PERSONAL NONMONETARY COSTS OF MOTOR-VEHICLE USE

Report #4 in the series: *The Annualized Social Cost of Motor-Vehicle Use in the United States, based on 1990-1991 Data*

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Of course, I alone am responsible for the contents of this report.

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LIST OF ACRONYMS AND ABBREVIATIONS AND OTHER NAMES

The following are used throughout all the reports of the series, although not necessarily in this particular report

AER = *Annual Energy Review* (Energy Information Administration)
AHS = *American Housing Survey* (Bureau of the Census and others)
ARB = Air Resources Board
BLS = Bureau of Labor Statistics (U. S. Department of Labor)
BEA = Bureau of Economic Analysis (U. S. Department of Commerce)
BTS = Bureau of Transportation Statistics (U. S. Department of Transportation)
CARB = California Air Resources Board
CMB = chemical mass-balance [model]
CO = carbon monoxide
dB = decibel
DOE = Department of Energy
DOT = Department of Transportation
EIA = Energy Information Administration (U. S. Department of Energy)
EPA = United States Environmental Protection Agency
EMFAC = California's emission-factor model
FHWA = Federal Highway Administration (U. S. Department of Transportation)
FTA = Federal Transit Administration (U. S. Department of Transportation)
GNP = Gross National Product
GSA = General Services Administration
HC = hydrocarbon
HDDT = heavy-duty diesel truck
HDDV = heavy-duty diesel vehicle
HDGT = heavy-duty gasoline truck
HDGV = heavy-duty gasoline vehicle
HDT = heavy-duty truck
HDV = heavy-duty vehicle
HU = housing unit
IEA = International Energy Agency
IMPC = Institutional and Municipal Parking Congress
LDDT = light-duty diesel truck
LDDV = light-duty diesel vehicle
LDGT = light-duty gasoline truck
LDGV = light-duty gasoline vehicle
LDT = light-duty truck
LDV = light-duty vehicle
MC = marginal cost
MOBILE5 = EPA's mobile-source emission-factor model.
MSC = marginal social cost

MV = motor vehicle
NIPA = National Income Product Accounts
NO_x = nitrogen oxides
NPTS = Nationwide Personal Transportation Survey
OECD = Organization for Economic Cooperation and Development
O_3 = ozone
OTA = Office of Technology Assessment (U. S. Congress; now defunct)
PART5 = EPA's mobile-source particulate emission-factor model
PCE = Personal Consumption Expenditures (in the National Income Product Accounts)
PM = particulate matter
PM_{10} = particulate matter of 10 micrometers or less aerodynamic diameter
$PM_{2.5}$ = particulate matter of 2.5 micrometers or less aerodynamic diameter
PMT = person-miles of travel
RECS = Residential Energy Consumption Survey
SIC = standard industrial classification
SO_x = sulfur oxides
TIA = *Transportation in America*
TSP = total suspended particulate matter
TIUS = *Truck Inventory and Use Survey* (U. S. Bureau of the Census)
USDOE = U. S. Department of Energy
USDOL = U. S. Department of Labor
USDOT = U. S. Department of Transportation
VMT = vehicle-miles of travel
VOC = volatile organic compound
WTP = willingness-to-pay

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APPENDIX 4A

4. PERSONAL NONMONETARY COSTS OF MOTOR-VEHICLE USE

4.1 BACKGROUND

Personal non-monetary costs are those unpriced costs of motor-vehicle use that a person imposes on herself as a result of her decision to travel. The largest personal costs of motor-vehicle use are personal travel time in uncongested conditions and the risk of getting into an accident that involves nobody else or would have happened regardless of the actions of others.

Note the distinction between personal nonmarket costs and externalities. Personal costs are caused and borne by the same party, whereas externalities, which are covered in Report #9 in the social-cost series, and column 6 of Table 1-1 of Report #1, are imposed by one party on another but not accounted for by the imposing party. The risk that I will cause an accident and injure myself is a personal non-monetary cost; the risk that someone else will injure me is an external cost, if the other person does not account for it, and if I would not have been injured had the other person not driven. The congestion delay that others impose on me is an external cost; the *rest* of my travel time is a personal non-monetary cost. These distinctions are relevant to policy making because personal costs are unpriced[1] but efficiently allocated if consumers are informed and rational, whereas externalities are unpriced and generally a source of inefficiency[2]. As discussed below and indicated in Table 1-2 of Report #1, the usual prescription for externalities is a Pigovian[3] tax, whereas the "prescription" for a personal cost is just that the affected party be fully aware of it. Thus, any individual should be taxed for the accident or travel time costs he imposes on others, *and* be fully aware of the costs that he himself faces as a result of using a motor-vehicle.

If an individual does not correctly assess the personal costs to himself, then he will consume more or less than he would have had he been fully informed and rational. It is likely that some drivers do make such mistakes some of the time, and that as a result the observed level of personal nonmarket costs is not optimal. For example, there is evidence that most drivers overestimate their alertness and driving skill, and

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[1]Explicit prices, which mediate transactions between buyers and seller, obviously are not necessary if the "buyer" and "seller" are one and the same , and there is no exchange, or no market. One might say that personal costs are priced implicitly or "internally".

[2]I recognize, though, that the distinction between personal nonmarket costs and nonmarket externalities is awkward to the extent that it is not realistic psychologically. In reality, if a motor-vehicle user accounts for, say, exposure to noise and the risk of an accident, she does not necessarily distinguish between the noise or risk that she is responsible for and the noise and risk imposed by others. Rather, she probably makes a qualitative judgment about overall exposure to noise and risk.

[3]Named after the English economist A. C. Pigou, who made significant contributions to the economic analysis of social welfare.

underestimate their chances of getting into an accident[4]. To the extent that they do, they underestimate the expected personal cost of driving, and make more trips, or more risky trips, then they would if they were properly apprised of their abilities and chances[5].

Report #2 in this series contains further discussion of the classification and interpretation of personal nonmarket costs.

4.2 TRAVEL TIME, EXCLUDING TRAVEL DELAY IMPOSED BY OTHERS, THAT DISPLACES UNPAID ACTIVITIES

4.2.1 Concepts and categories

The value of the time that people spend in their cars and trucks is the single largest item in this cost accounting. As documented in this social-cost analysis, all travel time in motor vehicles (including compensation of paid drivers) is worth roughly one trillion dollars annually.

In general, the cost of any travel time, whether monetary or nonmonetary, personal or external, can be estimated simply as the amount of travel time, in hours, multiplied by the cost per hour of travel. Total travel time can be estimated in a straightforward manner from data on travel times or data on average speeds and distances. It is not so straightforward, however, to estimate the cost per hour of travel time, and to separate the externality of travel delay from the total travel time.

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[4]Miller (1989) cites a 1978 study that found that people typically estimate their crash risk at 60% of the actual risk. Similarly, DeJoy (1989) refers to two studies that show "that while most drivers possess fairly accurate perceptions of total, societal traffic risks, they tend to believe that these aggregate estimates of risks do not apply to them personally. Most drivers consider themselves to be safer, more skillful, and less likely to be involved in an accident than the average driver". DeJoy's (1989) own study of the risk perceptions of 106 college students found that that was precisely how the students perceived themselves: namely, as safer, more skillful, and less likely to be involved in an accident than the average driver. DeJoy (1989) concluded that "in general, it appears that optimism arises because people persistently overestimate the degree of control that they have over events" (p. 333).

Other researchers have suggested that people believe that their probability of getting in an accident is zero. For example, Jansson (1994) states that "some researchers even go so far as... [stating] that the perceived accident cost is nil" (p. 34). This, however, seems too extreme.

[5]If, as seems to be the case, people really do substantially underestimate their expected personal accident costs, and if these personal accident costs are as large as estimated here, then it is important to correct the mis-perceptions. However, the proper corrective is by no means obvious -- certainly, a prescription for "better information" is too facile and not particularly helpful. DeJoy (1989) notes that because the core problem is that drivers exaggerate their ability to control events, "interventions must seek to counter the perception of exaggerated control by means that personalize the risk" (p. 340). Alternatively, one could make the true risk explicit by pricing it. Thus Jansson (1994) states that "Turvey (1973), for example, argued that it would be quite reasonable to charge road vehicles for their own expected accident costs to make the drivers fully aware of the risk" (p. 34).

In this section of this report, I estimate the value of travel time (excluding travel delay) that displaces unpaid activities, such as leisure. I estimate the largest component -- the cost of personal travel time in household vehicles -- in considerable detail, for different income classes, travel modes, and trip purposes. (The value of travel time, excluding travel delay, that displaces paid activities, is estimated in Report #5. External costs of travel delay are included with the items estimated in Report #8 and Report #9, but actually are documented here.)

The cost per hour of travel time: concepts. We may define the cost of travel time as the social willingness to pay (WTP) to have the travel time reduced to zero, all else (including access to whatever we travel to) equal. In principle, this cost, or social WTP, has two components: an opportunity-cost component, and a hedonic component (Hensher, 1997; Jiang and Morikawa, 2004).

The opportunity cost is the value of activities foregone while in the car. If one must give up some activity of value while driving or sitting in a car, then one will be willing to pay something to reduce travel time in the car to zero. Analytically, it is useful to distinguish monetary, or *paid* activities foregone, from nonmonetary, or *unpaid* activities foregone. If one would be working productively at a paying job were one not traveling, then the opportunity cost of the travel time would be paid work. If one would be watching a home video were one not traveling, then the opportunity cost of travel time would be unpaid activity. The distinction between paid and unpaid activity is relevant analytically because the dollar value of the paid activity is explicit, whereas the dollar value of the unpaid activity has to be estimated by non-market valuation or indirect market methods.

Note that, in determining whether the travel-time cost is monetary (paid), we care not whether the traveler is reimbursed for travel, but rather whether the activities that are foregone because of the travel are themselves directly valued in dollars. If travel displaces monetarily compensated work time, then the travel time has a monetary cost, and is included either in this report or, if it also is an external cost, in Report #8. But if the travel does *not* displace paid work time, then the travel time has a non-monetary cost and is included here or in Report #9.

For example, if business travel displaces paid work, then the cost of the travel time is the value of the foregone productivity, which is discussed in Report #5. In this case, regardless of whether the traveler is reimbursed explicitly for travel time per se, the business travel has a monetary cost. However, if business travel actually displaces leisure time, then, even if the traveler is paid a salary during the travel or is reimbursed, the travel time has a non-monetary cost, because leisure time, which is the opportunity cost, is not valued directly in dollars.

Of course, the opportunity cost of travel time can be zero. If one is able to do in the car precisely what one would do were travel time reduced to zero, then there is no opportunity cost. For example, if a person can conduct business by car phone, he or she might forego nothing, and hence have a zero time-opportunity cost.

Because the magnitude of the opportunity cost depends precisely on what is being foregone, it will vary considerably across individuals and trips. For simplicity, I will consider only two general kinds of foregone activities: leisure, or unpaid activities, and paid productive work. I estimate the value of both with respect to the individual's income.

The hedonic cost is the pure utility or disutility of the motoring experience itself. The hedonic cost is determined by several factors, including comfort, safety, privacy, available space, amenities, and the amount of effort and attention required to control or in general worry about vehicle. If one actually likes the experience of driving or being in a car, then the hedonic cost per se actually is negative. I expect, though, that most people, most of the time, find motoring stressful or boring, and hence would pay to eliminate the experience, although probably much less than they would pay to avoid foregoing activities. Because the hedonic cost is non-monetary, I include the entire amount with the estimates of non-monetary time costs, here and in Reports #9.

Categories of travel, by type of vehicle, according to the data. Because the cost per hour depends on the type of trip and the income of the traveler, I estimate cost per hour and travel time for several different kinds of trips and trip-makers. In the first instance, I distinguish the following general categories of travel, by type of vehicle[6]:

- Private vehicles, for personal purposes
  - -- daily travel (LDAs, LDTs)
  - -- long trips (LDAs, LDTs)
- Private vehicles, for business purposes
  - -- LDAs, without paid drivers
  - -- LDTs, without paid drivers
  - -- LDTs, with paid drivers
  - -- HDTs, with paid drivers
- Buses
  - -- intercity and transit buses
  - -- school buses
- Public (government) vehicles
  - -- federal civilian vehicles (LDAs, LDTs, HDTs)
  - -- federal military vehicles (LDAs, LDTs, HDTs)
  - -- state and local civilian vehicles (LDAs, LDTs, HDTs)
  - -- state and local police vehicles

The first category, daily travel in private vehicles for personal purposes, comprises travel to work, shopping and other personal business, and social and

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[6]Hensher et al. (1990) distinguish four kinds of trips: 1) private commuting to work in household vehicles; ii) commuting to work in company-supplied vehicles; iii) travel as a part of work; and iv) non-work related personal travel. They distinguished between commuters using private vehicles and commuters using company vehicles because the latter have a higher income than the former, and are willing to pay a higher percentage of that income to save time.

recreational trips, as reported in the Nationwide Personal Transportation Survey (NPTS).

These travel categories are shown and further explained in Table 4-1, which presents the data and results of the analysis of the cost of travel time. The table shows total travel data for each category, and then, within each travel category, estimates the portion of the total travel time that is due to delay and hence is an external cost, and the portion that is not, and the portion of travel that displaces paid work, and the portion that displaces unpaid activities. The portion that is not due to delay and that displaces unpaid activity is a non-monetary non-external cost, and is estimated below.

