

The Value of Travel Time: New Elements Developed Using a Speed Choice Model

WILLIAM F. MCFARLAND AND MARGARET CHUI

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 as well as those recommended by AASHTO's manual for calculating benefits of highway and bus transit improvements are outdated and new estimates are needed. In this study, the value of time was derived from a telephone survey by adopting a speed choice model in which each driver chooses speeds that minimize the total driving costs for each trip. Driving costs include vehicle operating costs, time costs, accident costs, and traffic violation costs. The value of time for each individual is proportional to the square of the individual's chosen speed, the reciprocal of the distance traveled, and the sum of the first derivatives with respect to speed of the driver's accident costs, vehicle operating cost, and speeding ticket costs. Among the driving cost components, fatal accident cost plays an important role in the determination of the value of time. Individuals' fatal accident costs directly relate to their values of life, which were derived using a foregone labor earnings approach. Different weights were considered and applied to arrive at weighted average values of time. The resulting value of time for a driver was \$8.03/hr, and for a passenger car \$10.44/hr, in 1985 dollars.

Benefits resulting from travel time savings represent a major portion of the total benefits in benefit-cost analysis used by highway planners and officials for evaluating highway improvement projects. To translate benefits from travel time savings between alternative projects to monetary terms, the unit value of time is needed. Many estimates of the value of time have been performed over the last 20 years. The methods most commonly used involve binary choices of transport modes or routes. The modal choice method is relevant mainly in areas that offer transit alternatives such as bus, subway, and train; the route choice method in areas that have toll roads. Therefore, in states or areas where transit alternatives or toll roads, or both, are few, or where alternate free roads are unavailable, these methods are not as readily applicable.

Another method used in estimating the value of time is based on the speed choice model (1) in which drivers are assumed to drive at speeds that minimize total trip costs. In rural areas of Texas for which this study was performed, few transit alternatives are available and toll roads are practically nonexistent. For estimating the value of travel time on rural highways in Texas, the speed choice model is more appropriate than either the modal choice or route choice model and hence was chosen for adoption for this study.

The speed choice model was introduced in 1965 in a study by Mohring (2), who roughly estimated a value of time of \$2.80 for a driver on a rural highway driving at his or her desired speed, with vehicle operating cost as the only trip cost considered. In 1975, Ghosh et al. (3) equated the marginal benefits of speed to the marginal costs of speed and obtained a set of optimal speeds for the British motorways using different combinations of the value of time and the cost per fatality. More recently, Jondrow et al. (4) used a similar approach but distinguished between the private optimum speed and the social optimum speed. Optimum speeds were calculated for different combinations of value of time and value of life. The speed choice model also has been used in several German studies (5).

A major shortcoming of previous speed choice models for use in estimating a value of time is that they use average values for motorist cost curves and speeds. This shortcoming may be overcome by estimating specific cost curves for each individual in the sample and by using each individual's desired speed in different cost situations.

MODEL

In the speed choice model for evaluating the value of time, it is assumed that a rational driver chooses a speed at which the driver's total trip cost is minimized. In this study, the total trip cost is assumed to include time costs, vehicle operating costs, accident costs, and traffic violation costs. Each of these cost components is related to speed and the relationship differs not only in magnitude among cost components but also in direction. Hence, when a driver attempts to decrease one of the costs, other cost components may increase, resulting in a higher total trip cost. For instance, by increasing travel speed, travel time is reduced and consequently, time costs are lowered. However, at higher speeds, other costs may increase, offsetting the lower time costs and resulting in a higher total trip cost. A rational driver who minimizes total cost (Point A in Figure 1) chooses the optimal speeds.

The total trip cost (TTC_i) for individual i traveling a distance of d (mi) at speed s_i (mph) is calculated as

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

where TMC_i , VOC_i , ACC_i , and TKC_i represent individual i 's time costs, vehicle operating costs, accident costs, and traffic ticket costs, respectively.

