight hours per aircraft type were available from 1964 - 1973. It is recognized that future analyses should consider aircraft miles as a function of aircraft type. These data were not immediately available for this initial analysis.

TABLE 4.3-2. FATAL ACCIDENT RATE PER MILLION FLYING HOURS BY AIRCRAFT SIZE FOR 1964 - 1973

Description of Aircraft Type	Range of Passenger Capacity	Range of Maximum Takeoff Weight (pounds)	Fatal Accident Rate Per Million Hours
Turboprops	35-90	< 100,000	3.23
Small jets	75-135	75,000 - 150,000	1.54
Medium jets	100-200	150,000 - 250,000	0.48
Large jets	100-220	250,000 - 400,000	0.34
Very large jets	250-500	400,000 - 700,000	1.12

TABLE 4.3-3. FATAL ACCIDENT RATE PER MILLION FLYING HOURS BY ENGINE TYPE AND NUMBER FOR 1964 - 1973

Description of Aircraft Type	Fatal Accident Rate Per Million Hours
Turboprops	3.23
Two-engine jets	1.54
Three-engine jets	0.71
Four-engine jets	0.32
Boeing-747	0

It would have been desirable to separate takeoff and landing, and enroute accidents. However, the number of operations by aircraft type was not available. Therefore, rates of all fatal accidents per million hours flown were calculated. The rates in Table 4.3-2 are not conclusive although risk declines with aircraft size except for the class of very large jets. It should be noted that the number of flight hours in this class is relatively small. Table 4.3-3 suggests that the risk declines with increasing engine number, for jet aircraft. This is surprising, since four-engine jets were the first to be introduced. Differentiation by aircraft type may permit future refinements of the model, but this will require extensive work to obtain data which were not readily available. A detailed tabulation of flight hours and aircraft accident data by aircraft type is given in Appendix D.

Finally, we studied the number of aircraft occupants killed, per fatal accident, again combining both enroute and takeoff/landing accidents. The results are given in Figure 4.3-2. There is a suggestion of an increase in fatalities per fatal accident, which is not surprising since recently introduced aircraft tend to have larger capacities than older ones. A linear trend appears to be an adequate fit and does not result in unreasonable projections twenty years ahead. The trend is represented by:

$$\text{Fatalities per fatal accident} = 21.6 + 2.976\times(\text{Year}-1962). \qquad (4.3\text{-}3)$$

We also studied the ratio of persons killed to persons aboard the aircraft in fatal accidents. The results are shown in Figure 4.3-3. There appears to be a slight increase with time, but this trend is dramatically reduced in 1972 and 1973. Thus, we have no basis for assuming a trend.

4.3.1.2 First Level Model

From the analyses described above the following decisions were made in the formulation of a first level Air Transport Model.

- The model will distinguish between enroute fatal accidents and takeoff and landing fatal accidents.
- Annual enroute fatal accidents are assumed to be proportional to annual revenue aircraft miles.

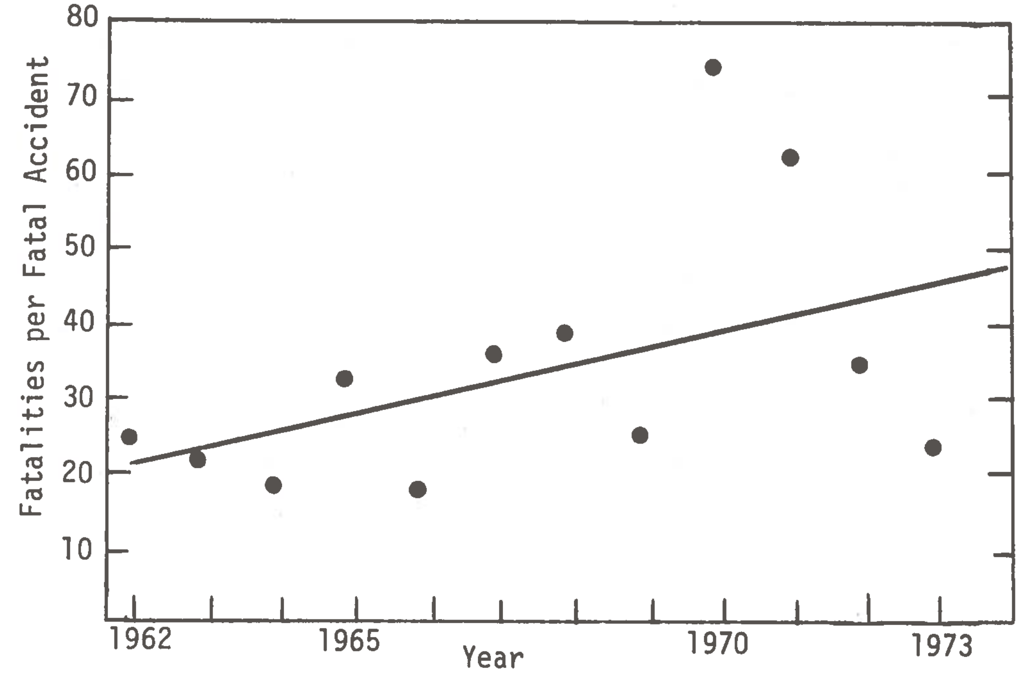


Figure 4.3-2. Annual rates of fatalities per fatal accident for Certificated Route Air Carrier from 1962-1973. Takeoff/landing and enroute accidents are combined.

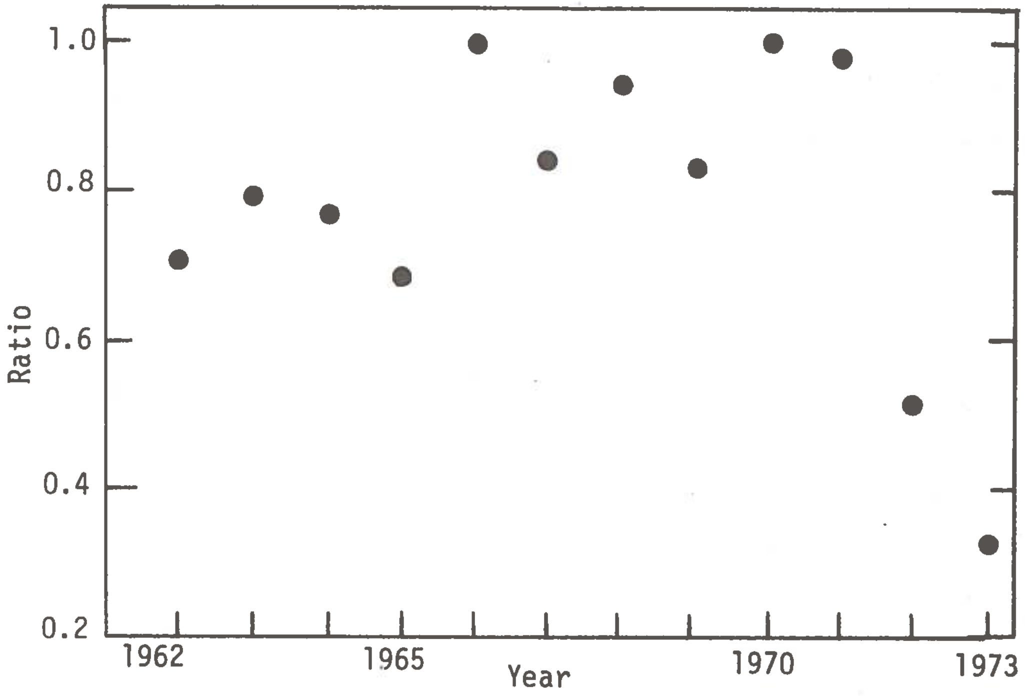


Figure 4.3-3. Ratio of persons killed to persons aboard aircraft in fatal accidents of Certificated Route Air Carriers.

- Annual takeoff and landing fatal accidents are assumed to be proportional to annual revenue aircraft departures.
- The proportionality factors (rates) are assumed to be exponentially declining with time.
- It is also assumed that the number of fatalities per fatal accident increases linearly with time.

The resulting model is described below:

AIRCRAFT TRANSPORTATION MODEL

Scheduled Domestic Passenger/Cargo Air Carrier Service

- Takeoff Landing Accidents

$$F1 = RD \times FF1 \times e^{(0.0126 - 0.0818 \times T)}, \qquad (4.3\text{-}4)$$

- Enroute Accidents

$$F2 = RM \times FF2 \times e^{(1.4713 - 0.2169 \times T)} \qquad (4.3\text{-}5)$$

where the parameters are defined as follows:

F1 = Annual Fatalities from Takeoff/Landing Accidents

F2 = Annual Fatalities from Enroute Accidents

RD = Annual Revenue Departures in Millions

RM = Annual Revenue Miles in Millions

FF1 = FF2 = Fatalities per Fatal Accident

T = Indicator of Year
(0 = 1962, 1 = 1963,...,28 = 1990)

- Fatalities per Fatal Accident Trend

$$FF1 = 21.6 + 2.2976 \times T \qquad (4.3\text{-}6)$$

A computer program for this model is described in Appendix F.

The results of the application of this model to the development sample from 1962 - 1973 are given in Figure 4.3-4. The application of the model yields slightly declining annual fatalities from 1969 on. This is generally indicated by the actual fatalities, although the year-to-year variations (scattered about the prediction line) are large. This is not surprising, since the number of fatal accidents per year is very small, but usually a large, greatly varying number of people is killed in each. Thus, in the present formulation of the model, the increasing fatalities per fatal accident do not overcompensate for the effects of the decline of the fatal accident rate with time.

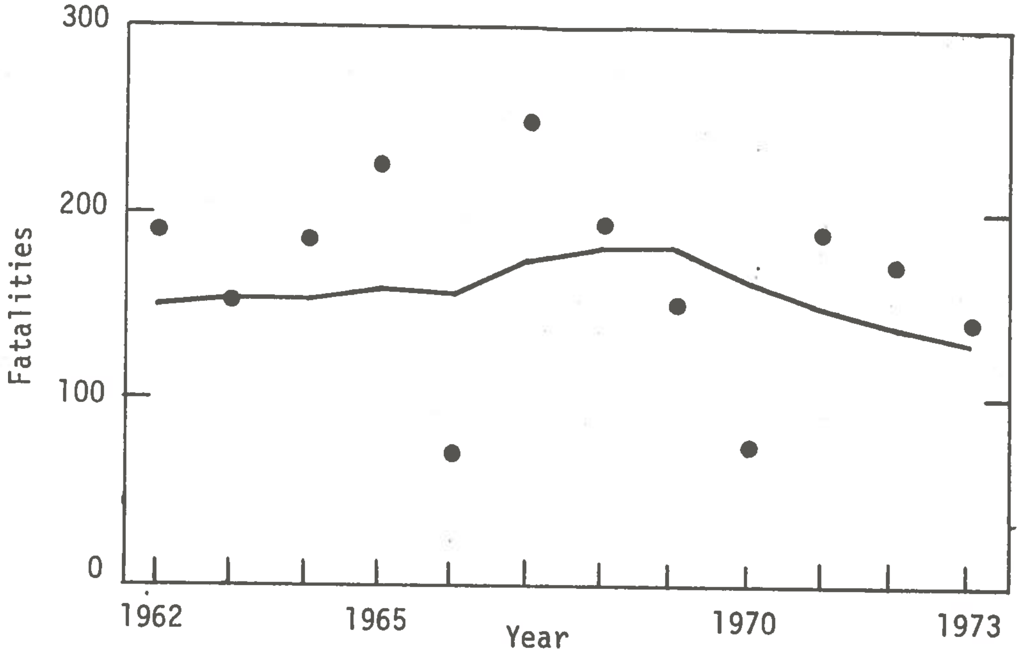


Figure 4.3-4. Annual fatalities in scheduled domestic passenger/cargo Certificated Route Air Carrier service. Dots give actual numbers, the line their representation by the model.

4.3.2 General Aviation

4.3.2.1 Analysis of Past Accident Experience

General aviation operations include all civil aircraft operations except those classified as air carriers. General aviation activities are quite heterogeneous; they include:

- Business (including executive)
- Commercial: air taxi, aerial applications and industrial/special
- Instructional (training and rental)
- Personal
- Other.

Much of it is not transportation, e.g., aerial application, instructional and much of personal flying. However, the readily available data do not allow the separation of these activities. On the basis of data for 1962-1966 and 1972-1973 [33, 40, 41,42] (the number of fatal accidents by class was not available for the years in between), Figure 4.3-5 shows the relations between fatalities and millions of miles flown by type of activity. For personal and commercial activities, there appears to be a relation; for instructional and business flying, the scatter of the points is too great to suggest a relation. For personal flying and for commercial flying, the points can be represented by the straight line indicated in the figure.

While it is obvious that fatalities increased with miles flown as indicated by the above described relationships, the question still must be considered as to whether fatality rates are changing with time. Figure 4.3-6 shows the ratio of fatalities to millions of miles flown (risk) for personal, commercial and business general aviation flying as a function of time from 1962-1966 and 1972-1973. As the figure shows, there is a long-term decline of the fatality rate (about 2% per year) for personal flying, while little or no change in the rate is noted for commercial and business flying. Data did not permit a complete analysis of all categories of general aviation flying. However, the preliminary and incomplete analysis of different types of general aviation flying

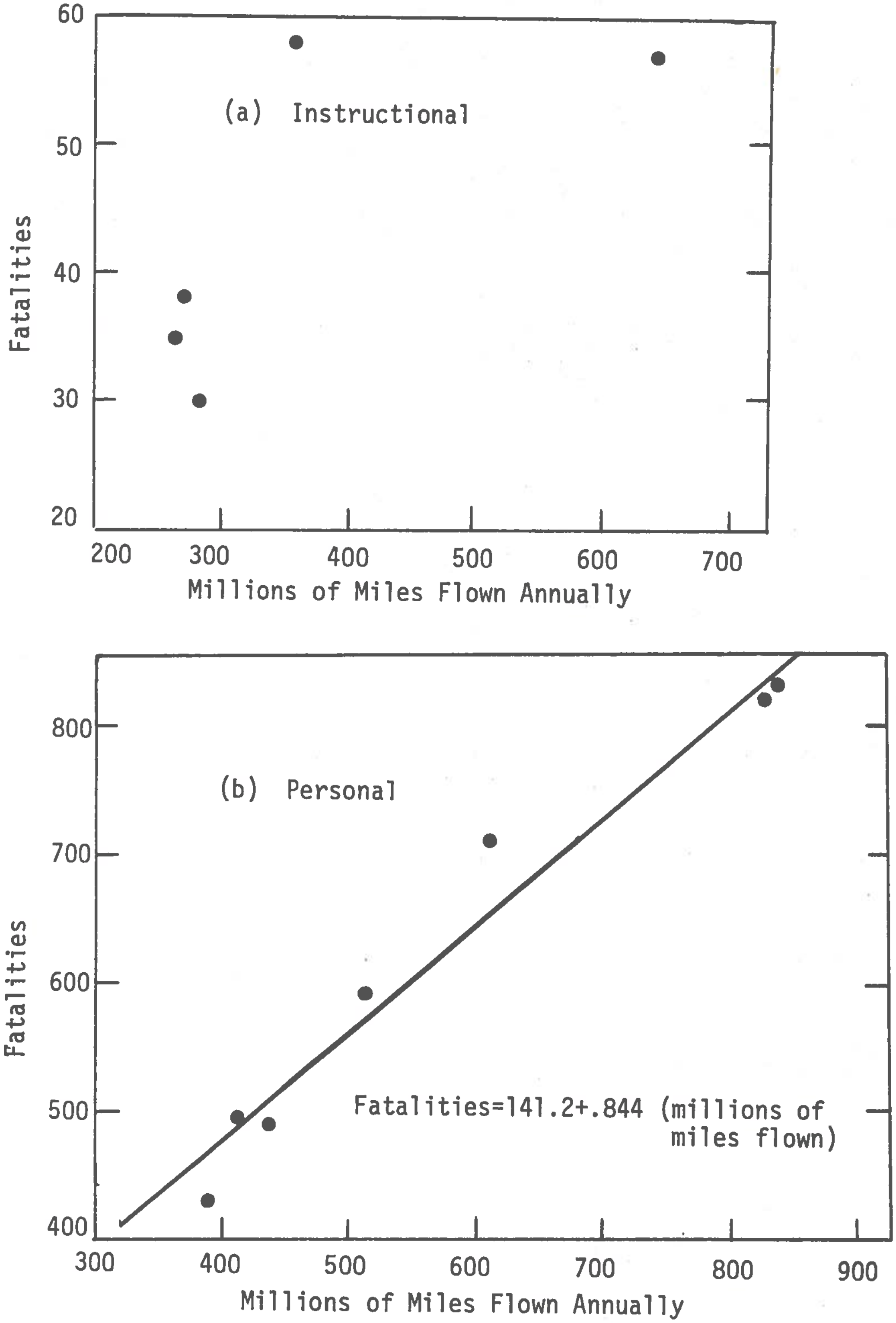


Figure 4.3-5. General aviation fatalities versus miles flown as a function of types of flying.

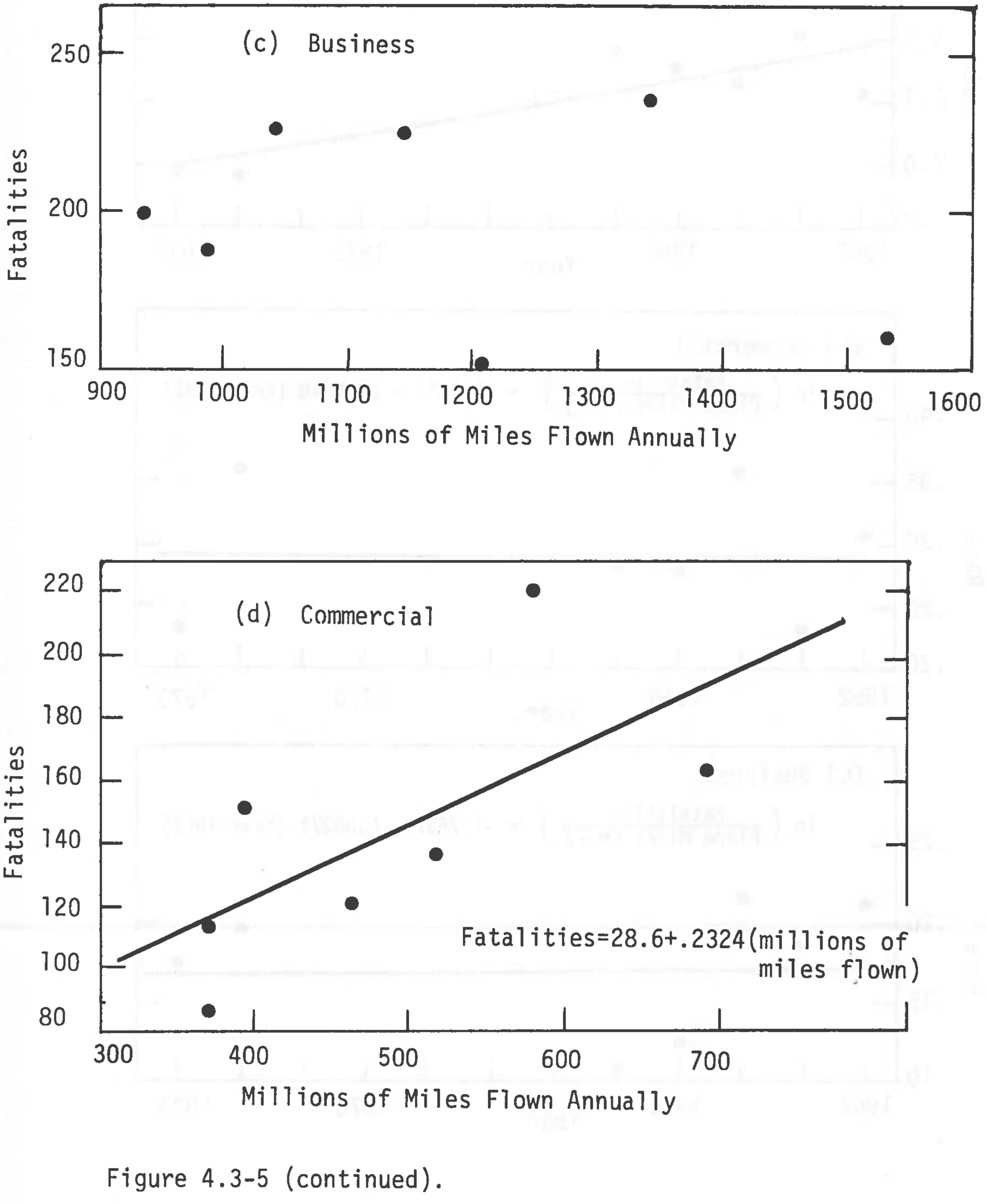


Figure 4.3-5 (continued).

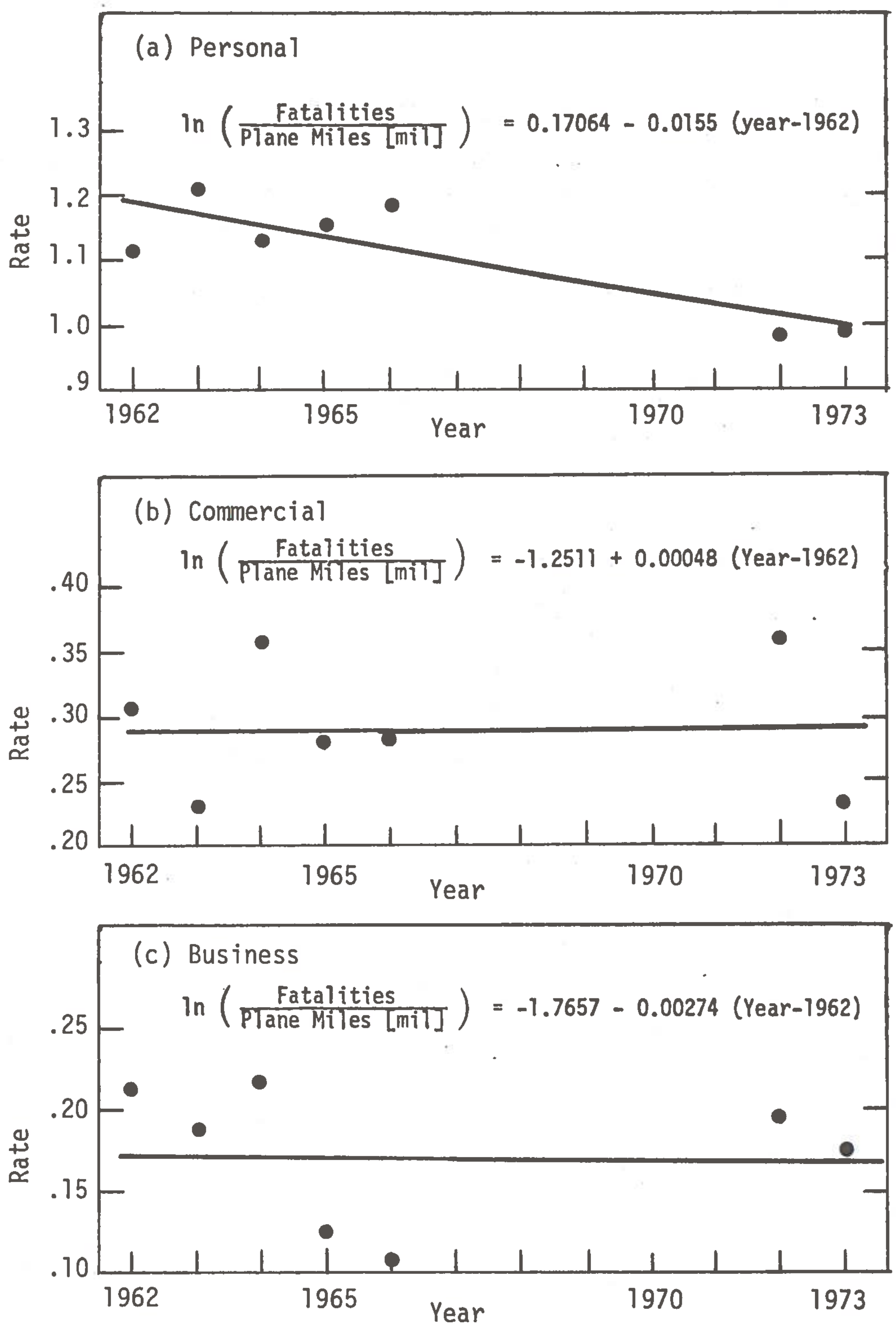


Figure 4.3-6. Changes in fatality rates with time in general aviation flying.

clearly demonstrates both the significant differences in fatality risk (about six times greater in personal flying compared with business flying) and also differences in how this risk is changing with time. These differences should be considered in an indepth analysis leading to a second level model.

Without undertaking the complete, detailed analysis outlined above, general aviation flying has to be treated as one homogeneous activity. Figure 4.3-7 shows the ratio of fatalities to billions of miles flown for all general aviation flying for the period from 1962-1973. The curve shown in the figure is the least squares fit to the logarithm of the accident rate. Since the decline in the overall general aviation fatality rate is very gradual with time, the choice of a logarithmic rather than a linear trend is not really necessary for any projection period within this century. However, while not absolutely required, the form of the equation is then consistent with the equations used for scheduled domestic air carrier service. The curve in Figure 4.3-7 is represented by:

$$\text{General aviation accident rate} = e^{5.3605-0.0127\times(\text{year}-1962)} \qquad (4.3\text{-}7)$$

4.3.2.2 First Level Model

From the analyses described above, the following decisions were made in the formulation of a first-level Air Transport Model for general aviation.

