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16. Abstract

In benefit-cost analysis, travel time saving represents a major determinant of the benefits from highway improvements. Current values of time adopted by the Texas Highway Evaluation Model (HEEM) as well as those recommended by the Redbook are fairly outdated. New estimates of the value of time for cars and trucks are needed for HEEM. Based on a telephone survey, this study derived the value of time by adopting a speed choice model which assumes that a rational driver chooses a speed so as to minimize his/her total driving costs. Driving costs include vehicle operating costs, time costs, accident costs, traffic violation costs, and other nonquantifiable costs such as comfort and convenience.

Among the driving cost components, fatal accident cost plays an important role in the determination of the value of time. Individual's fatal accident cost directly relates to his/her value of life which was derived in two approaches in this study: the foregone labor earnings and the willingness-to-pay to reduce his/her risk of getting killed. The two values of life produce two separate values of time for the individual. Different weights were considered and applied to arrive at weighted average values of time. After a review of the results, this study recommends the value of time for drivers to be $8.00 per person-hour and for passenger cars to be $10.40 per vehicle-hour, in 1985 dollars.

The speed choice model was not used in estimating truck value of time because of insufficient response from truck drivers in the survey. Instead, it was derived by updating values from previous research. The 1985 value of time for trucks was found to be $19.00 per vehicle-hour.

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THE VALUE OF TRAVEL TIME: NEW ESTIMATES DEVELOPED USING A SPEED-CHOICE MODEL

by

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Research Report No. 396-2F
Research Study No. 2-8-84-396
Improved Values of Travel Time and Accident Costs for Highway Project Evaluations

Sponsored by

Texas State Department of Highways and Public Transportation

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Federal Highway Administration

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Texas Transportation Institute
The Texas A&M University System
College Station, Texas

PREFACE

The authors wish to express their appreciation to those who have helped or facilitated in the study. Special acknowledgement is due Dr. Jeffery L. Memmott of Texas Transportation Institute for his valuable comments. Appreciation is extended to Mrs. Patricia Holmstrom for typing the manuscript and Dr. David Hill of the Texas A&M University Public Policy Resources Laboratory for directing the telephone survey. The authors also are indebted to the study contact representative, Mr. Bob Farrar, economist with the Texas State Department of Highways and Public Transportation.

SUMMARY OF FINDINGS

Travel time saving represents a major determinant of benefits from highway improvements in benefit-cost analysis. Current values of time adopted by the Texas Highway Evaluation Model (HEEM), as well as those recommended by the Redbook, are fairly outdated. New estimates of the value of time, which take into consideration characteristics of present users and transportation systems, are needed. The main objective of this study is to develop estimates of the value of time to be used in the HEEM for passenger cars and trucks on highways in Texas.

A speed choice model is used for the study. In this model, a rational driver is assumed to choose a speed at which his/her total driving costs are minimized. Total driving costs include vehicle operating costs, accident costs, time costs, traffic violation costs, and other nonquantifiable costs such as comfort and convenience. Based on the assumption, the value of time of each individual can be obtained in terms of the square of his/her chosen speed, the distance traveled and the derivatives of his/her driving cost components other than time costs. Traffic violation costs and other nonquantifiable costs are not considered in this study.

Among the driving cost components, fatal accident cost plays an important part in determining the value of time. Individual fatal accident cost is developed by first obtaining his/her value of life and, secondly, identifying his/her fatal accident rate curve. The value of life is estimated in two different approaches, one based on his/her foregone labor earnings and the other on his/her willingness-to-pay to reduce his/her risk of getting killed. The two different values of life derived result in two sets of values of time, the EARN set and the WTP set. In each set, the value of time is calculated for 4-lane interstate and 2-lane rural highways, for belted and nonbelted drivers of each sex, and, lastly, for daytime and nighttime driving. In one approach, each of the values of time calculated is weighted by the distribution of seatbelt wearers and nonbelted drivers, the state percentage distribution of male and female population, and distribution of day and night mileages traveled to arrive at an overall weighted value of time for the two highway types. In another approach, values of time in each of the EARN and the WTP sets are first weighted by the annual distribution of traveling time of males and females before the previously

mentioned weights for seatbelt usage and time of day are applied and the resulting sets are named the weighted EARN set and the weighted WTP set.

A telephone survey of 500 people randomly selected over Texas was conducted to gather information on driving habits, personal characteristics, and the willingness-to-pay for driving on a safer road.

Overall weighted values of time derived range from as high as $17.0 for the 4-lane divided highway subset in the WTP set to the low of $7.7 for similar subset in the weighted EARN set. After a review of the results obtained, this study recommends the 1985 value of time of passenger car drivers to be $8.00 and for passenger cars to be $10.40 per hour.

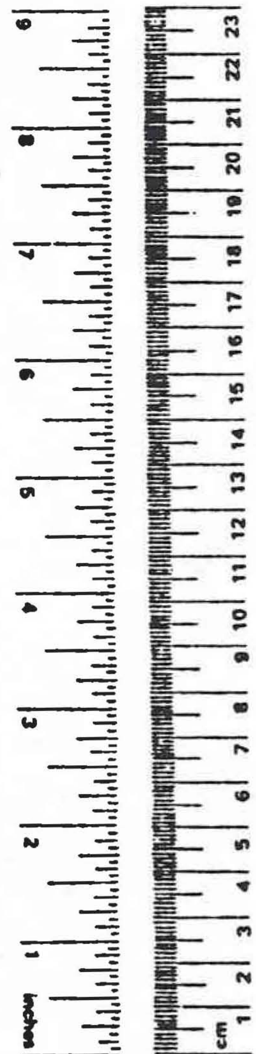
Because of insufficient response from truck drivers in the survey, the value of time for trucks cannot be estimated by the speed choice model; instead, an updating procedure using wholesale price indexes is used. The 1985 value of time for trucks is $19.00 per vehicle hour.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

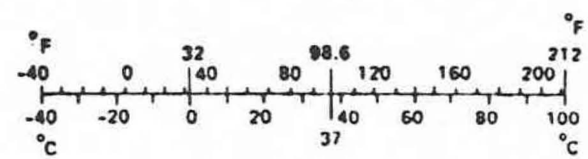
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

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



Approximate Conversions from Metric Measures

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



IMPLEMENTATION STATEMENT

This report presents the value of time developed for passenger car drivers, for passenger cars, and for trucks. These values can be used immediately by transportation officials in their planning and decision-making process.

It is recommended that the new values of travel time be used in the Highway Economic Evaluation Model and in other benefit-cost analyses performed in Texas. The new values of time are $10.40 per vehicle-hour for passenger cars and $19.00 per vehicle-hour for trucks, both in 1985 dollars.

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INTRODUCTION

Benefits resulting from travel time savings represent a major portion of the total benefits in benefit/cost ratios that are used by highway planners and officials for evaluating highway improvement projects. In order to translate benefits from travel time savings between alternative projects to monetary terms, the unit value of time is needed. In addition to the purpose of project evaluation, the value of time is important in the economic approach of analyzing travel demand and travel forecasts since travel time is one of the determinants of the price of making a trip in demand analysis.

Before the mid-sixties, methods of measuring the value of time were scarce and crude. Values adopted by transportation planners and officials were based mostly on intuition and non-behavioral estimates such as operating costs and/or tolls. In general, the wage rate was used as an index when measuring the value of time. Since 1965, interest in values of time has increased, and major studies on the subject have been carried out not only in the United States but also in other countries such as England, France, Italy, and Australia.

What should transportation officials use for the value of time savings when they evaluate highway improvement projects? Empirical results on values of time cover a rather wide range, from as low as 14 percent [13] to as high as 100 percent [10, 8] of the average wage rate. The Redbook [1] recommends a value of time that is about 32 percent of the wage rate for work trip for the \$14,000 - \$17,000 income range, and this is the value generally adopted by officials and researchers in transportation. However, this value was based on the Lisco [18] and Thomas and Thompson [25] studies done 15 years ago. Updated values of time are needed.

Objective of Study

One major determinant of the benefits from highway improvements is travel time savings. In order to incorporate these savings in the total benefits from improvements, travel time savings are converted to a dollar value through a unit measure of the value of time. Current values of time adopted by the Texas Highway Economic Evaluation Model (HEEM), as well as those recommended by the Redbook, are fairly outdated. New estimates of the value of time that take into consideration the characteristics of present users and transportation choices in Texas are needed for better project evaluation and prioritization.

The objective of this study is to develop a model for estimating new values of time for passenger cars and trucks to be used in HEEM.

Contents of Report

This report presents findings of the study on the value of time. A literature review was conducted and, based upon the review, the speed choice model of evaluating the value of time was chosen to be most appropriate for the purpose of this study. The data base required for the model came from a telephone survey. Based on information from the survey, an individual's value of life was derived in two different ways and, in turn, these values were used with other information to estimate the individual's value of time.

The major divisions of the body of the report are as follows: (1) literature review, (2) speed choice model, (3) data sources, (4) relevant variables, (5) results, and (6) conclusions and recommendations.

LITERATURE REVIEW

Before 1965, the value of time used was based more on intuition and non-behavioral estimates than on a reliable theoretical model [11]. Since then, interest on the value of time has grown. Studies on the subject have been carried out not only in the United States but also in England, France, Germany, and Australia. Among the studies, methods used for estimating the value of time range from simple to complex and also, no one single value of time is agreed upon for adoption. However, in most studies, an average value of time is assumed to be constant over a population.

Binary choices of transport modes or routes are situations dealt with in most of these studies. The reason for using these choices may be twofold: their simplicity and ease of handling and the close resemblance to real world situations facing travelers. Between mode and route choices, the former situations are encountered in value of time studies more frequently than the latter ones. Modal choices include rail vs. car as used in the studies by Lisco [18] and Hensher [14], and bus/public transport vs. car as appeared in studies by Beesley [2], Heggie [1], Lave [15], and others. Some less used modal choices are bus vs. train, as shown in studies of Lee and Dalvi [16, 17] and Charles River Associates [7], and shared taxi vs. express bus used in the recent study by S. Thomas [24].