4.2.2 Estimating the cost

In each vehicle travel category of Table 4-1 (daily travel, long trips, etc.), the non-monetary time cost of travel, excluding delay, is calculated as[7]:

$$TTCinm = (PHT - PHTd) \cdot \left(\frac{1}{Oc} + \left(1 - \frac{1}{Oc}\right) \cdot Pa \right) \cdot (Fnm,dr \cdot Cnm + Ch,dr) \quad \textbf{[4-1]}$$

$$Cnm = Cnm,ref \cdot \left(\frac{Sref}{Snd} \right)^{Bo}$$

$$Ch,dr = Ch,dr,ref \cdot \left(\frac{Sref}{Snd} \right)^{Bh} \quad \textbf{[4-1a, b]}$$

where:

TTCinm = the personal (internal) non-monetary travel-time cost (10^9 1991$)

PHT = total person-hours of travel time (10^9 person-hours of travel; discussed below and shown in Table 4-1)

PHTd = person-hours of delay (the travel-time externality) (10^9 person-hours of delay; discussed below and shown in Table 4-1))

Oc = average vehicle occupancy (persons/vehicle; Table 4-1)

Pa = the ratio of parameters [Fnm] and [Ch,ref] for passengers to [Fnm] and [Ch,ref] for drivers ([Fnm,pa]/[Fnm,dr] and [Ch,pa,ref]/[Ch,dr,ref]) (discussed below)

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[7]The equation for the bus categories is slightly different:

$$TTCinm = (PHT - PHTd) \cdot \left(1 - \frac{1}{Oc}\right) \cdot (Fnm \cdot Cnm + Ch)$$

where the cost parameters are for bus passengers. All of the time cost of the driver is monetary.

Fnm,dr = the fraction of travel time that displaces non-monetary (unpaid) activities rather than paid activities, for drivers (discussed below and shown in Table 4-1)
Cnm = The cost of the foregone non-monetary (unpaid) activities ($/person-hour)
Ch,dr = the pure hedonic cost of travel, for drivers ($/person-hour)
Cnm,ref = The cost of the foregone non-monetary (unpaid) activities, at the reference speed Sref ($/person-hour; see section 4.2.6 and Table 4-1)
Ch,dr,ref = the pure hedonic cost of travel, for drivers, at the reference speed Sref ($/person-hour; see section 4.2.7 and Table 4-1)
Sref = the reference speed, with respect to which the speed-dependence of Cnm and Ch are estimated (I assume 30 mph, which is close to the all-condition, all-vehicle average speed in the U. S.)
Snd = the average speed when there is no delay (mph; Table 4-1 and derived in section 4.2.4)
Bo = the exponent that determines the dependence of opportunity cost Cnm on average vehicle speed when there is no delay (section 4.2.8)
Bh = the exponent that determines the dependence of hedonic cost Ch on average vehicle speed when there is no delay (section 4.2.8)

The key parameters are discussed in the sections that follow..

4.2.3 Total person-hours of travel time, by vehicle-travel class (parameter PHT)

In each travel category of Table 4-1 except "private vehicles for personal purposes, daily travel" (column a), I calculate total travel time simply as:

$$PHT = \frac{PMT}{Sa} \qquad \textbf{[4-2]}$$

In most of the travel categories,

$$PMT = VMT \cdot Oc$$

where:

PHT = total person-hours of travel
PMT = total person-miles of travel (Table 4-1)
Sa = the actual average speed in 1990 (person-miles per person-hour, which is the same as vehicle-miles per vehicle-hour, or ordinary mph) (Table 4-1)
VMT = total vehicle miles of travel (Table 4-1)
Oc = average vehicle occupancy (persons/vehicle; Table 4-1)

The column notes to Table 4-1 explain the estimates and assumptions of PMT, VMT, Sa, and Oc.

In the category "private vehicles for personal purposes, daily travel" (column a), I estimate person-hours of travel as:

$$PHT = SUM3 \cdot 1.002$$

where:

SUM3 = total person hours of travel for all purposes except work-related business, according to the our analysis of the NPTS (SUM3 of Table 4-2)

1.002 = factor to account for car trips to access public transit, which trips are not included in Table 4-2 (see the discussion in the notes to Table 4-2).

See the notes to Table 4-2 for details. I have excluded work-related business travel here because I consider it to fall under the general category "Private vehicles, business purposes," of Table 4-1.

The NPTS data of Table 4-2 include all travel time, not just uncongested travel time. In the next section, we estimate the portion of travel time that is subject to congestion, or delay.

4.2.4 Total person-hours of delay (parameter PHTd).

I define person-hours of delay as the difference between the actual total person hours of travel, calculated above, and the total person hours of travel that would have obtained if all traffic flowed at the free-flow speed all of the time, but person-miles of travel remained the same. The free-flow speed is assumed to be the lowest speed at which an additional vehicle does not reduce the average speed. Thus, in each of the travel categories of Table 4-1 (private vehicles for personal purposes, etc.):

$$PHTd = PHT - \frac{PMT}{Snd} \qquad \textbf{[4-3]}$$

where:

PHTd = person-hours of travel delay

PHT = total person-hours of travel (Table 4-1)

PMT = total person-miles of travel (Table 4-1)

Snd = what the overall average speed in the travel category would have been, over all miles of travel, had there been no delay (mph) (discussed below)

Snd is derived as follows. First we have this relation for the overall actual average speed:

$$Sa = \frac{Snd^*}{R} \cdot Fd + (1 - Fd) \cdot Snd^\wedge \qquad \textbf{[4-3a]}$$

where (all variables are for 1990):

Sa = the actual average speed over all miles of travel (mph) (Table 4-1)
Snd*/R = the average speed over miles subject to delay (mph)
Snd^ = the average speed over miles that were not subject to delay (mph)
Snd* = what the average speed over miles subject to delay would have been had the miles not been subject to delay (mph)
R = over miles subject to delay, the ratio of average free-flow speed had there been no delay to the average speed given the actual delay (discussed below)
Fd = the ratio of vehicle-hours of travel subject to delay to total vehicle hours of travel (discussed below)

Note that R and Snd* pertain only to miles actually subject to delay in 1990, whereas Snd^ pertains only to miles not subject to delay in 1990, and Snd – the parameter of ultimate interest, which is shown in eq. 4-3 but not eq. 4-3a -- pertains to all miles. In order to get an expression for Snd, we must assume that Snd* = Snd^; i.e., that the average free-flow speed in the formerly congested conditions would be the same as the average free-flow speed in the originally uncongested conditions. This means that Snd* and Snd^ = Snd. Then we have:

$$\frac{Snd}{R} \cdot Fd + (1 - Fd) \cdot Snd = Sa$$

$$Snd = \frac{Sa}{\frac{Fd}{R} + (1 - Fd)} \qquad \textbf{eq. [4-3b]}$$

With this expression, we need to estimate the parameters Fd and R in order to calculate Snd. In the following sections we discuss our estimates of Fd and R.

The ratio of vehicle-hours of travel subject to delay to total vehicle hours of travel, in 1990, in each travel category (Fd). Our estimate of person-hours of delay is a function of three overall travel parameters estimated more or less on the basis of actual data – person-miles of travel (PMT), average speed (Sa) and person-hours of travel (PHT) – and of two parameters pertaining specifically to delay – the fraction of total travel time subject to any delay (Fd) and the ratio of average free-flow speed to actual average speed over miles subject to delay (R). The delay parameters, *Fd* and *R*, must be estimated in a mutually consistent manner: the denominator of *R*, the average speed given the actual delay, must be the average speed that corresponds with the numerator of *Fd*, the vehicle hours of travel subject to delay. For example, if we include in the numerator of *Fd* moments when traffic is slowed down by just a mph or two, then the average speed given the actual delay (the denominator of *R*) will be higher, and the value of *R* lower, than if we ignore such trivial slowdowns. We estimate *Fd* and *R* with this consistency requirement in mind.

Simple rough calculations and the best available data sources indicate that the value of *Fd* is in the range of 0.10 to 0.40. The rough calculation is as follows: Assuming that 65% of peak-period travel and 20% of off-peak travel is subject to some delay, and that 35% of total travel time occurs in the peak period, then 0.65 x 0.35 + 0.20 x 0.65 = 35% of total travel time is subject to delay.

The available data are as follows:

i). Lindley (1987) performed a detailed analysis of the Highway Performance Monitoring System Database (HPMS) and estimated that in 1984, freeways in urban areas of 50,000 or more persons had 1.25 billion vehicle hours of delay. The total freeway travel in these areas was 277 billion vehicle-miles, which, at, say, 40-50 mph on average, corresponded to 5.5 to 7 billion vehicle hours of total travel.

Lindley (1987) assumed that congestion began when traffic volume (V) was 77% of capacity (C). According to Lindley, a V/C ratio of 0.77 corresponds to a "service" level between C and D on the highway performance severity scale. At level of service (LOS) C, speeds are "at or near" free-flow speeds (Federal Highway Administration [FHWA], 1996). At LOS D, "speeds begin to decline slightly with increasing flows" (FHWA, 1996). (The FHWA [1996] assumes that congestion begins at V/C = 0.80, which corresponds to LOS D.) However, Lindley assumed that the average free-flow speed was 55 mph, which probably is a bit too low. If he had assumed a higher free-flow speed, he would have estimated more vehicle-hours of delay.

With these considerations, Lindley's analysis implies that vehicle-hours of delay, at least on urban freeways, were 15% to 30% of total vehicle hours of travel[8]. Now, on the one hand, the ratio of vehicle hours of delay to total vehicle hours of travel is likely to be smaller for rural freeways and for minor arterials, collectors and local roads than for urban freeways (see FHWA [1991a], item iii here). On the other hand, the ratio of vehicle hours subject to any delay to total vehicle hours (the parameter Fd, which we are interested in) is higher than the ratio of vehicle-hours of delay to vehicle hours. Thus, the Lindley data suggest that Fd is in the range of 0.15 to 0.30.

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[8] By contrast, Turner (1992?) reports that the Texas Transportation Institute (TTI) estimated 2.9 billion vehicle-hours of delay on freeways, and 1.3 billion on principal arterials, in 10 urban areas, apparently around 1987 or 1988. Nine of the 10 urban areas are included in Lindley's (1987) study; in all nine of these urban areas, the TTI estimates 3 to 5 times more vehicle hours of delay than did Lindley. Moreover, the congestion severity index, which is the ratio of vehicle-hours of delay to million vehicle-miles of travel, is at least 5 times higher in the TTI study than in Lindley's study.

However, the most likely explanation of this difference is either that I have misread Turner's report, or that Turner's estimates are too high. In support of this, I note that the most recent TTI report on congestion (Schrank and Lomax, 2003) estimates about 0.7 billion hours of delay on freeways and "major streets" in 75 urban areas in the U. S. in 1982 and roughly 1.2 billion in 1986, numbers reasonably consistent with Lindley's (1987) estimate of 1.25 billion vehicle-hours of delays on freeways in urban areas with a population of 50,000 or more, in 1984.

ii). Repetto et al. (1992) also performed an original analysis of data from the HPMS, and estimated that in 1989, the "most congested" VMT was about 40% of total VMT on urban roads.

iii). The FHWA (1991a) reports the number of miles of each type of roadway subject to various levels of congestion during the peak period, as estimated from the HPMS. In 1990, 45% of all urban interstate mileage, 33% of all other freeway mileage, 29% of principal arterial mileage, 17% of minor arterial mileage, and 8% of collector mileage was subject to delay (V/C >0.79) during the peak period. The bulk of this congestion was at V/C >0.95. This indicates that during the peak period, a substantial fraction of the roads in urban areas are severely congested. The FHWA (1991a) data also show that in rural areas in 1990, 8% of interstate mileage, and virtually none of the mileage of other road types, was subject to congestion. However, because these data refer to highway mileage (not VMT) congested during the peak period (not during all periods, on average), it is difficult to infer the ratio of vehicle hours of delay to total vehicle hours of travel.

iv). The Texas Transportation Institute (TTI) (Schrank and Lomax, 2003) estimates that in 75 urban areas of the U. S. in 1990, 26% of person-miles of daily travel (not just peak-period travel) on freeways and major roads was subject to some congestion. (The figure for 2002 was 34%.) If the average speed during uncongested conditions was 1.5 to 2.0 times the average speed during congested conditions, then the ratio of travel time subject to some delay to total travel time – our parameter Fd – was about 35% to 40% in 1990 (about 45% to 50% in 2002). If rural areas and minor roads were included, the percentages would be lower.

v). The Texas Transportation Institute (TTI) (Schrank and Lomax, 2003) also estimates what it calls a "Travel Time Index"(TRAVIX), which is the ratio of actual travel time in the peak period to what travel time would have been in the peak period were conditions free flowing:

$$TRAVIX = \frac{PHTp}{PHTp - PHTd,p}$$

where:

PHTp = person-hours of travel in the peak period
PHTd,p = person-hours of travel delay in the peak period

By manipulation of equations 4-3 and 4-3b it can be shown that person hours of delay and person hours of travel subject to delay are related as follows:

$$PHTd = \left(1 - \frac{1}{R}\right) \cdot PHTsd$$

where R is the speed ratio parameter defined for eq. 4-3a. Hence:

$$TRAVIX = \frac{PHTp}{PHTp - \left(1 - \frac{1}{Rp}\right) \cdot PHTsd,p}$$

where:

PHTsd,p = person-hours of travel subject to any delay in the peak period
Rp = the parameter R (eq. 4-3a) estimated for peak-period travel instead of for all travel

With this TRAVIX measure and some additional assumptions, we can derive a formal estimate of our parameter Fd.