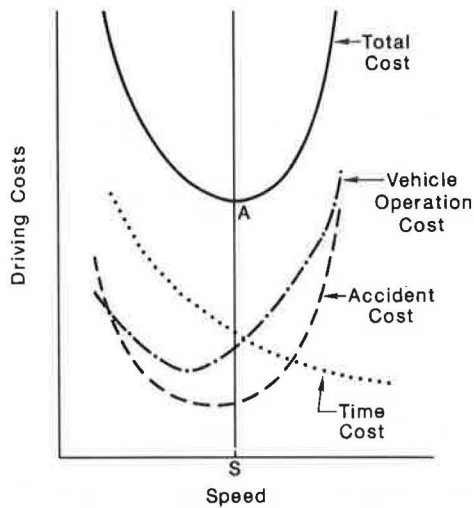


FIGURE 1 An individual's driving costs.

Individual i 's total trip cost is minimized by differentiating Equation 1 with respect to speed s_i and setting the resulting equation to zero. Thus

$$D_{s_i}(TMC_i) + D_{s_i}(VOC_i) + D_{s_i}(ACC_i) + D_{s_i}(TKC_i) = 0 \quad (2)$$

where D_{s_i} is the derivative with respect to speed of individual i . Time cost TMC_i of individual i is defined as

$$TMC_i = VT_i \times T_i \quad (3)$$

where VT_i represents the individual i 's value of time and T_i is individual i 's travel time needed to travel distance d at speed s_i .

$$T_i = d/s_i \quad (4)$$

Equation 3 can be rewritten as

$$TMC_i = VT_i \times d/s_i \quad (5)$$

Differentiating Equation 5 with respect to s_i gives

$$D_{s_i}(TMC_i) = -VT_i \times d/s_i^2 \quad (6)$$

By substituting Equation 6 into Equation 2 and solving for VT_i , the value of VT_i is obtained:

$$VT_i = (\hat{s}_i^2/d) \times [D_{\hat{s}_i}(VOC_i) + D_{\hat{s}_i}(ACC_i) + D_{\hat{s}_i}(TKC_i)] \quad (7)$$

where \hat{s}_i represents the optimal speed for individual i and the speed derivatives are all evaluated for $s_i = \hat{s}_i$.

DATA

Both primary and secondary data were used in this study.

Primary Data Source

A telephone survey was conducted to elicit Texas motorists' driving habits on rural highways as related to some personal

characteristics. Questions on driving habits included speeds during daytime and nighttime on four-lane divided and two-lane rural highways; use of seat belts; model, make, body style, and model year of an in-town vehicle and an out-of-town vehicle, if a different vehicle is used; and annual mileage. Personal characteristics elicited were age, sex, race, education level, and hourly wage.

A sample of 500 people ages 18 and older was randomly selected to participate in the telephone survey. Answers to each question were tested by following a procedure (6) to determine the existence of outlier data. Outliers were discarded because they were believed to belong to a population other than the one being studied.

The personal characteristics of the sample group were as follows: the average age was 36.5, 41.2 percent were male, 58.8 percent female, 7.8 percent Black, 79.8 percent Anglo, and 11.4 percent Hispanic. Further, 16.2 percent had less than a high school education, 31.4 percent finished high school, 27.6 percent had done some college work, 24.2 percent graduated from college or did graduate work, and the remaining 0.6 percent did not respond. The average hourly wage was \$10.05, slightly higher than the hourly wage of \$9.47 for the state. Compared with the 1980 census population of age 18 years and older in Texas, the sample group was younger and had a higher percentage of females. In 1980, the average age of adults in the state was 41.7 years and the female population was 51.6 percent of the total adult population.

To obtain data on various precincts' traffic ticket costs, a questionnaire was sent to 75 justices of the peace who represent Texas precincts.