- The model will not distinguish on a first level, between types of general aviation flying.
- Annual general aviation fatal accidents are assumed to be proportional to annual aircraft miles.
- The proportionality factors (rates) are assumed to be exponentially declining with time.
- It is also assumed, for the applications in this study, that the number of fatalities per fatal accident does not change with time; however, the model accepts time varying values.

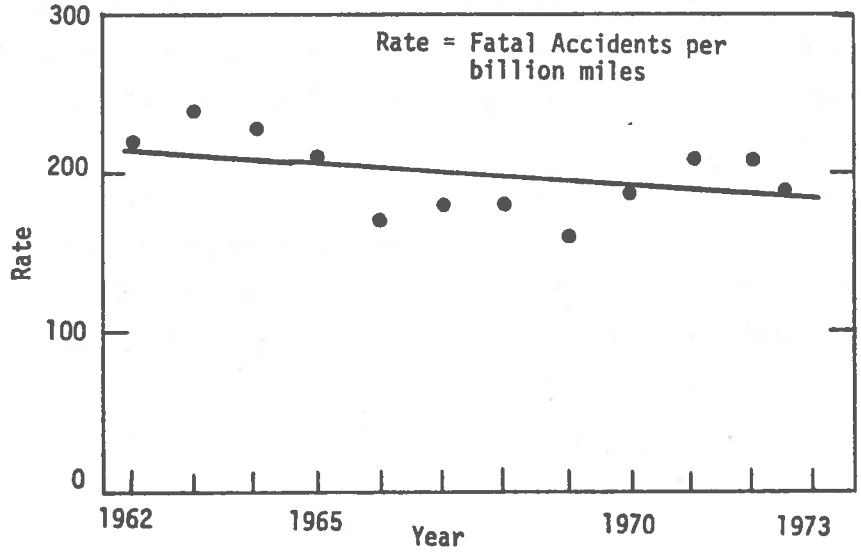


Figure 4.3-7. Change in fatality rates with time for all categories of general aviation flying combined.

The data to support the final assumption are given in Table 4.3-4 for the period from 1962-1973. Notice that for the entire period the annual fatalities per fatal accident is within the range 1.91 to 2.04.

TABLE 4.3-4. ANNUAL GENERAL AVIATION FATALITIES PER FATAL ACCIDENT

Year	Fatalities per Fatal Accident	Year	Fatalities per Fatal Accident
1962	1.99	1968	2.02
1963	1.85	1969	2.31
1964	2.01	1970	2.02
1965	1.91	1971	2.03
1966	2.01	1972	2.03
1967	2.04	1973	1.94

The only exception occurred in 1969. Note also that the rate for the first year was 1.99, and the rate for the final year of the period was 1.94.

The resulting model is described below:

AIRCRAFT TRANSPORTATION MODEL

General Aviation

$$F3 = GM \times FF3 \times e^{(5.3605 - 0.0127 \times T)}, \qquad (4.3\text{-}8)$$

where the parameters are defined as follows:

F3 = Annual Fatalities Resulting from General Aviation Accidents

GM = Annual General Aviation Miles in Billions

FF3 = Fatalities per Fatal Accident for General Aviation; A Constant Value of 2.0 was used.

T = Indicator of Year (0 = 1962, 1 = 1963, ..., 28 = 1990)

A computer program for this model is incorporated in the program described in Appendix F.

The results of the application of this model to the dependent sample from 1962-1973 are given in Figure 4.3-8. As the figure shows, the above equation produces a fairly good fit to the actual year-to-year variations of total fatalities occurring from general aviation flying.

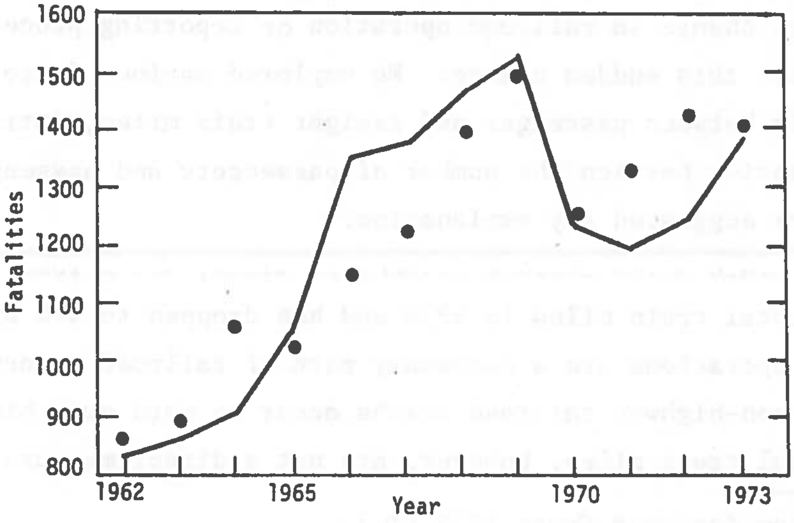


Figure 4.3-8. Annual fatalities in general aviation from 1962-1973. Dots are actual values, the broken lines their representation by the model.

4.4 RAIL TRANSPORT

4.4.1 The Basic Relations

Of nearly 2000 deaths in railroad accidents (1973), 1200 occurred at highway grade crossings (out of which 1100 were motor vehicle occupants), 600 to trespassers, 166 to railroad employees and only 6 to passengers on trains.* Since the motor vehicle occupants killed are already counted in the highway transport model, we restrict the analysis of rail transport accidents to non-highway accidents. Since the numbers of passengers killed is small, and since the available figure for railroad employees combines accidents of both freight and passenger trains,† separate models for passenger trains and freight trains were not considered for the first level model. Data for the analyses were obtained from [2, 43, 44].

A gross measure of railroad movements is train-miles. Therefore, relations between deaths and train-miles were sought. Figure 4.4-1 shows such a relation. It suggests that from 1962 through 1970 there were 1.55 deaths per million train miles, from 1971 through 1973 1.37 deaths per million train miles. An obvious suspicion was that the initiation of Amtrak in 1971 might have had some influence, but discussion with representatives of the Federal Railroad Admininstration,Railroad Union officials, and the National Safety Council failed to reveal any quantitative change in railroad operation or reporting procedures which could explain this sudden change. We explored various factors, such as changing mix between passenger and freight train miles, Amtrak mileage, and the relation between the number of passengers and passenger train miles. None suggested any explanation.

Total train miles include switchyard miles, which rose to a peak of 55% of total train miles in 1970 and has dropped to 47% by 1974. Switchyard operations are a necessary part of railroad transport, and 15% of all non-highway railroad deaths occur in yard switching operations. Total train miles, however, are not a direct measure of the

---

*Figures from *Accident Facts 1975* [2].

†The Federal Railroad Administration provided more detailed information but a sufficient time series was not available in time for the first level model.

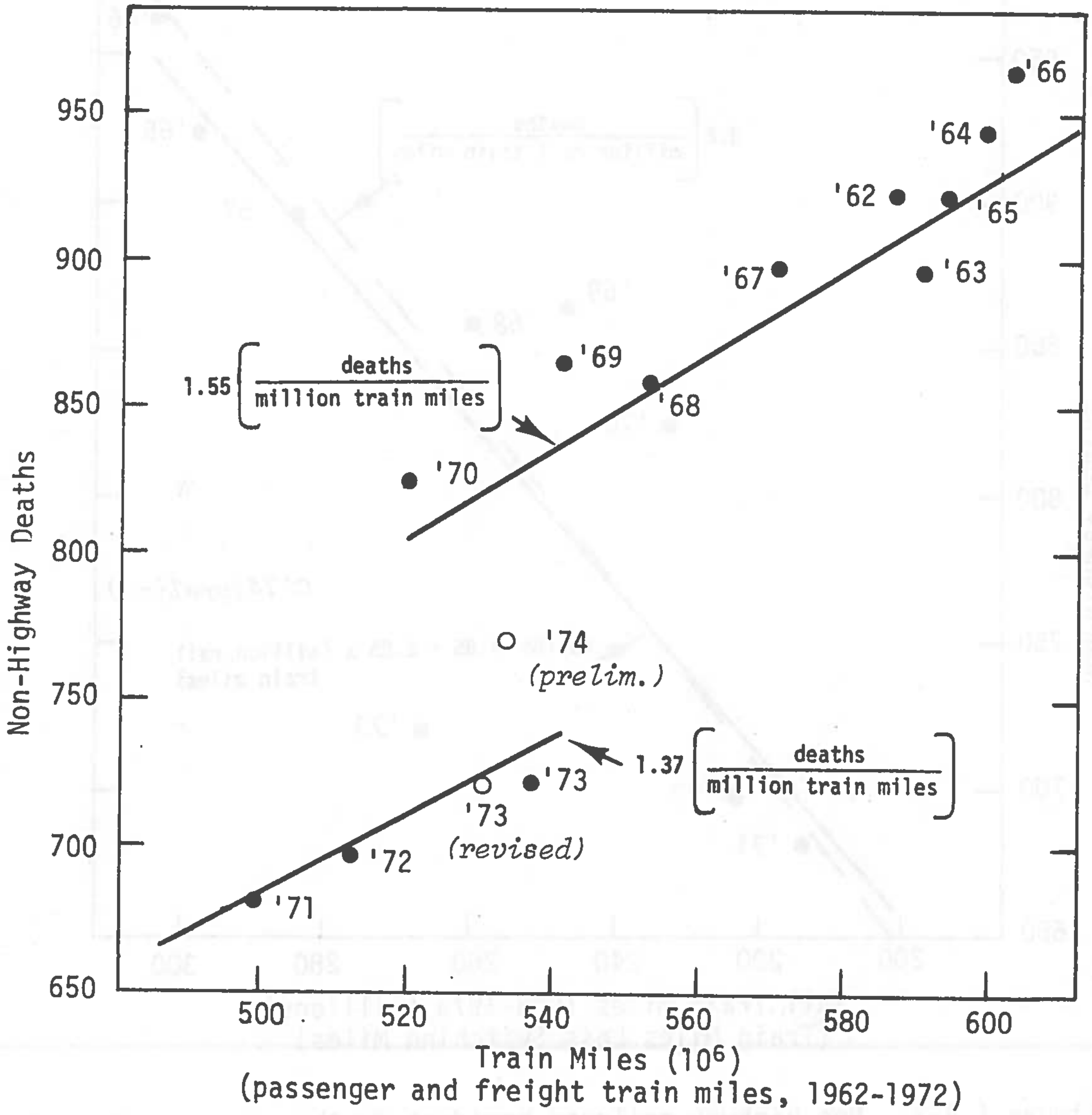


Figure 4.4-1. Non-highway railroad accident deaths versus train miles.

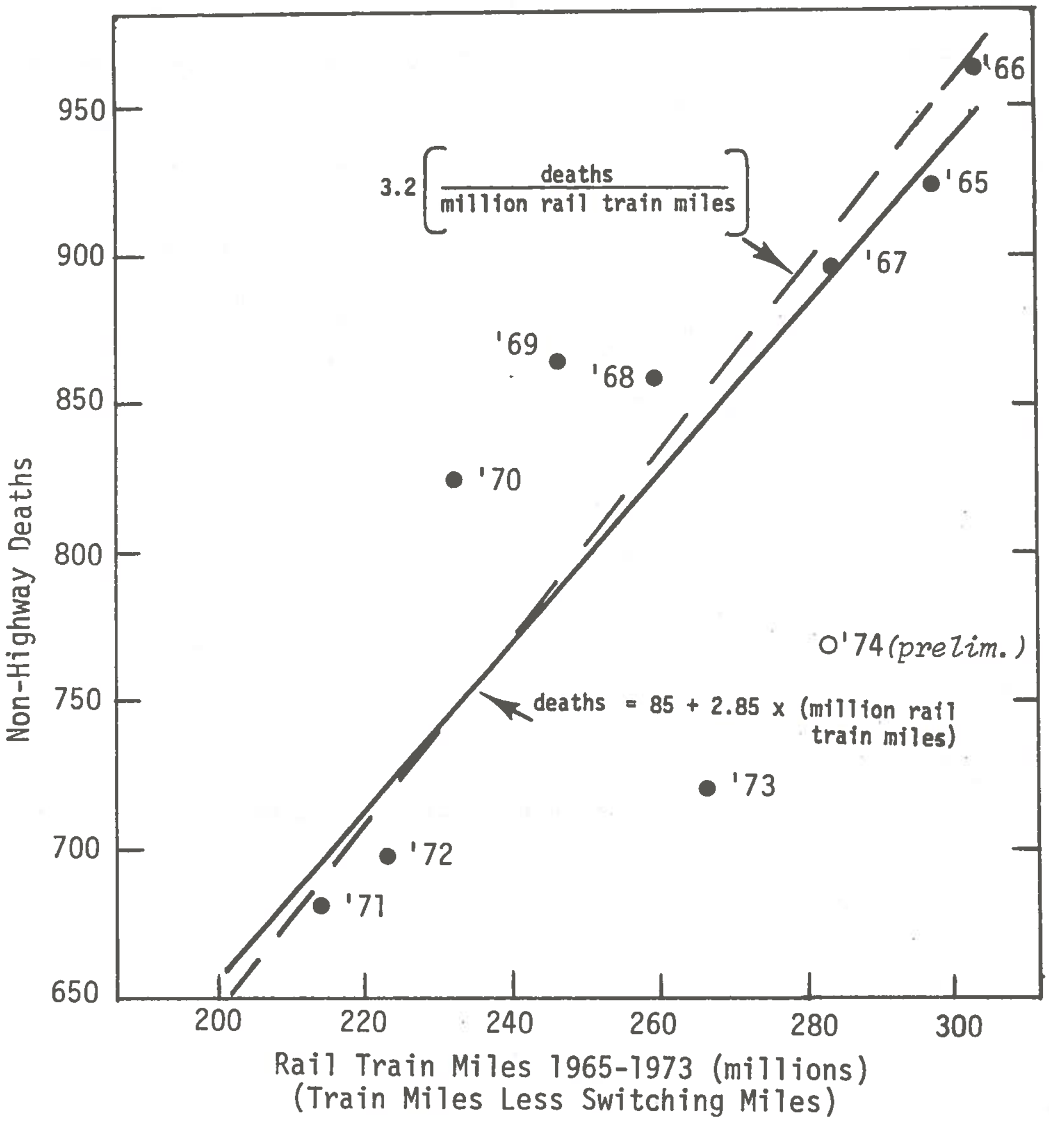


Figure 4.4-2. Non-highway railroad accident deaths versus rail train miles. The preliminary data for 1974 were not used in drawing the regression line.

transportation product of railroads. This is better measured by "rail train miles," which exclude switchyard operations. Since projections of rail activities were given in rail train miles, we also explored the relation between non-highway railroad deaths and rail train miles. Figure 3.4-2 shows the relation. The points appear to scatter around a line corresponding to a death rate of 3.20 per million rail train miles. A least squares fitted line with the equation

$$\text{Non-highway railroad deaths} = 85 + 2.847 \times (\text{million rail train miles}) \qquad (4.4\text{-}1)$$

is not appreciably different within the range of the data points.

However, a closer look at the points (especially if the one for 1974, which became available after the model had been developed, is included), also suggests the possiblity that a different linear relation applies from 1971 on than before. This suggests the retention of the equation (4.4-1) instead of assuming simple proportionality between non-highway railroad and rail-train miles, because its structure could easily accommodate a non-proportional linear relation from 1971 on.

The representation of the actual data by equation (4.4-1) is shown in Figure 4.4-3.

4.4.2 The Model

For the first level model we ignored the possibility of a discontinuity in the relation between non-highway railroad deaths and train miles. We assumed the relation expressed by equation (4.4-1). Thus, the model is:

RAIL TRANSPORT MODEL

$F = 85 + 2.847 \times M$,

where the parameters are defined as follows:

F = Annual Non-Highway Fatalities* Resulting from Rail Accidents

M = Annual Rail-Train Miles in Millions; Switching-Yard Miles are NOT Included.

---

* Grade crossing accidents involving motor vehicles are excluded.

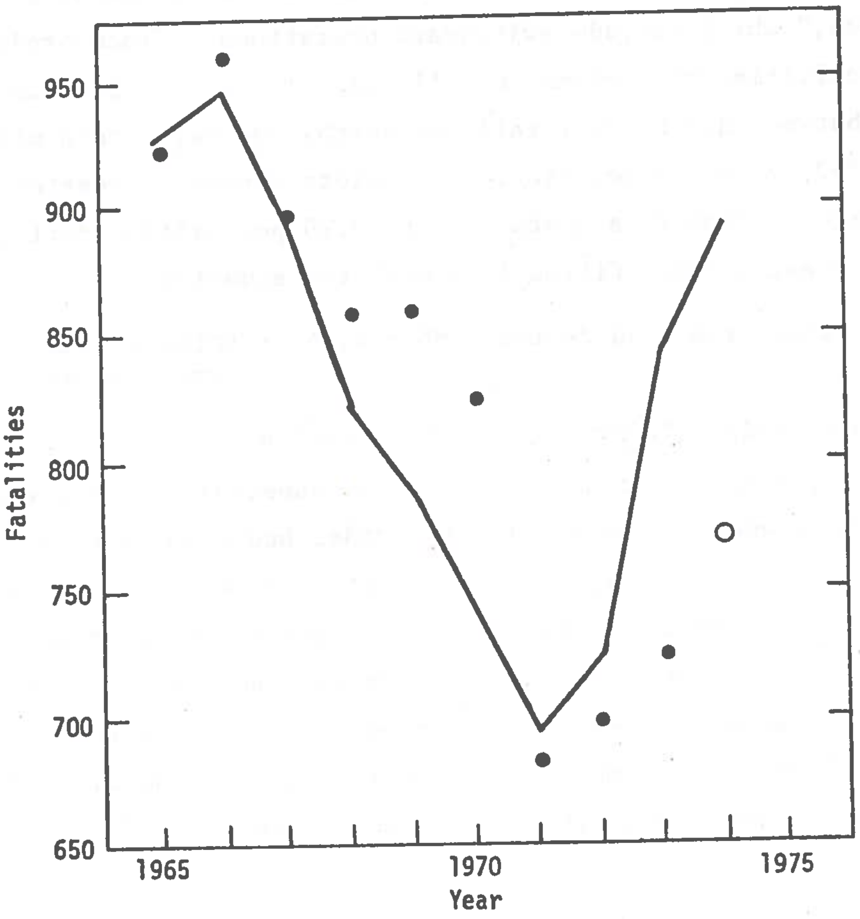


Figure 4.4-3. Representation of non-highway railroad accident deaths by the model. The preliminary value for 1974 (indicated by ○) was not used in deriving the model.

4.5 WATER TRANSPORT

The *Summary of Transportation Statistics* for 1972 [1] lists 1418 fatalities in water transport in 1971. This is the figure reported by the U.S. Coast Guard for deaths from boating accidents, of which 1305 were due to drowning, 113 due to other causes (*Accident Facts 1971* [2]). These figures include pleasure boating, which cannot be considered a transportation activity. Fatalities on commercial vessels, due to a vessel casualty are shown in Table 4.5-1. The overwhelming majority of fatalities are to crew members and harbor workers, with a significant percentage remaining unidentified. The majority of the passenger fatalities are not on passenger vessels or ferries, but on other vessels, freighters, tankships, etc. In summary, passenger fatalities and passenger vessel fatalities account for a small portion of total fatalities due to vessel casualties.

TABLE 4.5-1. FATALITIES CAUSED BY VESSEL CASUALTIES

Fiscal Year	Total	Fishing Vessel Fatalities	Transport Vessel Fatalities	Passenger Fatalities (included in the other columns)
1975				
1974	199	74	125	
1973	131	63	68	
1972	177	66	111	
1971	243	74	169	
1970	170	77	101	
1969	217	54	163	24
1968	140	40	100	11
1967	178	32	146	1
1966	202			5
1965	125	41	84	
1964	191	69	122	11
1963	226	68	158	9
1962	166			
1961	156			

*Includes tugs,foreign vessels in American waters and miscellaneous.

Source: *Merchant Marine Council Proceedings* and *Marine Safety Council Proceedings* published by U.S. Coast Guard [45, 46].

Since transport is only incidental to fishing, fishing vessel fatalities had to be excluded if one wants to find the effects of transport activity levels upon accidental deaths. The number of passenger fatalities is so small that they would not justify a separate model; therefore, they were not separated.

There is no measure such as "vessel-mile" for water transport activities. Activities are described in terms of tons or ton-miles [11,37].

Many potential relations were explored, such as with time, tons, ton-miles, excluding and not excluding petroleum trade and the level of Panama transit. There was a very weak suggestion that fatalities per ton, or fatalities per ton-mile declined with time. However, the effect was so weak that no inclusion in the first level model was justified.

4.6 PIPELINES

The number of deaths resulting from pipeline accidents varied between 22 and 45 per year during the period 1970 through 1974 [53]. Since pipeline transportation is a continuous process, quite distinct from the discrete units moved in other modes of transportation, there is no obvious simple model relating the number of accidents, or deaths to the transported quantity. One study by the Office of Pipeline Safety [47], found that the failure rate per mile increases with the age of the system. If this should prove to be the principal factor, a model quite different from those for other modes would be required. To develop this would have exceeded the scope of the first level model.

5. PROJECTIONS BASED ON THE FIRST LEVEL MODEL

5.1 HIGHWAY TRANSPORT PROJECTIONS

The highway transport model was run to predict traffic fatalities for the years 1975 to 1990 by road type and state. The Transportation Systems Center provided VMT forecasts for 1975 through 1990 by road type for passenger cars and in the aggregate for buses and combination trucks (Appendix H). They also provided two different scenarios for future changes in the vehicle population in terms of vehicle size (described in [14]. Therefore, two separate projections of traffic fatalities are included in this report. The model parameters were determined using previous data from the years 1967 to 1973, as described in Subsection 4.2.

5.1.1 Input Data and Assumptions

The model requires VMT data (in millions) for each year for which fatality predictions are desired. It must be input in one of the following forms: by state, road type, and vehicle type; by state and road type; by state and vehicle type; by road type and vehicle type. If data are not available by state, percentages for distributing VMT by state must be provided. The same requirement holds for road type. The VMT data provided for our projections were not broken down by state; therefore, we used percentages based on actual VMT data for 1973 in *Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems* [22]. It was also necessary to disaggregate the truck and bus VMT by road type. The percentages used were derived from Table VM-1 in *Highway Statistics* [21], and may be found in Table 5.1-1. Forecasts for single-unit trucks were not available. Therefore, CEM developed estimates of single-unit truck VMT for 1975-1990. It was observed that for the years 1963-1973 single-unit truck VMT correlated strongly with combination truck VMT and the relationship between them was determined:

$$\text{Single unit truck VMT} = -19.6 + 4.878\times(\text{combination truck VMT}) \quad (5.1\text{-}1)$$

VMT in billions

This relationship was assumed to continue into the future and since we had been provided with forecasts of combination truck VMT, single-unit truck VMT forecasts were derived therefrom. Graphs of the actual and predicted data may be found in Figure 5.1-1.

TABLE 5.1-1. DISTRIBUTION (%) OF TSC VMT DATA BY ROAD TYPE. (Derived from Table VM-1 *Highway Statistics* 1973)

	Single-unit Truck	Combination Truck	Bus	Motorcycle
1. Rural Interstate	.0	56.6	5.5	10.0
2. Urban Interstate	5.6	23.5	4.6	10.0
3. Main Rural Roads	25.7	5.9	31.0	35.0
4. Other Rural Roads	23.1	2.4	22.9	35.0
5. Urban Highways & Streets	45.6	11.6	36.0	10.0
TOTALS	100.0	100.0	100.0	100.0

Estimates of highway mileage in use must be provided by state and road type. The model has the capability to accept either one set of values or different values for each year. Highway construction has increased an average of 0.3 percent per year for the years 1967-1973. Since future construction is unknown and appears to be declining, the 1973 highway mileage figures have been used in projecting 1975-1990 fatalities.