In our analysis Fd is the ratio of total vehicle (or person) hours of travel subject to delay (which is not the same as vehicle-hours or person-hours of delay) under all conditions (not just peak period) to total vehicle- (or person-) hours of travel under all conditions. Thus we set up:

$$Fd \equiv \frac{PHTsd}{PHT} = \frac{PHTsd,p + PHTsd,np}{PHTp + PHTnp}$$

where:

PHTsd = total person-hours of travel subject to delay (peak and non-peak periods)
PHT = person-hours of travel (peak and non-peak periods)
PHTsd,p = person-hours of travel subject to delay in the peak period
PHTp = person-hours of travel in the peak period
PHTsd,np = person-hours of travel subject to delay in the non-peak period
PHTnp = person-hours of travel in the non-peak period

Let us assume that the hours subject to delay in the non-peak period is some fraction *DFnp* of the hours subject to delay in the peak period, and that the total travel time in the non-peak period is some fraction *TFnp* of the total travel time in the peak period. Then we have:

$$Fd = \frac{PHTsd,p \cdot (1 + DFnp)}{PHTp \cdot (1 + TFnp)}$$

Now, the expression for TRAVIX can be re-arranged to produce:

$$TRAVIX = \frac{PHTp}{PHTp - \left(1 - \frac{1}{Rp}\right) \cdot PHTsd,p}$$

$$\frac{\left(1 - \frac{1}{Rp}\right) \cdot PHTsd,p}{PHTp} = \frac{\left(1 - \frac{1}{Rp}\right) \cdot PHTsd,p}{\left(PHTp - \left(1 - \frac{1}{Rp}\right) \cdot PHTsd,p\right) \cdot TRAVIX} = \frac{TRAVIX - 1}{TRAVIX}$$

Thus, the parameter of interest, Fd, can be expressed as:

$$Fd = \frac{(TRAVIX - 1) \cdot (1 + DFnp)}{TRAVIX \cdot \left(1 - \frac{1}{Rp}\right) \cdot (1 + TFnp)}$$

We need values for TRAVIX, DFnp, TFnp, and Rp. Schrank and Lomax (2003) estimate that TRAVIX for freeways and "major streets" in 75 urban areas of the U. S was 1.29 in 1990 and 1.39 in 2001. We can bracket their estimates with a a range of 1.25 to 1.35 for 1991/91 and 1.35 to 1.45 for 2002. To estimate *DFnp* (nonpeak-delay/peak-delay), we use data from TTI (2004) showing the TRAVIX measure for the midday period versus the two peak periods. To estimate *TFnp* (nonpeak travel time/peak travel time), we note that in the TTI analyses (Schrank and Lomax, 2003), the peak period is defined to be the six hours from 6-9 am and 4-7 pm, and that these periods undoubtedly have a disproportionate share of daily (24-hour-period) travel. Regarding Rp, the ratio of average free-flow speed in the peak period to actual speed in the peak period, for miles subject to delay, we note that it is likely to be higher than what we estimate for R. With these considerations, we make the following assumptions, which we then combine with our assumptions for TRAVIX to calculate *Fd*. :

	1990		2002	
	low	*high*	*low*	*high*
TRAVIX	1.25	1.35	1.35	1.45
DFnp	0.25	0.35	0.30	0.40
TFnp	2.50	2.00	2.50	2.00
Rp	2.2	1.6	2.4	1.7
calculated Fd	**0.13**	**0.31**	**0.17**	**0.35**

Thus, the Schrank and Lomax (2003) estimates of TRAVIX suggest that the parameter Fd is between 0.10 and 0.35, for peak and non-peak travel on freeways and major roads in urban areas. If rural areas and minor roads were included, Fd would be lower.

However, our classification requires estimating Fd for different travel categories (see Table 4-1). In this respect, I make a few further observations. First, it is likely that most bus passengers spend a relatively high fraction of the time in congested conditions. Second most people traveling long distances probably spend a relatively small fraction of the time in congestion. Finally, the high average speed of private LDAs used for business suggests that these too spend a relatively small fraction of their time in congestion.

With these considerations, I have made the assumptions shown in Table 4-1.

The ratio of average free-flow speed without delay to average speed with delay (R).

In its annual Urban Mobility Study, the Texas Transportation Institute (TTI) estimates the following ratios of free-flow speed to delay speed (available on TTI's web site, http://tti.tamu.edu):

	free-flow	moderate congestion	heavy congestion	severe congestion
freeway speed (kph)	97	61	53	48
arterial speed (kph)	56	45	40	37
freeway ratio	1.00	1.59	1.83	2.02
arterial ratio	1.00	1.24	1.40	1.51

Other papers by TTI researchers suggest similar ratios. For example, Turner et al. (1996) suggest the following "default" values to represent free-flow travel conditions:

- freeways and expressways: 90 to 100 kph
- Class I arterials: 50 to 55 kph
- Class II arterials: 30 to 40 kph

Turner et al. (1996) also present functions that predict average peak-hour speed as a function of the average daily traffic per lane, and the number of access points per mile (in the case of freeways) or the number of signals per mile (in the case of arterials) The results of these functions, compared with the default free-flow speeds above, suggest free-flow/delay speed ratios of less than 2.0.

Finally, in the analysis discussed above, Lindley (1987) assumed that badly congested traffic moved at 20 mph (at V/C > 1.00, and LOS F), and uncongested traffic at 55 mph, giving a ratio of 2.75. However, it appears that most of the estimated vehicle delay hours occur at less than LOS F. Meyer (1994) reports that Cottrell calculated that the miles of travel at V/C > 1.00 (LOS F) was about 1-2% of total VMT on freeways and other principal arterials in 1990. Given that the ratio of all delayed miles to total miles of travel is at least 20%, Cottrell's analysis indicates that much of the measured congestion is occurring between LOS D ("the level at which speeds begin to decline slightly with increasing flow" [FHWA, 1996]; V/C = 0.80) and LOS F ("breakdowns in vehicular flow" [FWHA, 1996]; V/C >1.00). Thus, under "average" congestion, vehicles travel faster than the 20 mph assumed by Lindley, and the ratio of free-flow to average delay speed is 2.00 or less.

On the basis of these studies, I assume that the ratio of average free-flow speed to average speed during delay, on all types of roads, is 1.50 to 2.00 (Table 4-1).

Comparing our estimates of person-hours of delay with the estimates of others. Our estimate of total national person-hours of delay, shown in Table 4-1, can be compared with the detailed estimates of vehicle-miles of delay by the Texas Transportation Institute (TTI) , as part of its Urban Mobility Study. TTI estimates approximately 4 billion hours of vehicle delay in urbanized areas (see "Urban Mobility Study" under http://tti.tamu.edu). This corresponds to about 5-6 billion hours of *person* delay nationally, which is my lower-bound estimate.

4.2.5 The opportunity cost of travel time (parameter Fnm,dr).

The parameter Fnm,dr, the fraction of travel time that displaces nonmonetary rather than monetary activities, might be called an "opportunity-cost parameter." In general, we may distinguish travel time in motor vehicles with respect to three different kinds of opportunity costs:

i) Time spent productively in the car, doing what one would do anyway if all travel time could be reduced to zero (call this parameter Fo). This time has no opportunity cost.

ii) Time at the expense of unpaid (nonmonetary) activities (parameter Fnm). The value of these foregone nonmonetary activities must be estimated by indirect methods. This is discussed below

iii) Time at the expense of paid (monetary) activities (Fm; the monetary analog of the parameter Fnm). The value of these paid activities can be represented by the full compensation rate (the parameter Cm), which is estimated in Report #5.

All travel time falls into one of these three categories, so that the fraction of travel time that displaces nothing (cost C = 0), plus the fraction of travel time that displaces non-monetary activities (at cost/hour Cnm), plus the fraction of travel time that displaces monetary activities (at cost/hour Cm) -- is equal to one:

$$Fo + Fnm,dr + Fm,dr = 1.0$$

Because time spent productively in the car has zero opportunity cost, I need explicitly estimate only the fraction of time at the expense of unpaid or nonmonetary activity (Fnm) and the fraction of time at the expense of paid or monetary activity (Fm). Hence, Table 4-1 shows Fm and Fnm but not Fo. (Of course, Fo can be calculated as Fo = 1–Fnm,dr–Fm,dr.)

In the following, I estimate Fnm and Fm for the different travel categories. Except as noted, the estimates pertain to drivers.

Private vehicles, for personal purposes. This travel category is defined to exclude travel for business purposes, such as the "work-related" purpose of the NPTS (see above). It therefore is reasonable to assume essentially all travel in this category displaces unpaid rather than paid activities, and hence that Fm,dr = 0.0. However, not all personal travel will displace unpaid activities; for example, driving for pleasure is an activity in itself, and displaces nothing. I assume that Fnm,dr = 0.95 to 0.98, and that Fo therefore = 0.02 to 0.05.

Private LDAs and LDTs without paid drivers, used for business purposes, and government civilian vehicles I assume that travel in private vehicles for business vehicles usually, although not necessarily always, displaces productive work, and hence that for this category, Fm,dr is relatively large, and Fnm,dr relatively small.

Although Fm,dr in this category usually is large, in general it probably is not equal to 1.0. It would be equal to 1.0 only if business and government workers did nothing productive while in the car, and would have worked at full productivity were they not in the car. However, neither of these conditions are likely to obtain. In the first place, it appears that more and more travelers are using car phones, tapes, and other communication and information technologies in order to be productive while in transit. To the extent that a business traveler is able to work or even just think productively while in transit, the opportunity or productivity cost of the travel time is zero.

In the second place, business travel might be tantamount to overtime work, which means that if that travel were eliminated the traveler might spend *some* of the saved time at home or at play, not at work. In this case, some of the cost of business travel is leisure time, which generally is much less valuable than is fully compensated work.

So what, then, is the value of Fm,dr? It is not much help to approach the problem by estimating the extent to which business travel is "overtime," because one cannot presume that overtime travel displaces leisure time: it well might displace additional productive overtime work. With little more to go on than my judgment, I assume that for these travel categories, Fm,dr is between 0.65 and 0.75, and Fnm,dr is between 0.15 and 0.20. I assume that the remaining fraction of the travel time is used productively, at zero cost (Fo = 0.05 to 0.20).

Private LDTs with paid drivers, private HDTs with paid drivers, bus drivers, and military vehicles. Because truck drivers and bus drivers are paid to drive -- to produce "driving" -- one reasonably can assume that the drivers would be doing something else productive were they not driving. Driving *is* their job; if they were not doing that work, they would be doing other work, not playing. Consequently, it is reasonable to assume that truck driving and bus driving displaces other paid work entirely, and hence that for these categories, the parameter Fm,dr = 1.0, and Fnm,dr = 0.0 and Fo = 0.0.

I assume that military vehicles in effect have paid drivers.

Intercity and transit buses (passengers). I assume that most travel in intercity and transit buses is for "personal" reasons (note that the journey to work is a "personal" purpose), and hence liable to displace unpaid activities, and that only a relatively small fraction of is for "business" purposes and hence liable to displace paid activities (Fm = 0.10 to 0.15, and Fnm = 0.75 to 0.80, for passengers). The remaining travel time (Fo = 0.15 to 0.05) either is used productively while on the bus, or else is an end in itself.

School buses (passengers). I assume that no travel in school buses displaces paid activity. I would guess that about half of the time on a bus, school children are doing things -- socializing, studying, sleeping -- that they would do even if the bus travel time were reduced to zero. Hence, I assume that Fm = 0.0, Fnm = 0.50, and Fo = 0.50, for school-bus passengers.

Police vehicles. Only a portion of the time that police spend in their cars actually displaces other activity. If an officer is driving solely to get from point A to point B, and would do something else were zero-time transportation available, then all of the travel time has an opportunity cost. However, if an officer is driving to *patrol*, and not to get somewhere, and would spend the same amount of time doing the same patrol activity even if zero-time, zero-cost transportation were available, then nothing is foregone, and the travel-time cost is zero.

I assume that half of the time in police cars is patrol time, which has little or no opportunity cost. The other half -- the time spent actually traveling -- presumably displaces *other* police activities. I assume that these displaced police activities are paid. Thus, I assume that in this category, the parameter Fm,dr = 0.50, Fnm,dr = 0.0, and Fo = 0.50.

Adjustment for passengers. The foregoing estimates of Fm and Fnm are meant to apply to drivers, except as noted for buses. Because passengers can sleep, read, and do other things that drivers cannot, they forego less activity, uncompensated as well as compensated, than do drivers. Thus, it is reasonable to assume that for passengers, Fm and Fnm will be lower, and Fo higher, than for drivers. Statements in Hensher and Goodwin (2004) lend support to this: they report that studies of the value of travel time for passengers – as indicated by choices made by *drivers* – suggest that the drivers discount passenger travel-time values relative to their own (the drivers') values. With these considerations, I assume that Fm and Fnm for passengers in cars and trucks are 75% to 90% of the values for drivers.

4.2.6 The cost of foregone nonmonetary (unpaid) activities (parameter Cnm,ref)

The hourly cost of nonmonetary activities foregone during travel depends on the income of the traveler, and the purpose of the trip. The hedonic cost of travel (Ch) depends further on the mode of transportation. Because of this, we have analyzed the raw data of the NPTS in order to differentiate travel time by nine income classes, four trip purposes, and five modes.