An important study of the value of time using route choice is that by Thomas and Thompson [25] who adopted the logit model based on drivers' choices between toll roads and free roads. Data for their study were gathered through site interviews at state parks, schools, and shopping centers and mail-back surveys given out at stop lights and toll booths at sites in ten states across the country. A recent study by S. Thomas [24] also explores the value of time using a toll vs. free highway in a before-after situation in West Malaysia.

In the modal and route choice studies, situations are studied in which a driver makes a choice involving a trade-off between costs and time savings. By the alternative he/she chooses, whether it is a cost saving and time consuming alternative or a time-saving and more-costly one, a value of time can be indirectly derived. However, for the current study, both the modal and route choice approaches are difficult to use in Texas for estimating a value of time for highway travel. Only a small proportion of all Texas motorists typically make modal choices between bus travel and automobile travel and only a very small proportion of these are for rural trips. Also, since there are very few toll roads in Texas, the alternate route model is difficult to use in Texas because of lack of data sources. Because of these difficulties with using a mode choice or route choice model in Texas, other approaches were explored.

Further searches among studies of the value of time reveal another approach--the speed choice model which first appeared in 1965 in a study by Mohring [19] who claimed a utility maximizer will adopt a driving speed which minimizes the total operating costs and accident costs. Later, Ghosh et al. [9] attempted to locate the optimal speed on a British motorway using the same approach. A group of German studies on the value of time are also found to be based on the speed choice model [21].

Questions have been raised concerning the underlying assumption of the model which refers to the driver's knowledge of the relation of driving costs to driving speed. In order for a driver to choose an optimal speed so as to minimize costs, he/she must have an accurate knowledge of the running costs-speed relationship, a fact which both Winfrey [27] and Thomas [24] agreed to be difficult to observe in most drivers. However, it is contended in this study that, even if a driver does not know the individual relationship between vehicle operating costs and speed or between accident costs and speed or between other driving costs and speed, he/she must know his/her total driving costs related to speed in order for him/her to decide on using a specific speed. Even for someone who disregards time savings but likes fast driving per se, as questioned by Bruzelius [5], he/she is receiving the benefits of the pleasure of fast driving at the expense of paying higher accident costs. The reason why he/she does not drive faster than whatever speed he/she is driving, even though he/she enjoys fast driving, is because other costs, such as accident costs, come into the total costs picture. This driver is still operating at the speed where he/she equates his/her marginal costs to his/her marginal benefits.

Based upon the literature reviewed, it is concluded that the speed choice model is the most appropriate model for developing a value of time for use in Texas.

SPEED CHOICE MODEL

In the speed choice model for evaluating the value of time, it is assumed that a rational driver always drives at the speed at which his/her total trip cost is minimized. The total trip cost includes time costs, vehicle operating costs, accident costs, and other costs which can represent comfort and convenience costs, traffic violation costs, etc. Each of these cost components is related to speed and this relationship differs not only in magnitude among cost components but also in direction. Hence, it is possible, when a driver attempts to lower one of the costs, other cost components may increase resulting in a higher total trip cost. For instance, by increasing traveling speed, travel time is reduced and consequently, time costs are lowered. However, at higher speed, accident costs may increase off-setting the lower time costs and resulting in a higher total trip cost. For a rational driver who always operates where his/her marginal costs equates his/her marginal benefits (point A in Figure 1), he/she would not choose to increase speed under these circumstances.

Therefore, the total trip cost (TTC_i) for individual i traveling a distance of D miles at speed s mph is written as:

$$(1)\quad TTC_i = TMC_i + VOC_i + ACC_i + OC_i$$

where TMC_i, VOC_i, ACC_i, and OC_i represent functions of individual i's time costs, vehicle operating costs, accident costs, and other costs, respectively, with speed for making this trip of D miles distance away.

His/her total trip cost is minimized first by differentiating Equation 1 with respect to speed s:

$$(2)\quad \frac{d(TTC_i)}{ds} = \frac{d(TMC_i)}{ds} + \frac{d(VOC_i)}{ds} + \frac{d(ACC_i)}{ds} + \frac{d(OC_i)}{ds},$$

and then by setting Equation 2 to zero

$$\frac{d(TTC_i)}{ds} = 0,$$

or

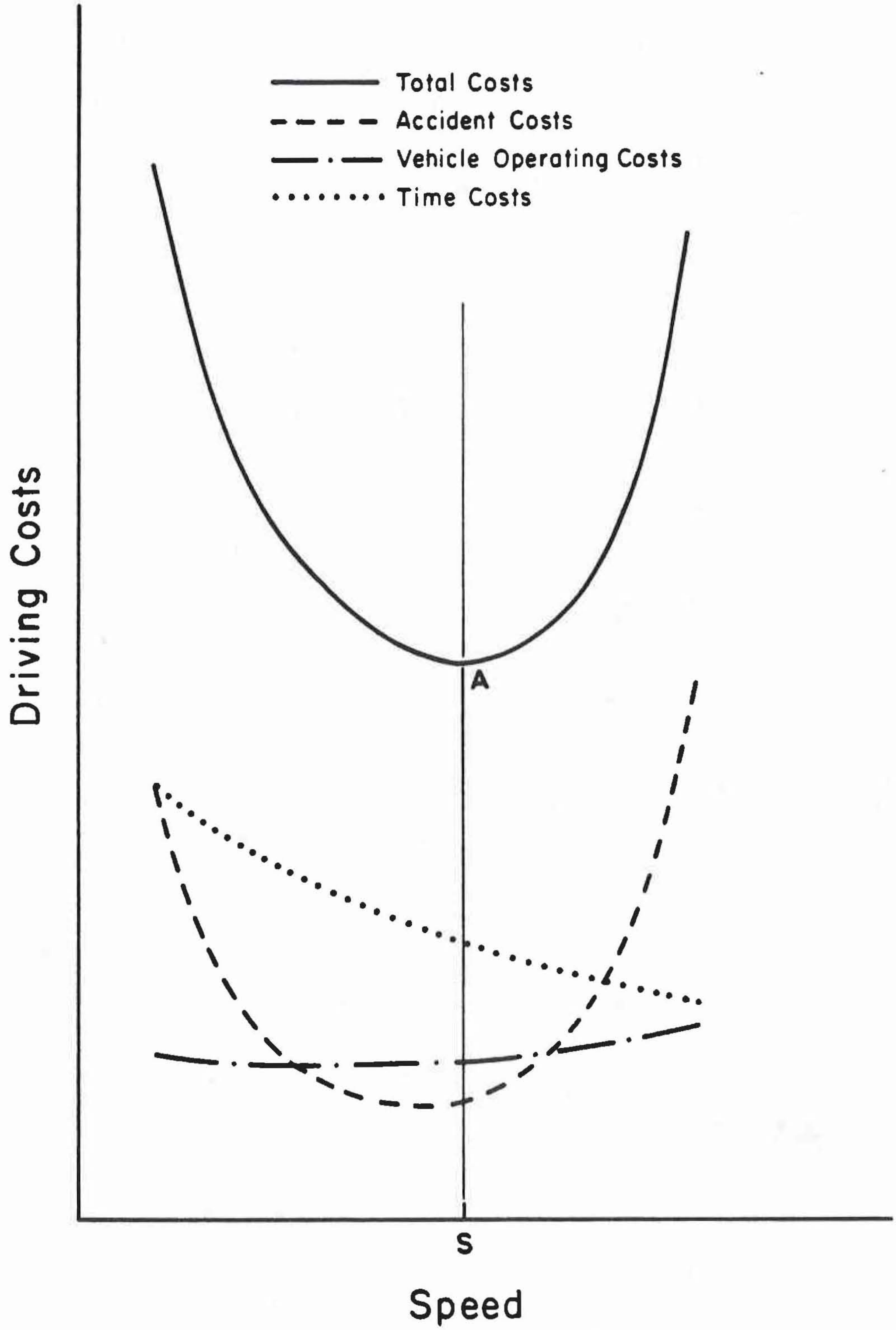

Figure 1. An Individual's Driving Costs

$$(3)\quad \frac{d(TMC_i)}{ds} + \frac{d(VOC_i)}{ds} + \frac{d(ACC_i)}{ds} + \frac{d(OC_i)}{ds} = 0.$$

Since time cost is defined as

$$(4)\quad TMC_i = V_{Ti} \times T_i$$

where V_{Ti} represents the value of time of individual i and T_i is his/her travel time needed to travel D miles at his/her speed s_i mph and obtained from the following equation

$$(5)\quad T_i = \frac{D}{s_i},$$

his/her time cost can be rewritten as

$$(6)\quad TMC_i = V_{Ti} \times \frac{D}{s_i}.$$

Differentiating Equation 6 with respect to s gives

$$(7)\quad \frac{d(TMC_i)}{ds} = \frac{-V_{Ti} \times D}{s_i^2}.$$

By substituting Equation 7 into Equation 3 and solving for V_{Ti}, the value of time is obtained

$$(8)\quad V_{Ti} = \frac{s_i^2}{D} \times \left(\frac{d(VOC_i)}{ds} + \frac{d(ACC_i)}{ds} + \frac{d(OC_i)}{ds}\right)$$

where s_i represents the optimal speed for individual i.

Equation 8 represents the value of time equation derived from the speed choice model for individual i. Each of the relevant variables with the exception of OC_i in the equation will be discussed in detail in the next section of this report. Owing to the lack of data available at this time for evaulating these other costs, the OC_i are assumed to be insignificant although this assumption may deserve further investigation. Also, for ease of using existing data for vehicle operating costs and accident costs, costs are calculated per 1,000 miles of travel (i.e., for D = 1,000 miles).

DATA SOURCES

Both primary and secondary data were used in this study. Sources for each of these two categories of data are presented in this section.