A "vehicle interaction factor," the "relative risk" factor was used as discussed in Subparagraph 3.2.3.4. For the future,two scenarios [14] were assumed:

Scenario A: *essentially returning through 1980, to the 1972 market shares of subcompacts, compacts, intermediates and full-size cars, but increasing the market share of large luxury cars by 50%.*

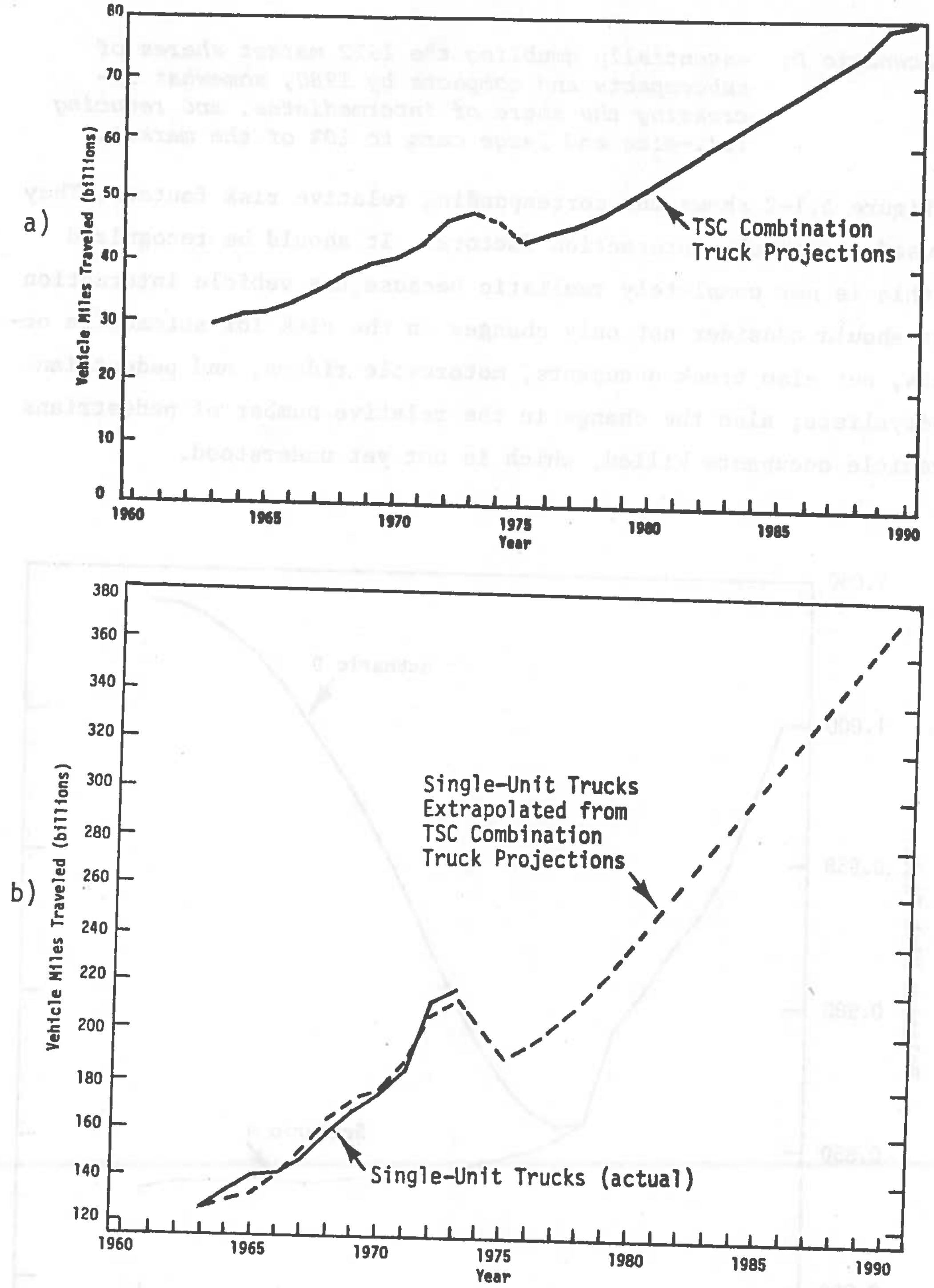


Figure 5.1-1. a) VMT for combination trucks 1963 through 1973 [21] and TSC projections of future VMT.

b) Actual VMT for single unit trucks 1963 through 1973 [21] and VMT calculated from VMT for combination trucks from equation 5.1-1.

Scenario D: *essentially doubling the 1972 market shares of subcompacts and compacts by 1980, somewhat increasing the share of intermediates, and reducing full-size and large cars to 10% of the market.*

Figure 5.1-2 shows the corresponding relative risk factors. They were used as vehicle interaction factors. It should be recognized that this is not completely realistic because the vehicle interaction factor should consider not only changes in the risk for automobile occupants, but also truck occupants, motorcycle riders, and pedestrians and bicyclists; also the change in the relative number of pedestrians and vehicle occupants killed, which is not yet understood.

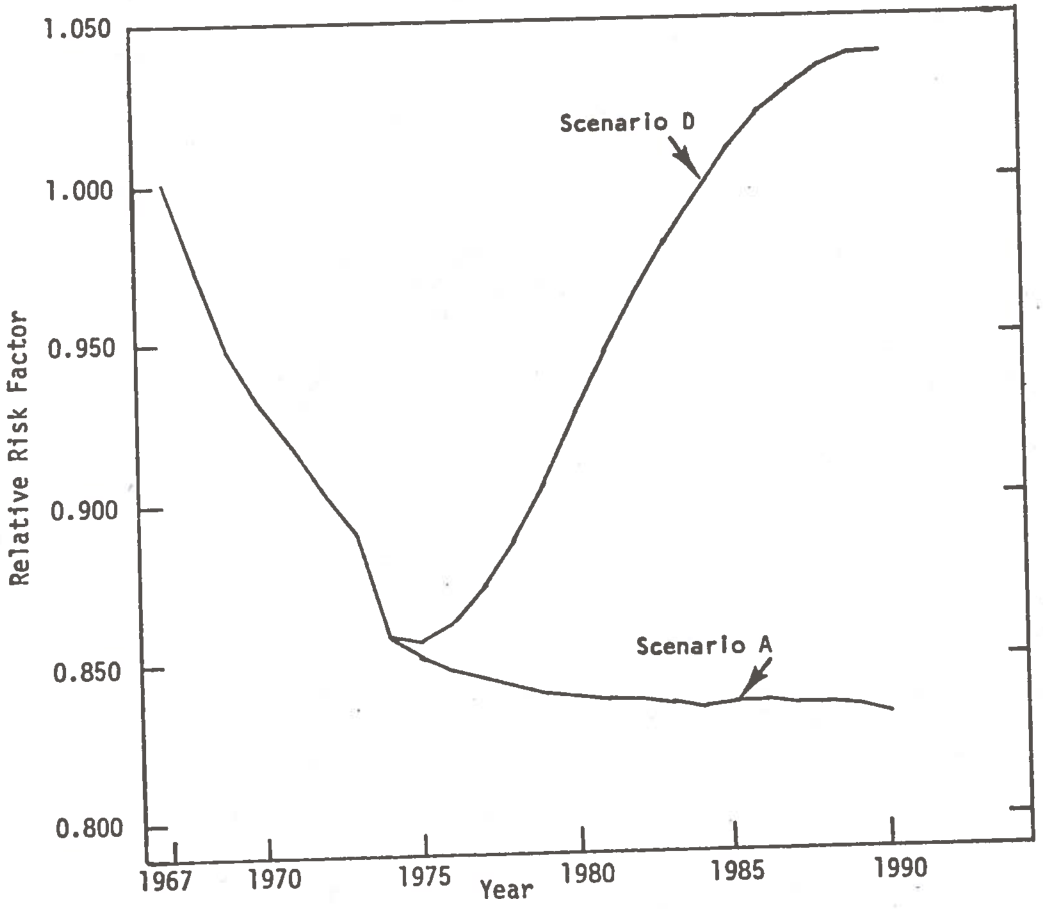


Figure 5.1-2. Relative risk factor for passenger car occupants, which was used as a vehicle interaction factor.

5.1.2 The Projections

Figures 5.1-3a through 5.1-3e show the fatality projections resulting under the given assumptions. The decline in deaths on main rural roads between 1967 and 1973 is partially due to a decline of the total mileage of these roads by 5% over this period.

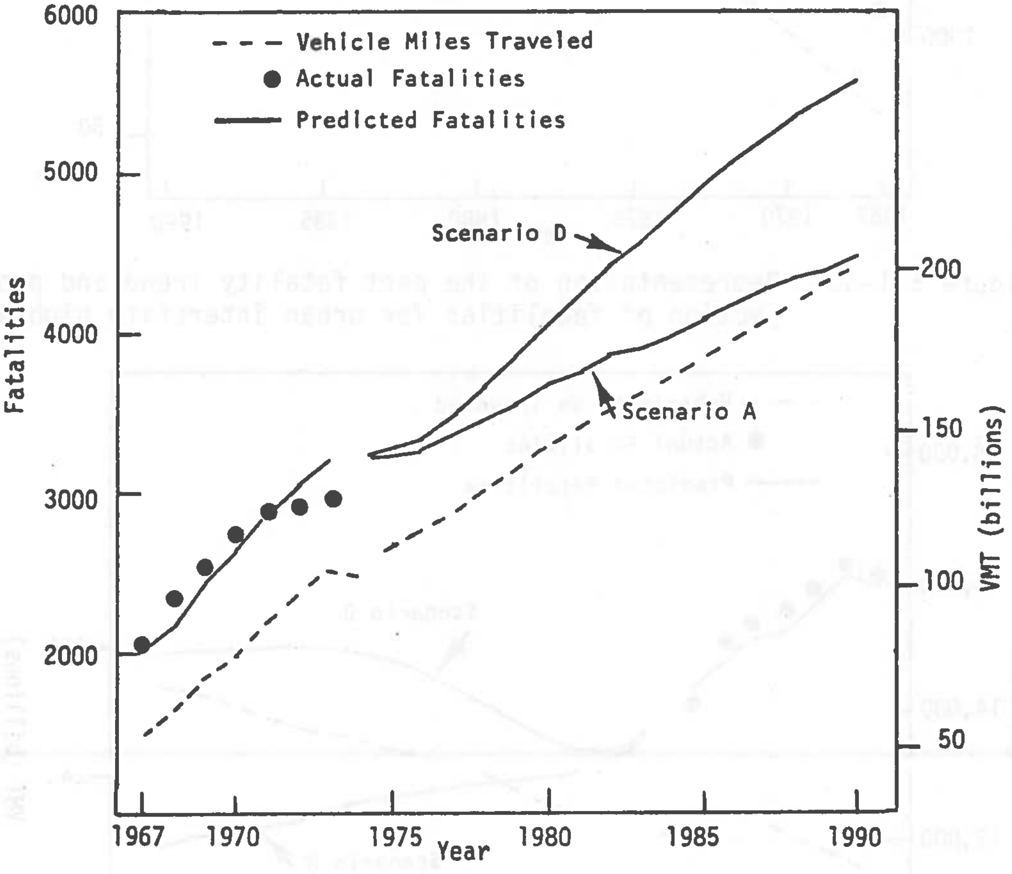


Figure 5.1-3a. Representation of the past fatality trend and projection of fatalities for rural interstate highways.

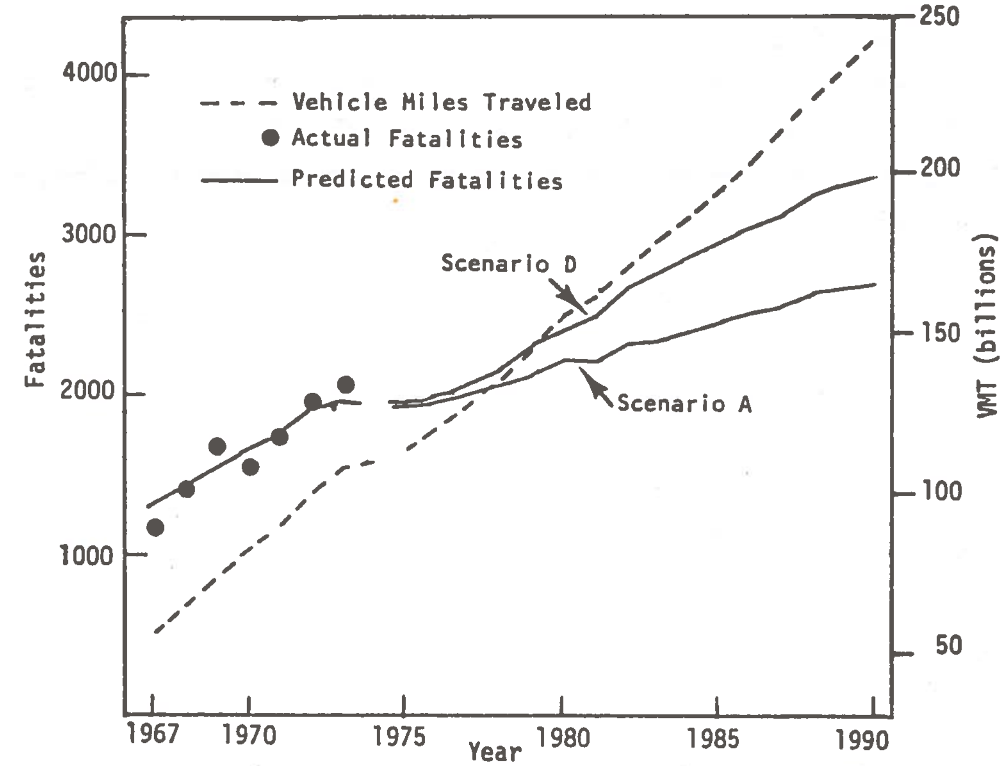


Figure 5.1-3b. Representation of the past fatality trend and projection of fatalities for urban interstate highways.

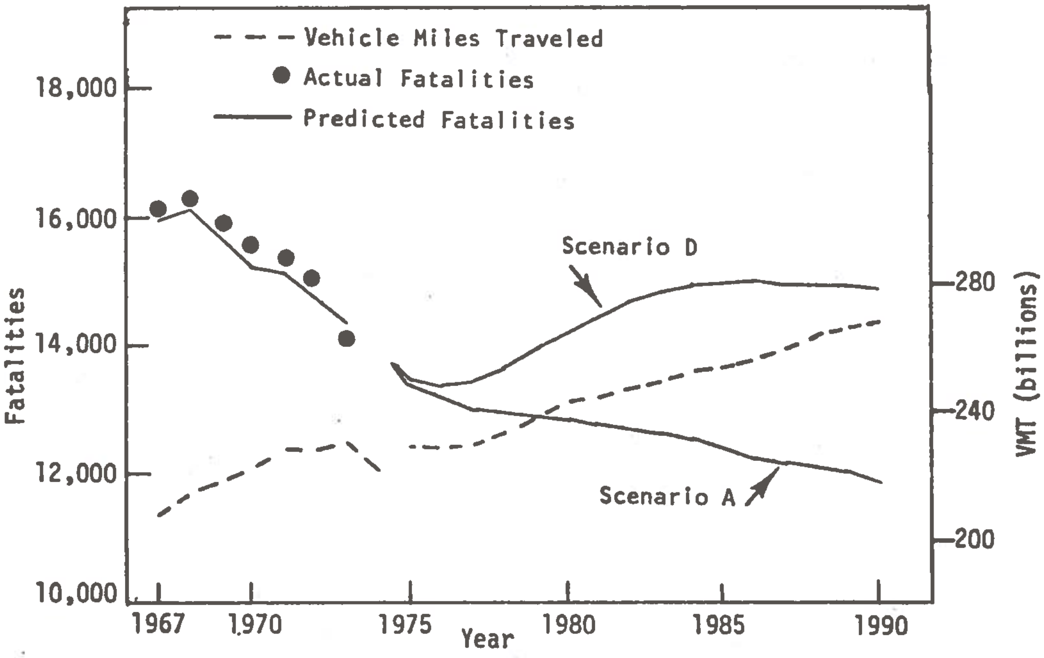


Figure 5.1-3c. Representation of the past fatality trend and projection of fatalities for main rural roads. It should be noted that part of the declining trend from 1967 through 1973 may be due to a decline in the number of main rural road highway miles by 5%.

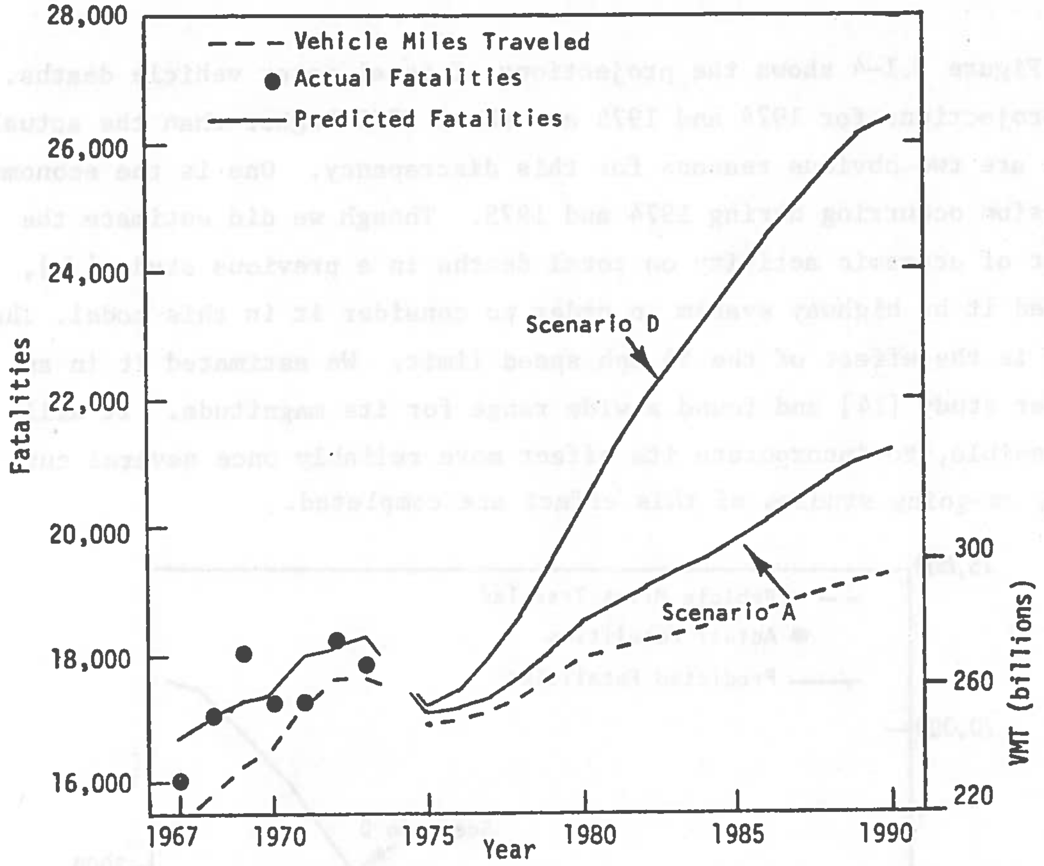


Figure 5.1-3d. Representation of the past fatality trend and projection of fatalities for other rural roads.

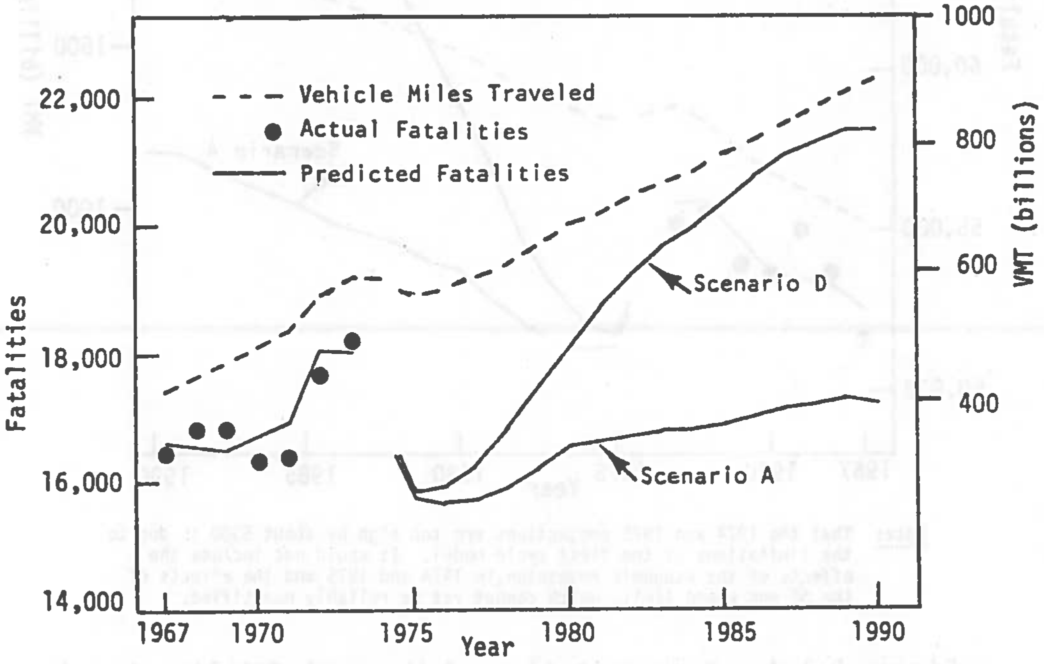
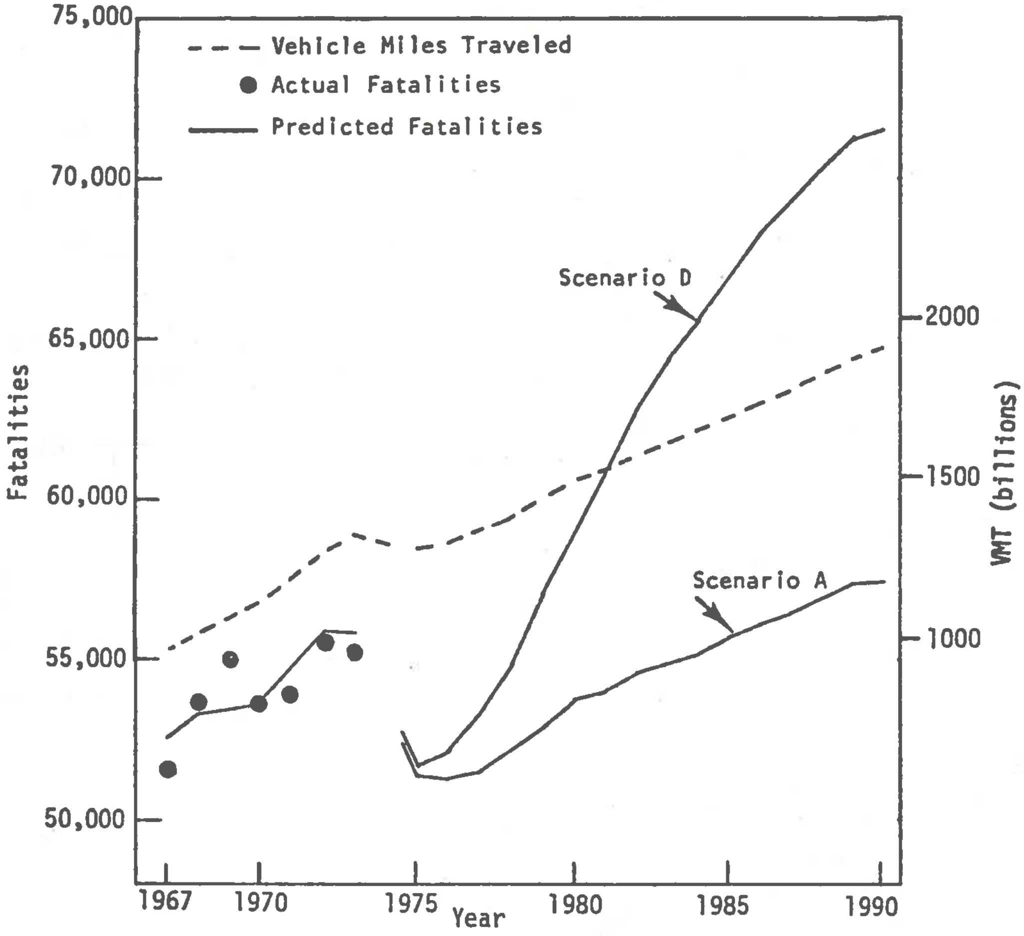


Figure 5.1-3e. Representation of the past fatality trend and projection of fatalities for urban highways and streets.

Figure 5.1-4 shows the projections of total motor vehicle deaths. The projections for 1974 and 1975 are about 5000 higher than the actual. There are two obvious reasons for this discrepancy. One is the economic recession occurring during 1974 and 1975. Though we did estimate the effect of economic activity on total deaths in a previous study [6], we need it by highway system in order to consider it in this model. The other is the effect of the 55 mph speed limit. We estimated it in an earlier study [14] and found a wide range for its magnitude. It will be possible, to incorporate its effect more reliably once several currently on-going studies of this effect are completed.



Note: That the 1974 and 1975 projections are too high by about 5000 is due to the limitations of the first cycle model. It could not include the effects of the economic recession in 1974 and 1975 and the effects of the 55 mph speed limit, which cannot yet be reliably quantified.

Figure 5.1-4. Representation of the past fatality trend and prediction of all motor vehicle deaths.

5.2 AIR TRANSPORT PROJECTIONS

5.2.1 Input Data

The following input data are required by the Aircraft Transportation Model:

- Number of years of the projection period, indicator for the first year of the projection period and identification of each calendar year in the period.
- Intercept and slope for the regression equations predicting fatalities for:
  - Scheduled domestic air carrier takeoff/landing operations
  - Scheduled domestic air carrier enroute operations
  - General aviation.
- Transportation data for each year of the projection period.
  - Domestic air carrier revenue departures in millions
  - Domestic air carrier revenue miles in billions
  - General aviation miles in billions.
- Fatality per fatal accident rates for each year of the projection period.
  - Domestic air carrier takeoff/landing operations
  - Domestic air carrier enroute operations
  - General Aviation.

The projections of air transportation data from 1976-1990 received from the DOT Transportation Systems Center, which form the basis for the projection of air fatalities during this period, are given in Table 5.2-1. During this period, air carrier revenue departures are projected to increase by 61.0%; air carrier revenue miles are projected to increase by 63.9%; and general aviation miles increase by 125.2%.