Income classes ($/year)

- < 10,000
- 10,000 - 19,999
- 20,000 - 29,999
- 30,000 - 39,999
- 40,000 - 49,999
- 50,000 - 59,999
- 60,000 - 79,999
- > 79,999
- not ascertained

It is important to differentiate travel by income class because the value of foregone nonmonetary activities usually is presumed to be related to income, and because as households get wealthier, they take more and longer trips (*Nationwide Personal Transportation Survey:* Pisarski, 1992; Hu and Young, 1993a; Vincent et al., 1994). For example, households with incomes above $40,000/year make slightly longer trips than do households with $30,000 to $39,999 yearly incomes, and at least 50% longer trips than do households with incomes below $10,000 per year. In urban areas, average weekday vehicle trips per household increases steadily from 2.09/day for households with an annual income of less than $5,000 to 7.01/day for households with an annual income of $45,000 to $49,000, and remains at about 7/day for all higher income groups (Vincent et al., 1994). (The length of work trips and of social and recreational trips is more strongly related to household income than is the length of personal-business and educational and religious trips.) As a result, an estimate of the travel-time cost based only on overall average income and all travel time by all travelers may underestimate the true total cost.

Trip purposes.

- Travel to or from work
- Work-related business
- Shopping, school, church, doctor, dentist, other family or personal business
- Visit friends or relatives, pleasure drive, vacation, other social or recreational trips

It is important to differentiate by trip purpose because the cost of the travel time can depend on the purpose of the trip (Hensher, 1997). For example, the time cost of a sightseeing trip probably is different from the cost of a commute trip.

Travel modes.

• Auto, station wagon, passenger van, cargo van, pickup truck (with or without camper), other truck, motorcycle, moped/motorized bicycle, taxi
• Bus
• Amtrak or commuter train
• Streetcar, trolley, elevated rail, or subway
• Bicycle or walk

As mentioned above, it is important to differentiate by travel mode because the hedonic cost of travel depends to some extent on the mode.

Table 4-2 shows the results of our analysis of the NPTS data tapes[9]. In the following, I first estimate hourly time costs for different income classes. Then, I will estimate an average hourly cost of time for each of the vehicle-travel categories above by weighting the time cost by income category by the amount of travel by each income group, for the particular vehicle-travel category.

Travel-time cost as a function of income. Studies of the value of travel time abound. I offer but a brief review of a few of those that related the cost of travel time to income.

Analysts often assume that the value of travel time is a fixed fraction of income, regardless of income. For example, Miller (1989) reviews several studies of the value of time, and concludes that it lies between 60% and 80% of an hour of pay. In earlier work, Miller et al. (1985) recommended a value of 55%, with sensitivity analysis of 30% and 80%. Barnes (1995) states that values in the literature center around 50% of the wage rate.

However, Hensher (1997) and Calfee and Winston (1998) have estimated somewhat lower percentages. Hensher (1997) designed a route choice experiment in Australia, in which drivers were given a survey asking them to choose, hypothetically, between a tolled route with a certain travel time and an un-tolled (free) route with a longer travel time. The amount of the toll and the travel times were varied. Respondents were asked to report their income and trip purpose. On the basis of the toll paid and the travel time saved, Hensher estimated the following travel-time values, as a fraction of the gross income of the traveler, for five different trip purposes[10]:

trip	*low*	*high*	*mean*
commute in personal vehicle	0.13	0.61	0.22

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[9]As discussed elsewhere, we also analyzed the NPTS data to estimate total person-miles of travel, for the same trips and modes and income classes (Table 4-3). Then, we calculated average travel speeds by income class, mode, and trip purpose, by dividing person miles by person hours (Table 4-4). Appendix A to this report compares the results of our analysis of the NPTS data with other similar analyses of the NPTS data.

[10]See also the earlier, similar survey by Hensher et al. (1990).

commute in company vehicle	0.14	0.71	0.27
travel as part of work	0.10	0.71	0.20
social-recreation	0.26	0.42	0.31
other personal business	0.22	1.07	0.44

The time value of travel as a part of work is surprisingly low here. Hensher (1997) speculates that they may have captured a large fraction of travel outside of normal working hours, and suggests that in any case, it is better to estimate the time value of travel as part of a work on the basis of marginal productivity, rather than on the basis of personal utility. (This is just what I do in Report #5, in which I estimate the value of paid activities foregone while traveling.)

Calfee and Winston (1998) used a stated preference survey to estimate the value that long-distance auto commuters who face some congestion were willing to pay to use toll roads to reduce travel time. They found that commuters' value of congested travel time was about 20% of the hourly wage rate – similar to the findings of Hensher (1997) cited immediately above. Calfee and Winston (1998) believe that the most likely reason for this relatively low value is that commuters who had a high value of travel time were not in their sample because those commuters had already chosen where to live and work so as to reduce time spent commuting and traveling in congestion (p. 95).They also note that some commuters "may have equipped their car with features, such a phone, that make their commute in congested traffic less onerous" (p. 96)[11].

More recently, Hensher (2001b) reports the results of stated-preference experiments in New Zealand in which the value of free-flow commute travel time ranged from 40-60% of the wage rate, depending on model specification. In most cases the value was around 50% of the wage rate. However, the value of slowed time was somewhat higher, and the value of start/top time was generally equal to or greater than the wage rate.

Brownstone et al. (2003) used revealed preference data from a congestion pricing demonstration project in San Diego, California, to estimate the willingness to pay to travel in a special toll lane and thereby reduce congested travel time. They estimate that the median value of travel time for respondents willing to pay for the toll lane was 88% of the imputed wage rate, which at first blush seems relatively high. However, Brownstone et al. (2003) note that this high percentage is readily explained by several factors: i) drivers were paying to avoid highly congested travel time, which is more unpleasant (costly) than is "average" or uncongested travel time (Brownstone et al. [2003] cite studies that indicate that value of travel time under congested conditions is about 30% higher than is the value under uncongested conditions); ii) because many drivers felt that the toll lanes were safer, they may have been willing to pay a safety premium for using them; and iii) drivers may have viewed the toll lane as an exclusive

[11] However, Brownstone and Small (2005), commenting on the work of Calfee and Winston (1998), argue that stated-preference surveys (as distinguished from revealed-preference surveys) might systematically underestimate the true willingness-to-pay for travel-time savings.

club worth paying extra for. If the premia for the safety and exclusivity benefits of the toll lane could be removed, and if the estimates could be adjusted to reflect the value of travel time in "average" rather than congested conditions, it is possible that the resultant value of pure travel time would be around 50% of the wage rage.

On the basis of this evidence, one might assume that the value of travel time is up to 50% of the wage rate. However, it is likely that the value of travel time is nonlinearly related to income, such that the value of time as a fraction of income depends on income. If this is correct, the question then becomes: does travel-time cost as a fraction of income increase or decrease with increasing income?Theory does not provide a clear answer (Hensher and Goodwin, 2003), and there is evidence both ways, but on balance it seem most likely that travel cost as a fraction of income decreases with increasing income.

First we consider the evidence that the travel-cost fraction increases with increasing income. Anderson and Mohring (1997), Barnes (1995), and Mohring et al. (1987) cite Lisco's 1968 findings that the value of journey-to-work time increases linearly from zero, for those with zero income, to 50% of the hourly wage, for those who earn about $35,000 year, and remains at 50% of the hourly wage for those with incomes above $35,000 (ca. 1995 dollars). Barnes (1995) says that his re-analysis of the Mohring et al. (1987) data on bus riders in Singapore suggests that Lisco's results are correct[12]. And Anderson and Mohring (1997) cite another study in which the value of travel time ranged from 31% of the hourly wage for the lowest income group to 55% for the highest.

However, according to Haight (1994), a large research project in the United Kingdom found that "although value of time increases with income, the trend is not linear...When income groups were compared, a threefold difference in income led to a difference of only 40 per cent in value of time" (p. 18). He also cites the following results from the study, presumably in 1985 dollars.

urban bus	$1.62/hour
long-distance bus or train	$3.67/hour
long-distance car	$3.78/hour
commuters	$3.24/hour
leisure	$4.86/hour

Barnes (1995) cites the same study as evidence counter to findings of Lisco. The stated preference study of Calfee and Winston (1998), mentioned here above, found that the absolute value of travel time ($/hr) rose with income, but that the ratio of travel-time value to income declined with rising income.

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[12]The Singapore data indicate that the cost of *waiting* time as a fraction of income increases with income, for Singapore bus riders: Mohring et al. (1987) estimate that the value of time spent waiting for the bus increases from about 60% of the wage rate for the bottom income decile to 120% for the top income decile.

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Most recently, Hensher and Goodwin (2004) review studies of the relationship between changes in income and changes in the value of travel time, and conclude that the evidence indicates that the rate of increase in the value of travel time is 50% to 75% of the rate of increase of income.

I believe that the findings of Henshser and Goodwin (2004), Calfee and Winston (1998), Hensher (1997), and of the UK research project (as reported by Haight, 1994), are more pertinent: the findings of Lisco are old, and the findings for bus riders in Singapore (Mohring et al., 1987) may not apply to car drivers in the U. S. For these reasons, I will assume that the travel time as a fraction of income declines with increasing income, and that the fractions themselves are relatively low (as estimated by Hensher [1997] and Calfee and Winston [1998]). (Of course, the absolute value of travel time should increase with increasing income.) Formally, I assume that the cost of unpaid or non-monetary travel time can be estimated as gross income multiplied by a constant fraction plus an income-dependent fraction:

$$Cnm,ref_{m,p,i} = \left(K_{m,p} + I_i^{-a}\right) I_i \qquad \textbf{[4-4]}$$

where:

$Cnm,ref_{m,p,i}$ = the cost of unpaid travel time by mode m for purpose p by people of household income class i ($/hr), at the reference speed Sref of equation 4-1

a = exponent that determines the income-dependent fraction; values of 0.60 (low case) to 0.30 (high case), combined with the values assumed for the constant K (below), give results consistent with those of the studies cited above

$K_{m,p}$ = constant income fraction, dependent on the trip purpose and mode; assumed values as follows:

	mode m = PV		mode m = bus	
purpose p =	*low*	*high*	*low*	*high*
To and from work	0.10	0.05	0.10	0.05
Work-related business	0.15	0.10	0.15	0.10
Shopping, school, etc.	0.15	0.10	0.15	0.10
Visit friends, pleasure, vacation, etc.	0.15	0.10	0.15	0.10

I_i = hourly income class i, equal to annual household income divided by 2024 work-hours per year[13]; for the nine income classes above, I make the following assumptions:

[13] This assumes in effect assumes that there is the equivalent of one full-time worker per household.

annual	*< 10*	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*
hourly	3.71	7.91	12.60	17.29	21.99	26.68	33.60	46.94	13.59

subscript m = travel mode (private vehicle [PV] or bus)
subscript p = trip purpose (4 purposes; see below)
subscript i = income class (9 classes; see below)

I specified the income in the category "n.a." (respondent refused to give income, or didn't know) by comparing the travel statistics (distribution of travel time across modes and purposes, and average speeds across modes and purposes) of the "n.a." persons with the statistics of the persons who reported their income. This comparison revealed that the "n.a." persons were similar to the persons in the $20,000 to $30,000 and the $30,000 to $40,000 categories.

Note that I estimate the cost of travel time as a function of speed. This dependence of the opportunity cost on average speed, as represented in equation 4-1, is discussed section 4.2.8.

Finally, note that although Table 4-1 shows estimates of the value of foregone paid (monetary) work (the parameter Cm), those estimates are derived in Report #5, not here, because they pertain to monetary rather than non-monetary costs.

The cost of nonmonetary travel time for trips in private vehicles for personal purposes (daily travel). Given the estimates of $Cu_{m,p,i}$ from equation 4-4, the overall average cost of unpaid time in this category is calculated as:

$$Cnm,ref_{PPV} = \frac{\sum_p \sum_i PHTh_{p,i} \times Cnm,ref_{m=PV,p,i}}{\sum_p \sum_i PHTh_{m=PV,p,i}} \qquad \textbf{[4-5]}$$

where:

i = nine income classes above
p = trip purposes "to and from work," "shopping, school, etc.," and "visit friends, pleasure, vacation, etc." (we treat the purpose "work-related business" separately, below)
m (the mode parameter) = values for "PV", in equation 4-4
Cnm,ref_{PPV} = the average cost of nonmonetary daily travel time in private vehicles for personal purposes, at the reference speed Sref ($/hour; shown in Table 4-1)
$Cnm,ref_{m=PV,p,i}$ = $Cnm,ref_{m,p,i}$ for mode m = PV, equation 4-4
$PHTh_{m=PV,p,i}$ = person-hours of travel in personal household cars for personal purpose p, by persons in income class i (data for mode m= PV in Table 4-2)
(Note that the denominator here is equal to Sum3 of Table 4-2)

The hourly cost of nonmonetary travel time in private vehicles for personal purposes (long trips). This is calculated with equations 4 and 5, except that the data for only one trip purpose, "visit friends, pleasure, vacation, etc.," are used. The results are shown in Table 4-1.

The hourly cost of nonmonetary travel time in private LDAs and LDTs, without paid drivers, used for business purposes. This is calculated with equations 4-4 and 4-5, except that the data for only one trip purpose, "work-related business," are used. The results are shown in Table 4-1.

The cost of nonmonetary travel time in intercity and transit buses. The hourly cost of travel time in buses is calculated with equations 4-4 and 4-5, except that in equation 4-4 the mode data are for "bus" (m = bus) rather than for "PV," and all four trip purposes p are included. The results are shown in Table 4-1.

The cost of nonmonetary travel time in school buses. I assume that displaced nonmonetary activities are worth very little to young school children. For a few especially busy high school students, displaced nonmonetary activities could be worth as much as $2 or $3/hour. On average, nonmonetary activities foregone on account of travel on school buses might be worth on the order of $0.50 to $0.75/hour.