Secondary Data Sources

Data on vehicle operating costs and on accident rates for three types of accidents—fatal, injury, and property damage only (PDO)—were obtained from literature sources. Although Zaniewski et al. (7) provided the most updated vehicle operating costs related to driving speed by vehicle size, Solomon's 1962 accident study (8) provided 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 Department of Highways and Public Transportation (DHPT), and the Highway Performance Monitoring System (HPMS) for Texas.

RELEVANT VARIABLES

The value of time (Equation 7) includes relevant variables of vehicle operating costs, accident costs, traffic ticket costs, and travel speed. Further, accident costs comprise two important variables: the value of life and accident rates.

Vehicle Operating Costs

Based on 1982 data (7), vehicle operating costs of large, medium, and small passenger cars and of pickup trucks traveling at different speeds on grade 0 and at service index (SI) of 3.5

are regressed against powers of the traveling speed. The estimated equations for the four vehicle types are as follows:

$$VOC_L = 197.879 - 3.45626(s) + .043516(s^2) \quad (8)$$

$$VOC_M = 194.973 - 3.73728(s) + .046126(s^2) \quad (9)$$

$$VOC_S = 217.440 - 4.89824(s) + .051209(s^2) \quad (10)$$

$$VOC_P = 167.368 - 3.13530(s) + .045907(s^2) \quad (11)$$

where

VOC_L = vehicle operating costs of large passenger cars (\$/1,000 mi),

VOC_M = vehicle operating costs of medium passenger cars (\$/1,000 mi),

VOC_S = vehicle operating costs of small passenger cars (\$/1,000 mi),

VOC_P = vehicle operating costs of pickups (\$/1,000 mi), and

s = traveling speed (mph).

The multiple correlation coefficients of determination for Equations 8–11 are $R^2 = 0.9540, 0.9703, 0.9721,$ and $0.9480,$ respectively.

No updating on vehicle operating costs was performed because it was believed that current gasoline prices, the major component of vehicle operating costs, have been 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 (24 km/hr) and higher operating costs than pickup trucks below 30 mph (48 km/hr). Small cars cost the least to operate at speeds over 30 mph (48 km/hr). Pickup trucks have the lowest operating costs among all vehicle sizes at speeds below 30 mph (48 km/hr) but are the most costly to operate over 65 mph (104 km/hr). A comparison of the minimum points of the four cost versus speed curves reveals that both large and medium passenger cars are least expensive to operate at about 40 mph (64 km/hr), whereas costs of operating a small car bottom out at about 48 mph (77 km/hr) and pickup trucks reach their minimum operating costs at 34 mph (54.5 km/hr), before all other vehicle sizes do. At a speed range of 47 to 70 mph (75.2 to 112 km/hr), the operating costs of the large, medium, and small vehicles perform as expected, with the large cars costing the most to operate and the small cars the least, whereas operating costs for pickup trucks lie between those of large and medium cars in most parts of this speed range.

After identifying the size of each individual's vehicle or vehicles from information on vehicles obtained from the survey, the individual's vehicle operating cost curve can be obtained using one of the estimated equations, whichever is appropriate for the person's 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 pickup trucks.

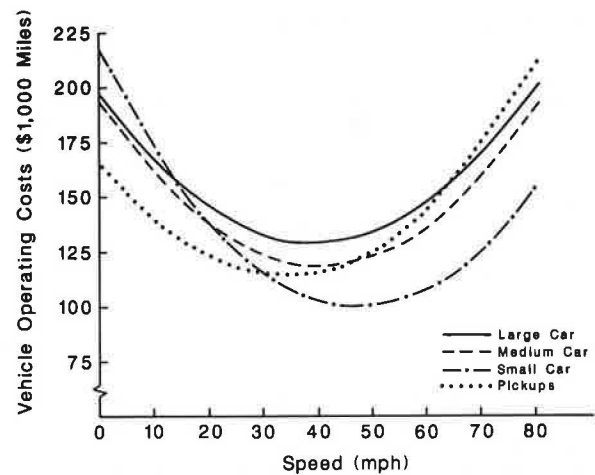


FIGURE 2 Vehicle operating costs by vehicle size.