Primary Data Source

A survey was conducted to elicit Texas motorists' willingness-to-pay for reducing their risks of getting killed while driving on rural highways. Other information on driving and personal characteristics is also determined in the survey. Questions on driving included individuals' driving speeds, during day and night, on 4-lane divided and 2-lane rural highways; usage of seatbelts; model, make, body style, and model year of their in-town vehicle and of their out-of-town vehicle, if a different one was used; and, also, annual mileage traveled. Personal characteristics sought in the survey were age, sex, race, education level, and hourly wage.

A sample size of five hundred people was randomly selected over Texas to participate in a telephone survey. Answers to each of the relevant questions were tested for the existence of 'outliers' which, if found, were set to missing. By following a procedure suggested by Sach [22], answers that fall beyond the 'four standard deviation from the mean region' are identified as 'outliers' and are believed to belong to a population other than the one being studied and, thus, should be discarded.

Personal characteristics of the sample showed the average age to be 36.5. In the sample group, 41.2 percent were male and 58.8 percent were female. As for the race distribution, 7.8 percent were black, 79.8 percent anglo, and 11.4 percent hispanic. On education levels, 31.4 percent of the sample finished high school, 27.6 percent had some college work, 24.2 percent graduated from college or did graduate work, 16.2 percent had less than a high school education, and the remaining .6 percent did not give an answer. The average hourly wage was $10.05, slightly higher than the hourly wage of $9.47 for the state. Compared to the 1980 census population of Texas, aged 18 and over, the sample population is younger and has a higher percentage of females. In 1980, the average age of adults in the state was 41.7 and the female population was 51.6 percent of the total adult population. Because of the fact that a major portion of drivers on highways are male, the deviation of the sex distribution of the sample population from that of the state population which came out to be statistically significant is considered relevant in calculating the value of time for a Texas motorist and, therefore, adjustment should be made to bring the sex distribution of the sample population close to the state level.

Secondary Data Sources

Data on vehicle operating costs and on accident rates for three types of accidents (fatal, injury, and PDO) were obtained from existing literature sources. While Zaniewski, et al. [28] provided the most updated vehicle operating costs related to driving speed by vehicle size, Solomon's 1962 accident study [23] gave the only available accident rates related to speed. Numbers of current accidents and vehicle-miles traveled on different highway classifications came from the Texas Department of Public Safety, the State Department of Highways and Public Transportation (SDHPT), and the Highway Performance Monitoring System (HPMS) for Texas.

RELEVANT VARIABLES

In an earlier section, it was shown that there are several variables such as vehicle operating costs, accident costs, and traveling speed that are relevant in the speed model for evaluating the value of time. Furthermore, accident costs embrace two important variables: the value of life and accident rates. Information and derivation of each of these variables is presented in detail in this section.

Vehicle Operating Costs

Based on data most recently published by Zaniewski et al. [28], in 1982, vehicle operating costs of large, medium, and small passenger cars, and also of pickups traveling at different speeds on grade = 0 and at SI = 3.5, are regressed against traveling speed. The estimated equations for the four vehicle types , with t-values in parentheses, are given below:

$$(9) \quad VOC_L = \underset{(53.04)}{197.879} - \underset{(-15.10)}{3.45626(s)} + \underset{(14.66)}{.043516(s^2)}, \qquad R^2 = .9540$$

$$(10) \quad VOC_M = \underset{(60.36)}{194.973} - \underset{(-18.86)}{3.73728(s)} + \underset{(17.95)}{.046126(s^2)}, \qquad R^2 = .9703$$

$$(11) \quad VOC_S = \underset{(43.31)}{217.440} - \underset{(-15.90)}{4.89824(s)} + \underset{(12.82)}{051209(s^2)}, \qquad R^2 = .9721$$

$$(12) \quad VOC_P = \underset{(38.45)}{167.368} - \underset{(-11.74)}{3.13530(s)} + \underset{(13.26)}{.045907(s^2)}, \qquad R^2 = .9480$$

where

VOC_L = vehicle operating costs of large passenger cars in dollars per 1,000 miles,

VOC_M = vehicle operating costs of medium passenger cars in dollars per 1,000 miles,

VOC_S = vehicle operating costs of small passenger cars in dollars per 1,000 miles,

VOC_P = vehicle operating costs of pickups in dollars per 1,000 miles, and

s = traveling speed in miles per hour.

No updating on vehicle operating costs was performed since it is felt that current gasoline prices, the major component of vehicle operating costs, have been rather stable since 1982. Figure 2 shows the estimated vehicle operating costs of the four vehicle sizes, each as a function of speed. Small passenger cars actually have the highest operating costs among all four sizes at speeds below 15 mph and higher than pickups below 30 mph. It is at speeds beyond 30 mph when they cost the least to operate. Pickups have the lowest operating costs among all vehicle sizes at speeds below 30 mph but are the most costly to operate beyond 65 mph. A comparison of the minimum points of the four cost vs. speed curves reveals that both large and medium passenger cars are least expensive to operate at about 40 mph while costs in operating a small car bottom out farther down on the speed axis (about 48 mph), and pickups reach their minimum operating costs before all other vehicle sizes do. At a speed range of 47 to 70 mph, the operating costs of the large, medium, and small vehicles behave as expected, with the large cars costing the most to operate and the small cars the least while operating costs for pickups lie between the large and the medium cars in most parts of this speed range.

After identifying the size of each individual's vehicle or vehicles from information on vehicles given in the survey, his/her vehicle operating cost curve can be obtained utilizing one of the estimated equations, whichever is appropriate, for his/her vehicle size. When the choice situation involves trips on rural highways, the cost curve for the out-of-town vehicles is used if it differs from the in-town vehicle. In the sample, the vehicle fleet driven is made up of nearly 28 percent of each of the three sizes of passenger cars, with the remaining 17 percent being pickups.

Accident Rates

Data on accidents occurring at various traveling speeds are practically nonexistent, except those reported by Solomon [23] in 1962. Some concern was raised as to the validity of using some of the old speed data because of the differences in speed limits and vehicle operating conditions [28]. However, an examination of Solomon's data set and the 1984 Texas accident data reveals their closeness in both fatal and injury accident rates. Fatal accident rates on rural 4-lane divided roads and 2-lane highways estimated from Solomon's data

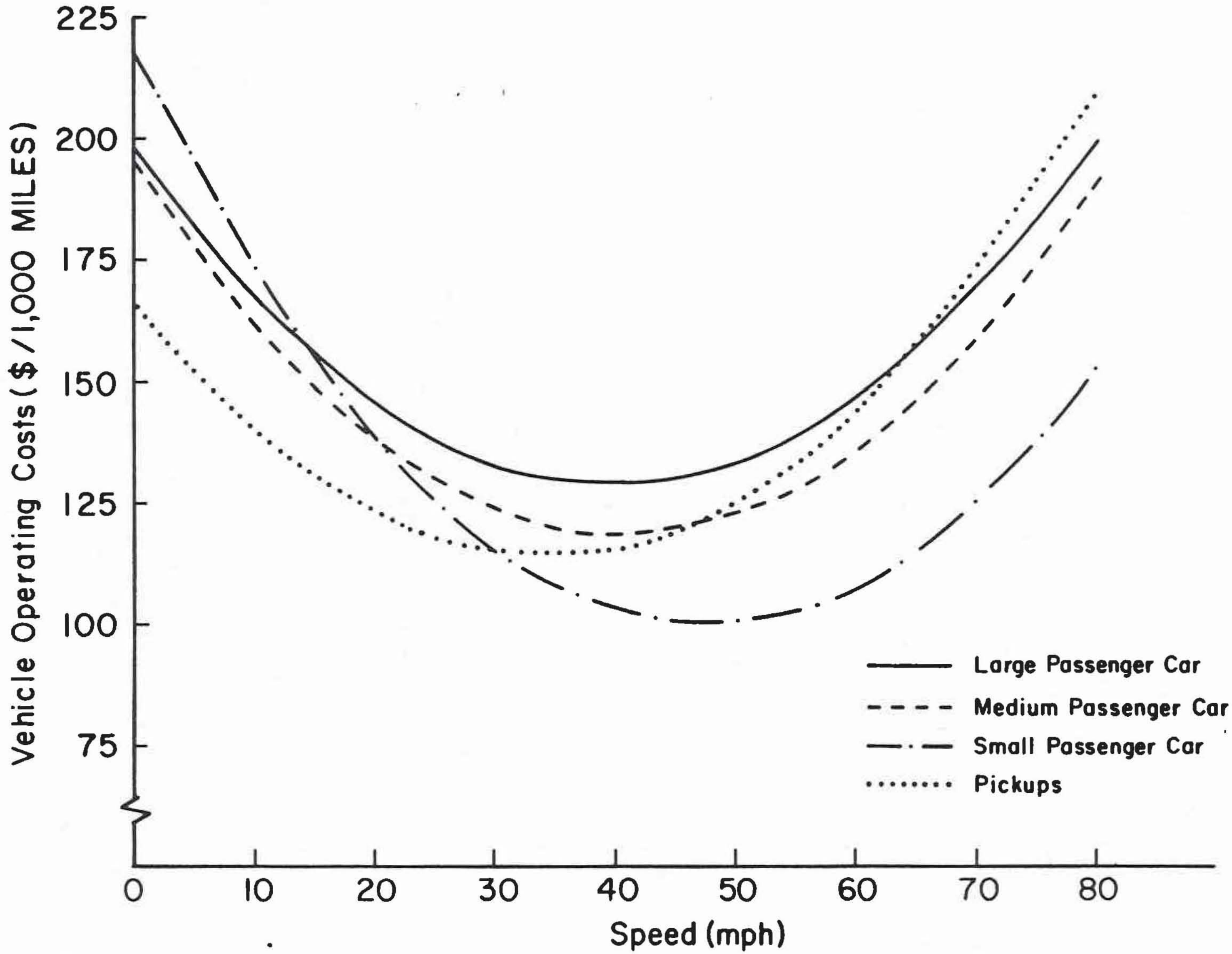

Figure 2. Vehicle Operating Costs by Vehicle Size

were .0153 and .0263 fatalities per million vehicle-miles (MVM), respectively, while the 1984 Texas fatal accident rates on interstate highways and on minor arterials were .0191 and .0325 fatalities per MVM, respectively. The injury rates between the two data sets show an even narrower gap. Table 1 gives the 1984 fatal and injury accident rates and vehicle-miles traveled on rural Texas highways and Table 2 shows the comparison of rural fatal and injury accident rates between th 1984 Texas accident record and the Solomon data.