The cost of nonmonetary travel time in government vehicles. I estimate the cost of nonmonetary travel time in government vehicles on the assumption that the ratio of the unpaid (non-monetary) time cost to the paid (monetary) time cost for travel in government vehicles equals the same ratio for travel in private LDAs used for business purposes (data in Table 4-1; monetary time costs are discussed in Report #5). This assumption is consistent with, and indeed required by, our assumption that the nonmonetary time cost is a function of the wage rate.

4.2.7 The hedonic cost of travel time (parameter Ch,dr,ref)

The pleasantness or unpleasantness of driving or being in a car, as an experience in itself, is a benefit or cost of motoring *apart* from the value of any activities foregone while in the car. For example, one might be able to conduct business over a car phone, but find it stressful and unpleasant because of the noise and distractions of motoring. In this case, the motoring experience itself has a cost, even though no productive activities are foregone. (Put another way, one would be willing to pay something to be able to conduct the same business in a more pleasant environment.) On the other hand, one might enjoy the privacy and freedom of being in a car, and value motoring positively as a sort of leisure (Redmond and Mokhtarian, 2001; Mokhtarian and Salomon, 2001)

I speculate that most of the time, most but certainly not all people find driving to be more of a chore or a bore than a pleasure (one reasonably may infer this from the work of Redmond and Mokhtarian [2001]). Thus, I assume that *on average* driving is *slightly* unpleasant, and has a pure "disutility" cost, apart from the value of the activities foregone, of (values for drivers, except as noted):

• Private vehicles, for personal purposes -- daily travel -- long trips • Private vehicles, for business purposes -- LDAs, without paid drivers -- LDTs, without paid drivers • Public (government) vehicles -- federal civilian vehicles -- state and local civilian vehicles	$1/hr to $1.50/hr.
• Buses -- intercity and transit buses	*drivers:* $0.00/hr., because in principle their compensation as drivers already includes the hedonic cost of driving *passengers:* $0.50/hr to $0.75/hr. -- less than the cost in private vehicles because nobody has to drive
• Buses -- school buses	*drivers:* $0.00/hr., because in principle their compensation as drivers already includes the hedonic cost of driving *passengers:* $0.00/hr, because the passengers are school children who can play or socialize or read on the bus
• Private vehicles, for business purposes -- LDTs, with paid drivers -- HDTs, with paid drivers • Public (government) vehicles -- state and local police vehicles	$0.00/hr., because in principle their compensation as drivers already includes the hedonic cost of driving (see Report #5)
• Federal military vehicles	$0.00/hr., because I assume that drivers of military vehicles effectively are compensated as drivers

Except as noted in the case of buses, these are costs for drivers, at the reference speed, Sref, in equation 4-1. It is likely that the hedonic cost per hour increases with decreasing speed, if only because driving in low-speed congested conditions usually is more stressful than is cruising on the open road (Brownstone et al., 2003; Hensher, 2001b; Mokhtarian and Salomon, 2001; Calfee and Winston, 1998). This speed dependence is discussed below. It also is likely that the cost for passengers is less than the cost of drivers, because driving is stressful. I assume that the cost for passengers is 75% - 90% of the cost for drivers.

4.2.8 The dependence of Cnm,ref and Ch,dr,ref on speed (parameters Bo, Bh)

In eq. 4-1, the total time cost is a nonlinear function of the speed parameters $\left(\frac{Sref}{Snd}\right)^{Bo}$ and $\left(\frac{Sref}{Snd}\right)^{Bh}$ where *Sref* is a reference speed, *Snd* is the no-delay speed, and *Bo* and *Bh* are exponential parameters. The higher the exponent *Bo* or *Bh* in equation 4-1, the more sensitive is the cost to deviations of the actual average speed *Snd* from the reference speed *Sref*. In the following paragraphs I explain why I have made the cost a function of speed rather than of, say trip length, and then present my assumptions for *Bo* and *Bh*.

In the route choice experiment in Australia mentioned above, Hensher (1997) found that the cost of time per hour declined as travel time increased from 5 to 10 minutes. (This, according to Hensher [1997], is consistent with findings from his own earlier work.) The dependence of hourly cost on travel time was rather strong: for business, commute, and personal-business travel, the cost per hour of a 10-minute trip was half that of a 5-minute trip, which means that the total cost was independent of trip length or time.

I suspect, however, that the total time cost is fixed, and independent of the travel time, only for relatively short travel times, for which the total time cost may be dominated by an initial, fixed, "psychological inertia" (or, to use an analogy from chemistry, a fixed "activation energy"), or for differences in travel time so small as to be perceived to be zero. However, as the time of travel increases, the opportunity and disutility cost of the lost time presumably begins to dominate the "fixed" inertial cost of making the trip. Similarly, as differences in travel time become larger, they presumably become more perceptible. Thus, it is unlikely that the total time cost of a 1-hour trip will be close to the total cost of a 30-minute, which in turn will not be close to the total cost of a 5-minute trip. Rather, it is likely that, over wide ranges of travel time, the cost/hour declines much less sharply with increasing travel than is implied by the Hensher (1997) results for 5 minutes vs. 10 minutes.

However, instead of assuming that the cost/hour declines with increasing trip length, I assume that it declines with increasing average speed. I do this for three reasons: 1) it is easier to estimate average speed than average trip length by vehicle/travel class; 2) a relationship between average speed and the hourly time cost can be made to reflect the additional opportunity cost and pure disutility of driving in congestion, because congestion reduces the average speed; 3) average speed is positively related to trip length anyway.

I assume that there is no threshold below which travel-time cost should be zero[14].

I believe that the hedonic-cost component is much more sensitive to average speed than is the opportunity-cost component, and so assume a much higher value for *Bh* than for *Bo*. A value of 1.5 for *Bh* and 0.15 for *Bo* seem to give reasonable results.

4.3 ACCIDENTAL PAIN, SUFFERING, DEATH, AND LOST NONMARKET PRODUCTIVITY INFLICTED ON ONESELF

4.3.1 Background and overview of method

In 1991, motor vehicle accidents damaged nearly 30 million motor vehicles, injured nearly 6 million people, and killed 42,000 people. This property damage, injury, and death cost society several hundred billion dollars in medical expenses, lost productivity, vehicle repair and replacement, pain and suffering, and other costs. In the entire analysis of the social cost of motor-vehicle use, only travel time is more costly.

In Report #19, I derive expressions for the total cost and the external cost of motor-vehicle accidents as a function of vehicle miles of travel, the rate of accidents, and the cost per accident. I begin with a simple expression that equates the total social cost of accidents to the product of the number of persons injured (or killed), or vehicles damaged, and the social cost per person injured or vehicle damaged. Then, I express the number of accidents as a function of vehicle miles of travel (VMT). The first derivative of this total social-cost function is the marginal social-cost function, which can be used to estimate what I call the potential external cost: the difference between the marginal social cost and the marginal private cost. The marginal nonmonetary private cost is estimated in this report.

With functions that distinguish external from "internal" (private, or personal) costs, and cost data that distinguish monetary from nonmonetary costs, I disaggregate the total accident cost into the four categories of accident costs in this social-cost analysis:

i) *personal (or private) nonmonetary* costs, such as pain and suffering due to injuries from accidents that are not externalities (for example, if a person falls asleep and runs into a tree and injures herself, the pain and suffering from the injury is a personal or private nonmonetary cost)

ii) *private monetary (or priced)* costs, such as the cost of repairing vehicles damaged in accidents that are *not* externalities, or the cost of liability insurance against damages inflicted on others;

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[14]Strand (1993) suggests that it might not make sense to treat 30 one-minute savings the same as one 30-minute saving, because the many small packets might be useless and so in toto amount to nothing. Haight (1994) disagrees.

iii) *external monetary* costs, such as vehicle repair costs inflicted by uninsured motorists; and

iv) *external nonmonetary* costs, such as pain and suffering and lost non-market production inflicted by others and not covered by user payments.

I distinguish external from private costs because the economically efficient policy is to price the externality but do nothing about the privately incurred costs, other than keep people informed of the risks they face (see Report #19 for details). I distinguish monetary from nonmonetary costs because the latter are much more difficult to estimate, and hence considerably more uncertain. Also, I distinguish accidents involving non-motorists, accidents involving single motor vehicles, and accidents involving two or more vehicles.

4.3.2 Condensation of the formal method

In essence, to estimate the personal nonmonetary cost of motor-vehicle accidents, I multiply the number of injuries of various types, and the number of fatalities, and the number of vehicles involved in property-damage-only (PDO) crashes, by the nonmonetary cost per injury or fatality or vehicle, and then by the private-cost fraction of accidents. The method is developed in Report #19. The simplifed formula for personal nonmonetary costs is:

$$PNM = \sum_i NM_i \cdot IO_i \cdot OFF_i \cdot PNCF_i$$

[4-6a, 4-6b]

$$NM_i = \sum_c NM_{i,c} \cdot W_c$$

where:

PNM = total personal nonmonetary cost of motor-vehicle accidents ($)
NM_i = Nonmonetary cost per injury of type i ($/injury or vehicle)
IO_i = number of persons with MAIS injury type i, or the number of fatalities, or the number of vehicles involved in PDO crashes, on public roads (Report #19), where the MAIS injury scale is as follows:

MAIS 0	person uninjured, in an accident in which at least one person is injured or checked for injury
MAIS 1	a minor injury (e.g., 1st-degree burn)
MAIS 2	a moderate injury (e.g., major abrasion)
MAIS 3	a serious injury (e.g., multiple rib fracture)
MAIS 4	a severe injury (e.g., spleen rupture)
MAIS 5	a critical injury (e.g., spinal cord injury)

OFF_i = factor to account for accidents off the road or on private roads, and for non-collision injuries or deaths (e.g., from falling down while getting into car) (Report #19)

$PNCF_i$ = of total MAIS injuries, or fatalities, or property-damage-only (PDO) vehicles, the fraction that is a private nonmonetary cost (Report #19)

$NM_{i,c}$ = the nonmonetary cost type c per accident type i (Report #19)

W_c = the fraction of $NM_{i,c}$ that is not counted elsewhere in the social-cost analysis) (Report #19)

subscript i = the type of accident (a total of 8 types: 6 types of injury-accidents, where injuries are expressed according to the MAIS 0 to MAIS 5 injury scale shown above; fatal accidents; and PDO accidents)

subscript c = the kinds of nonmonetary costs: pain and suffering, and lost nonmarket productivity (household productivity) (Report #19)

Note that equation 4-6 is a condensation of the actual method used, which as mentioned above specifies total cost functions, derives marginal cost functions, and estimates the marginal private cost as the average accident cost. This is done for three different categories of accidents (nonmotorist, single-vehicle, and two-or-more vehicle), as well as for the different accident severity classes

Table 4-6 shows the estimated personal nonmonetary costs of motor-vehicle accidents.

4.4 PERSONAL TIME SPENT WORKING ON MOTOR VEHICLES AND GARAGES, REFUELING, AND BUYING, SELLING, AND DISPOSING OF VEHICLES

4.4.1 The value of personal time spent working on motor vehicles and garages, and refueling motor vehicles

Data from surveys of time use can be used to estimate the amount of time people spend working on motor vehicles and garages and buying fuel. Wiley et al. (1991) surveyed the activity patterns of California residents over the age of 11, during 1987 and 1988, and reported what the respondents did, and where, over the course of a day.

They found that Californians over the age of 11 spent an average of 6.1 minutes per day buying fuel and repairing, cleaning, maintaining, and tuning-up their vehicles. Males aged 55-64 spent the most time in these activities (14 minutes/day), and females aged 12-17 spent the least (1 minute/day). Unemployed persons spent more time at these activities than did employed persons. Californians also spent 19.8 minutes per day working in their yard and painting and fixing up their homes (including their garages). Again, older men spent the most time doing this, and younger women the least, and unemployed people spent more time than employed people.

I assume that 10% of the 19.8 minutes spent on house and yard work was spent working on garages and driveways. Thus, I estimate that people in California spent a total of 6.1 minutes (working on cars and buying fuel[15]) + 0.1*19.8 minutes (working on garages and driveways) = 8 minutes/person/day working on cars and garages or buying fuel. I assume that this includes time spent disposing of motor-vehicles and motor-vehicle parts and equipment and maintenance supplies.

Wiley et al. (1991) also reported the amount of time spent in various locations. In 1987 and 1988, Californians spent 10.1 minutes/person/day in a car-repair shop, gas station, or parking garage, and 9.1 minutes/person/day in a home garage. Unemployed persons spent much more time in home garages than did employed persons, but less time in repair shops, gas stations, and parking garages. One should assign to motor-vehicle use all of the time spent in a car repair shop or parking garage, most but not all of the time in a gas station (some time is spent buying food), and some but not most of the time in a garage (people probably spend most of their time in a garage doing things unrelated to automobile use). This suggests something like 10-15 minutes/person/day related to motor-vehicle use, a figure that is roughly consistent with the 8 minutes/person/day derived from the activity data, above.

On the basis of these findings, I assume that on average every person in California over the age of 11 spends 8 to 11 minutes per day working on cars and garages or refueling vehicles[16]. I assume that people in other states spend about the same amount of time, so that the national average also is 8 to 11 minutes[17].