Accident Rates

Data on accidents occurring at various travel speeds are practically nonexistent, except those reported by Solomon (8) in 1964. Some concern was raised as to the validity of using old speed data because of the differences in speed limits and vehicle operating conditions (9). However, an examination of Solomon's data set and the 1984 Texas accident data reveals their similarity in both fatal and injury accident rates. Fatal accident rates on four-lane divided rural highways and two-lane rural highways estimated from Solomon's data were 0.0153 and 0.0263 fatalities per million vehicle-miles (MVM), respectively, whereas the 1984 Texas fatal accident rates on Interstate highways and on minor arterials were 0.0191 and 0.0325 fatalities per MVM, respectively. The injury rates between the two data sets present an even narrower gap. Table 1 gives the 1984 numbers of fatal and injury accidents and vehicle-miles traveled on rural Texas highways and Table 2 gives the comparison of rural fatal and injury accident rates between 1984 Texas accident record and the Solomon rates.

Based on Solomon's accident data, two sets of accident rate equations expressed as functions of speed were estimated, one for four-lane divided rural highways and one for two-lane rural highways. Each set comprises three equations, one each for fatal accidents, injury accidents, and property damage accidents. The estimated equations in log-linear form are as follows:

TABLE 1 1984 ACCIDENTS AND VEHICLE MILES TRAVELED ON RURAL HIGHWAYS IN TEXAS

Functional Classification	Accidents ^a		Distance Traveled ^b (veh-mi, thousands)
	Fatalities	Injuries	
Interstate	193	4,007	10,087,505
Two-lane ^c	202	3,840	6,212,300

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

^bFrom Texas data in the Highway Performance Monitoring System (HPMS).

^cMinor 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 ^a		Solomon's Accident Data ^b	
	Fatalities (\$/MVM)	Injuries (\$/MVM)	Fatalities (\$/MVM)	Injuries (\$/MVM)
Four-lane divided (Interstate)	0.0191	0.3972	0.0153	0.3155
Two-lane (minor arterials)	0.0325	0.6181	0.0263	0.5572

^aTexas accident data were made available by the Texas Department of Public Safety and the Texas State Department of Highways and Public Transportation.

^bFigures represent the estimated daytime accident rates at 55 mph from Equations 12, 13, 15, and 16.

Four-Lane Divided Rural Highways

$$\ln(FATAL) = 9.2299 - 0.4859(s) + 0.0047(s^2) - 0.8352(Q) \tag{12}$$

$$\ln(INJUR) = 11.6802 - 0.4264(s) + 0.0038(s^2) - 0.9827(Q) \tag{13}$$

$$\ln(PDO) = 18.2155 - 0.3992(s) + 0.0034(s^2) - 0.9520(Q) \tag{14}$$

Two-Lane Rural Highways

$$\ln(FATAL) = 5.0515 - 0.3206(s) + 0.0034(s^2) - 1.4074(D) \tag{15}$$

$$\ln(INJUR) = 7.8000 - 0.2846(s) + 0.0027(s^2) - 0.8484(D) \tag{16}$$

$$\ln(PDO) = 14.6954 - 0.2854(s) + 0.0026(s^2) - 0.7773(D) \tag{17}$$

where

- FATAL = number of fatalities per MVM,
- INJUR = number of injuries per MVM,
- PDO = dollars (1958) of property damage per MVM,
- s = traveling speed (mph), and
- Q = dummy variable for daytime and nighttime travel,
 - = 1 if daytime, and
 - = 0 if nighttime.

The multiple correlation coefficients of determination for Equations 12-14 are 0.9280, 0.9412, and 0.9568, respectively.