Based on Solomon's accident data, two sets of accident rate equations, expressed as functions of speed, were estimated, one for 4-lane divided rural highways and one for 2-lane rural highways. In each set, there are three equations, one for fatal accidents, one for injury accidents, and one for property damage accidents. The estimated equations in log-linear form, with t-values in parentheses, are shown below:

4-Lane Divided Rural Highways

$$\text{(13) Log (FATAL)} = \underset{(9.97)}{9.2299} - \underset{(-11.42)}{.4859(s)} + \underset{(10.45)}{.0047(s^2)} - \underset{(-1.40)}{.8352(D)}, \quad R^2 = .9280$$

$$\text{(14) Log (INJUR)} = \underset{(16.43)}{11.6802} - \underset{(-13.53)}{.4264(s)} + \underset{(11.66)}{.0038(s^2)} - \underset{(-4.12)}{.9827(D)}, \quad R^2 = .9412$$

$$\text{(15) Log (PDO)} = \underset{(28.90)}{18.2155} - \underset{(-14.29)}{.3992(s)} + \underset{(11.56)}{.0034(s^2)} - \underset{(-4.50)}{.9520(D)}. \quad R^2 = .9568$$

2-Lane Rural Highways

$$\text{(16) Log (FATAL)} = \underset{(3.74)}{5.0515} - \underset{(-5.38)}{.3206(s)} + \underset{(5.52)}{.0034(s^2)} - \underset{(-3.04)}{1.4074(D)}, \quad R^2 = .7268$$

$$\text{(17) Log (INJUR)} = \underset{(13.29)}{7.8000} - \underset{(-10.94)}{.2846(s)} + \underset{(9.88)}{.0027(s^2)} - \underset{(-4.31)}{.8484(D)}, \quad R^2 = .9054$$

$$\text{(18) Log (PDO)} = \underset{(23.80)}{14.6954} - \underset{(-10.43)}{.2854(s)} + \underset{(9.14)}{.0026(s^2)} - \underset{(-3.76)}{.7773(D)}. \quad R^2 = .9023$$

where

FATAL = number of fatalities per million vehicle-miles,

INJUR = number of injuries per million vehicle-miles,

PDO = dollars of property damage per million vehicle-miles,

Table 1. 1984 Accidents and Vehicle-Miles Traveled on Rural Highways in Texas

Functional Classification	Accidents[1]		Vehicle-Miles Traveled[2] (1,000)
	Fatalities	Injuries	
Interstate	193	4,007	10,087,505
2-Lane[3]	202	3,840	6,212,300

1 1984 accident data were calculated from accident data tapes from the Texas Department of Public Safety and the Texas State Department of Highways and Public Transportation.

2 From Texas data in the Highway Performance Monitoring System (HPMS) for 1984.

3 Minor arterials are represented in this category.

Table 2. Comparison of Rural Accident Rates Between 1984 Texas Accidents and Solomon's Accident Data

Functional Classification	1984 Texas Accidents[1]		Solomon's Accident Data[2]	
	Fatalities	Injuries	Fatalities	Injuries
	($ per million vehicle-miles)			
4-Lane Divided (Interstate)	.0191	.3972	.0153	.3155
2-Lane (Minor Arterials)	.0325	.6181	.0263	.5572

[1] Data were made available by the Texas Department of Public Safety and the Texas State Department of Highways and Public Transportation.

[2] Figures represent the estimated daytime accident rates at 55 mph from Equations 13-14 and 16-17.

s = traveling speed, in miles per hour, and

D = dummy variable for daytime and nighttime traveling,

= 1 if daytime, and

= 0 if nighttime.

Figures 3 and 4 illustrate the estimated fatality and injury rates, respectively, as functions of speed on 4-lane divided highways and on 2-lane rural highways, respectively. On 4-lane divided roads, the safest speeds for avoiding fatal, injury, and PDO accidents are 51.9, 55.7, and 59.2 mph, respectively, while on 2-lane rural roads, the safest speeds for the corresponding accident types are 46.9, 55.7, and 54.7 mph.

Since PDO is expressed in dollars, it needs to be updated from 1958 to the current level. The ratio of consumer price indexes (CPI) between 1984 and 1958, which shows to be 3.592, is used for updating the PDO figures obtained from the equations to represent the current PDO costs.

Accident rates differ not only from daytime to nighttime, they also vary according to road type and to the usage of seatbelts. From Solomon's data, it is indicated that nighttime driving has a higher accident rate. There are 429 traffic accidents per MVM at night as compared to 215 traffic accidents per MVM during the day. Also, 4-lane main rural highways are shown to be safer roads than 2-lane highways. The first road type is found to have an accident rate of 212 accidents per MVM while the second road type has 300 accidents per MVM. The third influential factor on accident rates is usage of seatbelts. Studies have shown that seatbelt drivers are 50 percent safer than nonbelted drivers and, in addition, seatbelts are reported to be responsible for reducing the number of fatalities and injuries by 30 percent [20][1]. Therefore, four groups of drivers are identified from our sample: daytime belted, daytime nonbelted, nighttime belted, and nighttime unbelted drivers. Using the accident statistics related to seatbelt usage and the ratios of belted and unbelted drivers in the sample, each for all drivers, adjustment factors are developed separately for interstate and for 2-lane rural highways to be used for adjusting the accident rate equations (Equations 13-18) for each of the four groups of drivers using these two road types. Derivation of these adjustment factors are given in

[1]Since the seatbelt law went into effect recently, these percentages have probably changed. However, because the survey was carried out before the law took effect, they were considered valid and used in this study.