The general form of the equation for predicting fatalities in an aircraft class is as follows:

$$\text{Fatalities} = \text{TM} \times \text{FFA} \times e^{(A+B\times T)}$$

where TM = a measure of travel (given in Table 5.2-1). (5.2-1)

FFA = Fatalities per fatal accident

A = intercept of regression equation

B = slope of regression equation

T = indicator of year (0 = 1962, 1=1963,...,28=1990)

The input data values for the regression equation coefficients are given in Table 5.2-2.

TABLE 5.2-1. PROJECTED AIR TRANSPORTATION DATA

Year	Scheduled Domestic Air Carrier Revenue Departures (millions)	Scheduled Domestic Air Carrier Revenue Miles (billions)	General Aviation Miles (billions)
1976	5.288	2.063	5.255
1977	5.561	2.136	5.449
1978	5.719	2.207	5.865
1979	5.923	2.281	6.202
1980	6.194	2.363	6.627
1981	6.357	2.456	6.991
1982	6.571	2.549	7.293
1983	6.731	2.641	7.735
1984	6.997	2.763	8.207
1985	7.208	2.834	8.711
1986	7.420	2.936	9.249
1987	7.687	3.042	9.824
1988	7.953	3.151	10.439
1989	8.228	3.265	11.096
1990	8.513	3.382	11.799

TABLE 5.2-2. REGRESSION EQUATION COEFFICIENTS FOR AIRCRAFT CLASS

Aircraft Class	Intercept A of Regression Equation	Slope B of Regression Equation
Air Carrier Takeoff/Landing	0.0126	- 0.0818
Air Carrier Enroute	0.4713	- 0.2169
General Aviation	5.3605	- 0.0127

The fatalities per fatal accident ratios used were dependent on a number of assumptions which are discussed in the next section.

5.2.2 Assumptions

The major assumptions made in the application of the Aircraft Transportation Model to the projection period from 1976-1990 centered on the treatment of the fatalities per fatal accident ratios. Analyses of the ratio of fatalities per fatal accidents in general aviation flying during the period from 1962-1973 revealed a fairly constant value close to 2.0

which persisted from year to year. It was assumed that this ratio would persist during the projection period.

The situation is not as simple for scheduled domestic air carrier operations. Analysis of the data in the 1962-1973 period revealed a tendency for increasing fatalities per fatal accident (FFA). This tendency is expressed by the equation

$$FFA = 21.6 + 2.2976 \times T, \qquad (5.2\text{-}2)$$

where T is defined as in (5.2-1). This equation applies to all air carrier operational accidents, both takeoff/landing and enroute.

In making projections of fatalities from accidents in domestic air carrier operations, two assumptions were implicit:

(1) The fatalities per fatal accidents ratio for enroute operations and takeoff/landing operations are equal.
(2) The ratio will either be defined by the above equation throughout the 1976-1990 period <u>or</u> alternatively the ratio will be set equal to the value for 1973.

The resultant input data for the fatalities per fatal accident ratio is given in Table 5.2-3.

TABLE 5.2-3. FATALITIES PER FATAL ACCIDENT RATIO

Year	Scheduled Domestic Air Carrier		General Aviation
	Fatality Trend Equation	Trend Equation Value for 1973	
1976	53.8	46.9	2.0
1977	56.1		
1978	58.4		
1979	60.7	For	For
1980	63.0		
1981	65.3	All	All
1982	67.6	Years	Years
1983	69.9		
1984	72.1		
1985	74.4		
1986	76.7		
1987	79.0		
1988	81.3		
1989	83.6		
1990	85.9		

5.2.3 Projections

Given the input data and the assumptions discussed in the preceding two subsections, projections of annual fatalities in scheduled domestic air carrier passenger/cargo service and in general aviation flying were made for the period from 1976 to 1990. These projections, together with observed and predicted fatalities from 1962 to 1973, are given in Figure 5.2-1 and Figure 5.2-2. In considering the projection results for both air carriers and general aviation, one must remember that these annual fatalities have been generated by a relatively simple, first level model. The air carrier results do not explicitly take into consideration the evolving fleet of jet aircraft with radically different passenger capacities. The general aviation flying results do not attempt to take into consideration significantly different safety trends among different types of commercial flying.

The projection of fatalities in scheduled domestic passenger/cargo air carrier service is a particularly challenging task. As Figure 5.2-1 shows, there are large year-to-year variations in fatalities. Data were not yet available for 1974 and 1975, accounting for the discontinuity between the past trend and the projection. Although both projections indicate declining fatalities through 1990, the assumptions made concerning changes in the fatalities per fatal accident ratio significantly influence the results. When the ratio is allowed to increase according to the trend described in Section 4.2.1, annual projected fatalities decline to 80. When the 1973 ratio trend value is used throughout the projection period, annual projected fatalities decline to 40.

Annual fatalities in general aviation flying are projected to increase significantly throughout the period to a level of about 3500 in 1990 from levels near 1400 during the early 1970's. Note in Figure 5.2-2 the discrepancies between the values predicted from the past trend and from the projections. The difference of about 200 fatalities annually in the years 1971, 1972 and 1973 is due to differences in the estimates used of annual miles of general aviation flying. Since the prediction equation was based on the lower estimates of general aviation miles and

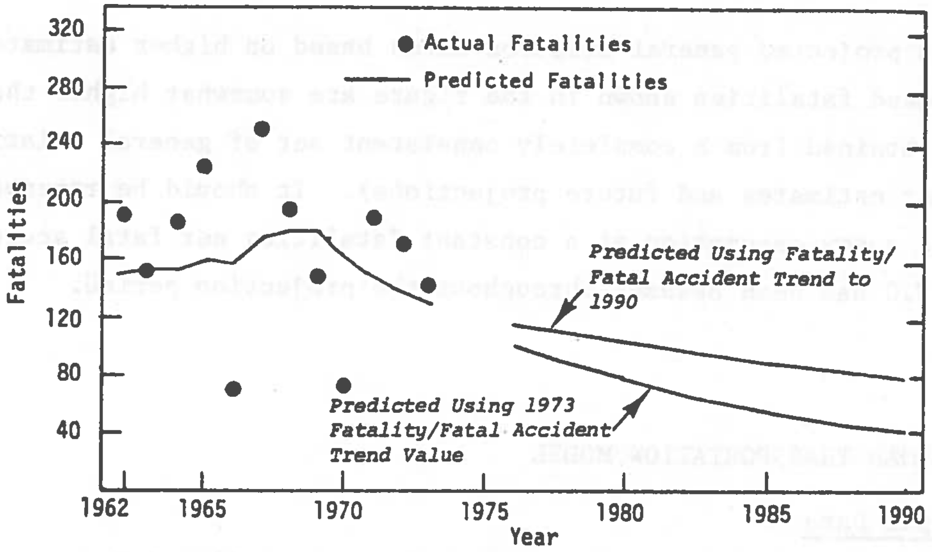


Figure 5.2-1. Scheduled domestic passenger/cargo air carrier fatalities.

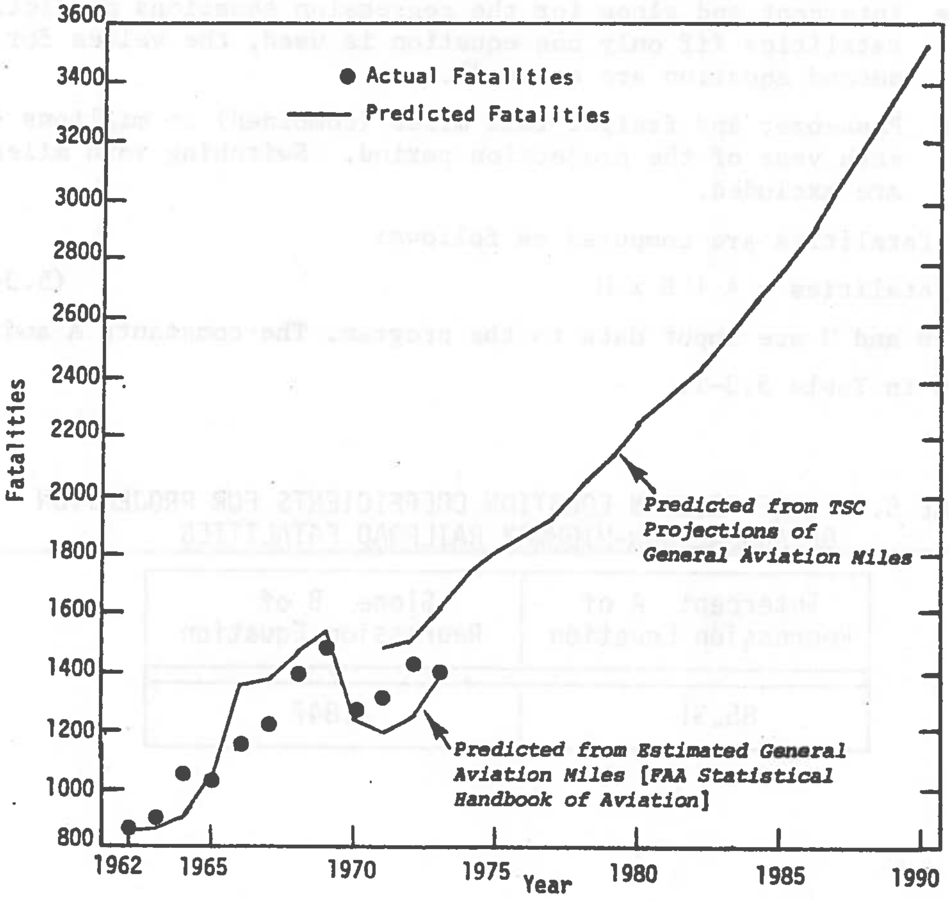


Figure 5.2-2. General aviation fatalities (fatalities per accident = 2.0).

applied to projected general aviation miles based on higher estimates, the projected fatalities shown in the figure are somewhat higher than would be obtained from a completely consistent set of general aviation miles (past estimates and future projections). It should be remembered also, that a key assumption of a constant fatalities per fatal accident ratio of 2.0 has been assumed throughout the projection period.

5.3 RAILROAD TRANSPORTATION MODEL

5.3.1 Input Data

The following input data are required by the Railroad Transportation Model.

- Number of years of the projection period.
- Intercept and slope for the regression equations predicting fatalities (if only one equation is used, the values for the second equation are omitted).
- Passenger and freight rail miles (combined) in millions for each year of the projection period. Switching yard miles are excluded.

Railroad fatalities are computed as follows:

$$\text{Fatalities} = A + B \times M \tag{5.3-1}$$

where A, B and M are input data to the program. The constants A and B are given in Table 5.3-1.

TABLE 5.3-1. REGRESSION EQUATION COEFFICIENTS FOR PROJECTION OF ANNUAL NON-HIGHWAY RAILROAD FATALITIES

Intercept A of Regression Equation	Slope B of Regression Equation
85.31	2.847

The projections of passenger and freight rail miles (M) from 1976-1990, which form the basis for the projections of annual non-highway railroad fatalities during this period, are given in Table 4.3-2. The rail miles are projected to increase 66.6% from 1976 to 1990.

TABLE 5.3.2. PROJECTED PASSENGER AND FREIGHT RAIL MILES

Year	Projected Rail Miles* (millions)	Year	Projected Rail Miles (millions)
1976	296	1984	398
1977	312	1985	417
1978	322	1986	426
1979	334	1987	447
1980	347	1988	460
1981	360	1989	475
1982	373	1990	493
1983	386		

*Does not include switching yard miles.

5.3.2 Assumptions

No additional assumptions are made in the application of the Railroad Transportation Model. The basic two factors to be kept in mind in the computation of annual fatalities are:

(1) The fatalities are "non-highway"; that is, fatalities in motor vehicles struck at grade crossings are excluded from this model and included in the Highway Transportation Model, and

(2) The projections of passenger and freight rail miles do <u>not</u> include switching yard miles, but deaths in switchyard accidents are included. The relation used for predicting fatalities are derived under the same assumptions.

5.3.3 Projections

The annual non-highway railroad fatalities projected to occur from 1975 to 1990 are given in Figure 5.3-1. This figure also shows the actual and "predicted" fatalities from 1965-1974. Annual rail fatalities are projected to increase from the current range between 700-800 to almost 1500 by the year 1990. The figure shows that fatalities declined from over 900 in 1965 to less than 700 in 1971-1972 but increased thereafter. The projections indicate a continued increase reflecting the projected increases in rail miles.

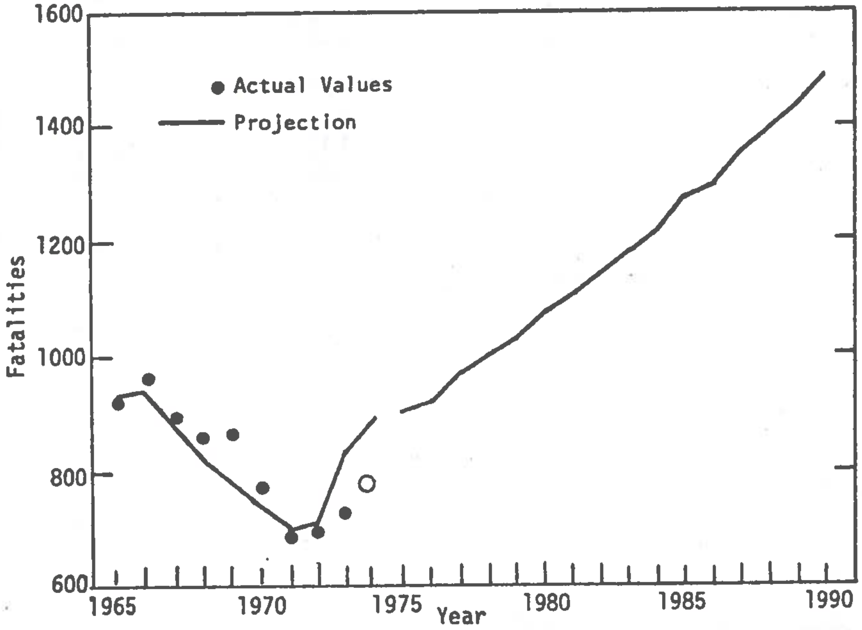


Figure 5.3-1. Representation of the past trend in non-highway railroad accident deaths and its projection. The actual value for 1974 (indicated by ○) was not used when developing the model.

6. A SECOND LEVEL MODEL

6.1 INTRODUCTION

The first level model has several obvious limitations:

- The basic equations are highly simplified and of limited numerical accuracy, and only a few relevant factors are incorporated.
- It requires traffic information as input, and cannot use information on transport requirements.
- It is limited to existing modes of transport.

Considering the complexity of the transportation process, as discussed in Paragraph 3.1.1, it is obvious that there can be no single "second level" model. There is rather a wide range of improvements and refinements possible. The scope of the second level model proposed in this section is based on the experience of developing the first level model, and on our perception of what is known about future transportation demand from economic and other studies.

Development of the second level model will require work in two areas:

- Improving the first level model by disaggregating data, considering more factors, and refining the basic equations, to make them more realistic and to expand the range of alternatives which can be explored with the model.
- Expanding the scope of the model. The main aspect of this is to add a submodel which will translate social and economic demand for travel and transportation into the traffic data used as inputs by the first level model (or the improved model) described above. Another expansion is to develop a methodology incorporating new, as yet unspecified modes of transport into the structure of the model.

6.2 IMPROVING THE FIRST LEVEL MODEL

6.2.1 The Highway Transport Model

The first level highway transport model needs improvement in the following areas:

- Disaggregation of different kinds of deaths. Motor vehicle occupant deaths, pedestrian deaths, railroad grade crossing deaths are influenced by different factors. A realistic model has to account for the influence of these factors separately.

- Reliably quantifying the interactions between motor vehicles. Collisions between cars, between cars and motorcycles, between cars and trucks, etc. have quite different consequences in terms of injuries and deaths. The current frequencies of the different types of collisions is not sufficiently known to provide a basis for estimating the effects of future changes in the mix of motor vehicles on the highways.

- Quantifying the influence of vehicle occupancy changes on the number of deaths. A change of vehicle occupancy will change the expected number of deaths per accident accordingly. "Accident" is, however, a practically undefined event. The probability of the well-defined events "fatal accidents," however, is dependent on occupancy.

- Quantifying the impact of other factors, especially speed and future vehicle improvements on highway deaths.

- Quantifying the impact of motor vehicle miles and train miles on the number of railroad grade crossing accidents.

- Improvement of the accuracy and reliability of the relation between vehicle miles of travel and motor vehicle accident deaths.

Improvements in all these areas are possible, using available data. To what extent the model can actually be improved depends on two factors: (1) the effort spent on analyzing the data, and(2) the reliability of the data, as established by the analysis under (1). The reliability determines, in turn, which effort can be productively spent in these areas.

Though improvements can be made in the areas listed above, a critical problem is to integrate them. For instance, disaggregation of deaths by type of victim is easily possible on a national basis, and overall models to represent the past time trends of these numbers can be developed. On the other hand, these disaggregations are not available on a state-highway system basis, data which are used in our model establishing the relations between vehicle miles of travel and deaths. Thus, the degree to which it is worthwhile to improve our knowledge in any single area depends on how well the results and the basic data can be integrated with those in the other areas.

The following subparagraphs describe how the first level model can be improved in the various areas, based on the experience of developing the first level model and additional studies of the literature and data bases.

6.2.1.1 Disaggregation of Fatality Figures

Different factors influence the number of highway accident deaths in the following categories:

- Passenger car occupant deaths
- Truck occupant deaths
- Bus occupant deaths
- Motorcycle rider deaths
- Bicyclists deaths, and
- Pedestrian deaths.

For the first five categories, one can expect that the number of deaths, *ceteris paribus*, depends only on the vehicle miles of travel of the various vehicle types. The number of pedestrian deaths, however, which are the second largest category, accounting for one-fifth of all highway deaths, will depend also on the number of pedestrians, which in turn, might be related to the total population. Total population may not be an adequate measure, because the risk of being killed as a pedestrian by a motor vehicle in a given year varies greatly between age groups, from a low of 3 per 100,000 in the 25-44 age group, to a high of 12 in the 65 and older group. In addition, the time trends of these population death rates for the different age groups differ considerably. This, together with a previous study of this problem [6], leads us to the conclusion that a functional model cannot be developed (within the scope of the second level model) which expresses the number of pedestrian highway deaths as a function of population by age group, vehicle miles of travel by vehicle type, and other factors which reflect the actual involvements of these groups in pedestrian accidents.

It might be possible to develop purely formal models which reflect the past trends well, but their predictive qualities will be questionable. Currently, the best approach appears to be trying to separate pedestrian deaths from the death figures used in the other analyses, and treat them separately in a purely formal manner.

For bicycle deaths the situation is similar--even worse: not only are there no exposure measures for bicycle use, but even for the total numbers of bicycles in use only crude estimates are available [2]. Again, we suggest trying to separate bicycle deaths wherever possible, and at most try to develop a simple formal model for the time trend of their number.

We will deal in the next subparagraph with a different aspect of the disaggregation of the other classes of motor vehicle deaths.

6.2.1.2 Interactions between Motor Vehicles

The consequences of single-vehicle crashes, in terms of personal injuries and death depend only on the characteristics of the vehicle involved. The consequences of collisions between two vehicles, however, depend on the characteristics of both. The consequences of collisions between passenger cars of different classes are fairly well-known (although they might change in the future due to changing design principles of cars). The consequences of collisions between cars and trucks are, however, not adequately understood. One reason is that "truck" covers a wide range of vehicles, from a weight as low as 5000 lbs to as high as 80,000 pounds. Another reason is that they have been studied less. As shown in Subparagraph 4.2.2.3, the number of deaths in collisions between cars and trucks is known with such low accuracy that it is useless for even gross analyses.

The problems are similar with collisions involving buses and other vehicles, and trucks and other vehicles. However, because of the much lower numbers of deaths involved, these problems have a lower priority. Without a numerically realistic taxonomy of the frequencies of the various kinds of motor vehicle occupant deaths--by single-vehicle, two-vehicle and multi-vehicle accidents, and by the types of vehicles involved--

no estimate of the effects of changing vehicle mix is possible. Therefore, we propose as one of the most important tasks in the development of the second level model, the processing of original accident data tapes, and the use of other relevant material, such as sufficiently detailed accident summaries, to obtain reliable information of the type presented in Tables 4.2-2 and 4.2-3. To the extent possible, the following tables should be produced: nationally representative tables; tables for specific highway types; and perhaps, regional tables. These should be compared against whatever aggregate information is available from other sources. A relatively minor step is to disaggregate the "cell" representing collisions between two passenger cars. The currently available information is sufficient to represent the involvement of different classes of passenger cars with an accuracy which is much higher than for the rest of the tables. However, when new data for the rest of the table are being developed, it requires only little additional work to develop more current data for disaggregating car-car collisions.

We consider a realistic vehicle interaction model as one of the most important parts of the second level model. Even though absolute numbers of deaths due to changes in various factors might not be predictable with high accuracy, a vehicle interaction model would allow predictions of relative changes in deaths due to changes in the vehicle mix with relatively higher accuracy.

6.2.1.3 The Influence of Vehicle Occupancy Changes

An increase in the number of vehicle occupants would, given a certain set of crashes, result in a proportional increase in the expected number of vehicle occupant deaths. However, trend analyses, as described in Subparagraph 4.2.2.2 cannot meaningfully be performed with numbers of crashes, because no uniform definition of "crash" exists. There are differences among the definitions of the various states, some of them changing with time, and there are additional reasons to assume that the definition of a "crash" does not stay constant over time. One is that the definition of a property-damage-only crash contains a dollar threshold, which corresponds to different physical damages in different years, and that the mix of cars with different repair costs changes over time. Thus one is restricted to the analysis of time trends of either fatal accidents or of fatalities, both of which are presumably known with much higher accuracy. Conceptually, the number of fatal accidents would be preferable, because they represent accidents exceeding a certain level of severity, and accidents are the event directly resulting from the presence of a certain number of vehicles under certain conditions on a highway. However, if the probability of an occupant's death in a severe accident is less than one, then the probability that an accident results in at least one fatality will be increasing with the number of occupants. If the probability is very small, then the probability of an accident's resulting in at least one fatality will be approximately proportional to the number of occupants. Thus both the number of fatal accidents and of fatalities are affected by the number of accidents and by vehicle occupancy. An analysis of the time trends of fatal accidents or of fatalities does not, therefore, allow the separation of the effects of time trends in the number of accidents, and in the vehicle occupancy.

For the second level model, relations between the number of fatal accidents and of fatalities should be studied more closely than was possible in the first level model. In addition to studying the past trend, additional information on vehicle occupancy, on the frequencies of the various types of accidents, and other information should be used.

A secondary point is that with increasing automobile occupancy, different seats in an automobile are occupied. The usual order is: first occupant is the driver, the second occupant takes the right front seat, the third and fourth the outboard rear seats, and the center front and center rear seats are occupied last. Since the fatality risks on the seats are likely to differ, one can expect a nonlinear relation between occupancy and fatalities.

Empirical studies of the effects of occupancy are limited by the availability of relevant data: there is little information available on the presence of occupants other than the driver, if they are not injured.

Aggregate data on fatalities and fatal accidents can be used only if corollary information on occupancy is available. Accident data alone can be used only when very detailed analysis can be performed (for instance, the frequency of injured occupants when the driver is killed, compared to the frequency of driver injury when an occupant is killed).

6.2.1.4 The Impact of Other Factors

Speed is known to have a strong influence on the fatality risk, and less so on the injury risk, once an accident has occurred. Its influence on the occurrence of accidents, however, is complicated: the variance of travel speeds seems to have a strong influence, but it is highly plausible from physical arguments that the absolute value of the travel speed should also have an influence.

Up to 1973, travel speeds showed a continuously increasing trend, which leveled off during the last years. However, due to the stability of this trend, it is not empirically possible to separate its effects from those of other factors which showed a smooth time trend. Thus, the time changing coefficients of the death-VMT relations derived in Subparagraph 4.2.2.2 are probably to some extent affected by the past trend in travel speeds. Therefore, extrapolations to future years might implicitly assume a continuation of such a trend. A realistic model, however, should include speed as an explicit variable in order to make predictions under alternative assumptions on future speed trends.

Previous studies on the effects of speed on accident severity and frequency have been revised by us, and additional analyses performed [6, 14, 48]. The results, however, were not sufficient to credibly model the influence of speed on accidents and their severity. Following the introduction of the 55 mph speed limit, various studies have been conducted, or are currently being conducted [50,51 , 52], which will provide new material. These studies should be reviewed and if they allow, together with earlier studies, credible conclusions on the overall relations between travel speed, accident frequency, and accident severity, these should be incorporated into the second level model.

One reason not to be too optimistic about firm conclusions is that an economic recession began about the same time as the fuel crisis and imposition of the 55 mph speed limit. It is well-known that the number of traffic deaths closely parallels the level of economic activity, as measured, e.g., by the Federal Reserve Board *Index of Industrial Production*. This relation has been formally, but not functionally, quantified [6]. However, the current recession had a depth far beyond those of the recessions of 1954,1958 and 1970, on which the empirical relation was primarily based. Therefore, a quantitative estimate of its effects on the basis of this relation is somewhat speculative. So we have to expect that studies of the effects of the 55 mph speed limit may not be able to fully separate them from those of the recession.