Figures 3 and 4 show the estimated fatality and injury rates,

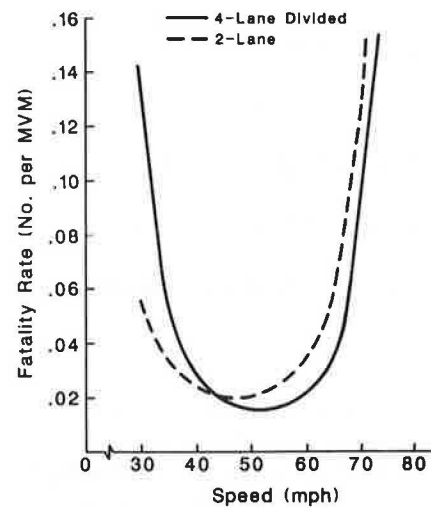


FIGURE 3 Daytime fatality rate by road type versus speed.

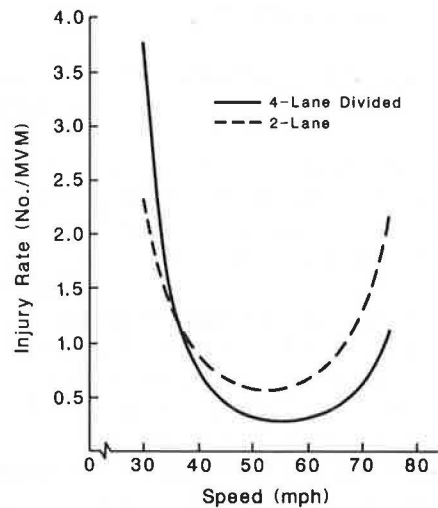


FIGURE 4 Daytime injury rate by road type versus speed.

respectively, as functions of speed on four-lane divided rural highways and on two-lane rural highways. On four-lane divided rural highways, the safest speeds for avoiding fatal, injury, and PDO accidents are 51.9, 55.7, and 59.2 mph (83, 89, 95 km/hr), respectively, while on two-lane rural highways, the safest speeds for the corresponding accident types are 46.9, 55.7, and 54.7 mph (75, 89, and 87.5 km/hr).

The PDO figures obtained from the equations are expressed in 1958 dollars and are updated to the current level using consumer price indexes (CPI) to represent the 1984 PDO costs.

Accident rates also vary according to road type and to the use of seat belts. From Solomon's data, nighttime driving has a higher accident rate. There are 429 traffic accidents per MVM at night as compared with 215 traffic accidents per MVM during the day. Also, four-lane rural highways are safer than two-lane highways. The four-lane highway had an accident rate of 212 accidents per MVM whereas the two-lane highway had 300 accidents per MVM.

Studies have shown that drivers who use seat belts are 50 percent safer than those who do not. Seat belts are reported to be responsible for reducing the number of fatalities and injuries by 30 percent (9). Because the seat belt law in Texas went into effect only recently, these percentages may be invalid. However, because the survey was carried out before the law took effect, the percentages were considered valid and were therefore used in this study. Four groups of drivers are identified from the sample: daytime belted, daytime unbelted, nighttime belted, and nighttime unbelted. Using the accident statistics related to seat belt use and the ratios of belted and unbelted drivers in the sample, adjustment factors were developed separately for Interstate and for two-lane rural highways. These factors are to be used for adjusting the accident rate equations (Equations 12-17) for each of the four groups of drivers using these two road types (see Table 3). A general functional form of the adjusted accident rate (AAR) of accident type *j* on highway type *H* for driver group (*T,B*), where *T* is for time of day and *B* is for seat belt use, is as follows:

$$(AAR_{j,H})_{T,B} = (a_j)_{T,B} \times (AR_{j,H})_T \quad (18)$$

where *a_j* represents the adjustment factor from Table 3 and *AR_j*, one of the estimated accident rates. In this study, these adjusted accident rate curves are assumed to be applicable to everyone within the same driver group on the same highway type at the same time of day.