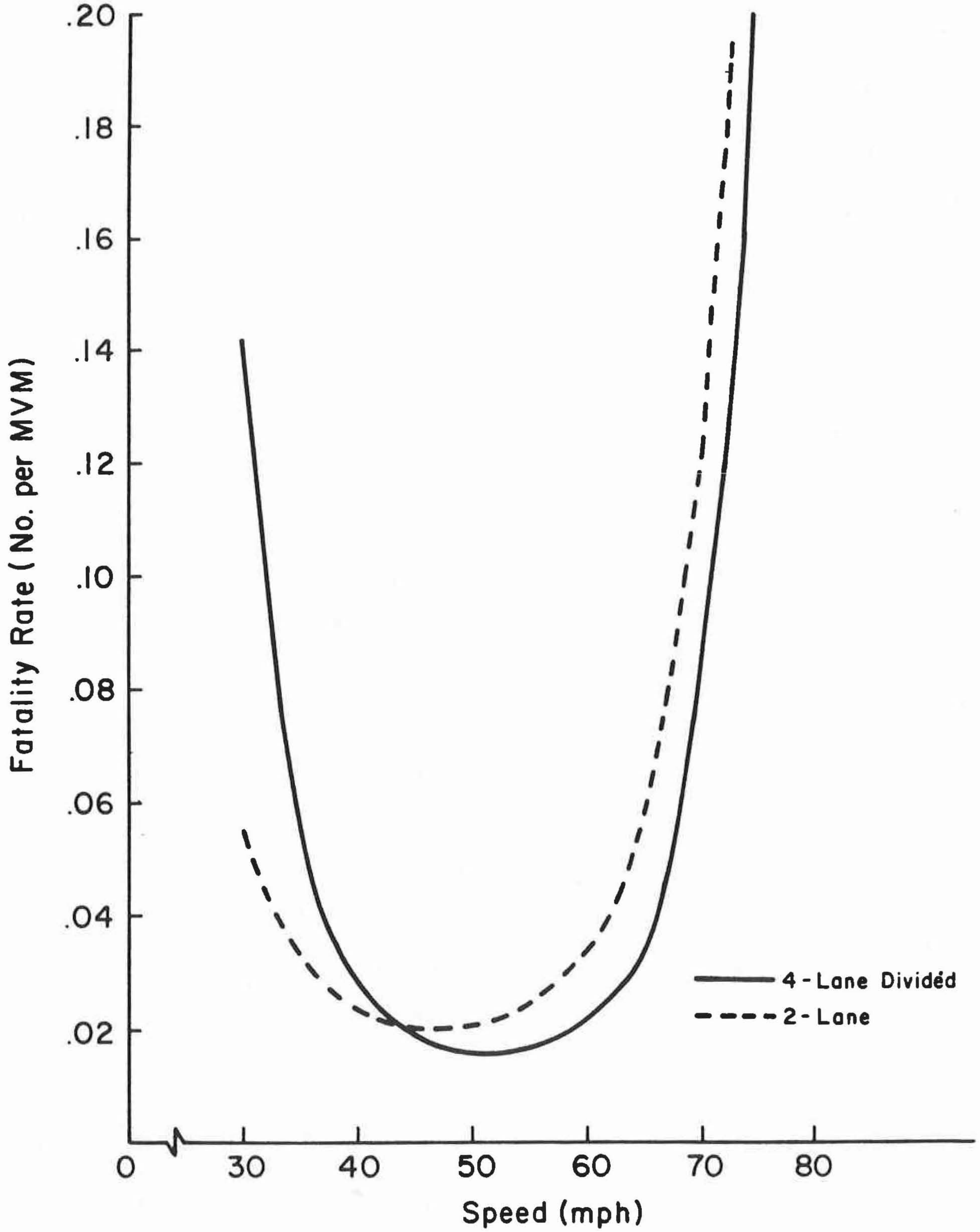

Figure 3. Daytime Fatality Rate by Road Type vs. Speed

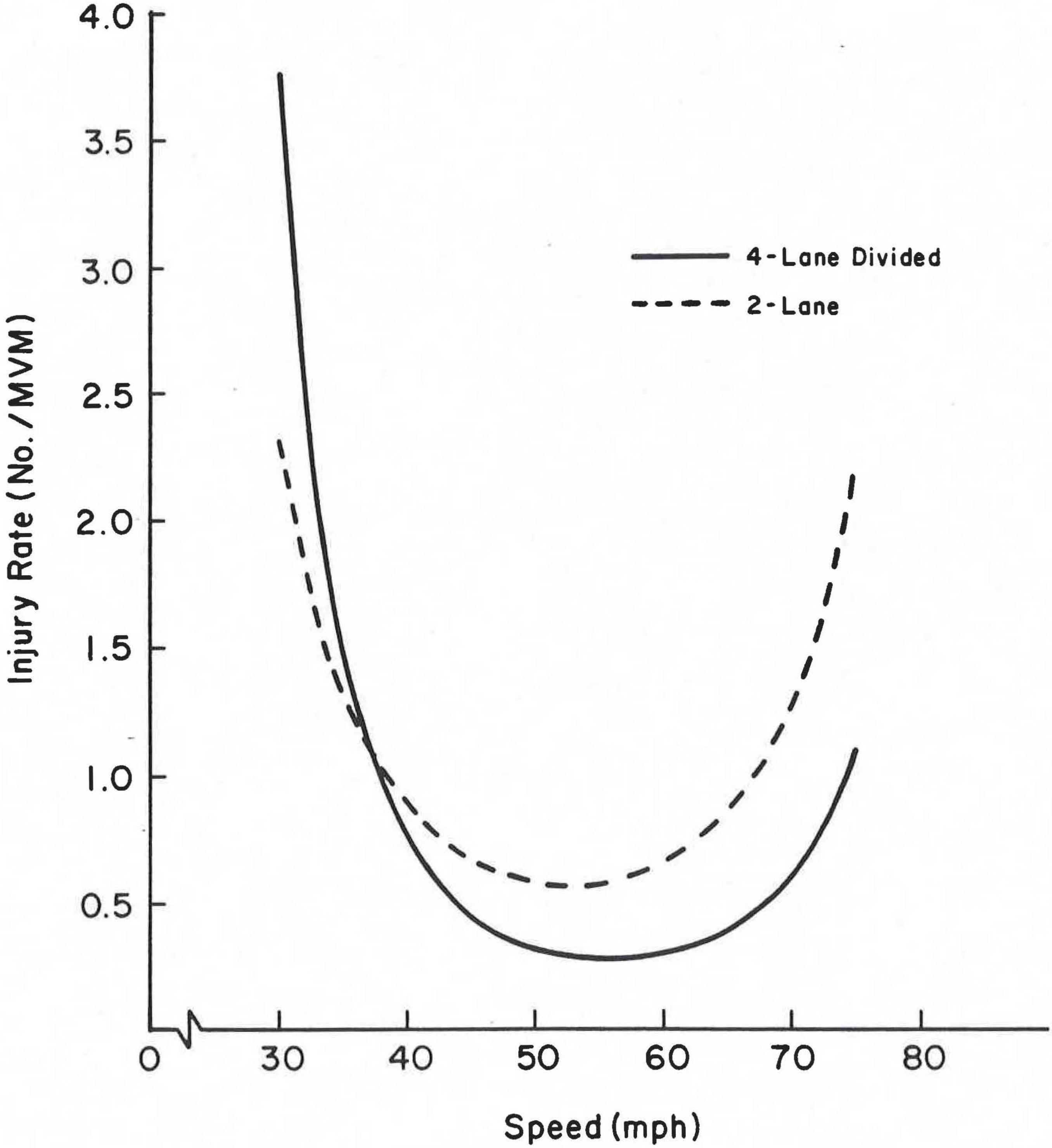

Figure 4. Daytime Injury Rate by Road Type vs. Speed

detail in Appendix I and their values shown in Table A1. A general functional form of the adjusted accident rate (AAR) of accident type j, on highway type H, and for driver group (D,B) where D is for time of day and B is for seatbelt usage, is shown as follows:

$$(19)\quad (AAR_{j,H})_{D,B} = (d_H)_{D,B} \times (AR_{j,H})_D$$

where the d term represents the adjustment factor from Table A1 in Appendix I and AR is calculated using one of the estimated accident rate equations. In this study, these adjusted accident rate curves are assumed to be applicable to everyone in the same driver group.

Value of Life

The cost of a fatality represents the value of an individual's life. Two different approaches are used to estimate the value of an individual's life and, based upon these two values of life, two different values of time were derived. The first approach is the foregoine earnings approach and the second is a willingness-to-pay approach. Each of them is discussed separately below.

Foregone Earnings Approach - In the foregoing earnings approach, the human wealth is measured by the present value of expected future labor earnings which, in turn, is determined by age, sex, race, education, and earnings. Ordinarily, one's earnings rise with one's age, reach a peak around middle age, and fall until retirement. Also, levels of earnings are higher and peak at later age for the more educated than the less educated. Using Mincer's data, Blomquist [3] was able to derive a set of age-earnings equations for seven different education levels which are shown in Table 3. An individual's foregone earnings (EARN) represent the summation from the current age up to age 70 of his/her expected annual discounted labor earnings multiplied by the appropriate probability of survival which is age, sex, and race dependent. Mathematically speaking, EARN can be expressed as follows:

$$(20)\quad (EARN_{b,c,d})_a = \sum_{j=a+1}^{70} E_j \times \frac{1}{(1+i)^{j-a}} \cdot \prod_{k=a}^{j-1} (P_{b,c})_a$$

Table 3. Age-Earnings Profiles by Education Level

Grade Level	Age - Earnings Profiles
0 - 4	$E = c + 497.9(A) - 4.46(A)^2 + .0581(A)^3$
5 - 8	$E = c + 653.3(A) - 11.65(A)^2 + .0662(A)^3$
9 - 11	$E = c + 264.7(A) - 2.62(A)^2$
12	$E = c + 929.2(A) - 16.92(A)^2 + .1008(A)^3$
13 - 15	$E = c + 1036.1(A) - 15.74(A)^2 + .0708(A)^3$
16	$E = c + 1145.9(A) - 15.77(A)^2 + .0623(A)^3$
17+	$E = c + 238.9(A) - 38.98(A)^2 + .2055(A)^3$

Where E is earnings, A is age, and c is calculated by substituting into the appropriate equation the current annual earnings and current age.

Source: Blomquist, Glenn, "Value of Life: Implications of Automobile Seat Belt Use", Ph.D. dissertation, University of Chicago, Illinois, March 1977.

where

- a = current age,
- b = race,
- c = sex,
- d = education level,
- i = annual discount rate,
- E_j = predicted annual labor earnings in year j, and
- p = annual probability of survival.

In this study, an annual discount rate of 4 percent is used. The probability of survival by age, sex, and race is calculated, using the 1980 mortality data supplied by the Department of Health, from the following formula:

$$(21)\quad (p_{b,c})_a = 1 - \frac{(D_{b,c})_a}{(pop_{b,c})_a},$$

where

- a = age,
- b = race,
- c = sex,
- p = probability of survival,
- D = number of deaths, and
- pop = population.

Information on wage and population characteristics is obtained from the survey.

Findings from Blomquist's value of life study showed the average value of life to be 2.5 times the amount of the average foregone earnings (EARN). In other studies of the value of life, the ratio of value of life to foregone earnings was found to range as low as 1.3 to as high as 107 [4]. The inconsistency of the results and the complexity of the problem warrants further investigation and is left for future research. In this section of the study, the ratio of value of life to EARN is assumed to be 2.5.

Willingness-to-Pay Approach. In the willingness-to-pay approach, the value of life is estimated indirectly. A person makes a trade-off between the amount he is willing to pay and the reduction in the probability of getting killed. In the survey, each interviewee was asked of his/her willingness-to-pay to use a safer rural road to travel 100 miles during the daytime and also at night. The questions posed are as follows:

(Q1) Assume you are making a 100-mile rural trip during the day. What is the maximum amount per one-way trip you would be willing to pay to use a 4-lane divided interstate highway instead of a 2-lane highway if your average speed is the same at 55 miles-per-hour on both highways?

(Q2) Would you be willing to pay more if you are driving at night?

(Q3) (If Q2 is yes) How much more?

Note that it is explicitly stated in the question that the average speed on each highway is 55 miles per hour. Therefore, it is presumed that the amount the individual respondents indicate they are willing to pay to travel on the 4-lane divided highway, versus the 2-lane highway, does not include any value for travel time savings or vehicle operating cost savings. In this analysis, it is further assumed that the comfort of having controlled access is negligible, but it is recognized that this assumption should be tested in future research. Given these assumptions, the answers to the preceding questions show the amount that an individual is willing to pay to travel on the improved highway should equal the value of the reduced probability of being killed in a fatal accident plus the savings in injury costs and in property damage costs from taking the safer highway. It should be noted that inclusion of property damage costs may not be appropriate in those cases where the individual has insurance and, therefore, does not expect to fully pay these costs. The preceding relationship for the amount the individual is willing to pay (AMT), as given by the answer to question one, can be expressed mathematically as follows:

$$(22) \quad AMT = (VL \times \Delta p_{2-4}) + \Delta INJ_{2-4} + \Delta PDO_{2-4},$$

where

VL = Value of life,

Δp_{2-4} = Reduction in the probability of getting killed between driving on a 2-lane highway and driving on a 4-lane divided highway,

ΔINJ_{2-4} = Savings in injury costs between driving on a 2-lane highway and driving on a 4-lane divided highway, and

ΔPDO_{2-4} = Savings in PDO costs between driving on a 2-lane highway and driving on a 4-lane divided highway.