The mechanism by which economic activity influences highway deaths--which is not (at least not entirely) due to a change in the number of vehicle miles of travel, or truck miles of travel--is not understood. However, a brief analysis of this relation might be worthwhile for the second level model. As shown in Subparagraph 4.2.4 the effects of the 1970 recession were visible in the death trends on urban interstate highways, urban highways, and "other rural roads," but not on rural Interstate Highways, and main rural roads; it was present on highways carrying mainly local travel, but not on highways carrying mainly long distance travel. Thus, if this difference should hold not only for the effects of short term fluctuations in economic activities, but also for the long term effects, then incorporation of projections of economic activity might improve projections of deaths for the different highway classes. We consider, however, such an attempt as somewhat speculative; it might not be possible to achieve reliable results.

Important factors influencing automobile occupant deaths during the last decade were the increasing use of small cars, and the effects of the Federal Motor Vehicle Safety Standards. We have previously developed a model for the effect of these factors [6 , 14]. The resulting "risk factor" has been incorporated, in a crude fashion, in the first level model (Subparagraph 4.2.3.4).

The basis for modeling the effects of car size and collisions between cars of different sizes was primarily accident data for cars of the model years 1965 through 1973. The only characteristic of cars used was weight.

Actually, weight, size, and design characteristics influence the occupant injury risk in a crash. Even though in the past, weight and size were fairly closely correlated, this correlation is likely to change in the future. When gasoline prices increased, many car buyers selected smaller cars with better gas mileage, but added a lot of optional equipment which increased the weight (and thereby reduced the gas mileage). Thus, the relation between weight and size was changed. Currently, automobile manufacturers are, in order to improve fuel economy, reducing the weight of cars as much as possible. Therefore, one has to expect in the near future a much looser relation between vehicle weight and size, and in the future a changed relation between occupant injury risk and vehicle weight.

Therefore, not only an updating of the coefficients of the automobile occupant risk model is desirable, but also a refinement which incorporates weight and size separately.

6.2.1.5 Railroad Grade Crossing Accidents

Railroad grade crossing accidents are influenced both by vehicle traffic, and by rail traffic at grade crossings. There is, however, no simple relation between the number of traffic deaths at railroad grade crossings, and the total vehicle miles of travel, and total train miles: deaths at railroad grade crossings changed much less over time than these measures of traffic.

Since the number of deaths at railroad grade crossings is fairly large--about 1200--a special model is desirable as part of the second level model. To develop such a model, disaggregated measures of highway traffic, and rail traffic should be used. Interstate highway traffic should be excluded, and possibly also traffic on other highway types with few grade crossings. For rail traffic, main lines with no or few grade crossings, such as the Boston-Washington line should also be excluded. In addition to studying aggregate data in this manner, special studies of accident frequencies at railroad grade crossings (a review of such studies is [14]) should be reviewed to determine whether they can give insight into the interactions between trains and cars at grade crossings.

6.2.1.6 Relations between Vehicle Miles of Travel and Motor Vehicle Deaths

The relations between Vehicle Miles of Travel and Motor Vehicle Deaths derived in Paragraph 4.2.2 are crude in several respects. They use aggregated numbers of deaths, they use only a crude adjustment for changes in vehicle mix and vehicle characteristics, and they lump many factors together into simple time trends. The most important deficiency, however, is that in some cases arbitrary adjustments had to be made to obtain equations which represented the actual time trends of deaths.

Therefore, a more thorough analysis of these relations is desirable for the second level model. First, it is highly desirable to disaggregate total deaths into classes and separate pedestrian and bicyclist deaths and deaths at railroad grade crossings. The effects of changing vehicle characteristics and vehicle mix should be considered to the extent possible, and the effects of speed and other factors if possible. Then, the adjusted death numbers should be subjected to a more thorough analysis than in Paragraph 4.2.2. Vehicle miles of travel per highway mile is not a perfect measure of traffic density, because the number of lanes is not considered. The national average for rural Interstate Highways is four lanes, for urban Interstate Highways 5.6 lanes. However, the average number of lanes varies between states. Therefore, a more thorough analysis would have to use lane-miles rather than highway miles for each state-highway type combination.

After these adjustments, a preliminary analysis should be performed to determine whether an influence of other factors is suggested. Figure 6.2-1 illustrates a potential effect: that states with a wide range of traffic densities on their highways will show a lower figure of deaths per lane mile than states with less variation in traffic density. Various analyses should be performed to determine whether there are any obvious factors related with states consistently higher or lower than the average relation.

In the development of the first level model, it was found that for main rural roads a relation between deaths/highway mile and VMT/highway mile best fitting the points representing the various states consistently under-predicted the figures of total deaths on main rural roads, which

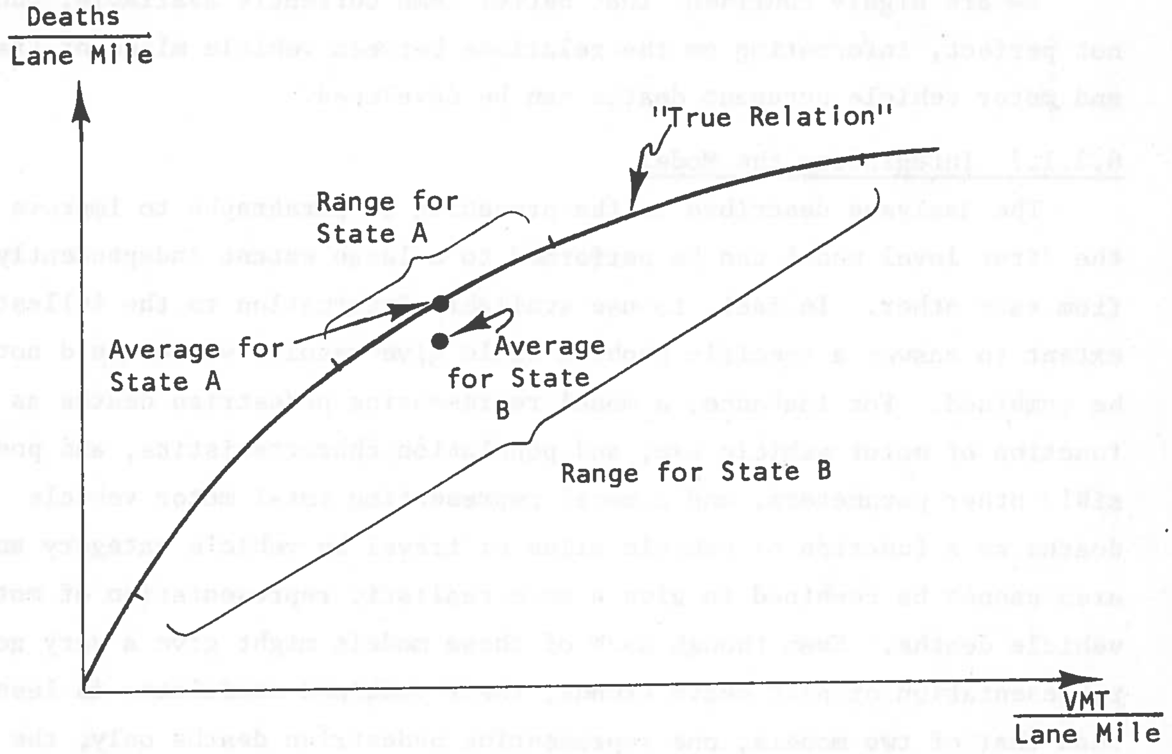


Figure 6.2-1. Illustration of the effect of using state averages when the relation between deaths per lane mile and VMT per lane mile is non-linear. It is assumed that the highway segments in state A vary less in traffic density than those in state B. Even though the average densities may be the same in both states, state B has a lower average of deaths per lane mile.

could, however, be satisfactorily corrected by arbitrarily changing one factor. The reason for this may be that all states were weighted equally, and that therefore, states with relatively few deaths had as much influence as states accounting for a large share of total deaths. It would be desireable to develop in future studies an appropriate system of weights so that states with few deaths do not unduly affect the results.

Finally, it should be studied whether the relations between deaths/lane mile and VMT/lane mile can be better represented by some continuous function rather than a broken linear function, if any linear function. Also, it should be studied whether highway type could be further aggregated, possibly after introducing certain adjustment factors.

We are highly confident that better than currently available, though not perfect, information on the relations between vehicle miles of travel and motor vehicle occupant deaths can be developed.

6.2.1.7 Integrating the Model

The analyses described in the preceding subparagraphs to improve the first level model can be performed to a large extent independently from each other. In fact, to use available information to the fullest extent to answer a specific problem would give results which could not be combined. For instance, a model representing pedestrian deaths as a function of motor vehicle use, and population characteristics, and possibly other parameters, and a model representing total motor vehicle deaths as a function of vehicle miles of travel by vehicle category and area cannot be combined to give a more realistic representation of motor vehicle deaths. Even though each of these models might give a very good representation of past death trends, their combined usefulness is less than that of two models, one representing pedestrian deaths only, the other nonpedestrian deaths only, even though the accuracies of these models might be less than in the aggregate case above.

Therefore, it is important when developing the second level model to use compatible disaggregations of deaths,of accident categories, and, to the extent possible, input requirements which are, as far as possible, common to all submodels (although one or several submodels may require input data which no other submodel uses).

6.2.2 Air Transport

6.2.2.1 Certificated Air Carriers

The most obvious shortcoming of the model developed in Paragraph 4.3.1 is that it assumed time trends in the fatal accident rates (per mile flown, and per operation), and in aircraft occupancy. Considering the change in the aircraft fleet, their differing risks of fatal accidents, and their differing passenger capacities, as shown in Tables 4.3-2 and 4.3-3, it seems that the time trends might, at least partially, be a consequence of a changing aircraft fleet. This should be studied for the second level model. Considering the relatively low number of deaths in scheduled air traffic accidents, we do not suggest further refinements for the second level model.

6.2.2.2 General Aviation

The first level model gave overall an acceptable fit of the past fatality trend in general aviation. Conceptually, however, this model is unsatisfactory because it considers only aircraft miles, and not operations, as input variables. In addition, Figures 4.3-5 and 4.3-6 show that there are great differences between the fatality rates per plane mile for the different kinds of general aviation activities--personal flying having the highest, business flying the lowest fatality rate. Therefore, a change in the composition of general aviation flying would result in a change in the number of deaths, even though total aircraft miles may remain unchanged.

Therefore, we suggest for the second level model to perform a more detailed analysis, disaggregating by type of flying, and separating the influence of the number of miles flown, from that of the number of operations.

6.2.3 Rail Transport

The first level rail transport accident model developed in Subsection 3.4 is unsatisfactory because of the unexplained drop in the fatality rate between 1970 and 1971. To develop a better second level model, we suggest disaggregating railroad accident non-highway deaths, primarily into employees on duty and trespassers. The number of train passengers killed is too small to justify development of a separate model. We suggest studying whether a further disaggregation of railroad employee deaths into those due to train accidents, train service accidents, and non-train accidents, together with a distinction of switchyard train-miles, and rail train-miles, will lead to an explanation of the change between 1970 and 1971 and thereby to a more realistic model.

6.2.4 Water Transport

We have not been able to develop a first level model for water transport fatalities, where we take water transport in the narrow sense of involving commercial vessels. In order to develop a second level water transport model that is comparable with those of the other modes would require obtaining more detailed data from the U.S. Coast Guard on vessel casualties and selected deaths. Explorations of measures of waterborne transport and of relationships among the various categories of accidents and deaths would also be necessary. At best, only simple linear realtions could be expected from this effort.

6.3 EXPANDING THE SCOPE OF THE FIRST LEVEL MODEL

The scope of the first level model can be expanded in three ways:

- Adding a model which will convert transport and travel volume data into conveyance miles which are used as inputs in the first level model.
- Adding a model which will translate highway travel and shipping patterns given in terms of origin to destination flows into vehicle miles of travel by state, which is used as an input in the first level model.
- Adding a model accounting for access to modes.
- Adding new modes of transportation.

6.3.1 Use of Travel and Transport Volume as Input Data

The demand for travel and transport is described by the number of passenger miles of travel, or of ton-miles. The number of conveyance miles--be they cars, buses, trains, aircraft--needed to satisfy this demand depends on the capacity of the conveyances and load factors. Thus, given travel or transport volume, capacities and load factors, it is easy to calculate conveyance miles. This, of course, is only a first approximation. Load factors and frequency of service are related, and frequency of service often determines the choice of a mode. Thus, the simple model is valid,at best,in a narrow range of load factors.

An important aspect is that average capacities have sometimes increased over the years, especially for aircraft. In this case, a realistic model would have to account for the changing mix of the aircraft fleet, and the correspondingly changing average capacity. The average capacity, however, might not be an adequate measure: aircraft of different operating ranges tend to have different capacity. Thus, the distribution of the lengths of flights will affect the mix of aircraft used, and will also determine the number of operations (take-offs and landings) needed to provide the aircraft miles of travel. Therefore, in the case of air travel, a model using passenger miles of travel, the distribution of trip lengths, the available aircraft fleet, and load factors, and giving aircraft miles, and number of operations by type of aircraft is not trivial.

6.3.2 Geographical Disaggregation of Highway Transport

A projection of transport and travel demand on an economic basis provides volumes of travel or transport from the various origins to the various destinations (where certain or all origins and destinations may be the same geographical areas). How origin and destination are defined depends on the level of detail of the models used for the projection. A very gross model might use very few regions (perhaps 4-6) as origins and destinations. Using the 50 states as origins and destinations would be a very detailed model, and using the Standard Metropolitan Statistical Areas would probably be the highest level of detail which is meaningful.

The highway transport model, on the other hand, needs vehicle miles of travel by state and highway type as inputs (and the second level model may accept them separately by vehicle type). To translate the flows from origins to destinations, into travel within states, one needs a matrix which assigns to each origin and destination pair appropriate highway miles, on certain highway types, by state. To develop such a matrix would be the main task of this extension of the model. In addition, one has to provide for distributing "local" transport, that is transport beginning and ending in an area represented by one origin/destination point over the appropriate states and highways.

6.3.3 Access to Certain Modes

With very limited exceptions, use of any transport mode but motor vehicle requires use of automobiles or trucks for access to the terminals. Therefore, the overall consequences, in terms of deaths, of using other modes are not adequately described by only counting the deaths actually occurring when using that mode. The deaths occurring when traveling to and from airports might be a minimal fraction of all automobile accident deaths, but their number might be comparable to those resulting from aircraft accidents. Therefore, if one wants to obtain a realistic estimate of the safety impact of shifting travel from the automobile to air, or between any other modes, one has to include the access modes.

A precise modeling of these relations could be very difficult, because the length of the access trip can vary greatly not only between areas, but even between cities in the same area. Therefore, only approximate estimates of averages appear practicable. Even they require study of fairly detailed data.

6.3.4 New Modes of Transport

Obviously, it is not possible to give a detailed outline for a model accommodating all conceivable new modes of transport. However, it is possible to give a generally applicable structure which can be specialized for any new mode described in sufficient detail. One can grossly classify accident causes in the following way:

- Factors in the conveyance or operation,
- Interactions between conveyances of the same mode,
- Interactions between conveyances of different modes,
- Road, track, etc. traffic-control and environmental factors.

Factors in the conveyance or operation will result in an expected number of accidents proportional to the number of conveyance hours. Thus, assuming comparable speeds, the number will be proportional to conveyance miles. This assumes that there are no interactions between conveyances. Interactions can occur in the following way: "dense traffic" may affect the speed of the conveyances, it may affect the probability of an accident, and it may create the possibility of "interaction accidents":

accidents where another conveyance is being involved in an accident occurring to another, or events which became accidents only because another conveyance was nearby. In general, one might expect that new modes of transportation will incorporate traffic control systems which will reduce the probability of interaction accidents.

An example for interactions between conveyances of different modes are railroad grade crossing accidents. Their frequency is a function of the activities on both modes. However, one can imagine more complex interactions, e.g., between air cushion boats and conventional boats, where more complicated interactions are possible. In general, one can again expect that new transportation modes will have only minimal possibilities of interactions with other modes.

The last group of factors, related to roads, tracks, traffic control and environmental factors might become more important for new modes of transport. Failure of a traffic control system can affect a large number of conveyances simultaneously. If the system is "saturated," so that the physical separation of conveyances depends critically on the control system, major accidents can result. In such a case, one can expect that the number of accidents will not depend much on the number of conveyances, but more on the number of control system failures.

To develop these basic arguments into meaningful models requires at least gross specifications of the new modes to be considered.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

The review of the literature on transportation accidents, and the analyses of accident fatality trends, which were performed for the development of the first level model have shown that, currently, only a very crude model of the relations between accident deaths and the level of transportation activities can be developed.

Highway traffic accident deaths account for the vast majority of all transportation accident deaths, and have been extensively studied. However, not even the relations between highway deaths and vehicle miles of travel is reasonably well understood. Indeed, there seems to a widespread lack of understanding that the existence and structure of such a relation is an empirical question. Otherwise, the common practice of comparing deaths per vehicle mile of travel over time and concluding that the change is due to specific safety activities is unexplainable. Some studies have implicitly recognized the existence of such a relation and derived empirical equivalents (for a review, see [6]). In this study we have derived empirical relations. They are, however, purely formal, and their reliability for projections into the future is not established.

A large part of highway deaths is represented by pedestrians. Currently no model exists which relates pedestrian deaths to traffic or other parameters.

The interactions between passenger cars of different sizes are reasonably well understood. Conceptually, these relations can be extended to interactions between cars and trucks, etc. Data to quantify such interactions are, however, currently wholly inadequate.

The influence of an important factor, speed, is only partially understood. An analysis of the past trend provides little information since speed had an increasing trend similar to many other factors, the influence of which, therefore, cannot be separated. The 55 mph speed limit, effective in 1974 and 1975, has interrupted the trend; therefore, a better analysis of the effects of speed might be possible now. However, there was concurrently an economic recession. Historically, economic recessions have had strong impacts on traffic deaths. Since the current recession is unusually severe, its effect cannot be estimated with a high degree of confidence. Therefore, estimates of the effects of the speed reduction in 1974 and 1975 will remain unreliable.

Figure 5.1-4 gives an idea how well the first level model represents the past trend. It also shows that the predictions for 1974 and 1975 are too high by about 5000 deaths, presumably due to the effect of the 55 mph speed limit and the recession.

We expect that a more extensive analysis of earlier data, and of 1974 and 1975 data, when they become available, will allow improvement of the highway transport model. However, we do not expect that such an improved model will allow very reliable predictions of *absolute* numbers of deaths. More reliable, however, will be *comparisons* between predictions based on alternative assumptions.

The air transport model developed is of much simpler conceptual scope and represents the historical trend reasonably well. However, conceptual refinements are possible, and data are available on which a refined model can be based. Predictions based on such a model would have greater credibility than predictions from the current, purely descriptive model.

The data on rail transport suggested a very simple model: proportionality between deaths and train miles. A discontinuity in 1971, which could not be explained, however, raises serious questions about the validity of the simple model for future projections.

For water transport deaths, no relation could be found between their number and the available measures of water transport.

Pipeline accident deaths require a model of a completely different structure to explain their numbers. Age of the system appears to be the key factor.

7.2 RECOMMENDATIONS

Potential improvements and refinements of the first level model are outlined in Section 6. On the basis of numbers of deaths, improvement of the highway transport model should have the highest priority. There exists very little reliable knowledge on the interactions between passenger cars, buses and trucks. However, data exist to develop quantitative relations. Such relations would be useful for examining the consequences of policies leading to different characteristics or uses of cars, trucks and buses. Therefore, this appears to be an area of high priority within highway transport. The relations between vehicle miles of travel and deaths would have second priority; the overall structure of the relations is established, though not very reliably. They are important, however, since major shifts in the use of passenger cars and buses, or in the use of large trucks and small trucks, would also affect total vehicle miles of travel. The study of the factors speed and economic activity should get the lowest priority; it appears unlikely that useful relations can be established within the near future without extensive effort. Also it appears likely that their impact will not vary much with changes in vehicle mix or vehicle use.

In air transport, general aviation should have the highest priority because of the number of deaths involved. Though the model for scheduled air traffic can be improved, it is questionable whether this is worthwhile in consideration of the low numbers involved.

Similarly, it appears questionable whether models for water transport deaths and pipeline deaths would be worthwhile because of the numbers involved.

An improved rail traffic model, however, appears worthwhile, first, because of a predicted considerable increase in rail transport, and because of the grade crossing interactions between rail and highway traffic.

To compare the net effects of shifts between modes, it is desirable to extend the scope of the model and to include complementarities: the access to airports, railroad stations, and bus terminals (usually by automobile). Including deaths occurring during access might change the relative safety of various modes.

APPENDIX A: ALTERNATIVE METHOD TO ESTIMATE THE REGRESSION COEFFICIENTS FOR THE HIGHWAY TRANSPORT MODEL

The basic formulas (Subparagraph 4.2.2.1) for the highway transport model are:

$$y_{it} = A + Bx_{it} \qquad \text{(A-1)}$$

where y_{it} is the number of deaths per highway mile in state i during year t, and x_{it} the number of vehicle miles of travel per highway mile in state i during year t (for a certain highway class). In Subparagraph 4.2.2.1 we estimated the A and B from the y_{it} and x_{it}. Another approach is to sum equation (A-1) multiplied with the number of highway miles h_{it} for state i in year t for one year over all states:

$$\sum_i y_{it}h_{it} = A\sum_i h_{it} + B\sum_i x_{it}h_{it} \qquad \text{(A-2)}$$

or

$$Y_t = AH_t + BX_t \qquad \text{(A-3)}$$

where Y_t, H_t and X_t are abbreviations for the sums in (A-2). If one interprets A and B as coordinates, then (A-3) represents the equation of a straight line in the (A,B) coordinate system. If the relation between traffic density and the density of fatalities remained unchanged over time, and consequently the A and B constant, then the lines (A-3) for several years should all intersect in one point with the coordinates A and B. If A and B would change slowly over time, then the lines for consecutive years should intersect at a point with approximate averages of the A and B of the two years as coordinates, and the sequence of intersections of lines of consecutive years would indicate time trends in A and B. This approach was tried, because we expected that it would give more realistic values of the A and B than the approach used in Subparagraph 4.2.2.1, the results of which are influenced by a few outlying states. However, no usable results were obtained because the lines of consecutive years intersected at very small angles, giving only very imprecise "points" and the time sequence of these "points" failed to reveal clear trends. Therefore, this approach was not further pursued.

APPENDIX B: DISTRIBUTION OF VMT BY VEHICLE TYPE

The fraction of vehicle miles of travel, traveled by different types of motor vehicles, based on data in [21] is shown in Table B-1.

TABLE B-1. MOTOR VEHICLE TRAVEL MIX 1963-1974 (IN PERCENT) BASED ON VEHICLE MILES TRAVELED

Year	Passenger Car	Single Unit Truck	Combination Truck	Bus	Motorcycle
1963	80.1	15.6	3.7	0.5	-
1964	80.1	15.8	3.6	0.5	-
1965	79.6	15.8	3.5	0.5	0.6
1966	80.0	15.1	3.5	0.5	0.7
1967	79.7	15.3	3.6	0.5	0.8
1968	79.3	15.6	3.7	0.5	0.8
1969	79.4	15.6	3.7	0.5	0.9
1970	79.5	15.6	3.6	0.5	0.9
1971	79.0	15.5	3.6	0.4	1.3
1972	78.0	17.0	3.7	0.4	1.3
1973	78.0	17.0	3.7	0.4	1.5
1974	77.0	16.0	4.3	0.4	1.7

APPENDIX C: DISTRIBUTION OF VMT BY HIGHWAY CLASS AND STATE

The distribution of vehicle miles of travel by highway class--as defined in Paragraph 4.2.1--as given in Table C-1, was derived from [21]. It was used for distributing the VMT projections provided by TSC over states and highway classes.