TABLE 3 ADJUSTMENT FACTORS OF ACCIDENT RATES BY DRIVER TYPE AND BY TIME OF DAY

Time of Day	Fatal and Injury by Driver Type		Property Damage Only by Driver Type	
	Belted	Unbelted	Belted	Unbelted
Day	0.53	1.52	0.68	1.35
Night	0.55	1.56	0.69	1.38

Value of Life

The cost of a fatality represents the value of an individual's life. In the foregone earnings approach, which is used to estimate the value of an individual's life, human wealth is measured by the present value of expected future labor earnings determined by age, sex, race, education, and past earnings. Ordinarily, earnings increase with age, peak around middle age, and remain stable until retirement. Levels of earnings are higher and peak at a later age the higher the educational level. Blomquist (10) was able to derive a set of age-earnings equations for seven different education levels, as given in Table 4. An individual's foregone earnings (EARN) represent the summation from the current age up to age 70 of the individual's expected annual discounted labor earnings multiplied by the appropriate age-, sex-, and race-dependent probability of survival. EARN is expressed as follows:

$$(EARN_{b,c,e})_a = \sum_{j=a+1}^{70} (E_e)_j \times 1/(1+i)^{j-a} \pi_{k=a}^{j-1} (P_{b,c})_a \quad (19)$$

TABLE 4 AGE-EARNINGS PROFILES BY GRADE LEVEL (10)

Grade Level	Age-Earnings Profiles
0-4	$E = c + 497.9(A) - 4.46(A)^2 + 0.0581(A)^3$
5-8	$E = c + 653.3(A) - 11.65(A)^2 + 0.0662(A)^3$
9-11	$E = c + 264.7(A) - 2.62(A)^2$
12	$E = c + 929.2(A) - 16.92(A)^2 + 0.1008(A)^3$
13-15	$E = c + 1036.1(A) - 15.74(A)^2 + 0.0708(A)^3$
16	$E = c + 1145.9(A) - 15.77(A)^2 + 0.0623(A)^3$
17+	$E = c + 238.9(A) - 38.98(A)^2 + 0.2055(A)^3$

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

where

- a* = current age,
- b* = race,
- c* = sex,
- e* = education level,
- i* = annual discount rate,
- (*E_e*)_{*j*} = predicted annual labor earnings at education level *e* 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 (*P_{b,c}*)_{*a*} by age, sex, and race is calculated from the following formula, using the 1980 mortality data supplied by the Texas Department of Health:

$$(P_{b,c})_a = 1 - (M_{b,c})_a / (pop_{b,c})_a \quad (20)$$

where

- a* = age,
- b* = race,
- c* = sex,
- P* = probability of survival,
- M* = 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 determined the average value of life to be 2.5 times the amount of the average foregone earnings. In other studies of the value of life, the ratio of value of life to foregone earnings was found to range from as low as 1.3 to as high as 107 (11). The inconsistency of the results and the complexity of the problem warrant further investigation. In this study, the ratio of value of life to average foregone earnings is assumed to be 2.5.

Accident Costs

Costs for accidents other than the cost per fatality are based on a recent Texas study (12) that estimated detailed injury and property damage costs for each accident type for different types of rural highways.

Depending on the group (daytime belted, nighttime belted, daytime unbelted, or nighttime unbelted) an individual belongs to, the injury and PDO cost functions are different between the highway types but are assumed to be alike for all people within a group. However, fatal cost functions are unique. Each individual has a unique fatal cost function because the individual's value of life is used as the unit fatal accident cost.

Traffic Ticket Cost

Fifty-one of the 75 questionnaires sent to justices of the peace in various Texas precincts were returned, and all indicated that traffic ticket cost increases with driving speed. The relationship is estimated using ordinary least squares regression technique. The estimated equation is as follows:

$$\ln(TK) = 1.01889 + 0.03991s \quad (21)$$

where TK equals cost per speeding ticket fine for ticketed speed s , and s equals travel speed (mph). The correlation coefficient of fit for Equation 21 is 0.7296.