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[15]I estimate that out of this 6.1 minutes, 1 to 2 minutes per person per day were spent just buying gasoline. In 1990, motorists consumed 131.6 billion gallons of highway fuel (FWHA, 1991a). Assuming 10 gallons per refill, 5 minutes per refill (including paying), and 1.4 persons (over age 11) per car per refueling, we calculate (131.6/10)*5*1.4/365 = 0.252 billion person-minutes per day spent refueling. Given 0.2056 billion people over age 11 in the U.S. in 1990 (Bureau of the Census, *Statistical Abstract of the United States 1992*, 1992), we calculate 1.2 minutes/person/day refueling vehicles. We exclude persons under the age of 12 because the time-diary survey of Wiley et al. (1991) excludes them, and because the time cost for children under 12 presumably is relatively low.

[16]This includes all time spent repairing vehicles -- even time spent repairing vehicles damaged in automobile accidents. Now, the primary sources of data that I use to estimate the cost of motor-vehicle crashes count the cost of personal time spent repairing accidentally damaged vehicles as a household-productivity cost. To avoid double counting the personal time-cost of repair, I have deducted from the crash-cost estimates my estimate here of the cost of personal time spent repairing accidentally damaged vehicles.

What is this time worth? I suspect that it is worth considerably less than average wage rate, in part because older men and unemployed persons do most of the work on cars and garages. (On the other hand, wage earners might do most of the vehicle refueling.) Also, some people might enjoy working on cars and around house[18]. I assume that the time cost is $5 to $8/hour (1991 $) -- somewhat less than the cost of time in cars (Table 4-1), on account of it being more pleasant for some people to work on a car than drive one. Given 0.2056 billion people over age 11 in the U.S. in 1990 (Bureau of the Census, *Statistical Abstract of the United States 1992*, 1992), the total value of time spent working on cars and garages and buying fuel is a substantial $50 to $110 billion per year.

Included in this amount is the cost of time spent repairing vehicles damaged in motor-vehicle accidents. However, as mentioned in Report #19, this particular time cost also is embedded in my estimate of the nonmarket productivity cost motor-vehicle accidents. Therefore, to avoid double counting the cost of time spent repairing vehicles damaged in accidents, I estimate the amount included in my estimate of the nonmarket productivity cost of accidents, and deduct it from the total cost of time spent time spent working on cars and garages and buying fuel, estimated in this section. As explained in Report #19, the amount to be deducted is about 4% of the total nonmarket productivity cost, or about $0.5 billion.

Thus, summarizing the calculation:

	Low	*High*

[17]So far, we have been able to find only these barely relevant data from other states: Walker and Woods (1976) reported that in 1967 and 1968, 1296 husband-wife households in Syracuse, New York spent an average of about 30 minutes per day per household (i.e., 30 minutes total for all those doing household work) on care of the car and the yard. Car care included washing the car at home, taking the car to a car wash, waxing the car, and servicing the car at home, but apparently not servicing the car away from home, or buying gas. Yard care included care of driveways, walkways, lawns, shrubs and trees, flower beds, and vegetable gardens, but not care of the garage. If we assume that there were three working household members per household, then each person spent an average of 10 minutes per day on yard and car care. If the time spent on the motor-vehicle related activities that were not covered (buying gas, repairing the car away from home, and cleaning the garage) was about equal to the time spent on the non-motor-vehicle-related activities that were included (yard work other than work on the driveway), then people in Syracuse spent about 10 minutes per person per day on doing work related to motor vehicles. This rather ad-hoc calculation is consistent with the recent findings in California.

[18]I perhaps could analyze the value of the time spent dealing with motor vehicles in the same way that I analyze the value of compensated travel time in a car: as equal to the value of the activities foregone, plus the value of the pleasantness or unpleasantness of the actual experience (see Report #5 in this social-cost series). However, in the case of time spent working on cars or buying and selling cars, I doubt that one could make a good enough estimate of what is foregone, the value of what is foregone, and the pure hedonic cost of the experience to make the resulting estimate of the total cost of the time more accurate then simply estimating the total cost directly on the basis of one’s judgment.

minutes/day maintenance, buying gas	6.0	6.0
minutes/day working on garages, driveways	2.0	5.0
persons over age 11 (10^6)	205.6	205.6
value of time ($/hour)	5.0	8.0
calculated total cost (10^9 $/year)	*50.0*	*110.1*
amount included in lost nonmarket productivity due to motor-vehicle accidents	-0.5	-0.5
net total cost (10^9 $/year)	*49.3*	*109.4*

4.4.2 The value of time spent buying, selling, and disposing of vehicles

Finally, one must count the value of time spent buying, selling, and disposing of motor vehicles. (Dealer costs are estimated in Report #5 of this social-cost series; see the list at the beginning of this report). I estimate this as the number of vehicle transactions multiplied by the average time per transaction multiplied by the value of time:

$$PTBS = (NP \cdot PHNP + UP \cdot PHUP + VS \cdot PHVS) \cdot CBS \qquad \textbf{[4-7]}$$

where:

PTBS = the personal time cost of buying, selling, and scrapping vehicles (10^9 1991 $)

NP = purchases of new vehicles in 1990 (in 1990, 14.1 million new cars and trucks were sold in the U.S. [Motor Vehicle Manufacturers Association, 1992])

PHNP = person-hours per new-vehicle purchase (I assume that buying a vehicle requires a total of 3 to 6 hours of one person's time, for research, test drives, paper work, and so on)

UP = purchases of new cars in 1990 (I estimate about 26 million: in 1990, households purchased $93 billion worth of used vehicles [Division of Consumer Expenditure Surveys, 1993]; at about $3,600 per transaction [see estimates of registration weighted used-car prices, in Report #5])

PHUP = person-hours per used-car purchase (I assume 4 to 8 person hours -- more than for new-car purchases, because in this case the time of the seller must be counted [in the case of new cars, the cost of the dealer's time is included in the price of the car])

VS = vehicles scrapped (I estimate about 10 million per year: from 1970 to 1990, U.S. retail sales of cars and trucks averaged 13 to 14 million per year [Motor Vehicle Manufacturers Association, 1992], and the fleet of registered vehicles grew by nearly 4 million per year [FHWA, 1987, 1991a])

PHVS = person-hours per vehicle scrapping (I assume 2 to 3 hours).

CBS = the time-cost of a person-hour spent buying, selling, or scrapping vehicles (I assume the same value for time as in section 4.3.1, \$5 to \$8 hour)

The result of the calculation expressed by equation 4-7 is \$0.8 to \$2.6 billion per year -- a relatively small amount.

4.5 MOTOR-VEHICLE NOISE AND AIR POLLUTION INFLICTED ON ONESELF

Noise costs and air pollution costs in principle can be disaggregated into costs inflicted by motor-vehicle users on themselves (personal nonmonetary costs), and costs inflicted on others (external costs). However, most analysts do not make this distinction, presumably because they believe that the personal nonmarket costs are trivial compared to the external costs. This assumption most likely is correct in the case of air pollution, because the exhaust plume is directed away from the vehicle, and most pollutants disperse widely -- although researchers have found that levels of carbon monoxide (CO) inside vehicles are much higher than ambient levels (Ott et al., 1994). In the case of noise, though, it is not immediately obvious that personal nonmarket costs are trivial compared to external costs, because vehicular noise is intense at the source, and diminishes rapidly with distance. Nevertheless, we have followed the usual practice, and have not estimated personal noise or air pollution costs apart from the external costs. We report the total external+personal-nonmonetary cost of noise and air pollution as an externality. The total noise costs are estimated in Report #14, and the total air-pollution health costs are estimated in Report #11. Both are summarized in Report #9.

4.6 SUMMARY OF PERSONAL NONMARKET COSTS

Table 4-6 summarizes the personal nonmarket costs estimated above. The largest personal costs of motor-vehicle use are personal travel time in uncongested conditions and the risk of getting into an accident that involves nobody else.

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TABLE 4-1. THE COST OF TRAVEL TIME BY VEHICLE CLASS, 1990

Travel in:	Private vehicles, personal purposes		Private vehicles, business purposes				Buses		Public (government) vehicles				All vehicles
	daily travel	long trips	LDAs	LDTs, no paid drivers	LDTs, paid drivers	HDTs, paid drivers	inter-city and transit	school	federal civilian	federal mili-tary	state, local civilian	state, local police	
Notes -->	a	b	c	d	e	f	g	h	i	j	k	l	m
Vehicle-miles of travel (VMT) (10^9)	1,367	192.8	251	168	17	105	2.6	3.1	3.4	0.4	27	6.04	**2,144**
Occupancy (Oc)	1.48	2.79	0.96	1.10	1.00	1.00	14.08	27.10	1.50	2.00	1.50	2.00	**1.54**
Person-miles of travel (PMT) (10^9)	2,030	538	240	185	17	105	36	85	5	0.7	41	12.1	**3,295**
Actual average speed (Sa) (mph)	34.7	45.0	43.0	34.7	31.0	32.0	17.9	18.9	34.9	34.9	34.9	34.9	**35.3**
Person-hours of travel (PHT) (10^9)	58.5	12.0	5.6	5.3	0.6	3.3	2.0	4.5	0.1	0.0	1.2	0.3	**93.5**

Table continued on next page.

TABLE 4-1, CONTINUED: LOW-COST CASE

Travel in:	Private vehicles, personal purposes		Private vehicles, business purposes				Buses		Public (government) vehicles				All vehicles
	daily travel	long trips	LDAs	LDTs, no paid drivers	LDTs, paid drivers	HDTs, paid drivers	inter-city and transit	school	federal civilian	federal mili-tary	state, local civilian	state, local police	
Fraction of travel time that displaces unpaid activities (Fnm)	0.95	0.95	0.15	0.15	0.00	0.00	0.75	0.50	0.15	0.00	0.15	0.00	n.e.
Fraction of travel time that displaces paid work (Fm)	0.00	0.00	0.65	0.65	1.00	1.00	0.10	0.00	0.65	1.00	0.65	0.50	n.e.
Value of foregone nonmonetary activities (Cnm) ($/hr)	5.71	5.98	6.89	6.89	n.e.	n.e.	4.73	0.50	11.93	7.32	7.93	n.e.	n.e.
Value of foregone paid (monetary) work (Cm) ($/hour)	n.e.	n.e.	16.08	16.08	13.11	16.59	11.04	n.e.	27.85	17.08	18.52	18.78	n.e.
Additional "hedonic" cost of travel (Ch) ($/hour)	1.00	1.00	1.00	1.00	0.00	0.00	0.50	0.00	1.00	0.00	1.00	0.00	n.e.
Ratio of average speed without delay to speed with delay (R)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	n.e.
Fraction of travel time subject to delay (Fd)	0.20	0.15	0.15	0.20	0.20	0.20	0.25	0.25	0.20	0.20	0.20	0.20	0.05
Average speed, all miles, if no delay anywhere (Snd) (mph)	37.2	47.4	45.3	37.2	33.2	34.3	19.5	20.6	37.3	37.3	37.3	37.3	n.e.
Calculated person-hours of delay (PHTd) (10^9)	3.9	0.6	0.3	0.4	0.0	0.2	0.2	0.4	0.0	0.0	0.1	0.0	6.0
Personal nonmonetary cost (10^9 $)[n]	314.4	62.6	10.5	9.4	0.0	0.0	6.8	1.0	0.3	0.0	2.1	0.0	407.1
Private monetary cost (10^9 $)[o]	0.0	0.0	56.1	50.9	6.7	50.7	3.7	2.1	2.3	0.3	12.1	2.7	187.6
External monetary cost (10^9 $)[p]	0.0	0.0	3.0	3.6	0.5	3.6	0.3	0.2	0.2	0.0	0.9	0.2	12.5
External nonmonetary cost (10^9 $)[q]	26.4	3.9	0.8	1.0	0.0	0.0	0.7	0.1	0.0	0.0	0.2	0.0	33.0
Total time cost (10^9 $)[r]	*340.7*	*66.5*	*70.3*	*64.9*	*7.2*	*54.4*	*11.6*	*3.3*	*2.8*	*0.3*	*15.2*	*2.8*	***640.2***
External time cost (cents/person-mi)	1.30	0.72	1.56	2.48	2.82	3.46	2.89	0.33	3.80	2.86	2.62	1.57	1.38
Total time cost (cents/person-mi)	16.8	12.3	29.3	35.0	42.3	51.8	31.9	3.9	54.8	42.9	37.3	23.6	19.4

Table continued on next page.