From Equation 22, the value of life can be calculated from the following equation:

$$(23) \quad VL = \frac{AMT - \Delta INJ_{2-4} - \Delta PDO_{2-4}}{\Delta P_{2-4}}$$

According to the time of day (day vs. night), driver type (belted vs. unbelted), and road type (interstate vs. 2-lane), the probability of getting killed varies. Derivations of ΔP_{2-4} for daytime belted, daytime unbelted, nighttime belted, and nighttime unbleted drivers are given in detail in Appendix II, and Table A2 shows ΔP_{2-4} calculated for each of these four types of drivers for driving 100 miles.

Savings in injury costs come from two sources. One source is from savings in injury costs in a fatal accident and the other source comes from savings in njury costs in an injury accident. Derivation of ΔINJ_{2-4} and ΔPDO_{2-4} are described in Appendix III, and the calculated values for each of the four driver types traveling 100 miles are shown in Table A4.

If savings in injury costs and PDO costs exceed the amount the individual is willing to pay, a negative value of life results. In this study, some negative values of life resulted from using Equation (23) when individuals were not willing to pay to travel on the 4-lane divided highway. In those cases where negative values of life were calculated using Equation (23), these were set equal to zero.

Accident Costs

Accident costs include fatal accident costs, injury accident costs, and PDO accident costs. For any individual to travel one million miles on an interstate highway, his/her fatal accident costs in terms of speed is derived by multiplying the unit cost of a fatality (his/her value of life) to the adjusted equation of fatality rate on an interstate highway (Equation 13 multiplied by the appropriate adjustment factor for the individual). Since costs are calculated per 1,000 miles, as indicated previously, the fatality equation needs to be divided by 1,000 to arrive at the fatal accident costs for traveling 1,000 miles on an interstate highway. Similarly, as individual's fatal costs for traveling 1,000 miles on a 2-lane rural highway are obtained by using the adjusted fatality rate equation for 2-lane highways (Equation 16 multiplied by the appropriate adjustment factor). The two different approaches, the foregone labor earnings and the willingness-to-pay, for evaluating the value of life as discussed in the previous section result in two different values to be placed on an individual's life. Using each of these values as unit fatality costs, two equations of fatal accident costs on each road type as related to speed are obtained and they, in turn, result in two different sets of value of time for each individual driving on each type of road.

Injury costs are derived by the same method. The 1984 unit costs per injury on an interstate highway and on a 2-lane rural highway are $7,760 and $7,228, respectively. The estimated injury rate equations for interstate and 2-lane rural highways are Equations 14 and 17, respectively.

For PDO accident costs, the procedure of multiplying unit costs to accident rate equations is deleted since the unit used in the PDO accident rate equations (Equations 15 and 18) are already in dollars per MVM. However, as mentioned earlier, PDO costs estimated from the equations are in 1958 dollars and an updating factor of 3.592 is used to update the costs to 1984 dollars.

Depending on the group (belted or nonbelted) an individual belongs to, the injury and PDO cost functions are different between the two groups but are assumed to be alike for all people within a group. However, fatal cost functions are unique. Each individual has his/her own fatal cost functions because his/her value of life is used as the unit fatal cost.

Speed

Each interviewee in the survey was asked to indicate his/her driving speed during the day and also at night separately on a 4-lane divided interstate rural highway and on a 2-lane rural highway under the current speed limit of 55 mph. The speed given for each of the four situations (daytime interstate, daytime 2-lane, nighttime interstate, and nighttime 2-lane) by an individual represents the optimal speed at which he/she perceives that his/her total driving costs are minimized. As indicated in the value of time equation (Equation 8) discussed earlier, the optimal speed of an individual is needed in the evaluation of his/her value of time.

In our sample, the average speeds driven during the day on a 4-lane divided and 2-lane rural highway are: 57.5 and 53.2 mph, respectively, while nighttime driving on the same two road types are 54 and 49 mph, respectively. This is consistent with the hypothesis that people tend to drive more slowly at night because they perceive a higher accident cost for night driving.

RESULTS

Two sets of value of time are derived, one using the fatality cost equations with value of life obtained from foregone labor earnings as the unit fatality cost (EARN set), and the other using the fatality cost equations which adopt the value of life derived from the willingness-to-pay approach (WTP set). The final sample size of the EARN set is about 130 less than that of the willingness-to-pay set. After deleting the nonworkers, the refusals, and the outliers, the number of useful questionnaires in the EARN set is about 253 and 266 depending on the subsets (4-lane or 2-lane), or the time of day (day or night). The willingness-to-pay set is somewhat larger mainly because it includes many people without earnings (especially housewives, retirees, and unemployed individuals) who could not be included in the EARN set. The final sample size of the WTP set is between 396 and 405. Each of the sets is broken down into two subsets, one for 4-lane divided rural highways and the other for 2-lane rural highways. In each of the subsets, value of time is calculated for every individual in each of the four driver groups (daytime belted, daytime unbelted, nighttime belted, and nighttime unbelted) by utilizing his/her optimal speed, his/her vehicle operating cost curve, and his/her accident cost curves. From the results, it is shown that some people have negative values of time. A combination of two factors can result in a negative value of time. These are a low indicated travel speed together with a relatively high value of life. If the optimal speed is below the speeds where accident rate curves (see Figures 3 and 4) reach their minimum points, the curves indicate that an individual can reduce his/her accident costs by increasing his/her speed even though his/her other costs, such as vehicle operating costs and/or time costs, can be higher. Like the negative values of life, the negative values of time are assumed to be zero.

The calculated values of time are weighed by three sets of weights: day vs. night, belted vs. unbelted, and male vs. female. The first two sets are needed in order to adjust for the differences in accident rates between the two periods of the day and the two types of drivers. The last set of weights is used because of the presence of the larger than the state distribution of female in the survey sample compounded by the fact that a major portion of drivers on highways are male. The 1980 Texas population distribution percentages of females and males are 51.6 percent and 48.4 percent, respectively, while the sample population shows the similar distribution percentages to be 58.8 percent and 41.2 percent. The difference between the two populations is found to be statistically significant by the statistical method, difference between proportion, with a t-value of -3.23.

In each subset (road type), the values of time of each of the driver groups in the specific time period are first averaged according to sex, and the resulting averaged values of time for each sex are weighted by sex to arrive at a weighted average value of time for a driver in that particular cell. The sex weights used are: .484 and .516 for male and female, respectively, representing the state population distribution according to sex. The weighted average values are further weighted across driver type (belted vs. unbelted) and time of day (daytime vs. nighttime) to arrive at an overall weighted value of time of a specific road type. The weights used to weight the belted and the unbelted drivers respectively are: .52 and .48 for daytime driving and .55 and .45 for nighttime driving. Each pair of weights represents the split of the two driver types in the sample during the specific time of the day. The weights used to weight the time of the day are: .75 and .25 for daytime and nighttime, respectively, representing the split on total vehicle-miles traveled between day and night drivings in the Solomon data. Table 4 lists weights used in weighting value of time by driver type split, by day/night split, and by sex split.

Table 5 lists average values of time for each sex, weighted average values of time for both sexes, and an overall weighted value of time in the EARN set for each of the 4-lane divided and 2-lane rural highway subsets. Between the two sexes, the weighted values of time for males are shown to be higher than female values of time. A comparison between belted and nonbelted drivers across the same time of day within a subset indicates that the nonbelted ones invariably have higher values of time. Except the belted group in the 4-lane divided road subset, nightime drivers are shown to value their time only slightly higher than their daytime counterparts. The weighted values of time for males are shown to be higher than female values of time. The overall weighted average values of time in both subsets come out to be practically the same, with \$11.7 and \$11.8 for the 4-lane and 2-lane subsets, correspondingly.

Table 6 shows average values of time for each sex, weighted average values of time for both sexes, and an overall weighted value of time in the WTP set for each of the 4-lane divided and 2-lane rural highway subsets. A comparison

Table 4. Weights Used in Weighting Value of Time

	Day		Night
Driver Type:			
Belted	.52		.55
Nonbelted	.48		.45
Time of Day	.75		.25
Sex:			
Male		.484	
Female		.516	

Table 5. Value of Time of EARN Set (1984 Dollars)

	4-Lane						2-Lane					
	Belted			Unbelted			Belted			Unbelted		
	Male	Female	Weighted Average	Male	Female	Weighted Average	Male	Female	Weighted Average	Male	Female	Weighted Average
Day	14.7	6.9	10.7	16.1	9.9	12.9	9.4	5.2	7.2	17.6	8.9	13.1
Night	12.7	6.6	9.6	16.9	11.7	14.2	16.4	5.9	11.0	36.5	13.0	24.3
Overall Weighted Value of Time	11.7						11.8					

Table 6. Value of Time of WTP Set (1984 Dollars)

	4-Lane						2-Lane					
	Belted			Unbelted			Belted			Unbelted		
	Male	Female	Weighted Average	Male	Female	Weighted Average	Male	Female	Weighted Average	Male	Female	Weighted Average
Day	24.1	11.0	17.3	31.0	15.7	23.1	24.5	11.7	17.9	17.5	18.7	18.1
Night	10.8	6.7	8.7	7.7	5.8	6.7	12.7	6.5	9.5	25.6	11.4	18.3
Overall Weighted Value of Time	17.0						16.9					

between male and female, the males once again are shown to place higher values on their time with the exception of the daytime unbelted females in the 2-lane subset whose value of time is \$18.7 as opposed to \$17.5 for their male counterparts. Between driver types within each subset, the belted nighttime drivers are the only ones whose value of time is higher than the nonbelted nighttime drivers. In all other cases, values of time are higher for the nonbelted than the belted drivers. However, in each subset, the daytime drivers, regardless whether they are belted or not, have higher values of time than the nighttime drivers, with the exception of the unbelted male in the 2-lane subset whose values of time for day and for night are \$17.5 and \$25.6, respectively, making the weighted average values of time for an unbelted driver to be \$18.1 for the day and \$18.3 for the night. The overall weighted average values of time are \$17.00 for the 4-lane subset and \$16.9 for the 2-lane subset.