TABLE C-1. DISTRIBUTION OF VMT BY HIGHWAY CLASS AND STATE

VMT DATA IN MILLIONS FOR 1973

STATE NAME	TYPE OF ROAD				
	RURAL INTERSTATE	URBAN INTERSTATE	RURAL MAIN ROAD	RURAL OTHER ROADS	URBAN HIGHWAY& STREET
ALAB	1776.	726.	6363.	3326.	8047.
ARIZ	2192.	722.	2803.	3180.	7322.
ARK.	1639.	523.	3308.	4158.	3789.
CAL.	6729.	17357.	13249.	21791.	70723.
COLO	1648.	1398.	3036.	3202.	6926.
CONN	797.	2718.	1552.	1643.	11711
DELA	0.	506.	894.	424.	1717.
FLA.	3545.	2755.	8009.	12507.	32449.
GEOR	3915.	2963.	8729.	7280.	13203.
IDAH	906.	84.	1621.	1563.	1281.
ILL.	4291.	6667.	9974.	6841.	32999.
IND.	4234.	2671.	7416.	7915.	16491.
IOWA	2087.	639.	6485.	3243.	7121.
KANS	1534.	680.	4411.	3555.	5222.
KTKY	3203.	976.	5228.	7433.	7555.
LOU.	1355.	1110.	7696.	6595.	6564.
MAIN	636.	97.	1786.	2614.	1797.
MARY	1586.	3510.	3612.	6815	10020.
MASS	2297.	2321.	2438.	1911.	20324.
MICH	3801.	5146.	7819.	11719.	29993.
MINN	1123.	2112.	5409.	6521.	9995.
MISS	1454.	465.	4770.	3099.	3924.
MISO	3361.	3430.	6501.	6383.	11073.
MONT	720.	52.	2147.	1615.	1155.
NEBR	1235.	330.	3112.	2190.	4286.
NEV.	771.	88.	1024.	696.	1702.
N. H.	619.	211.	1547.	1338.	1520.
N. J.	690.	3098.	3137.	6656.	34586.
N. M.	1749.	496.	2212.	1832.	3179.
N. Y.	3504.	7201.	9378.	8954.	38549.
N. C.	2306.	1002.	7800.	13127.	11563.
N. D.	591.	26.	1381.	1472.	830.
OHIO	6304.	7997.	8090.	14081.	28699.
OKLA	2089.	1780.	4342.	4739.	8722.
OREG	2018.	1022.	2750.	5381.	4791.
PENN	5993.	2907.	10390.	15303.	31915.
R. I.	136.	879.	320.	439.	3699.
S. C.	1984.	697.	6902.	4614.	6231.
S. D.	808.	27.	1940.	1389.	976.
TENN	3712.	2269.	6638.	4590.	12218.
TEX.	6089.	10365.	15229.	13958.	34974.
UTAH	781.	819.	1825.	1430.	2419.
VERM	596.	50.	1052.	1046.	547.
VIRG	3557.	2394.	6137.	8911.	13665.
WASH	1381.	3219.	3750.	5010.	10097.
W. V.	961.	182.	2687.	3461.	2912.
WISC	2271.	1030.	5897.	6029.	13472.
WYOM	994.	27.	1132.	665.	641.
TOTAL	105968.	107744.	229928.	262644.	593594.

TABLE D-1. FATAL TAKEOFF AND LANDING ACCIDENTS INVOLVING CERTIFICATED U.S. AIR CARRIERS

Year	Airport	Aircraft	Fatalities	Takeoff or Landing (a)	Airport Class (b)	Aircraft Engine (c)	
						Number	Type
1962	Idlewild, N.Y.	B-707/123B	95	T	L	4	TJ
	Adak, Alaska	L-1049	1	L	S	4	P
	Idlewild, N.Y.	DC-7	25	L	L	4	P
	Hollywood, Cal.	L-1049H	8	L	L	4	P
1963	Barter Is., Ak.	Beech A7-11	5	T/L	S	2	P
	Kansas City, Mo.	Viscount 81D	8	L	L	4	TP
	San Francisco, Cal.	L-1049	4	L	L	4	P
	Rochester, N.Y.	M-404	7	T	M	2	P
	Idlewild, N.Y.	Vertol-107	6	T	L		Rotary
1964	New Orleans, La.	DC-8	58	T	L	4	TJ
	Boston, Ma.	DC-4	3	L	L	4	P
	Miles City, Mont.	DC-3	4	L	S	2	P
	San Ramon, Cal.	F-27	44	L	S	2	TP
	Otter Lake, Ak.	Vultee 28-SACF	1	L	S	2	P
	Las Vegas, Nev.	F-27	29	L	L	2	TP
	San Francisco, Cal.	L-1049H	3	T	L	4	P
1965	Kennedy Int., N.Y.	DC-7B	84	T	L	4	P
	Chicago, Ill.	B-727	30	L	L	3	TJ
	Cincinnati, Ohio	B-727	58	L	M	3	TJ
	Salt Lake City, Ut.	B-727	43	L	M	3	TJ
1966	NONE						
1967	Klamath Falls, Ore.	F-27	4	T	S	2	TP
	Vandalia, Ohio	DC-6	1	L	S	4	P
	Cincinnati, Ohio	B-707	1	T	M	4	TJ
	Cincinnati, Ohio	CV-880	69	L	M	4	TJ
	Denver, Col.	DC-3	2	T	L	2	P
1968	Charleston, W.Va.	FH-227	35	L	S	2	TP
	Hanover, N.H.	FH-227	32	L	S	2	TP
1969	Bradford, Pa.	CV-580	11	L	S	2	TP
	Los Angeles, Cal.	B-727	38	T	L	3	TJ
	Lake Minchumino, Ak.	DHC-6	1	L	S	2	TP
	Kennedy Int., N.Y.	DHC-6	3	T	L	2	TP
	New Orleans, La.	B-727	1	T	L	3	TJ
	Lake George, N.Y.	F-227	14	L	S	2	TP
	St. Louis, Mo.	FH-227	1	PPA	L	2	TP
1970	Huntington, W.Va.	DC-9	75	L	S	2	TJ
	Atlanta, Ga.	M-404	1	PPA	L	2	P
1971	New Haven, Ct.	CV-580	28	L	S	2	TP
	Juneau, Ak.	B-727	111	L	S	3	TJ
	Chicago, Ill.	DC-9	1	T/L	L	2	TJ
1972	Albany, N.Y.	F-227	17	L	M	2	TP
	Chicago, Ill.	B-737	45	L	L	2	TJ
	Chicago, Ill.	DC-9	10	T	L	2	TJ
	Miami, Fla.	L-1011	99	L	L	3	TJ
	Islip, N.Y.	FH-227	1	PPA	S	2	TP
1973	St. Louis, Mo.	FH-227B	38	L	L	2	TP
	Boston, Ma.	DC-9	88	L	L	2	TJ
	Boston, Ma.	B-707	3	L	L	4	TJ

[a] T = Takeoff; L = Landing; PPA = Propeller to Person.

[b] L = Large; M = Medium; S = Small.

[c] P = Piston; TP = Turboprop; TJ = Turbojet.

TABLE D-2. FATAL ENROUTE ACCIDENTS INVOLVING CERTIFICATED U.S. AIR CARRIERS

Year	Location	Aircraft	Fatalities	Accident Type	Aircraft Engine	
					Number	Type
1962	Unionville, Mo.	B-707/124	45	dynamite	4	TJ
	Golovia, Alaska	Stinson V77	3	mountain	1	P
	Hartford, Ct.	CV-440	1	door open	2	P
	Ellicott City, Md.	Viscount	17	birds	4	TP
1963	Miami, Fla.	B720B	43	crashed	4	TJ
	Elkton, Md.	B-707/121	81	crashed	4	TJ
1964	Elim, Alaska	Cessna 185	2	crashed	1	P
	Knoxville, Tenn.	Caravelle	1	turb.	2	TJ
	Newport, Tenn.	Viscount	39	crashed	4	TP
1965	Lake Tustumena, Ak.	Aero-Comm-60	4	hit water	2	TP
	North Salem, N.Y.	L-1049	4	mid-air	4	P
		B-707	0	collision	4	TJ
	Alamosa, Col.	L-1049H	3	crashed	4	P
1966	Falls City, Neb.	BAC 111	42	crashed	2	TJ
	Juneau, Ak.	G-44	9	crashed	2	P
	Portland, Ore.	DC-9	18	crashed	2	TJ
	New Bern, N.C.	M-404	3	crashed	2	P
1967	Marseilles, Ohio	CV-580	38	crashed	2	TP
	Urbana, Ohio	DC-9	25	mid-air	2	TJ
	Blossburg, Pa.	BAC 111	34	crashed	2	TJ
	Hendersonville, N.C.	B-727	79	mid-air	3	TJ
1968	St. Louis, Mo.	DC-9	0	mid-air	2	TJ
	Dawson, Tex.	L-188	85	crashed	4	TP
	Los Angeles, Cal.	S-6IL	23	crashed		Rotary
	Milwaukee, Wis.	CV-580	0	mid-air	2	TP
	Los Angeles, Cal.	S-61	21	crashed		Rotary
1969	Indianapolis, Ind.	DC-9	82	mid-air	2	TJ
1970	NONE					
1971	Edison, N.J.	B-707	0	mid-air	4	TJ
	Duarte, Cal.	DC-9	49	mid-air	2	TJ
	Raleigh, N. C.	DC-9	0	mid-air	2	TJ
1972	Appleton, Wis.	CV-580	5	mid-air	2	TP
		DHC-6	8	mid-air	2	TP
1973	Los Angeles, Cal.	B-707	1	porpoising	4	TJ
	Mena, Ark.	CV 600	11	crashed	2	TP
	Albuquerque, N.M.	DC-10	1	de-pressure	3	TJ

TABLE D-3. FLIGHT TIME FOR THE MOST COMMON AIRCRAFT (Thousands of Hours)

Aircraft	Year									
	1973	1972	1971	1970	1969	1968	1967	1966	1965	1964
B-747	388	356	310	119	186	-	-	-	-	-
DC-10	231	109	5	-	-	-	-	-	-	-
L-1011	63	15	-	-	-	-	-	-	-	-
B-707	1011	1084	1186	1353	1523	1425	1165	833	653	522
DC-8	753	829	885	934	912	745	602	499	441	389
B-727	1922	1758	1745	1665	1676	1394	1022	596	341	106
CV-880	87	100	106	120	128	138	149	138	141	135
B-737	342	319	298	301	234	54	-	-	-	-
DC-9	930	921	902	934	795	553	254	71	1	-
L-188 (TP)	68	73	72	84	122	201	323	276	330	324
CV-600 (TP)	40	40	45	48	-	-	-	-	-	-
F-27 (TP)	47	39	50	61	92	116	146	169	144	134
FH-227 (TP)	57	79	86	103	129	137	97	8	-	-
B-720	123	174	244	307	396	435	430	404	388	358
BAC 111	88	84	90	121	141	134	128	101	19	-
Viscount 810 (TP)	-	-	-	-	-	-	5	37	34	34
CV 580/640 (340/440) (TP)	225	235	233	231	260	222	166	95	33	5

TABLE D-4. AIRCRAFT INVOLVED IN FATAL ACCIDENTS OF CERTIFICATED U.S. AIR CARRIERS

Aircraft	Passenger Capacity	Fatal Accidents 1964 - 1973	Number of Aircraft	
			1966	1973
B-707	150-220	5	245	316
B-727	140-189	7	287	733
B-720		0	129	45
B-737	103-115	1		152
B-747	380-500	0		111
DC-3		2	137	12
DC-4		1	10	4
DC-6		1	164	31
DC-7		0	91	5
DC-8	105-173	1	149	233
DC-9	90-139	9	56	340
DC-10	250-380	1	0	9
CV-440		0		
TPCV-580	60-80	5		105
TPCV-600	40-56	1		24
CV-880	88-110	1	46	37
L-1049		3		
TPL-188	74-98	1	125	52
L-1011	256-400	1		48
TP F-27	30-40	3	64	25
TP FH-227	40-44	7	16	31
TP Viscount 810		1	8	0
BAC 111		2	54	31
DHC-6		3		9
M-404		2		75

APPENDIX E: HIGHWAY TRANSPORTATION MODEL COMPUTER PROGRAM DESCRIPTION

Abstract

The number of projected annual fatalities from motor vehicle accidents are computed in the following five roadway classes: (1) rural interstate, (2) urban interstate, (3) rural main roads, (4) other rural roads, and (5) other urban roads. Fatalities are calculated as a function of vehicle miles of travel (VMT), roadway miles, vehicle-occupant interaction and time factors.

E.1 INTRODUCTION

Separate projections of annual fatalities resulting from motor vehicle accidents in the following categories of road classes are made: (1) rural interstate, (2) urban interstate, (3) rural main roads, (4) other rural roads, and (5) other urban roads. The fatalities in each category are computed from vehicle miles of travel (VMT), roadway miles, vehicle-occupant interaction and time factors.

VMT data are required for each year of the projection period. These data can be input in any one of several forms which are a function of road class, state and motor vehicle type. To date, the model has been tested using VMT data input as a function of road class and state. Roadway miles as a function of road class and state may be input for each year of the projection period or held constant throughout the period.

A separate relationship between annual fatalities and the independent variables (VMT, roadway miles, vehicle-occupant interaction and time) is employed for each road class. Two equations are used for Road Classes Three and Four (rural main roads and other rural roads). For these classes, the equation used in computing the projected annual fatalities is dependent on the value of the ratio of VMT (in millions) to roadway miles.

In the current version of the first level model, the projected number of fatalities is modified in two ways. The intercept (A) and slope (B) of each road class regression equation is multiplied by a time factor which accounts for time-trends in the relationship between actual fatalities and VMT-road class miles. The projected fatalities in all road classes for a given year are in turn multiplied by a vehicle-occupant interaction factor which accounts for projected changes in fatality risk to occupants due to safety measures and changes in the composition of the mix of vehicle types.

E.2 PROBLEM DESCRIPTION

A first level model was required which would permit the calculation of projected annual fatalities resulting from motor vehicle accidents. This was to be accomplished by relating fatalities in different classes of roads to variables which indicated the level of activity in the highway transportation mode. An analysis of the period from 1967-1973 revealed that VMT and road class miles are satisfactory for this purpose when the computed fatalities are modified according to vehicle occupant interaction and time factors.

E.3 METHOD OF SOLUTION

The annual motor vehicle fatalities are computed as follows:

$$\frac{\text{Deaths}}{\text{HM}}_{h,s,t} = \text{VIO}_t \left[\text{TFA(I)}_{h,t} \times \text{A(I)}_h + \left(\text{TFB(I)}_{h,t} \times \text{B(I)}_h \times \frac{\text{VMT}_{h,s,t}}{\text{HM}_{h,s,t}} \right) \right]$$

where the parameters are defined as follows:

VIO_t = Vehicle Interaction Factor for Year t

A(I)_h = Regression Intercept for Highway Type (h) in Traffic Density Range I

B(I)_h = Regression Slope for Highway Type (h) in Traffic Density Range I

$\text{TFA(I)}_{h,t}$ = Time Factor for A(I)_h in Year t

$\text{TFB(I)}_{h,t}$ = Time Factor for B(I)_h in Year t

$\text{VMT}_{h,s,t}$ = Vehicle Miles Traveled (in millions) for Highway Type (h) in State(s) in Year t

$\text{HM}_{h,s,t}$ = Highway Mileage for Highway Type (h) in State(s) in Year t

Two sets of time factors and regression intercepts and slopes can, on option, be used in each of the five road classes. The second set is used when the traffic density (I) exceeds a critical value C defined as

$$C = \frac{VMT_{h,s,t}}{HM_{h,s,t}}$$

E.4 PROGRAM DESCRIPTION

This program is written in FORTRAN IV for the IBM 360-65 computer. The program requires 27K bites of core storage for execution and includes one subroutine VEHTYP. This subroutine is not functionally utilized in the first-level version of the model. The purpose of the subroutine will be to compute a more detailed vehicle interaction factor in place of the single number now input for this variable for each year.

The program executes in about 15 seconds with 15 years of projection data. The vehicle interaction factor and the time factors are card input to the program, although the values may be derived from functional representations of these parameters. VMT data may be input in any one of five data forms, but the same form must be maintained for all years of data. Highway miles for each road class may be varied by input for each year or a constant set of miles may be used throughout the period. VMT and highway miles can be printed out, on option.

E.5 PROGRAM USE

E.5.1 Input

Control Card

The input format is (7I5).

Column	Parameter
1-5	Number of years for which projection fatalities are to be calculated (Maximum number of years allowed is 20.)
6-10	Type of VMT data. 1 = VMT by state, road class, and vehicle type 2 = VMT by state and road class 3 = VMT by state and vehicle type 4 = VMT by road class and vehicle type 5 = non-interactive VMT for state, road class and vehicle type (The program has at present been used only with Type 2 VMT data.)
11-15	Distribution percentages 0 = Fixed percentages 1 = Different percentages for each year (Use 0 presently.)
16-20	Occupancy factor for vehicle type. 0 = Fixed values 1 = Different values for each year (Use 0 presently.)
21-25	Number of states.
26-30	Highway miles. 0 = Fixed set of values 1 = Different set each year
31-35	Optional printout for VMT/Highway Miles 0 = Do NOT print 1 = Print data.

Vehicle-Occupant Interaction Factor Card(s)

The input format is (16F5.3). A second card is required for more than 16 years of projections.

Column	Parameter
1-5	Vehicle-Occupant Interaction Factor for first year.
6-10	Vehicle-Occupant Interaction Factor for second year.
.	.
.	.
.	.
.	.
.	.
76-80	Vehicle-Occupant Interaction Factor for sixteenth year.

Time Factor Cards

The input format is (5F5.3). One card is required for each year of projection data. The sequence is as follows:

- Time factors for first regression equation intercept, Year 1 to last year
- Time factors for first regression equation slope, Year 1 to last year.
- Time factors for second regression equation intercept, Year 1 to last year.
- Time factors for second regression equation slope, Year 1 to last year.

Note: If a second regression equation is not being employed in a given road class, leave the associated column blank.

Column	Parameter
1-5	Time factor for first road class.
6-10	Time factor for second road class.
11-15	Time factor for third road class.
16-20	Time factor for fourth road class.
21-25	Time factor for fifth road class.

Year Identification Card

The input format is (20I4).

Column	Parameter
1-4	First year of projection period.
5-8	Second year of projection period.
.	.
.	.
.	.
.	.
76-80	Twentieth year of projection period.

State Identification Card(s)

The input format is (14 [A4,1x]). The card is repeated if more than 14 states are included. Four cards are required by 48 or 50 states.

Column	Parameter
1-4	Abbreviation of name of state 1
6-10	Abbreviation of name of state 2
.	.
.	.
.	.
66-70	Abbreviation of name of state 14

Regression Equations Constants Cards

The input format is (5F10.4). Four input cards are required in the following sequence:

- Intercept for first regression equation
- Slope for first regression equation
- Intercept for second regression equation
- Slope for second regression equation.

Note: If a second regression equation is not being used in a given road class, leave the associated column blank.

Column	Parameter
1-10	Constant (intercept or slope) for first road class.
11-20	Constant (intercept or slope) for second road class.
21-30	Constant (intercept or slope) for third road class.
31-40	Constant (intercept or slope) for fourth road class.
41-50	Constant (intercept or slope) for fifth road class.

Critical Ratio (VMT [in millions]/Highway Miles) Card

The input format is (5F10.4).

Column	Parameter
1-10	Critical ratio of VMT/Highway Miles for first road class.
11-20	Critical ratio of VMT/Highway Miles for second road class.
21-30	Critical ratio of VMT/Highway Miles for third road class.
31-40	Critical ratio of VMT/Highway Miles for fourth road class.
41-50	Critical ratio of VMT/Highway Miles for fifth road class.

Number of Regression Equations Card

The input format is (5I5). The number of regression equations used with each road class is currently limited to one (1) or two (2).

Column	Parameter
1-5	Number of regression equations for first road class.
6-10	Number of regression equations for second road class.
11-15	Number of regression equations for third road class.
16-20	Number of regression equations for fourth road class.
21-25	Number of regression equations for fifth road class.

THE USER SHOULD NOTE THAT THE FOLLOWING CARD TYPES ARE REPEATED IN SEQUENCE FOR EACH YEAR UNLESS OTHERWISE INDICATED BY OPTION CONTROL.

Highway Miles Cards

The input format is (5F10.0). These data are included only for the first year if a zero (0) is entered in Column 30 of the Control Card. The highway miles data are input in sequence by state:

- Card 1 - State 1
- Card 2 - State 2

. .
. .
. .

- Last Card - Last State

Column	Parameter
1-10	Highway miles for first road class.
11-20	Highway miles for second road class.
21-30	Highway miles for third road class
31-40	Highway miles for fourth road class.
41-50	Highway miles for fifth road class.

VMT Data Card

VMT data in millions of miles are input in one of five formats as specified in Column 10 of the Control Card. The form specified for a given run must be used for all years.

FORMAT 1 - VMT by state, road class and vehicle type.

The sequence of data is as follows:

State 1	Road Class 1 Road Class 2 Road Class 3 Road Class 4 Road Class 5
State 2	Road Class 1 Road Class 2
	. . .
Last State	Road Class 4
Last State	Road Class 5

Thus 50 states would require 250 input cards for one year.

The input format is (4F10.0).

Column	Parameter
1-10	VMT (millions) for first vehicle type.
11-20	VMT (millions) for second vehicle type.
21-30	VMT (millions) for third vehicle type.
31-40	VMT (millions) for fourth vehicle type.

FORMAT 2 - VMT by state and road class.

The sequence of data is as follows:

State 1
State 2
.
.
.
Last State

Thus, 50 states would require 50 input cards for one year.

The input format is (5F10.0).

Column	Parameter
1-10	VMT (millions) for first road class.
11-20	VMT (millions) for second road class.
21-30	VMT (millions) for third road class.
31-40	VMT (millions) for fourth road class.
41-50	VMT (millions) for fifth road class.

FORMAT 3 - VMT by state and vehicle type.

The sequence of data is as follows:

State 1
State 2
.
.
.
Last State

Thus, 50 states would require 50 input cards for one year.

The input format is (4F10.0).

Column	Parameter
1-10	VMT (millions) for first vehicle type.
11-20	VMT (millions) for second vehicle type.
21-30	VMT (millions) for third vehicle type.
31-40	VMT (millions) for fourth vehicle type.

FORMAT 4 - VMT by road class and vehicle type.

The sequence of data is as follows:

Road Class 1

Road Class 2

.

.

.

Road Class 5

Thus, five road classes would require five cards for one year.

The input format is (4F10.0).

Column	Parameter
1-10	VMT (millions) for first vehicle type.
11-20	VMT (millions) for second vehicle type.
21-30	VMT (millions) for third vehicle type.
31-40	VMT (millions) for fourth vehicle type.

FORMAT 5 - Non-Interactive VMT.

Three card types are required under Format 5.

a. Non-Interactive Vehicle Type VMT

The input format is (4F10.0).

Column	Parameter
1-10	VMT (millions) for first vehicle type.
11-20	VMT (millions) for second vehicle type.
21-30	VMT (millions) for third vehicle type.
31-40	VMT (millions) for fourth vehicle type.

b. Non-Interactive Road Class Type VMT

The input format is (5F10.0).

Column	Parameter
1-10	VMT (millions) for first road class type.
11-20	VMT (millions) for second road class type.
21-30	VMT (millions) for third road class type.
31-40	VMT (millions) for fourth road class type.
41-50	VMT (millions) for fifth road class type.

c. Non Interactive State VMT

The input format is (7F10.0). Seven input cards are required by 48 states while 50 states would require eight input cards.

Column	Parameter
1-10	VMT (millions) for first state.
11-20	VMT (millions) for second state.
21-30	VMT (millions) for third state.
31-40	VMT (millions) for fourth state.
41-50	VMT (millions) for fifth state.
51-60	VMT (millions) for sixth state.
61-70	VMT (millions) for seventh state.

<u>Vehicle Type Distribution Percentages Card</u>

The input format is (4F5.3). Omit card if VMT Format 1 data are used ("1" in Column 10 of Control Card). Include only for first year, if a zero (0) is entered in Colunn 15 of Control Card.

Column	Parameter
1-5	Distribution percentage for first vehicle type.
6-10	Distribution percentage for second vehicle type.
11-15	Distribution percentage for third vehicle type.
16-20	Distribution percentage for fourth vehicle type.

The sum of the above percentages in 1.00.

Road Class Type Distribution Percentages Card

The input format is (5F5.3). Omit card if VMT Format 1 data are used ("1" in Column 10 of Control Card). Include only for first year,if a zero (0) is entered in Column 15 of Control Card.

Column	Parameter
1-5	Distribution percentage for first road class type.
6-10	Distribution percentage for second road class type.
11-15	Distribution percentage for third road class type.
16-20	Distribution percentage for fourth road class type.
21-25	Distribution percentage for fifth road class type.

The sum of the above percentages is 1.00.

State Distribution Percentages Card

The input format is (14F5.3). Omit card if VMT Format 1 data are used ("1" in Column 10 of Control Card). Include only for first year,if a zero (0) is entered in Column 15 of Control Card.

Column	Parameter
1-5	Distribution percentage for first state.
6-10	Distribution percentage for second state.
.	.
.	.
.	.
66-70	Distribution percentage for fourteenth state.

The sum of the aobve percentages is 1.00. Fifty states would require four input cards.

Occupancy Factor Card

The input format is (4F10.4). Include only for first year, if a zero (0) is entered in Column 20 of Control Card.

Column	Parameter
1-10	Occupancy factor for first vehicle type.
11-20	Occupancy factor for second vehicle type.
21-30	Occupancy factor for third vehicle type.
31-40	Occupancy factor for fourth vehicle type.

E.5.2 Output

E.5.2.1 Printed Output

The printed output contains the following:

(a) Control data;

(b) Vehicle-occupant interaction factor for each year;

(c) Time factors for each year for one or two regression equations in each road class;

(d) Critical ratio and number of regression equations for each road class;

(e) Regression equation slopes and intercepts;

(f) Road class miles by state for each year (optional);

(g) VMT by road class and state for each year (optional);

(h) Projected fatalities by road class and state for each year;

(i) Summary table of annual fatalities by state; and

(j) Summary table of annual fatalities by road class.

E.5.2.2 Punched Card Output

There is no punched card output from this program.