The frequency of getting a traffic ticket is calculated by dividing the number of traffic tickets by the total mileage traveled. In 1984, 45,189.555 million mi were traveled on rural Texas state highways and 940,640 traffic tickets were given on these highways. The frequency of getting a traffic ticket is thus 0.021 tickets per 1,000 mi of travel on rural state highways, and the traffic ticket cost (TKC) per 1,000 mi is this rate multiplied by the cost per ticket:

$$TKC = 0.021 \times e^{1.01889 + 0.03991s} \quad (22)$$

Speed

Respondents were asked to indicate their daytime and nighttime driving speeds under the current speed limit of 55 mph (88 km/hr) on a four-lane divided Interstate rural highway and on a two-lane rural highway. The speed given for each of the four situations (daytime Interstate, daytime two lane, nighttime Interstate, and nighttime two-lane) by a respondent represents the optimal speed at which the respondent perceives that total driving costs are minimized for the specific situation. As indicated in the value of time equation (Equation 7) discussed earlier, the optimal speed of a respondent is needed in the evaluation of the respondent's value of time.

In this sample, the average speeds driven during the day on a four-lane divided rural highway and on a two-lane rural highway are 57.5 and 53.2 mph (92 and 85 km/hr), respectively, whereas average speeds for nighttime driving on the same two road types are 54 and 49 mph (86 and 74 km/hr), respectively. This finding 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

Four values of speed—at night and during the day on four-lane

and two-lane roads—were calculated for each respondent for whom complete data were available. Because speeds on four-lane roads are less affected by physical restraints, it is surmised that these values probably are the best estimates, although the overall weighted averages for the two types of road were similar.

The estimated values of time using desired speeds of travel on four-lane highways are given in Table 5 by sex, time of day,

TABLE 5 VALUES OF TIME BY SEX, TIME OF DAY, AND SEAT BELT USAGE

Time of Day	1984 \$/hr			
	Belted		Unbelted	
	Male	Female	Male	Female
Day	14.84	6.93	16.21	9.99
Night	12.77	6.66	17.01	11.70

and seat belt usage. The values of time for male drivers are consistently greater than those for female drivers. This difference results mainly from males' driving at higher speeds and having higher average earnings (and, thus, higher assumed fatality costs). Average values of time also tend to be higher for unbelted drivers. This finding could be the result of unbelted drivers actually having higher values of time or an error in the cost curves that are used to represent drivers' perceived costs. The average values of time tend to be fairly close between night and day for any given subgroup of male-female and belted-unbelted. Weighted across male-female and belted-unbelted, the average value of time using day speeds is \$11.84/hr and using night speeds is \$11.71/hr.

These values are not weighted to account for the amount of driving per year. In a benefit-cost analysis, the value of time needs to represent the average driver using a highway. To derive this type of value, the values in Table 5 were weighted by the estimated number of hours per year that each driver spent driving. The weights that were used to derive the weighted averages are given in Table 6. These hours per year

TABLE 6 WEIGHTS USED IN WEIGHTING VALUE OF TIME

Condition	Day	Night
Driver type		
Belted	0.52	0.55
Unbelted	0.48	0.45
Time of day	0.75	0.25

were estimated by dividing each person's estimated miles per year by the average speed, both of which were items in the questionnaire. Because the ratio of males to females in the completed questionnaire was significantly less than statewide estimates, values of time were calculated separately for males and females and the statewide population estimates were used as weights. Average values of time not weighted by hours of travel are given in the top half of Table 7, and values weighted by hours of travel are given in the bottom half. As these results show, persons with higher values of time tended to indicate that they drove less hours per year, so the unweighted average value of time is \$11.81/hr and the weighted value of time is only