A comparison between sets indicates that the overall weighted average values of time in both the 4-lane and 2-lane subsets of the WTP set are higher than the corresponding ones in the EARN set even though each individual cell in the nighttime group of the WTP set in general shows a lower value than the corresponding cell in the EARN set. As mentioned before, the overall weighted average values of time for the 4-lane divided subsets are \$11.7 for the EARN set and \$17.0 for the WTP set while the overall weighted average values of time for the 2-lane subsets are \$11.8 and \$16.9 for the EARN set and for the WTP set, respectively.

Since the purpose of this study is to develop average values of time for use in benefit-cost analyses, it is desirable to derive an average value of time weighted by the amount of travel time spent by individuals in the survey. Therefore, the derived value of time for each individual is weighted by his/her annual travel time which is equal to the total vehicle-miles traveled divided by his/her speed, information on which is obtained from the survey. Consideration is given in this weighting process to the difference in the sample distribution by sex and the state distribution by sex. The formula used in weighting the value of time by travel time is given in Appendix IV. After these weighted values of time are developed for each driver group in each time period for each road type, they are averaged and weighted using weights listed in Table 4 to arrive at the weighted EARN set and the weighted WTP set. Tables 7 and 8 list the average and weighted values of time for the weighted EARN set and for the weighted WTP set, respectively.

Table 7. Value of Time of Weighted EARN Set (1984 Dollars)

	4-Lane		2-Lane	
	Belted	Unbelted	Belted	Unbelted
Day	6.6	8.7	4.7	8.5
Night	5.7	10.9	7.2	18.7
Overall Weighted Value of Time	7.7		8.0	

Table 8. Value of Time of Weighted WTP Set (1984 Dollars)

	4-Lane		2-Lane	
	Belted	Unbelted	Belted	Unbelted
Day	18.2	15.8	17.3	14.9
Night	8.3	6.0	9.0	24.0
Overall Weighted Value of Time	14.6		16.0	

Trends observed in the earlier nonweighted sets between subsets within a set and between sets hold true in the weighted EARN and weighted WTP sets. When comparing between the nonweighted and weighted sets, both the weighted EARN set and the weighted WTP set have lower values of time than their nonweighted counterparts. The overall weighted average values of time in the weighted EARN set are $7.7 and $8.0 for the 4-lane and 2-lane subsets, respectively, and the corresponding values in the nonweighted EARN set are $11.7and $11.8, as mentioned before. In the weighted WTP set, the overall weighted average values of time are $14.6 for the 4-lane subset and $16.0 for the 2-lane subset compared to $17.0 and $16.9 for the corresponding subsets in the nonweighted WTP set.

The values shown in Tables 5-8 are in 1984 dollars. Each of these values can be updated to 1985 by multiplying by a ratio of the consumer price indexes between 1985 and 1984 (CPI_{85}/CPI_{84}) or 323.5/311.1 which is equivalent to 1.04. Also, the values of time obtained so far are for drivers of passenger cars. To obtain the value of time for a passenger car, the value of time of passenger car drivers is multiplied by an occupancy rate of 1.3 adopted by the HEEM.

Because of lack of adequate responses from truck drivers in the survey, the value of time of truck drivers is not obtained by using the speed choice model; instead, it is derived by updating the 1975 values of Buffington and McFarland [6] in the following manner.

The value of time of each of the three truck types (3, 4, and 5) listed in the Buffington and McFarland study is first weighted by the 1980 percentage distribution of the respective truck type in all trucks on Texas highways to arrive at the weighted value of time of each truck type. Secondly, the three weighted values of time of truck types 3, 4, and 5 are summed together to yield a 1975 value of time for all trucks. Lastly, the 1975 value of time for all trucks is updated to 1985 by multiplying by the ratio of wholesale price index for industrial commodities (WPI) of 1985 to that of 1975 to arrive at the 1985 value of time for trucks. Table 9 shows the three types of trucks and lists the 1975 values of time for each type, the 1980 percentage distributons of the three truck types, the 1975 weighted value of time for each truck type, the 1975 value of time for all trucks, and the 1985 value of time for all trucks.

Table 9. Derivation of Value of Time for Truck Drivers

Type	Description	1975 Value[1] of Time	Percentage[2] Distribution	1975 Weighted Value of Time
		(Dollars)	(%)	(Dollars)
3	Single-unit trucks other than 2-axle, 4-tires	8.02	31.2	2.50
4	Truck semitrailer combinations, 4 or less axles	10.00	8.4	.84
5	All other trucks and semitrailers or trailer combinations, 5 or more axles	11.10	60.4	6.70

1975 Value of Time for all trucks = \$2.50 + \$.84 + \$6.70 = \$10.04

1985 Value of Time for all trucks = $\$10.04 \times \frac{WPI_{85}}{WPI_{75}} = \$10.04 \times \frac{323.5}{171.5} = \$19.00$

Sources:

[1]Buffington, Jesse L. and McFarland, William F., "Benefit Cost Analysis: Updated Unit Coss and Procedures", Research Report No. 202-2, Texas Transportation Institute, The Texas A&M University System, Texas, August 1975.

[2]State Department of Highways and Public Transportation, Transportation Planning Division, "Percentage of Various Types of Vehicles on Rural State Highways and Farm-to-Market Roads", 1980.

CONCLUSIONS AND RECOMMENDATIONS

The speed-choice model was chosen for estimating values of time because it can be applied across a representative, statewide sample of Texas motorists. Two other techniques that are judged to be good theoretical approaches, the choice of mode (especially bus vs. auto) and the choice of route (especially toll road vs. alternate free route) methods cannot be used as effectively because many Texans seldom, if ever, ride buses (especially not for rural trips) and few situations are available in Texas where choices involving toll roads are made. The speed-choice model has been criticized by some researchers as having the weakness of assuming that motorists know their expected costs of different types as related to travel speed. This criticism, however, can also be applied to the other techniques. For example, in the bus/auto modal choice situation, it is assumed that the driver knows his out-of-pocket vehicle operating costs, even though the trip usually involves several different highway types, intersections, etc., not to mention widely varying traffic volumes and other operating conditions. In addition, expected accident costs, as perceived by the motorist, must be estimated to use this approach in a valid way. Similar calculations must be made of operating costs and accident costs on toll roads versus alternate free routes to use the route-choice models. Therefore, in this study, it is concluded that the speed-choice model is at least as valid theoretically as the other techniques and has the definite advantage of being applicable to a statewide cross-section of Texas motorists.

The principal data problem in using the speed-choice model involves the estimation procedure for the cost of fatalities. To estimate this cost, two different approaches were used in this study to estimate the value of life, the earnings approach, and the willingness-to-pay approach. For many of the individuals in the survey both approaches gave roughly the same value of time. However, for some individuals that indicated a willingness to pay a very high amount to travel on a 4-lane divided highway as compared to a 2-lane highway, the willingness-to-pay approach to calculating the value of life gave a very high value of life. It is the authors' opinion that some of these answers may be misleading when used as a guide to the value of life. More research is needed on the willingness-to-pay approach to the value of life, including further study of the data developed in this study. At this time, it is the authors' opinion that the values of time based on the EARN data set are the best values to use in benefit-cost analyses in Texas even though further refinement of the data set and techniques may change this opinion to favor the willingness-to-pay data set.

It is recommended, therefore, that the values of time developed in this study using the speed-choice model with the EARN data set be used in benefit-cost analyses in Texas. The recommended value of time of a passenger vehicle driver calculated using the EARN data set for 4-lane divided highways is $7.70 per hour in 1984 dollars (or $8.00 per hour when updated to 1985 using the consumer price index). These values represent the average values weighted by estimated annual hours of travel for each individual in the data set. Using an occupancy rate of 1.3 persons per car, the recommended 1985 value of time for passenger vehicles is $10.40 per vehicle-hour. As discussed in the preceding section, the recommended 1985 value of time for trucks is $19.00 per vehicle-hour.

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APPENDIX

APPENDIX I

Derivation of Adjustment Factors of Accident Rates for Belted Drivers and Nonbelted Drivers

Recent statistics indicate that accident rates differ between seatbelt wearers and nonbelted drivers [20]. People who wear seatbelts are 50 percent safer drivers than those who do not. In addition, seatbelts are estimated to reduce fatalities and injuries by 30 percent for those involved in accidents. Therefore, accident rates are adjusted for these two groups of drivers according to these percentage differences. Furthermore, people seem to recognize the higher accident rates at night by buckling up. In our survey, for long rural trips, out of the 471 drivers, there are 247 daytime belted drivers as compared to 260 nighttime belted drivers. Given the overall daytime fatal accident rate (RFD), injury rate (RID), and PDO rate (RPD), the daytime fatal accident rate (RFD_w), injury rate (RID_w), and PDO rate (RPD_w), for the seatbelt wearers, are calculated as follows:

$$RFD_w = \frac{(.5) \times (.7) \times (RFD)}{(.5) \times (.7) \times \frac{247}{471} + \frac{224}{471}} = .53\ (RFD),$$

$$RID_w = \frac{(.5) \times (.7) \times (RID)}{(.5) \times (.7) \times \frac{247}{471} + \frac{224}{271}} = .53\ (RID), \text{ and}$$

$$RPD_w = \frac{(.5) \times RPD)}{(.5) \times \frac{247}{471} + \frac{224}{471}} = .678\ (RPD).$$

A similar set of equations are developed for the nonbelted drivers. Their daytime fatal, injury, and PDO accident rates, RFD_{nw}, RID_{nw}, and RPD_{nw} are shown below.