E.6 PROGRAM LISTING

```
C
C HIGHWAY TRANSPORT MODEL
C
C VIO(4,5,51)=VEHICLE INTERACTION AND OCCUPANCY FSCTOR
C VMT(4,5,51)=VEH. MILES OF TRAVLL(MILLIONS OF MI.)   NYR=NO OF YRS.
C TFA(5,51),TFB(5,51),TFC(5,51)=TIME FACTORS    ITYP=TYPE OF VMT DATA
C A(5,51),B(5,51),C(5,51)=CONSTANTS    IPC=FIXED OR ANNUAL PCTS
C VTPCT(4)=VEH. TYPE PCTS.   HTPCT(5)=HIWAY TYPE PCTS  STPCT(5)=STATE PCTS
C VMT(4),VMTH(5),VMTS(51)=NON-INTERACTIVE VMTS
      DIMENSION XTF(20,5),XTG(20,5),XFA(5,51),XFB(5,51)
      DIMENSION A1(5),B1(5),A2(5),B2(5),CRIT(5),NEQ(5),XRAT(5,51)
      DIMENSION TTF(20,5),TVM(5)
      DIMENSION TTG(20,5)
      DIMENSION VMT(4,5,51),VIO(5,51),TFA(5,51),TFB(5,51),
     1             V(5,51),VTPCT(4),HTPCT(5),STPCT(51),VMTV(4),
     2 VMTH(5),VMTS(51),FATAL(5,51),                       COL(20,5),ROW(20,51),
     3 CRT(20),IYEAR(20),ISTAT(51),HM(5,51),TVIO(20)
      COMMON /VEH/ VMT,IOCC,IY,VIO,NST
C READ IN CONTROL DATA
      READ(5,10) NYR,ITYP,IPC,IOCC,NST,IMI,IOP
   10 FORMAT(715)
C READ IN TEMPORARY VALUES FOR VEHICLE-OCCUP. INTRACTION
      READ(5,4) (TVIO(I),I=1,NYR)
    4 FORMAT(16F5.3)
C READ IN TIME FACTORS FOR EACH YEAR
      DO 3 I=1,NYR
    3 READ(5,4) (TTF(I,J),J=1,5)
      DO 6 I=1,NYR
    6 READ(5,4) (TTG(I,J),J=1,5)
      DO 7 I=1,NYR
    7 READ(5,4) (XTF(I,J),J=1,5)
      DO 8 I=1,NYR
    8 READ(5,4) (XTG(I,J),J=1,5)
C READ IN IDENTIFICATION FOR YEARS
      READ(5,11)(IYEAR(I),I=1,NYR)
   11 FORMAT(2014)
C READ IN STATE NAMES
      READ(5,12)(ISTAT(I),I=1,NST)
   12 FORMAT(14(A4,1X)/14(A4,1X)/14(A4,1X)/14(A4,1X))
C READ IN A1,B1,  A2,B2
      READ(5,20) (A1(I),I=1,5)
      READ(5,20) (B1(I),I=1,5)
      READ(5,20) (A2(I),I=1,5)
      READ(5,20) (B2(I),I=1,5)
C CRIT=CRITICAL VALUE FOR VMT/HM RATIO  NEQ=NO. OF EQ. FOR ROAD CAT. 1-2
      READ(5,20) (CRIT(I),I=1,5)
      READ(5,10) (NEQ(I),I=1,5)
   20 FORMAT(6F10.4)
C PRINT OUT INPUT DATA
      WRITE(6,600) NYR,ITYP,IPC,IOCC,NST,IMI,IOP
  600 FORMAT(1X,'C O N T R O L   D A T A'/1X,'NYR= ',I2,' ITYP= ',I1,
     1' IPC= ',I1,' IOCC= ',I1,' NST= ',I2,' IMI= ',I1,' IOP= ',I1//)
      WRITE(6,605) (TVIO(I),I=1,NYR)
  605 FORMAT(1X,'VEHICLE OCCUPANT INTERACTION FACTOR FOR EACH YEAR'/1X,
     1'TVIO(IY)= ',15(F5.3,1X))
      WRITE(6,610)
  610 FORMAT(//1X,'TIME FACTOR FOR FIVE ROADWAY CLASSES FOR EACH YEAR
     1 A CONSTANT - FIRST EQUATION'/)
      DO 615 I=1,NYR
  615 WRITE(6,620)(TTF(I,J),J=1,5)
```

```
  620 FORMAT(6(1X,F10.3))
      WRITE(6,611)
  611 FORMAT(//1X,'TIME FACTOR FOR FIVE ROADWAY CLASSES FOR EACH YEAR
     1 B CONSTANT - FIRST EQUATION'/)
      DO 616 I=1,NYR
  616 WRITE(6,620)(TIG(I,J),J=1,5)
      WRITE(6,612)
  612 FORMAT(//1X,'TIME FACTOR FOR FIVE ROADWAY CLASSES FOR EACH YEAR
     1 A CONSTANT - SECOND EQUATION'/)
      DO 617 I=1,NYR
  617 WRITE(6,620)(XTF(I,J),J=1,5)
      WRITE(6,613)
  613 FORMAT(//1X,'TIME FACTOR FOR FIVE ROADWAY CLASSES FOR EACH YEAR
     1 B CONSTANT - SECOND EQUATION'/)
      DO 618 I=1,NYR
  618 WRITE(6,620)(XTG(I,J),J=1,5)
      WRITE(6,626)
  626 FORMAT('1',1X)
      WRITE(6,625) (NEQ(I),I=1,5)
  625 FORMAT(//1X,'THE NUMBER OF REGRESSION EQUATIONS USED TO PREDICT FA
     1TALITIES IN EACH ROADWAY CLASS    NEQ(5)'/5(5X,I5))
      WRITE(6,630) (CRIT(I),I=1,5)
  630 FORMAT(//1X,'THE CRITICAL RATIO OF VMT(MIL)/HM FOR THE ROADWAY CLA
     1SS   CRIT(5)'/5(5X,F5.3))
      WRITE(6,635) (A1(I),I=1,5),(B1(I),I=1,5)
  635 FORMAT(//1X,'THE SLOPE A1 AND THE INTERCEPT B1 FOR THE FIRST EQ. FO
     1R EACH ROADWAY CLASS'/1X,'A1(5)= ',5(1X,F9.5)/1X,'B1(5)= ',
     2 5(1X,F9.5))
      WRITE(6,640) (A2(I),I=1,5),(B2(I),I=1,5)
  640 FORMAT(//1X,'THE SLOPE A2 AND THE INTERCEPT B2 FOR THE SECOND EQ.
     1FOR EACH ROADWAY CLASS'/1X,'A2(5)= ',5(1X,F9.4)/1X,'B2(5)= ',
     2 5(1X,F9.4))
C-----------------------------------------------------------------------
C BEGIN CYCLING ON YEAR OF DATA IY
      DO 1000 IY=1,NYR
C READ IN HIGHWAY MILES
      IF(IY.GE.2.AND.IMI.EQ.0) GO TO 35
      DO 30 J=1,NST
   30 READ(5,25) (HM(I,J),I=1,5)
   25 FORMAT(5F10.0)
C OPTIONAL PRINTOUT OF HIGHWAY MILES
      IF(IOP.EQ.0) GO TO 35
      DO 40 I=1,5
   40 TVM(I)=0.0
      DO 45 K=1,NST
      DO 45 J=1,5
   45 TVM(J)=TVM(J)+HM(J,K)
      WRITE(6,50)
   50 FORMAT('1',1X,'HIGHWAY MILEAGE DATA'/)
      WRITE(6,441)
  441 FORMAT(     1X,'      STATE',6X,'T Y P E',11X,'O F',11X,'R O A D',7X,
     1'      '/ 5X,'NAME',3X,
     2     'RURAL      URBAN      RURAL      RURAL      URBAN'/
     312X,'INTER-     INTER-     MAIN       OTHER      HIGHWAY&'/
     412X,'STATE      STATE      ROAD       ROADS      STREET'/)
      DO 55 K=1,NST
   55 WRITE(6,180) ISTAT(K),(HM(J,K),J=1,5)
      WRITE(6,185) (TVM(J),J=1,5)
   35 CONTINUE
C READ IN VMT(MILLIONS) DATA ACCORDING TO ITYP INDICATOR
```

```
          GO TO ( 100, 150, 200, 250, 300 ), ITYP
      100 CONTINUE
C READ IN COMPLETE VMT DATA
          DO 105 K=1, NST
          DO 105 J=1, 5
      105 READ( 5, 110 )( VMT( I, J, K ), I=1, 4 )
          GO TO 400
      150 CONTINUE
C READ IN VMT DATA FOR HIGHWAY TYPE AND STATES
          DO 155 K=1, NST
      155 READ( 5, 110 )( VMT( 1, J, K ), J=1, 5 )
C OPTIONAL PRINTOUT OF VMT
          IF( IOP. EQ. 0 ) GO TO 325
          DO 160 I=1, 5
      160 TVM( I )=0. 0
          DO 165 K=1, NST
          DO 165 J=1, 5
      165 TVM( J )=TVM( J )+VMT( 1, J, K )
          WRITE( 6, 170 ) IYEAR( IY )
      170 FORMAT( '1', 1X, 'VMT DATA IN MILLIONS FOR ', I4/ )
          WRITE( 6, 441 )
          DO 175 K=1, NST
      175 WRITE( 6, 180 ) ISTAT( K ), ( VMT( 1, J, K ), J=1, 5 )
      180 FORMAT( 1X, A4, 1X, 5F10. 0 )
          WRITE( 6, 185 ) ( TVM( J ), J=1, 5 )
      185 FORMAT( /1X, 'TOTAL', 5( F10. 0 ))
          GO TO 325
      110 FORMAT( 5F10. 0 )
      200 CONTINUE
C READ IN VMT DATA FOR VEHICLE TYPE AND STATES
          DO 205 K=1, NST
      205 READ( 5, 110 )( VMT( I, 1, K ), I=1, 4 )
          GO TO 325
      250 CONTINUE
C READ IN VMT DATA VEHICLE TYPE AND HIGHWAY TYPE
          DO 255 J=1, 5
      255 READ( 5, 110 )( VMT( I, J, 1 ), I=1, 4 )
          GO TO 325
      300 CONTINUE
C READ IN NON-INTERACTIVE VMT DATA
          READ( 5, 110 )( VMTV( I ), I=1, 4 )
          READ( 5, 110 )( VMTH( I ), I=1, 5 )
          READ( 5, 305 )( VMTS( I ), I=1, NST )
      305 FORMAT( 7F10. 0 )
C COMPUTE VMT FOR CAR TYPES
      325 CONTINUE
          IF( IPC. EQ. 0. AND. IY. GE. 2 ) GO TO 330
          READ( 5, 335 )( VTPCT( I ), I=1, 4 )
          READ( 5, 335 )( HTPCT( I ), I=1, 5 )
          READ( 5, 335 )( STPCT( I ), I=1, NST )
      335 FORMAT( 14F5. 3/14F5. 3/14F5. 3/14F5. 3 )
      330 CONTINUE
          IF( ITYP. GT. 2 ) GO TO 350
C COMPUTE VMT FOR ITYP=2
          DO 345 K=1, NST
          DO 345 J=1, 5
          XT=VMT( 1, J, K )
          DO 345 I=1, 4
      345 VMT( I, J, K )=XT*VTPCT( I )
          GO TO 400
```

```
  350 IF(ITYP.GT.3) GO TO 360
C COMPUTE VMT FOR ITYP=3
      DO 355 K=1,NST
      DO 355 I=1,4
      XT=VMT(I,1,K)
      DO 355 J=1,5
  355 VMT(I,J,K)=XT*HTPCT(J)
      GO TO 400
  360 IF(ITYP.GT.4) GO TO 370
C COMPUTE VMT FOR ITYP=4
      DO 365 I=1,4
      DO 365 J=1,5
      XT=VMT(I,J,1)
      DO 365 K=1,NST
  365 VMT(I,J,K)=XT*STPCT(K)
      GO TO 400
  370 CONTINUE
C COMPUTE VMT FOR ITYP=5
      TOT=0.0
      DO 375 I=1,4
  375 TOT=TOT+VMTV(I)
      DO 380 I=1,4
      DO 380 J=1,5
      DO 380 K=1,NST
  380 VMT(I,J,K)=VMTV(I)/TOT*VMTH(J)/TOT*VMTS(K)
  400 CONTINUE
      CALL VEHTYP
C COLLAPSE VMT(I,J,K) TO VMT(1,J,K)
      DO 405 J=1,5
      DO 405 K=1,NST
      DO 405 I=2,4
  405 VMT(1,J,K)=VMT(1,J,K)+VMT(I,J,K)
C TEMPORARY SET FOR VIO,TFA,TFB
      DO 406 J=1,5
      DO 406 K=1,NST
      TFA(J,K)=TTF(IY,J)
      TFB(J,K)=TTG(IY,J)
      XFA(J,K)=XTF(IY,J)
      XFB(J,K)=XTG(IY,J)
  406 VIO(J,K)=TVIO(IY)
C COMPUTE CRITICAL RATIO AND FATALITIES FOR CURRENT YEAR
      DO 410 J=1,5
      DO 410 K=1,NST
      IF(NEW(J).EQ.1) GO TO 411
      XRAT(J,K)=VMT(1,J,K)/HM(J,K)
      IF(XRAT(J,K).GE.CRIT(J)) GO TO 412
  411 FATAL(J,K)=VIO(J,K)*(TFA(J,K)*A1(J)*HM(J,K)+TFB(J,K)*B1(J)*
     1 VMT(1,J,K))
      GO TO 410
  412 FATAL(J,K)=VIO(J,K)*(XFA(J,K)*A2(J)*HM(J,K)+XFB(J,K)*B2(J)*
     1 VMT(1,J,K))
  410 CONTINUE
C PRINT INTERMEDIATE RESULTS
      WRITE(6,420) IYEAR(IY)
  420 FORMAT('1',1X,'F A T A L I T I E S   C O M P U T E D   I N   T H E
     1   H I G H W A Y   T R A N S P O R T A T I O N   M O D E L'/
     240X,'F O R   T H E   Y E A R   ',I4//)
C COMPUTE COLUMN AND ROW TOTALS AND GRAND TOTAL
      DO 425 J=1,5
  425 COL(IY,J)=0.0
```

```
      DO 430 K=1,NST
  430  ROW(IY,K)=0.0
      CRT(IY)=0.0
      DO 435 J=1,5
      DO 435 K=1,NST
      COL(IY,J)=COL(IY,J)+FATAL(J,K)
      ROW(IY,K)=ROW(IY,K)+FATAL(J,K)
  435 CRT(IY)=CRT(IY)+FATAL(J,K)
      WRITE(6,440)
  440 FORMAT(     1X,'NO.  STATE',6X,'T Y P E',11X,'O F',11X,'R O A D',7X,
     1'TOTAL'/ 5X,'NAME',3X,
     2      'RURAL      URBAN      RURAL      RURAL      URBAN'/
     312X,'INTER-     INTER-     MAIN       OTHER      HIGHWAY&'/
     412X,'STATE      STATE      ROAD       ROADS      STREET'/)
      DO 445 K=1,NST
  445 WRITE(6,450) K,ISTAT(K),(FATAL(J,K),J=1,5),ROW(IY,K)
  450 FORMAT(1X,I2,2X,A4,1X,6(F7.0,3X))
      WRITE(6,455)(COL(IY,J),J=1,5),CRT(IY)
  455 FORMAT('0',1X,'T O T A L',F6.0,3X,5(F7.0,3X))
 1000 CONTINUE
C-------------------------------------------------------------------------
C END OF CYCLING ON YEAR OF DATA IY
C
C SUMMARY OF FINAL RESULTS
      WRITE(6,500)
  500 FORMAT('1',1X,'S U M M A R Y   O F   D E A T H S   F R O M   H I
     1 G H W A Y   T R A N S P O R T A T I O N   M O D E L'//)
      WRITE(6,505)(IYEAR(I),I=1,NYR)
  505 FORMAT(1X,'NO.  STATE',18(1X,I4,1X))
      WRITE(6,506)
  506 FORMAT('0',1X)
      DO 510 K=1,NST
  510 WRITE(6,515) K,ISTAT(K),(ROW(IY,K),IY=1,NYR)
  515 FORMAT(1X,I2,2X,A4,18(F6.0))
      WRITE(6,500)
      WRITE(6,520)
  520 FORMAT(     1X,'NO.  YEAR ',6X,'T Y P E',11X,'O F',11X,'R O A D',7X,
     1'TOTAL'/
     212X,'RURAL      URBAN      RURAL      RURAL      URBAN'/
     312X,'INTER-     INTER-     MAIN       OTHER      HIGHWAY&'/
     412X,'STATE      STATE      ROAD       ROADS      STREET'/)
      DO 525 IY=1,NYR
  525 WRITE(6,530) IY,IYEAR(IY),(COL(IY,J),J=1,5),CRT(IY)
  530 FORMAT(1X,I2,2X,I4,1X,6(F7.0,3X))
      STOP
      END
      SUBROUTINE VEHTYP
      COMMON /VEH/ VMT,IOCC,IY,VIO,NST
      DIMENSION VMT(4,5,51),VIO(5,51),OCCF(4)
      IF(IOCC.EQ.0.AND.IY.GE.2) GO TO 100
      READ(5,10)(OCCF(I),I=1,4)
  100 CONTINUE
   10 FORMAT(4F10.4)
C COMPUTE VEHICLE INTERACTION AND OCCUPANCY FACTOR
C             VIO(J,K)=F(VMT(I,J,K),OCCF(I))
C
C
      RETURN
      END
```

APPENDIX F: AIRCRAFT TRANSPORTATION MODEL COMPUTER PROGRAM DESCRIPTION

Abstract

The number of projected fatalities in General Aviation and scheduled domestic passenger/cargo air carrier service is computed in this model. Fatalities in General Aviation are calculated as a function of general aviation miles and time. Fatalities in scheduled domestic service are calculated as a function of revenue miles, revenue departures and time.

F.1 INTRODUCTION

Separate projections of annual fatalities resulting from aircraft accidents in the following categories are made: (1) general aviation flying, (2) scheduled domestic passenger/cargo air carrier service during takeoff/landing operations and (3) scheduled domestic passenger/cargo air carrier service during enroute operations. International and unscheduled passenger cargo service is excluded. General aviation flying includes all civil aircraft operations except those classified as air carriers.

Annual fatalities in general aviation are computed as a function of time and miles of general aviation flying. Annual fatalities in air carrier takeoff/landing operations are computed as a function of time and revenue departures. Annual fatalities in air carriers enroute operations are computed as a function of time and revenue miles.

F.2 PROBLEM DESCRIPTION

A relatively simple first level model was required which would permit the calculation of projected annual fatalities resulting from domestic aircraft accidents. This was to be accomplished by relating fatalities in classes of aircraft flying to variables which indicated the level of activity in the air transportation mode. An analysis of the period from 1962-1973 revealed that general aviation miles, air carrier revenue miles and air carrier revenue departures are satisfactory for this purpose.

F.3 METHOD OF SOLUTION

The annual aircraft fatalities in the three classes of aircraft operations are computed as follows:

$$F1 = RD \times FF1 \times e^{A1 - B1 \times T} \quad \text{(Class 1)}$$

$$F2 = RM \times FF2 \times e^{A2 - B2 \times T} \quad \text{(Class 2)}$$

$$F3 = GM \times FF3 \times e^{A3 - B3 \times T} \quad \text{(Class 3)}$$

where the parameters are defined as follows:

F1 = annual fatalities during takeoff/landing of domestic air carriers

F2 = annual fatalities during enroute operation of domestic air carriers

F3 = annual fatalities in general aviation flying

RD = domestic air carrier annual revenue departures in millions

RM = domestic air carriers annual revenue miles in billions

GM = general aviation annual miles in billions

FF1 = Fatalities per fatal accident for takeoff/landing

FF2 = Fatalities per fatal accident for enroute operations

FF3 = Fatalities per fatal accident for general aviation

A1,A2,A3 = Intercept for respective regression equation

B1,B2,B3 = Slope for respective regression equation

T = indicator of year (0 = 1962, 1 = 1963,..., 28 = 1990)

F.4 PROGRAM DESCRIPTION

This program is written in FORTRAN IV for the IBM 360-65 computer. The program requires 3K bites of core storage for execution, does not include any subroutines, and executes in less than 5 seconds. The program permits users to vary the fatality per fatal accident ratio over the projection period if so desired.

F.5 PROGRAM USE

F.5.1 Input

Control Card

The input format is (2I5).

Column	Parameter
1-5	Number of years for which projection fatalities are to be calculated. (Maximum Number of years allowed is 20.)
6-10	Indicator for first year of projection period (0=1962, 1=1963,28 = 1990).

Projection Equations Constants Card

The input format is (6F10.4).

Column	Parameter
1-10	Intercept A1 for takeoff/landing fatality regression equation.
11-20	Slope B1 for takeoff/landing fatality regression equation.
21-30	Intercept A2 for enroute fatality regression equation.
31-40	Slope B2 for enroute fatality regression equation.
41-50	Intercept A3 for general aviation fatality regression equation.
51-60	Slope B3 for general aviation fatality regression equation.

Year Identification Card

The input format is (20I4).

Column	Parameter
1-4	First year of projection period.
5-8	Second year of projection period.
. . .	
76-80	Twentieth year of projection period.

Transportation Data and Fatality Factor Cards

The input format is (6F10.4). One card is required for each year of data.

Column	Parameter
1-10	Annual domestic air carrier revenue departures in millions.
11-20	Annual domestic air carrier revenue miles in billions.
21-30	Annual general aviation miles in billions.
31-40	Fatalities per fatal accident for air carrier takeoff/landing.
41-50	Fatalities per fatal accident for air carrier enroute operations.
51-60	Fatalities per fatal accident for general aviation.

F.5.2 Output

F.5.2.1 Printed Output

The printed output contains the following:

a) Projection regression equations constants;

b) Revenue departures, revenue miles and general aviation miles for each year;

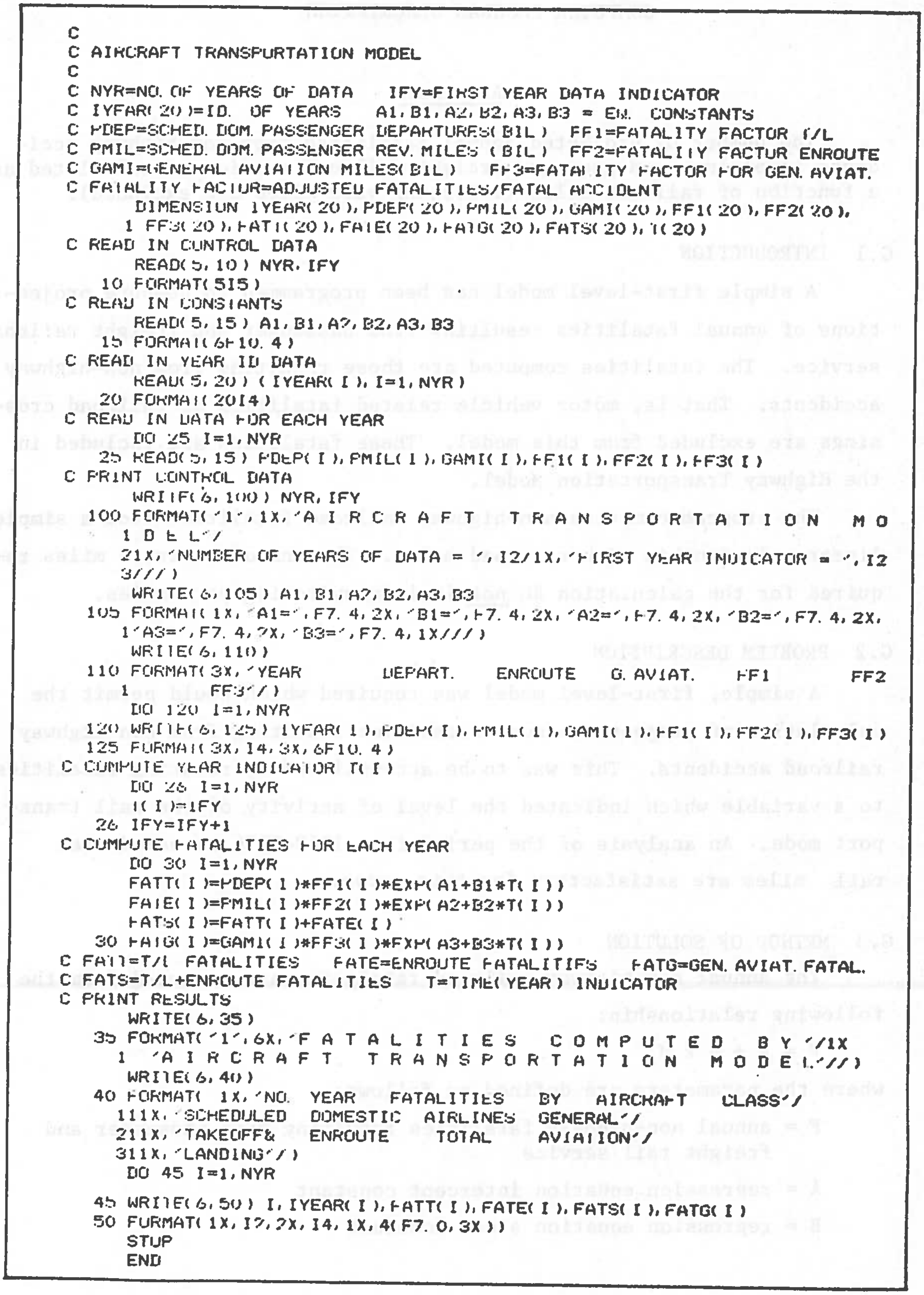
c) Fatalities per fatal accident for each class of air transport for each year; and

d) Fatalities projected for air carrier takeoff/landing, enroute and combined and general aviation for each year.