TABLE 4-1, CONTINUED: HIGH-COST CASE

Travel in:	Private vehicles, personal purposes		Private vehicles, business purposes				Buses		Public (government) vehicles				All vehicles
	daily travel	long trips	LDAs	LDTs, no paid drivers	LDTs, paid drivers	HDTs, paid drivers	inter-city and transit	school	federal civilian	federal mili-tary	state, local civilian	state, local police	
Fraction of travel time that displaces unpaid activities (Fnm)	0.98	0.98	0.20	0.20	0.00	0.00	0.80	0.50	0.20	0.00	0.20	0.00	n.e.
Fraction of travel time that displaces paid work (Fm)	0.00	0.00	0.75	0.75	1.00	1.00	0.15	0.00	0.75	1.00	0.75	0.50	n.e.
Value of foregone nonmonetary activities (Cnm) ($/hr)	9.22	9.51	11.11	11.11	n.e.	n.e.	7.51	0.75	15.01	9.21	9.98	n.e.	n.e.
Value of foregone paid (monetary) work (Cm) ($/hour)	n.e.	n.e.	20.62	20.62	13.11	16.59	13.93	n.e.	27.85	17.08	18.52	18.78	n.e.
Additional "hedonic" cost of travel (Ch) ($/hour)	1.50	1.50	1.50	1.50	0.00	0.00	0.75	0.00	1.50	0.00	1.50	0.00	n.e.
Ratio of average speed without delay to speed with delay (R)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	n.e.
Fraction of travel time subject to delay (Fd)	0.30	0.20	0.25	0.30	0.30	0.30	0.35	0.35	0.30	0.30	0.30	0.30	n.e.
Average speed, all miles, if no delay anywhere (Snd) (mph)	40.8	50.0	49.2	40.8	36.5	37.6	21.7	22.9	41.0	41.0	41.0	41.0	n.e.
Calculated person-hours of delay (PHTd) (10^9)	8.8	1.2	0.7	0.8	0.1	0.5	0.4	0.8	0.0	0.0	0.2	0.1	13.4
Personal nonmonetary cost (10^9 $)[n]	480.9	105.3	16.7	15.0	0.0	0.0	10.0	1.3	0.5	0.0	3.0	0.0	632.8
Private monetary cost (10^9 $)[o]	0.0	0.0	75.9	69.5	6.1	46.2	4.9	1.9	2.5	0.3	13.4	2.6	223.4
External monetary cost (10^9 $)[p]	0.0	0.0	10.8	12.3	1.1	8.2	1.0	0.4	0.4	0.1	2.4	0.5	37.1
External nonmonetary cost (10^9 $)[q]	111.3	15.4	4.1	4.5	0.0	0.0	2.7	0.3	0.1	0.0	0.9	0.0	139.5
Total time cost (10^9 $)[r]	*592.3*	*120.7*	*107.7*	*101.4*	*7.2*	*54.4*	*18.6*	*3.9*	*3.6*	*0.3*	*19.7*	*3.1*	***1,032.9***
External time cost (cents/person-mi)	5.49	2.87	6.23	9.08	6.34	7.78	10.20	0.83	11.43	6.98	8.06	3.84	5.36
Total time cost (cents/person-mi)	29.2	22.4	44.8	54.8	42.3	51.8	51.1	4.6	70.4	46.6	48.2	25.6	31.3

Notes on next page.

The parameters PHT, Fnm, Fm, Cnm, Ch, R, Fd, Snd, and PHTd are discussed in the text. The parameter Cm is discussed in Report #5. The other parameters are discussed in these notes.

[a]This category is daily travel in privately owned vehicles for "personal" rather than "business" purposes. I consider the following purposes, as used in the NPTS, to be "personal":

i) travel to work;
ii) shopping, school, church, doctor, dentist, other family or personal business;
iii) visit friends or relatives, pleasure drive, vacation, other social or recreational trips.

Note, though, that the NPTS travel data actually might include some personal travel in publicly owned vehicles (see the discussion in Appendix A).

Vehicle miles of travel (VMT) is equal to the 1,409.6 billion non-commercial VMT reported in the "travel-day" section of the NPTS (Hu and Young, 1993a) less 42.3 billion VMT for "work-related" trips (Hu and Young, 1993b). (I exclude the work-related trips because I classify these as trips for business purposes.) These figures include VMT as part of "segmented" trips, which are trips that involve a change of mode.

The occupancy is equal to PMT/VMT .

Person miles of travel (PMT) is SUM3 from Table 4-3, multiplied by 1.002 to account for car trips to access public transit, which trips are not included in Table 4-3 (see the discussion in the notes to Table 4-3).

The average speed is Sum3 from Table 4-4 (the average speed in motor vehicles for all purposes except work related business; equal to PMT divided by PHT).

[b]This category is long-distance travel in privately owned vehicles for personal rather than business purposes, *in addition* to any long-distance travel already included in the daily travel estimates of column *a*. Personal and business purposes are as defined for column/note *a.*

VMT is equal to:

$$VMT_{LD,POV,Pers} = VMT_{TP,POV} - VMT_{TD,POV,LD} - VMT_{TP,POV,Busi} \cdot \left(1 - \frac{VMT_{TD,POV,LD}}{VMT_{TP,POV}}\right)$$

where:
LD = long-distance
POV = privately owned vehicle
TP = travel-period section of the NPTS
TD = travel-day section of the NPTS
Pers = personal purposes
Busi = business purposes
$VMT_{LD,POV,Pers}$ = long-distance VMT in privately owned vehicles for personal reasons
$VMT_{TP,POV}$ = total VMT in POVs, reported in the travel-period section of the NPTS (Hu and Young, 1993a, 1993b)
$VMT_{TD,POV,LD}$ = long-distance travel, in POVs, that is reported in the travel-day section as well as the travel-period section (Hu and Young, 1993a)
$VMT_{TP,POV,busi}$ = work-related VMT in POVs, reported in the travel period section (Hu and Young, 1993b)

This method starts with total VMT by POVs in the travel period, deducts the portion that already is included in the travel-day estimates (column *a* of this table), and then deducts work-related travel in POVs that is reported in the travel-period section but not already deducted via the deduction for all VMT already included in the travel-day section. That is, the long-distance travel reported in the travel-day and deducted here ($VMT_{TD,POV,LD}$) already includes some work-related travel, so we must remove from this already-deducted amount from the total work-related travel reported for the travel period. We assume that the fraction of total long-distance work-related travel that is included in the travel-day section is equal to the fraction of total long distance travel (for any purpose) that is included in the travel-day section.

The occupancy is equal to PMT/VMT .

PMT is calculated with the same equation used to calculate VMT, except of course that PMT instead of VMT data are used.

The average speed is my estimate. I assume that the average speed for long-distance travel is slightly greater than the average speed for work-related business travel in light-duty autos (column *c*).

[c]This category is travel in privately owned automobiles (i.e., motor vehicles excluding vans and trucks) for business purposes (publicly owned vehicles, and trucks used for business purposes, are treated separately).

The estimate of VMT is a residual, equal to total VMT in all categories in 1990 (FHWA, 1992) minus VMT in all categories other than this one. See the discussion in Appendix A to this report.

The occupancy is equal to PMT/VMT .

The estimate of PMT is a residual, equal to total PMT in all categories in 1990 (FHWA, 1992) minus PMT in all categories other than this one.

The average speed is the average for the work-related business travel, as estimated from the NPTS data (Table 4-4).

[d]This category is travel in privately owned light-duty trucks without paid drivers, for business purposes. In the analysis presented here, an LDT has a gross vehicle weight (GVW) of 8,500 lbs or less, which I assume corresponds to an average weight of 7,500 lbs or less. (See Report #10 for details.)

VMT is equal to total VMT by all business-use LDTs, with and without paid drivers, less business-use VMT in LDTs with paid drivers. Total VMT by all business-use LDTs in 1990 is linearly interpolated between total business-use (non-personal) VMT for LDTs in 1987 (calculated from the data in columns e and k of Table 10-6, for average weight classes 1,425 to 6,000 lbs and 6,001 lbs to 7,500 lbs) and total business-use VMT for LDTs in 1992 (calculated from the 1992 TIUS; Bureau of the Census, 1995). Business-use VMT in LDTs with paid drivers is estimated in column e.

I assume an occupancy rate of 1.1 persons per vehicle.

PMT is equal to VMT multiplied by the occupancy rate.

I assume that business-use LDTs without paid drivers travel in the same traffic conditions as do private passenger vehicles used for daily personal purposes, and thus have the same average speed. This results in a lower average speed than that for business-use LDAs, which is reasonable because salesman and others who travel long distances at relatively high speeds probably use LDAs more than LDTs.

[e]This category is travel in privately owned light-duty trucks, with paid drivers.

VMT is equal to the number of paid operators of LDTs in 1990, multiplied by the miles driven per operator. The Bureau of Labor Statistics (1993) reports 570,000 operators of light trucks in 1990. Assuming 30,000 miles per year, the result is 17 billion VMT. (Note that I use the same BLS source to calculate the wage rate of operators of LDTs, in Report #5.

I assume an occupancy rate of 1.0 persons per vehicle -- i.e., that the vehicle has the driver only.

PMT is equal to VMT multiplied by the occupancy rate.

I assume that business-use LDTs with paid drivers on average have a somewhat lower average speed than do private vehicles used for daily personal purposes.

[f]This category is travel in privately owned heavy-duty trucks, for business purposes. In the analysis presented here, an HDT has a GVW of over 8,500 lbs, which I assume corresponds to an average weight of over 7,500 lbs. (See Report #10 for details.)

VMT in 1990 is linearly interpolated between business-use VMT for HDTs in 1987 (calculated from the data in columns e and k of Table 10-6, for average weight classes over 7,500 lbs) and business-use VMT for HDTs in 1992 (calculated from the 1992 TIUS; Bureau of the Census, 1995). Note that the result is consistent with 1.614 million operators of heavy trucks in 1990 (Bureau of Labor Statistics, 1993) each driving about 60,000 miles per year. (I use the same BLS (1993) data to estimate the wage of operators of HDTs, in Report #5.)

The FHWA (1992) estimates that combination (cab+trailer) trucks (most heavy-duty trucks are combinations) have an occupancy of 1.0 -- i.e., that the vehicle has the driver only.

PMT is equal to VMT multiplied by the occupancy rate.

Average speed: on any given road, HDTs travel more slowly than do LDAs and LDTs. However, data from the FHWA (1991c) indicate that HDTs travel a larger fraction of their total VMT on high-speed roads (interstates and other freeways) than do LDAs and LDTs. Thus, the average speed of HDTs, over all road types, should be close to the average speed of LDAs.

[g]VMT is equal to the FHWA's (1992) estimate of total VMT in buses in 1990 minus my estimate of VMT in school buses in 1990.

The occupancy is equal to PMT/VMT. I assume that the driver is counted as an occupant.

PMT is equal to the FHWA's estimate of total PMT in buses in 1990 minus my estimate of PMT in school buses in 1990.

The average speed is equal to total person-miles of travel in buses (Table 4-3, all trip purposes, except that only half of the bus person-miles for "Shopping, school, church, doctor, dentist, other family or personal business" is counted, on the assumption that half of that is in school buses) divided by total person-hours of travel in buses (Table 4-2, all trip purposes, except that only half of the bus person-miles for "Shopping, school, church, doctor, dentist, other family or personal business" is counted, on the assumption that half of that is in school buses).

Note that the values shown for the cost parameters Fnm, Fm, Cnm, Cm, and Ch are those for passengers. Parameter values for drivers are discussed in the text. The total calculated costs (TTCinm, TTCim, TTCem, TTCenm) include the cost of driver time as well.

[h]VMT is estimated as: FHWA's estimate of total VMT by buses in 1990 (FHWA, 1992), multiplied by Davis and Strang's (1993) estimate of the ratio of VMT by school buses to VMT by all buses in 1990. (Davis and Strang [1993] estimate VMT separately for transit buses, intercity buses, and school buses, whereas the FHWA reports only total VMT for all buses. I use Davis and Strang's (1993) estimate to disaggregate the FHWA total, rather than use the Davis and Strang estimate directly, because I rely heavily on FHWA estimates of VMT, person-miles of travel, vehicle registrations, and highway finances throughout.)

The occupancy rate is calculated using VMT and PMT data from Davis and Strang (1993) and FHWA (1992). I assume that the driver is counted as an occupant.

PMT is equal to the occupancy rate multiplied by VMT.

The average speed is from Table 4-4, purpose "Shopping, school, church, doctor, dentist, other family or personal business," row "bus," column "total".

Note that the values shown for the cost parameters Fnm, Fm, Cnm, Cm, and Ch are those for passengers. Parameter values for drivers are discussed in the text. The total calculated costs (TTCinm, TTCim, TTCem, TTCenm) include the cost of driver time as well.

[i]VMT is calculated as: the total number of vehicles in the federal fleet in 1990 less military vehicles and buses (General Services Administration, 1993?), multiplied by miles traveled per vehicle in large federal fleets in 1990 (General Services Administration, 1993?).

The occupancy rate is my estimate.

PMT is equal to VMT multiplied by the occupancy rate.

I assume that the average speed of these vehicles is the same as the average for all cars and all trip purposes (Table 4-4).

[j]VMT is equal to the number of domestic military vehicles in 1990 multiplied by miles per military vehicle in 1990 (General Services Administration, 1993?), multiplied by 50% (I assume that 50% of travel by military vehicles is on military bases, and therefore probably should not be included in this analysis).

The occupancy rate is my assumption.

PMT is equal to VMT multiplied by the occupancy rate.

I assume that the average speed of these vehicles is the same as the average for all cars and all trip purposes (Table 4-4).

[k]VMT is calculated as: the number of state and local passenger vehicles (FWHA, 1992) less police vehicles (this table) multiplied by average miles per passenger vehicle for all passenger vehicles (FWHA, 1992), plus the number of state and local trucks multiplied by average miles per truck for all trucks (FWHA, 1992), plus the number of state and local motorcycles multiplied by average miles per motorcycle for all motorcycles (FWHA, 1992) (all data for 1990).

The occupancy rate is my estimate.

PMT is equal to VMT multiplied by the occupancy rate.

I assume that the average speed of these vehicles is the same as the average for all cars and all trip purposes (Table 4-4).

[l]VMT is estimated as: the number of police vehicles multiplied by my assumption of 15,000 miles per vehicle per year. The number of police vehicles is calculated as: the number of

vehicles per sworn officer multiplied by the number of sworn officers (Bureau of Justice Statistics, 1992a, 1992b).

I assume two officers per vehicle, on average.

PMT is equal to VMT multiplied by the occupancy rate.

I assume that the average speed of these vehicles is the same as the average for all cars and all trip purposes (Table 4-4).

Note that some of the police travel-time cost estimated here is counted already in our estimates of police expenditures in Report #7. In Report #5, we estimate and deduct this overlap, to avoid double counting.

[m]This category is all travel by all vehicles.

VMT and PMT are from FHWA (1992).