$$RFD_{nw} = \frac{RFD}{(.5) \times (.7) \times \frac{247}{471} + \frac{224}{471}} = 1.52\ (RFD),$$

$$RID_{nw} = \frac{RID}{(.5) \times (.7) \times \frac{247}{471} + \frac{224}{471}} = 1.52\ (RID), \text{ and}$$

$$RPD_{nw} = \frac{RPD}{(.5) \times \frac{247}{471} + \frac{224}{471}} = 1.35\ (RPD).$$

Given the overall nighttime fatal, injury, and PDO accident rates, RFN, RIN, and RPN, the corresponding accident rates for the belted driver, represented by RFN_w, RIN_w, and RPN_w, respectively, and for nonbelted drivers, RFN_{nw}, RIN_{nw}, and RPN_{nw}, respectively, are developed likewise and given below:

$$RFN_w = \frac{(.5) \times (.7) \times (RFN)}{(.5) \times (.7) \times \frac{260}{471} + \frac{211}{471}} = 0.55\ (RFN),$$

$$RIN_w = \frac{(.5) \times (.7) \times (RIN)}{(.5) \times (.7) \times \frac{260}{471} + \frac{211}{471}} = 0.55\ (RIN),$$

$$RPN_w = \frac{(.5) \times (RPN)}{(.5) \times \frac{260}{471} + \frac{211}{471}} = 0.69\ (RPN),$$

$$RFN_{nw} = \frac{RFN}{(.5) \times (.7) \times \frac{260}{471} + \frac{211}{471}} = 1.56\ (RFN),$$

$$RIN_{nw} = \frac{RIN}{(.5) \times (.7) \times \frac{260}{471} + \frac{211}{471}} = 1.56\ (RIN, \text{ and}$$

$$RPN_{nw} = \frac{RPD}{(.5) \times \frac{260}{471} + \frac{211}{471}} = 1.38\ (RPN).$$

Table A1 lists the adjustment factors calculated above for fatal, injury, and PDO accident rates by driver type and by the time of day.

Table A1. Adjustment Factors of Accident Rates by Driver Type and by Time of Day

Time of Day	Fatal and Injury Driver Type Belted	 Nonbelted	PDO Driver Type Belted	 Nonbelted
Day	.53	1.52	.68	1.35
Night	.55	1.56	.69	1.38

APPENDIX II

Derivation of Probability Change in Getting Killed Driving on Interstate vs. 2-Lane Rural Highways

Traveling on a highway, a driver faces some probability of getting killed and this probability varies according to several factors. Among them, driver type (belted vs. nonbelted), road type (4-lane vs. 2-lane, for example), and the time of day (day vs. night) are the three factors that the current study is interested in. From the estimated equations (Equations 13 and 16) based on Solomon's data and presented in the text earlier, daytime fatality rates at 55 mph on 4-lane divided rural highways and on 2-lane rural highways are: .0153 and .0263 fatalities per MVM, respectively. For a daytime driver who chooses to travel on a 4-lane divided road instead of a 2-lane road, his probability of getting killed is reduced by .0110 (.0263 - .0153) fatalities per MVM. This probability change is further decreased or increased depending upon whether he is a belted driver or a nonbelted driver. By using the adjustment factors calculated in Appendix I, the changes in probability of getting killed traveling on a 4-lane divided instead of a 2-lane road during the day for a belted driver and for a nonbelted driver are: .0058 (.0110 x .53) and .0167 (.0110 x 1.52) fatalities per MVM, respectively.

The estimated nighttime fatality rates at 55 mph on 4-lane divided and 2-lane highways are: .0352 and .1076 fatalities per MVM, respectively. By choosing to travel on a 4-lane divided road instead of a 2-lane road, a night-time driver's probability of getting killed goes down to .0724 (.1076 - .0352) fatalities per MVM. After applying the corresponding adjustment factors calculated in Appendix I for a belted driver and a nonbelted driver, the final probability changes are equal to .0398 (.0724 x .55) fatalities per MVM for a night-time seatbelted driver and .1129 (.0724 x 1.56) fatalities per MVM for a night-time non-belted driver.

Table A2 summarizes the reduction in the probability of getting killed when traveling on a 4-lane divided rural highway instead of a 2-lane rural highway by driver type and by the time of the day.

Table A2. Reduction in Probability of Death by Traveling on a 4-Lane Divided Highway vs. 2-Lane Highway by Driver Type and by Time of Day

Day		Night	
Belted	Nonbelted	Belted	Nonbelted
.0058	.0167	.0398	.1129

(Fatalities Per Million Vehicle-Miles)

APPENDIX III

Savings in Injury and PDO Costs by Driving on a 4-Lane Divided Highway vs. a 2-Lane Highway

Savings in injury costs consist of two parts. The first part comes from savings in injury costs in a fatal accident (S_{IF}) which represent the difference in injury costs resulted in a fatal accident on a 2-lane highway (I_{F2}) and those on a 4-lane divided highway (I_{F4}). The other part of savings comes from savings in injury costs in an injury accident (S_{II}) which is equal to the difference in injury costs in an injury accident on a 2-lane highway (I_{I2}) and those on a 4-lane divided highway (I_{I4}). Derivation of total savings in injury costs (TS_I) is shown as follows:

$$TS_I = S_{IF} + S_{II}$$
$$= (I_{F2} - I_{F4}) + (I_{I2} - I_{I4}).$$

After expanding the various components of savings, TS_I can be written as below:

$$\text{(A1)}\quad TS_I = a\left\{[(RF_2) \times (b_2) \times (CI_{F2}) - (RF_4) \times (b_4) \times (CI_{F4})] + [(RI_2) \times (CI_{I2}) - (RI_4) \times (CI_{I4})]\right\},$$

where

a = Adjustment factor for injury accident listed in Table A1,

b_2 = Ratios of number of injuries to number of fatalities in all fatal accidents on 2-lane rural highways in 1984,

b_4 = Ratios of number of injuries to number of fatalities in all fatal accident on interstate highways in 1984,

RF_2 = Fatal accident rate on 2-lane rural highways at 55 mph obtained from the estimated Equation 8, in number per MVM,

RF_4 = Fatal accident rate on 4-lane divided highways at 55 mph obtained from the estimated Equation 5, in number per MVM,

RI_2 = Injury accident rate on 2-lane rural highway at 55 mph obtained from the estimated Equation 9, in number per MVM,

RI_4 = Injury accident rate on 4-lane rural highway at 55 mph obtained from the estimated Equation 6, in number per MVM,

RI_4 = Injury accident rate on 4-lane rural highway at 55 mph obtained from the estimated Equation 14, in number per MVM,

CI_{F2} = Injury costs in a fatal accident on rural minor arterials in 1984 dollars per injury,

CI_{F4} = Injury costs in a fatal accident on an interstate highway in 1984 dollars per injury,

CI_{I2} = Injury costs in an injury accident on rural minor arterials in 1984 dollars per injury, and

CI_{I4} = Injury costs in an injury accident on an interstate highway in 1984 dollars per injury.

Table A3 lists the calculated values of these variables with the exception of a, the values of which are shown on Table A1. After substituting the apporopriate values from Tables A1 and A3, TS_I are derived separately for the daytime belted and unbelted drivers and for the nighttime belted and unbelted drivers. Table A4 shows the savings in injury costs for traveling 100 miles for each of these four categories of drivers.

Total savings in PDO costs (TSp) represent the difference in PDO accident costs driving on an interstate highway (PDO_4) and those on a rural minor arterial (PDO_2). A general functional form is given as follows:

$$(A2)\ TSp = c \times (PDO_2 - PDO_4)$$

where c is the adjustment factor for PDO accidents and its values are listed in Table A1. Meanwhile, PDO_2 and PDO_4 represent the values of PDO in dollars per MVM at 55 mph for 2-lane and 4-lane divided rural highways estimated from Equations 18 and 15, respectively. Since Solomon's data were from 1958, the estimated PDO values need to be updated from 1958 to 1984 when other cost data were collected. A ratio of consumer price indexes between these two years is used and is equal to 3.59 (311.1 ÷ 86.6). The updated estimated PDO_2 and PDO_4 for daytime and nighttime are included in Table A3 together with other calculated values of variables in Equation A1. Substituting the appropriate values from Tables A1 and A3, TSp are derived for the daytime belted and unbelted drivers and for the nighttime belted and unbelted drivers for traveling 100 miles. These savings of PDO are also listed in Table A4.

Table A3. Calculated Values of Variables in Equations A1 and A2

	b_2	b_4	RF_2	RF_4	RI_2	RI_4	CI_{F2}	CI_{F4}	CI_{I2}	CI_{I4}	PDO_2	PDO_4
Day	.86	.96	.0263	.0153	.5572	.3155	33,020	29,735	7,228	7,760	1,638.5	890.0
Night	.86	.96	.1076	.0352	1.3015	.8430	33,020	29,735	7,228	7,760	3,564.5	2,305.9

Table A4. Savings in Injury Costs and PDO Costs by Driver Type and by Time of Day in Dollars Per 100 Miles

	Injury Costs		PDO Costs	
	Driver Type		Driver Type	
Time of Day	Belted	Nonbelted	Belted	Nonbelted
Day	.100	.287	.051	.101
Night	.271	.768	.087	.174

APPENDIX IV

Formula for Weighting Value of Time by Travel Time

$$VT_w = \frac{a_M \sum_i^m (VT_{M_i} \times TT_i) + a_F \sum_j^n (VT_{F_j} \times TT_j)}{a_M \sum_i^m TT_M + a_F \sum_j^n TT_{F_j}},$$

where

VT_w = Value of Time weighted by annual travel time by sex, \$/hour,

VT_{m_i} = Value of Time of Male i, in \$/hour,

VT_{F_j} = Value of Time of Female j, in \$/hour,

TT_{M_i} = Annual Travel Time (Annual Travel Mile/Speed) of male i, in hour,

TT_{F_j} = Annual Travel Time of Female j, in hour,

a_M = Ratios of male percentages between state and sample population, 48.4/41.2,

a_F = Ratios of female percentages between state and sample population, 51.6/58.8,

m = Total male population in the sample, and

n = Total female population in the sample.