F.5.2.2 Punched Card Output

There is no punched card output from this program.

F.6 PROGRAM LISTING



```
C
C AIRCRAFT TRANSPORTATION MODEL
C
C NYR=NO. OF YEARS OF DATA   IFY=FIRST YEAR DATA INDICATOR
C IYEAR(20)=ID. OF YEARS   A1,B1,A2,B2,A3,B3 = EQ. CONSTANTS
C PDEP=SCHED. DOM. PASSENGER DEPARTURES(BIL)  FF1=FATALITY FACTOR T/L
C PMIL=SCHED. DOM. PASSENGER REV. MILES (BIL)  FF2=FATALITY FACTOR ENROUTE
C GAMI=GENERAL AVIATION MILES(BIL)  FF3=FATALITY FACTOR FOR GEN. AVIAT.
C FATALITY FACTOR=ADJUSTED FATALITIES/FATAL ACCIDENT
      DIMENSION IYEAR(20),PDEP(20),PMIL(20),GAMI(20),FF1(20),FF2(20),
     1 FF3(20),FATT(20),FATE(20),FATG(20),FATS(20),T(20)
C READ IN CONTROL DATA
      READ(5,10) NYR,IFY
   10 FORMAT(5I5)
C READ IN CONSTANTS
      READ(5,15) A1,B1,A2,B2,A3,B3
   15 FORMAT(6F10.4)
C READ IN YEAR ID DATA
      READ(5,20) (IYEAR(I),I=1,NYR)
   20 FORMAT(20I4)
C READ IN DATA FOR EACH YEAR
      DO 25 I=1,NYR
   25 READ(5,15) PDEP(I),PMIL(I),GAMI(I),FF1(I),FF2(I),FF3(I)
C PRINT CONTROL DATA
      WRITE(6,100) NYR,IFY
  100 FORMAT('1',1X,'A I R C R A F T   T R A N S P O R T A T I O N   M O
     1 D E L'/
     21X,'NUMBER OF YEARS OF DATA = ',I2/1X,'FIRST YEAR INDICATOR = ',I2
     3///)
      WRITE(6,105) A1,B1,A2,B2,A3,B3
  105 FORMAT(1X,'A1=',F7.4,2X,'B1=',F7.4,2X,'A2=',F7.4,2X,'B2=',F7.4,2X,
     1'A3=',F7.4,2X,'B3=',F7.4,1X///)
      WRITE(6,110)
  110 FORMAT(3X,'YEAR        DEPART.    ENROUTE    G. AVIAT.    FF1         FF2
     1       FF3'/)
      DO 120 I=1,NYR
  120 WRITE(6,125) IYEAR(I),PDEP(I),PMIL(I),GAMI(I),FF1(I),FF2(I),FF3(I)
  125 FORMAT(3X,I4,3X,6F10.4)
C COMPUTE YEAR INDICATOR T(I)
      DO 26 I=1,NYR
      T(I)=IFY
   26 IFY=IFY+1
C COMPUTE FATALITIES FOR EACH YEAR
      DO 30 I=1,NYR
      FATT(I)=PDEP(I)*FF1(I)*EXP(A1+B1*T(I))
      FATE(I)=PMIL(I)*FF2(I)*EXP(A2+B2*T(I))
      FATS(I)=FATT(I)+FATE(I)
   30 FATG(I)=GAMI(I)*FF3(I)*EXP(A3+B3*T(I))
C FATT=T/L FATALITIES   FATE=ENROUTE FATALITIES   FATG=GEN. AVIAT. FATAL.
C FATS=T/L+ENROUTE FATALITIES   T=TIME(YEAR) INDICATOR
C PRINT RESULTS
      WRITE(6,35)
   35 FORMAT('1',6X,'F A T A L I T I E S   C O M P U T E D   B Y '/1X
     1 'A I R C R A F T   T R A N S P O R T A T I O N   M O D E L'//)
      WRITE(6,40)
   40 FORMAT( 1X,'NO.  YEAR    FATALITIES     BY    AIRCRAFT    CLASS'/
     111X,'SCHEDULED  DOMESTIC  AIRLINES  GENERAL'/
     211X,'TAKEOFF&   ENROUTE    TOTAL     AVIATION'/
     311X,'LANDING'/)
      DO 45 I=1,NYR
   45 WRITE(6,50) I,IYEAR(I),FATT(I),FATE(I),FATS(I),FATG(I)
   50 FORMAT(1X,I2,2X,I4,1X,4(F7.0,3X))
      STOP
      END
```

APPENDIX G: RAILROAD TRANSPORTATION MODEL COMPUTER PROGRAM DESCRIPTION

Abstract

The number of projected annual fatalities from non-highway accidents involving passenger and freight railroad service is calculated as a function of railroad miles (switching yard miles are excluded).

G.1 INTRODUCTION

A simple first-level model has been programmed to compute projections of annual fatalities resulting from passenger and freight railroad service. The fatalities computed are those resulting from non-highway accidents. That is, motor vehicle related fatalities at railroad crossings are excluded from this model. These fatalities are included in the Highway Transportation Model.

The program computes non-highway railroad fatalities from a simple linear relationship with railroad miles. The annual railroad miles required for the calculation do not include switching yard miles.

G.2 PROBLEM DESCRIPTION

A simple, first-level model was required which would permit the calculation of projected annual fatalities resulting from non-highway railroad accidents. This was to be accomplished by relating fatalities to a variable which indicated the level of activity of the rail transport mode. An analysis of the period from 1962-1974 revealed that rail miles are satisfactory for this purpose.

G.3 METHOD OF SOLUTION

The annual non-highway railroad fatalities are computed from the following relationship:

$$F = A + B \times M,$$

where the parameters are defined as follows:

F = annual non-highway fatalities resulting from passenger and freight rail service

A = regression equation intercept constant

B = regression equation slope constant

M = passenger and freight rail miles in millions (excluding switching yard miles).

G.4 PROGRAM DESCRIPTION

This program is written in FORTRAN IV for the IBM 360/65 computer. The program requires less than 2K bites of core storage for execution, does not include any subroutines, and executes in less than 5 seconds. Provision is made in the program for the computation of alternative sets of projected rail fatalities. Two sets of regression equation constants based on analysis of historical data from different periods can be input.

G.5 PROGRAM USE

G.5.1 Input

Control Card

The input format is (I5).

Column	Parameter
1-5	Number of years for which projection fatalities are to be calculated. (Maximum number of years allowed is 20.)

Projection Equations Constants Card

The input format is (4F10.4).

Column	Parameter
1-10	Intercept A for first projection regression equation.
11-20	Slope B for first projection regression equation.
21-30	Intercept A for second projection regression equation. Leave blank if second equation not used.
31-40	Slope B for second projection regression equation. Leave blank if second equation not used.

Train Mile Data Cards

The input format is (I4, 6X, F10.0).

Columns	Parameter
1-4	Year of projected train mile data.
11-20	Passenger and freight rail miles in millions (excluding switching yard miles).

G.5.2 Output

G.5.2.1 Printed Output

The printed output contains the following:

a) Projection regression equation constants;

b) Train miles by calendar year; and

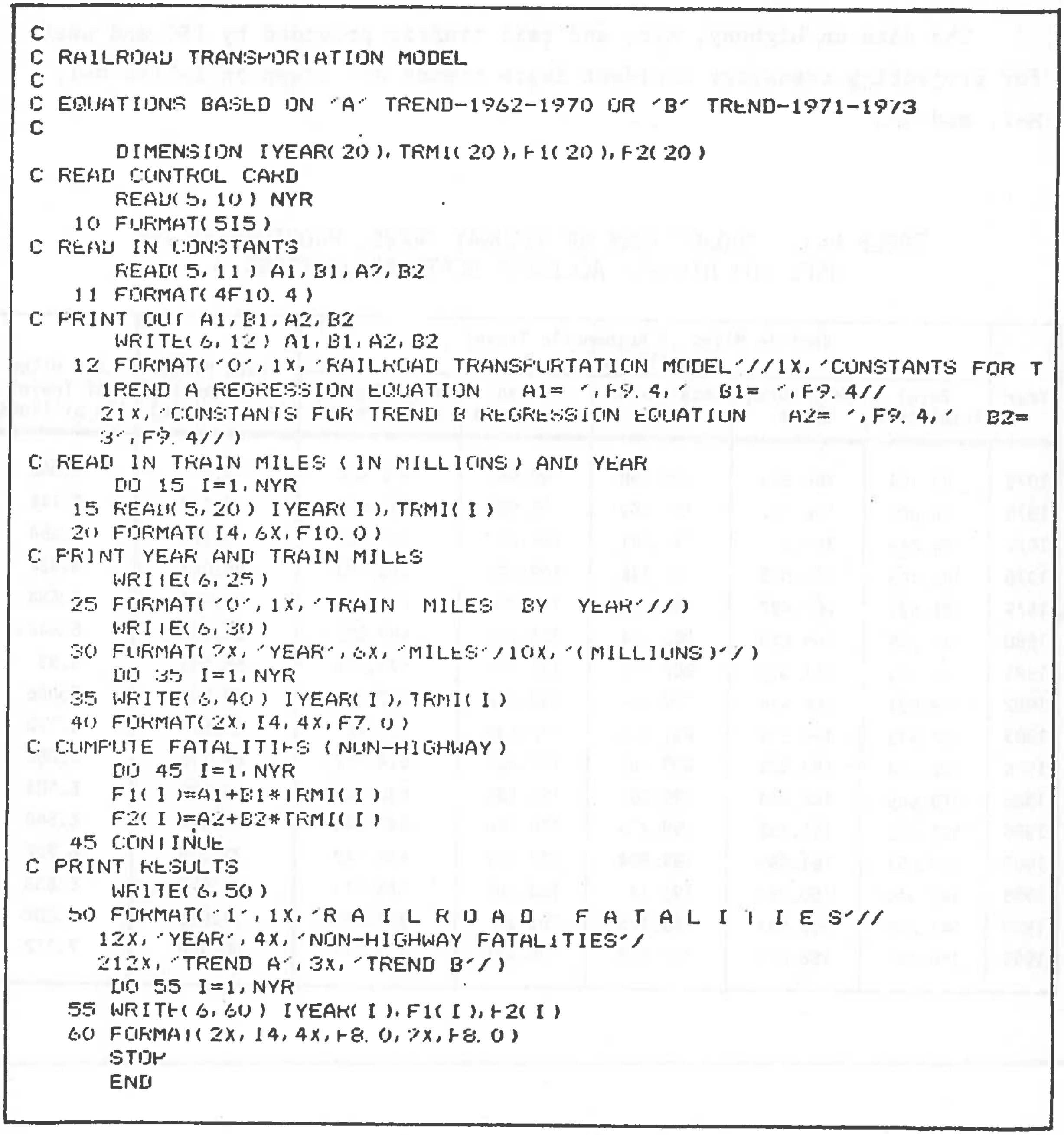
c) Non-highway rail fatalities by calendar year.

G.5.2.2 Punched Card Output

There is no punched card output from this program.

G.6 PROGRAM LISTING

(On following page)



```
C
C RAILROAD TRANSPORTATION MODEL
C
C EQUATIONS BASED ON 'A' TREND-1962-1970 OR 'B' TREND-1971-1973
C
      DIMENSION IYEAR(20),TRMI(20),F1(20),F2(20)
C READ CONTROL CARD
      READ(5,10) NYR
   10 FORMAT(5I5)
C READ IN CONSTANTS
      READ(5,11) A1,B1,A2,B2
   11 FORMAT(4F10.4)
C PRINT OUT A1,B1,A2,B2
      WRITE(6,12) A1,B1,A2,B2
   12 FORMAT('0',1X,'RAILROAD TRANSPORTATION MODEL'//1X,'CONSTANTS FOR T
     1REND A REGRESSION EQUATION   A1= ',F9.4,'   B1= ',F9.4//
     21X,'CONSTANTS FOR TREND B REGRESSION EQUATION   A2= ',F9.4,'   B2=
     3',F9.4//)
C READ IN TRAIN MILES (IN MILLIONS) AND YEAR
      DO 15 I=1,NYR
   15 READ(5,20) IYEAR(I),TRMI(I)
   20 FORMAT(I4,6X,F10.0)
C PRINT YEAR AND TRAIN MILES
      WRITE(6,25)
   25 FORMAT('0',1X,'TRAIN  MILES  BY  YEAR'//)
      WRITE(6,30)
   30 FORMAT(2X,'YEAR',6X,'MILES'/10X,'(MILLIONS)'/)
      DO 35 I=1,NYR
   35 WRITE(6,40) IYEAR(I),TRMI(I)
   40 FORMAT(2X,I4,4X,F7.0)
C COMPUTE FATALITIES (NON-HIGHWAY)
      DO 45 I=1,NYR
      F1(I)=A1+B1*TRMI(I)
      F2(I)=A2+B2*TRMI(I)
   45 CONTINUE
C PRINT RESULTS
      WRITE(6,50)
   50 FORMAT('1',1X,'R A I L R O A D   F A T A L I T I E S'//
     12X,'YEAR',4X,'NON-HIGHWAY FATALITIES'/
     212X,'TREND A',3X,'TREND B'/)
      DO 55 I=1,NYR
   55 WRITE(6,60) IYEAR(I),F1(I),F2(I)
   60 FORMAT(2X,I4,4X,F8.0,7X,F8.0)
      STOP
      END
```

APPENDIX H: TRAFFIC PROJECTIONS USED AS BASIS FOR FATALITY TREND PROJECTIONS

The data on highway, air, and rail traffic provided by TSC and used for projecting transport accident death trends are given in Tables H-1, H-2, and H-3.

TABLE H-1. PROJECTIONS OF HIGHWAY TRAVEL PROVIDED BY TSC USED FOR HIGHWAY ACCIDENT DEATH PROJECTIONS

Year	Vehicle Miles of Automobile Travel (in billions)					Truck Miles of Travel (in billions)	Bus Miles of Travel (in billions)
	Rural Interstate	Main Rural Roads	Local Rural Roads	Urban Interstate	Urban Highway and Streets		
1975	87.184	168.399	196.158	90.987	470.472	43.251	5.066
1976	90.803	166.167	195.149	96.068	480.614	44.472	5.144
1977	94.861	165.017	195.241	101.82	493.861	46.176	5.254
1978	100.109	166.015	197.746	109.077	513.853	48.061	5.434
1979	105.691	167.492	200.726	116.949	535.941	50.418	5.634
1980	111.399	169.053	203.724	125.222	559.002	53.224	5.842
1981	114.765	167.075	202.358	131.084	570.719	56.055	5.93
1982	118.991	166.434	202.511	138.122	587.142	58.805	6.066
1983	122.572	164.935	201.535	144.608	600.75	61.527	6.172
1984	126.174	163.525	200.583	151.307	614.812	64.216	6.282
1985	129.969	162.394	199.902	158.426	630.109	66.889	6.404
1986	134.173	161.762	199.775	166.246	647.643	69.558	6.548
1987	138.553	161.299	199.804	174.502	666.242	72.219	6.702
1988	142.949	160.797	199.74	183.002	685.111	74.975	6.858
1989	147.072	159.934	199.185	191.37	702.839	77.698	7.002
1990	150.449	158.245	197.558	198.971	717.177	80.350	7.112

TABLE H-2. PROJECTIONS OF AIR TRAFFIC PROVIDED BY TSC USED FOR AIR ACCIDENT DEATH PROJECTIONS

Year	U.S. Air Carrier Miles (in millions) Flown on Domestic Rates*	U.S. Air Carrier Operations On Domestic Rates*	General Aviation Aircraft Miles Flown (in millions)
1976	2,063	10,577	5,254.75
1977	2,136	11,122	5,499.0
1978	2,207	11,438	5,865.25
1979	2,281	11,864	6,201.5
1980	2,363	12,389	6,626.75
1981	2,456	12,714	6,990.75
1982	2,549	13,142	7,292.75
1983	2,641	13,463	7,735.23
1984	2,763	13,995	8,207.34
1985	2,834	14,416	8,711.28
1986	2,936	14,840	9,249.44
1987	3,042	15,375	9,824.41
1988	3,151	15,907	10,439.0
1989	3,265	16,456	11,096.2
1990	3,382	17,026	11,799.3

*Includes supplemental intrastate and contract carriers.

TABLE H-3. PROJECTIONS OF RAIL TRANSPORT PROVIDED BY TSC USED FOR RAIL ACCIDENT DEATH PROJECTIONS

Year	Passenger Train Miles (In Thousands)	Rail Freight Train Miles (In Billions)
1975	66466.8	0.220175
1976	68634.1	.226880
1977	70872.0	.240910
1978	73182.9	.248246
1979	75569.1	.258378
1980	78033.2	.268922
1981	80577.6	.279618
1982	83204.9	.289866
1983	85918.	.300193
1984	88719.5	.309335
1985	91612.4	.325195
1986	94599.6	.331763
1987	97684.1	.348773
1988	100869.	.359394
1989	104158.	.370340
1990	107555.	.385455

APPENDIX I: LIST OF REFERENCES

1. U.S. Department of Transportation, *Summary of National Transportatation Statistics.* Assistant Secretary for Policy and International Affairs, Office of Systems Analysis and Information, U.S. Department of Transportation, Washington, D.C., November 1972, June 1975.

2. National Safety Council, *Accident Facts.* Chicago, published annually.

3. Slatterly, Gilbert T., Jr. and Donald E. Cleveland, "Traffic Control and Roadway Elements--Their Relationship to Highway Safety." (revised), Chapter 2 in *Traffic Volume.* Automotive Safety Foundation, Washington, D.C., 1969.

4. Fromm, Gary, "Aviation Safety Law and Contemporary Society." Reprint No. 152, The Brookings Institution, Washington, D.C., 1969.

5. Richards, Hay A. and G. Sadler Bridges, "Traffic Control and Roadway Elements--Their Relation to Highway Safety" (revised), Chapter 1 in *Railroad Grade Crossings.* Automotive Safety Foundation, 1968.

6. Joksch, H.C., *An Accident Trend Model.* Report No. DOT-HS-801420, National Technical Information Services, Springfield, VA, March 1975.

7. U.S. Department of Transportation, *Summary of National Transportation Statistics (1963-1973).* Washington, D.C., 1975.

8. American Trucking Association, *American Trucking Trends.* Washington, D.C., published annually.

9. Motor Vehicle Manufacturers Association, *Motor Truck Facts.* Detroit, published annually.

10. Transportation Association of America, *Transportation Facts and Trends.* 11th Edition, Washington, D.C., 1974.

11. U.S. Bureau of the Census, *Statistical Abstract of the United States.* Washington, D.C., published annually.

12. U.S. Department of Commerce, *1972 Census of Transportation, Truck Inventory and Use Survey.* Washington, D.C.

13. U.S. Department of Transportation, Federal Highway Administration, *Nationwide Personal Transportation Study.* Washington, D.C. 1972-74.

14. Joksch, H.C., *Analysis of the Future Effects of Fuel Shortage and Increased Small Car Usage Upon Traffic Deaths and Injuries.* Report No. DOT-TSC-OST-75-21, U.S. Department of Transportation/Transportation Systems Center, Cambridge, 1976.

15. Joksch, H.C., and H. Wuerdemann, *Comparative Estimates of Losses in Transportation Accidents.* TRC Report 4046-381, The Travelers Research Corporation, Hartford, 1970.

16. Peltzman, S., "The Effects of Automobile Regulation," *Journal of Political Economy, 83* (1975), pp 677-725.

17. Peltzman, S., "The Effects of Automobile Safety Regulation: Reply," *Accident Analysis and Prevention,* to appear.

18. Joksch, H.C., Critique of Sam Peltzman's Study "The Effects of Automobile Safety Regulation," *Accident Analysis and Prevention,* to appear.

19. Joksch, H.C., "Comments on Peltzman's Reply," *Accident Analysis and Prevention,* to appear.

20. Robertson, L.S., A Critical Analysis of Peltzman's "The Effects of Automobile Safety Regulation." Unpublished (1975).

21. U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics.* Washington, D.C., published annually.

22. U.S. Department of Transportation, Federal Highway Administration, *Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems.* Washington, D.C., published annually.

23. Highway Safety Research Center, University of North Carolina, *Single Variable Tabulations for 1973 North Carolina Accidents.* Chapel Hill, N.C., 1974.

24. Clark, V.J., *Single Variable Tabulations for 1974 North Carolina Accidents.* Highway Safety Research Center, University of North Carolina, Chapel Hill, N.C., 1975.

25. Carroll, P.S., et al., *Current Information on Frequency of Injury and Death by Crash Configuration and Speeds.* Highway Safety Research Institute, University of Michigan, Ann Arbor, 1973.

26. Ernst & Ernst, *Truck Accident Study*, prepared for Automobile Manufacturers Association, Detroit, 1968.

27. Cerrelli, E., "Truck Accident Study" (Draft), Hearings before the Subcommittee on Transportation of the Committee on Public Works, United States Senate, 93rd Congress, 2nd Session. February 20, 21 and March 26, 1974.

28. Robertson, L.S. and S.P. Baker, *Motor Vehicle Sizes in 1440 Fatal Crashes.* Insurance Institute for Highway Safety, Washington, D.C., 1975.

29. Lohman, L.S. deSavornin and P.F. Waller, *Trucks: An Analysis of Accident Characteristics by Vehicle Weight.* Highway Safety Research Center, University of North Carolina, Chapel Hill, 1975.

30. Center for the Environment and Man, Inc., *Evaluation of Motor Vehicle Safety Standards.* Hartford, Conn., 1973.

31. Griffin, L.I., III, *Analysis of the Benefits Derived from Certain Presently Existing Motor Vehicle Safety Devices: A Review of the Literature.* Highway Safety Research Center, University of North Carolina, Chapel Hill, 1973.

32. Stewart, J.R., *An Analysis of Automobile Accidents to Determine Which Variables are Most Strongly Associated with Driver Injury. Relationships Between Driver Injury and Vehicle Model Year.* Highway Safety Research Center, University of North Carolina, Chapel Hill, 1975.

33. Department of Transportation, Federal Aviation Administration, *FAA Statistical Handbook of Aviation.* Washington, D.C. published annually.

34. Air Transport Association of America, *Air Transport Facts and Figures.* Washington, D.C., published annually.

35. National Transportation Safety Board, *Annual Review of U.S. Air Carrier Accidents.* Department of Transportation, Washington, D.C., published annually.

36. Civil Aeronautics Board, *A Statistical Review and Briefs of U.S. Air Carrier Accidents.* Washington, D.C., published annually.

37. Gay, W.F., *Energy Statistics, A Supplement to the Summary of National Transportation Statistics.* Transportation Systems Center, Cambridge, 1974.

38. *Aviation Week and Space Technology,* McGraw Hill, New York, published weekly.

39. Taylor, J.W. (editor), *Jane's All the Worlds Aircraft.* McGraw Hill, New York, published annually.

40. Civil Aeronautics Board, *General Aviation Accidents, A Statistical Review.* Washington, D.C., published annually.

41. National Transportation Safety Board, *Annual Review of U.S. General Aviation Accidents*. Washington, D.C., published annually.

42. Department of Transportation, Federal Aviation Administration, *General Aviation Statistics*, Washington, D. C., 1969.

43. U. S. Department of Transportation, Federal Railroad Administration, Office of Safety, *Accident Bulletin: Summary and Analysis of Accidents on Railroads in the United States*, Nos. 132-143 (1963-1974).

44. Moody's Investors Service, *Moody's Transportation Manual*. New York, 1975.

45. U. S. Department of Transportation, United States Coast Guard, *Proceedings of the Merchant Marine Council*, Vols. 19-26. Washington, D. C., 1961-1968.

46. U. S. Department of Transportation, United States Coast Guard, *Marine Safety Council Proceedings*, Vols. 27-31. Washington, D. C., 1969-1973.

47. University of Oklahoma, Office of Research Administration, *Analysis and Management of a Pipeline Safety Information System*. Report No. DOT-TST-75-47, Department of Transportation, Office of Pipeline Safety, Washington, D. C., 1975.

48. Joksch, H. C., "An Empirical Relation Between Fatal Accident Involvement per Accident Involvement and Speed," *Accident Analysis and Prevention, 7*, 1975, pp. 129-132.

49. AASHTO, Subcommittee on Traffic Engineering, *Effects of the 55 mph Speed Limit*. AASHTO, Washington, D. C., Nov. 1974.

50. Michaels, R. and C. Schneider, "The Energy Crisis, Characteristics of Traffic Flow, and Highway Safety," *Accident Analysis and Prevention*, to appear.

51. O'Day, J., et al., "The Effects of the Energy Crisis and the 55 mph Speed Limit in Michigan," *HIT-Lab Reports*, Vol. 5, No. 11, University of Michigan, Highway Safety Research Institute, July 1975.

52. Pennsylvania State University, "Safety Aspects of Reduced Speed Limits and Reduction in Travel Caused by the Energy Crisis." Being prepared under current contract with the Federal Highway Administration, to be published.

53. Unpublished material on file.

APPENDIX J: REPORT OF INVENTIONS

The purpose of this contract was to review and analyze accident data and therefore, as expected, nothing of a patentable nature was developed.

However, the state-of-the-art of safety modeling and forecasting was advanced through the development of the various modal safety models, the examination of data availability and limitations, and the forecasting of fatality levels by mode.