The occupancy is equal to PMT/VMT.

The average speed is equal to PMT/PHT.

Person-hours of travel, person-hours of delay, and the total cost of travel time are calculated as the sum of the figures from columns *a* through *l*.

Note that the FHWA's estimate (*Highway Statistics*) of total vehicle-miles of travel includes travel on public roads by passenger cars and trucks used by the military (because the VMT estimates are based on traffic counts), but that its estimates of the number of publicly owned vehicles does not include any vehicles used by the military. Also, the estimate of VMT apparently excludes travel on military bases and other nonpublic roads. I assume that 50% of all VMT by military vehicles (as reported by the General Services Administration, 1993?) occurs on public roads and therefore is included in the FHWA's estimates of VMT. (The assumption is unimportant, because all VMT by military vehicles is less than 0.05% of all VMT on public roads.)

[n]Calculated using equation 4-1.

[o]Calculated using this equation from Report #5:

$$TTCim = (PHT - PHTd) \cdot \left(\frac{1}{Oc} + \left(1 - \frac{1}{Oc} \right) \cdot Pa \right) \cdot Fm,dr \cdot Cm$$

where:

TTCim = the internal, monetary travel-time cost (10^9 1991$)

Fm,dr = the fraction of travel time that displaces monetary (paid) activities rather than unpaid activities, for drivers

Cm = the cost of the foregone monetary (paid) activities ($/person-hour)

all other variables defined in text

(Note that the equation for buses is slightly different.)

[p]Calculated using this equation from Report #8:

$$TTCem = PHTd \cdot \left(\frac{1}{Oc} + \left(1 - \frac{1}{Oc} \right) \cdot Pa \right) \cdot Fm,dr \cdot Cm$$

where:

TTCem = the external, monetary travel-time cost (10^9 1991$)
all other variables as defined in notes and text above

(Note that the equation for buses is slightly different.)

[q]Calculated using this equation from Report #9:

$$TTCenm = PHTd \cdot \left(\frac{1}{Oc} + \left(1 - \frac{1}{Oc}\right) \cdot Pa\right) \cdot \left(Fnm,dr \cdot Cnm,ref \cdot \left(\frac{Sref}{\frac{Snd}{R}}\right)^{Bo} + Ch,dr,ref \cdot \left(\frac{Sref}{\frac{Snd}{R}}\right)^{Bh} \right)$$

where:

TTCenm = the external, non-monetary travel-time cost (10^9 1991$)
all other variables as defined in notes and text above

(Note that the equation for buses is slightly different.)

[r]The sum of personal nonmonetary, private monetary, external monetary, and external nonmonetary costs. The totals shown here include some monetary costs of police time already counted as government costs of police protection in Report #7. See Report #5 for further discussion. In the final totals reported for monetary costs in Report #5 and Report #8, this double-counted police time cost is removed.

TABLE 4-2. BILLION PERSON-HOURS OF TRAVEL (CONGESTED AND UNCONGESTED CONDITIONS), BY MODE, TRIP PURPOSE, AND INCOME CLASS, FOR NON-SEGMENTED TRIPS, 1990

Trip purpose[a] / mode	*Annual household income (10^3 \$)[b]*									
Travel to or from work										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	0.488	1.332	1.823	2.192	1.584	1.557	1.469	1.064	3.335	**14.843**
Bus	0.060	0.118	0.092	0.080	0.036	0.026	0.039	0.040	0.217	**0.709**
Train1	0.005	0.006	0.035	0.026	0.017	0.026	0.055	0.051	0.075	**0.297**
Train2	0.008	0.045	0.045	0.047	0.038	0.043	0.043	0.021	0.092	**0.382**
Walk	0.040	0.049	0.059	0.032	0.029	0.017	0.023	0.017	0.102	**0.368**
Work-related business										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	0.035	0.051	0.108	0.169	0.100	0.185	0.152	0.169	0.257	**1.227**
Bus	0.005	0.014	0.002	0.000	0.002	0.006	0.002	0.000	0.003	**0.034**
Train1	0.000	0.000	0.005	0.000	0.018	0.000	0.009	0.000	0.000	**0.032**
Train2	0.000	0.001	0.004	0.002	0.001	0.000	0.000	0.002	0.002	**0.013**
Walk	0.006	0.001	0.001	0.003	0.002	0.007	0.001	0.002	0.013	**0.036**
Shopping, school, church, doctor, dentist, other family or personal business										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	1.496	2.821	3.631	3.652	2.589	2.080	1.946	1.535	5.464	**25.214**
Bus	0.135	0.184	0.102	0.044	0.041	0.016	0.020	0.058	0.265	**0.867**
Train1	0.012	0.002	0.003	0.001	0.022	0.002	0.004	0.015	0.022	**0.082**
Train2	0.014	0.019	0.022	0.024	0.010	0.005	0.009	0.011	0.050	**0.163**
Walk	0.316	0.218	0.215	0.182	0.098	0.072	0.068	0.053	0.324	**1.546**
Visit friends or relatives, pleasure drive, vacation, other social or recreational trips										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	0.937	1.927	2.426	2.683	2.177	1.756	1.534	1.188	3.716	**18.345**
Bus	0.046	0.053	0.045	0.057	0.026	0.011	0.006	0.004	0.093	**0.342**
Train1	0.000	0.037	0.014	0.003	0.000	0.006	0.000	0.002	0.014	**0.077**
Train2	0.013	0.021	0.027	0.014	0.008	0.001	0.010	0.003	0.015	**0.111**
Walk	0.205	0.159	0.169	0.172	0.124	0.087	0.137	0.083	0.278	**1.412**
Sum1	**3.820**	**7.060**	**8.828**	**9.383**	**6.921**	**5.901**	**5.527**	**4.318**	**14.339**	**66.099**
Sum2	**2.955**	**6.132**	**7.989**	**8.696**	**6.449**	**5.577**	**5.101**	**3.957**	**12.773**	**59.629**

Sum3	**2.921**	**6.081**	**7.881**	**8.527**	**6.349**	**5.392**	**4.949**	**3.788**	**12.516**	*58.402*

Source: our analysis of the NPTS data files.

We summed minutes of travel (variable TRP_MIN, survey question H13) by household income (HHFAMINC, survey question K), main means of transportation on day trip (TRPTRANS, survey question H15), and reason for day trip (WHYTRP, survey question H7), from the data files of the 1990 Nationwide Personal Transportation Survey (see FHWA, 1991b). Then, we multiplied the resultant travel hours in each category by 1.03062, to account for the people who refused to answer or did not know the answer to any of the questions about travel time, trip purpose, and trip mode, or who gave "other" as the reason for the trip. This scaling by 1.03062 assumes that: i) the people who refused to answer or did not answer one question are not the same as the people who refused to answer or did not answer the others; and ii) that had these people answered the questions, the distribution of their responses would have been the same as those who did answer.

Note that the estimates presented in this table are of the distance of all trips that did not involve public transit, plus the distance of all public transit trips that did not involve a transfer to another vehicle or mode. (All such trips are called "non-segmented".) That is, the estimates exclude the distance of all parts of all trips that involved a transfer to or from public transit. Data in Hu and Young (1993b) suggest that the omitted segmented mileage is only 0.2% of the non-segmented mileage by cars. Therefore, the estimates of total travel in Table 4-1 are equal to the estimates of this table multiplied by 1.002.

Note too that the estimates here are of travel time in all conditions, congested as well as uncongested. In Table 4-1 I separate congested from uncongested travel.

[a]Car = auto, station wagon, passenger van, cargo van, pickup truck (with & w/out camper), other truck, motorcycle, moped/motorized bicycle, taxi
Bus = bus (excluding school bus)
Train1 = Amtrak or commuter train
Train2 = streetcar, trolley, elevated rail, or subway
Walk = walk or bicycle
We did not include "school bus" or "other" modes. We distributed "not ascertained", and "refused" proportionately to the other modes.

SUM1 = total person hours, all trip purposes, all modes
SUM2 = total person hours, all trip purposes by car
SUM3 = total person hours, all trip purposes except work-related business, by car

[b]n.a. = not ascertained, or refused to answer.

TABLE 4-3. BILLION PERSON-MILES OF TRAVEL (CONGESTED AND UNCONGESTED CONDITIONS) BY MODE, TRIP PURPOSE, AND INCOME CLASS, FOR NON-SEGMENTED TRIPS, 1990

Trip purpose[a] mode	*Annual household income (10^3 $)[b]*									
Travel to or from work										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	16.8	46.1	60.8	79.0	56.9	54.5	51.4	37.6	111.0	514.0
Bus	0.8	1.9	1.1	1.0	0.7	0.5	0.8	0.8	2.8	10.5
Train1	0.2	0.1	1.0	0.4	0.5	0.6	1.4	1.7	1.3	7.2
Train2	0.2	0.5	0.7	0.6	0.6	1.1	0.9	0.2	1.6	6.3
Walk	0.2	0.3	0.4	0.2	0.2	0.1	0.1	0.1	0.6	2.2
Work-related business										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	1.4	2.0	5.3	7.2	3.6	8.4	6.9	7.8	10.2	52.8
Bus	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.4
Train1	0.0	0.0	0.3	0.0	0.7	0.0	0.1	0.0	0.0	1.1
Train2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Walk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Shopping, school, church, doctor, dentist, other family or personal business										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	43.2	86.1	117.2	120.4	83.8	67.2	65.4	53.4	176.1	812.9
Bus	1.7	5.4	1.5	0.9	0.5	0.3	0.8	1.4	4.0	16.4
Train1	0.2	0.0	0.1	0.0	0.4	0.1	0.1	0.2	0.2	1.4
Train2	0.1	0.2	0.3	0.3	0.2	0.0	0.1	0.1	0.5	1.9
Walk	1.3	1.1	0.9	0.8	0.4	0.3	0.4	0.2	1.5	6.9
Visit friends or relatives, pleasure drive, vacation, other social or recreational trips										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	31.1	71.3	87.7	106.1	87.0	67.6	62.3	50.6	134.8	698.5
Bus	0.4	1.4	0.6	2.1	0.8	0.0	0.0	0.1	2.6	8.1
Train1	0.0	2.2	0.1	1.4	0.0	0.4	0.0	0.0	0.5	4.6
Train2	0.0	0.5	0.3	0.1	0.3	0.1	0.0	0.0	0.1	1.5
Walk	0.9	0.7	0.8	1.1	0.5	0.4	0.8	0.5	1.4	7.2
Sum1	98.8	219.8	279.1	321.7	237.2	201.9	191.6	154.6	449.3	2,154
Sum2	92.6	205.4	271.0	312.7	231.3	197.8	186.0	149.4	432.2	2,078

Sum3	91.2	203.4	265.7	305.5	227.7	189.3	179.1	141.6	422.0	2,025

Source: our analysis of the NPTS data files.

We summed miles of travel (variable TRPMILES, survey question H13) by household income (HHFAMINC, survey question K), main means of transportation on day trip (TRPTRANS, survey question H15), and reason for day trip (WHYTRP, survey question H7), from the data files of the 1990 Nationwide Personal Transportation Survey (see FHWA, 1991b). Then, we multiplied the resultant mileage in each category by 1.02949, to account for the people who refused to answer or did not know the answer to any of the questions about trip distance, trip purpose, and trip mode, or who gave "other" as the reason for the trip. This scaling by 1.02949 assumes that: i) the people who refused to answer or did not answer one question are not the same as the people who refused to answer or did not answer the others; and ii) that had these people answered the questions, the distribution of their responses would have been the same as those who did answer.

Note that the estimates presented in this table are of the distance of all trips that did not involve public transit, plus the distance of all public transit trips that did not involve a transfer to another vehicle or mode. (All such trips are called "non-segmented".) That is, the estimates exclude the distance of all parts of all trips that involved a transfer to or from public transit. Data in Hu and Young (1993b) suggest that the omitted segmented mileage is only 0.2% of the non-segmented mileage by cars. Therefore, the estimates of total travel in Table 4-1 are equal to the estimates here multiplied by 1.002.

Note too that the estimates here are of travel miles in all conditions, congested as well as uncongested. In Table 4-1 we separate congested from uncongested travel.

[a]Car = auto, station wagon, passenger van, cargo van, pickup truck (with & w/out camper), other truck, motorcycle, moped/motorized bicycle, taxi
Bus = bus (excluding school bus)
Train1 = Amtrak or commuter train
Train2 = streetcar, trolley, elevated rail, or subway
Walk = walk or bicycle
We did not include "school bus" or "other" modes. We distributed "not ascertained", and "refused" proportionately to the other modes.

SUM1 = total person miles, all trip purposes, all modes
SUM2 = total person miles, all trip purposes by car
SUM3 = total person miles, all trip purposes except work-related business, by car

[b]n.a. = not ascertained, or refused to answer.

TABLE 4-4. AVERAGE TRAVEL SPEED, BY MODE, TRIP PURPOSE, AND INCOME CLASS, FOR NON-SEGMENTED TRIPS, 1990 (MPH)

Trip purpose[a]										
mode	*Annual household income (10^3 $)*[b]									
Travel to or from work										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	34.5	34.6	33.3	36.0	35.9	35.0	35.0	35.3	33.3	34.6
Bus	13.2	15.7	12.4	12.7	19.0	21.0	20.1	20.5	12.9	14.7
Train1	40.8	13.9	28.4	15.0	30.7	24.1	25.8	32.9	16.7	24.2
Train2	20.5	11.7	15.7	13.2	15.4	24.9	21.2	7.8	17.0	16.5
Walk	4.8	6.3	7.5	6.0	6.8	6.3	3.6	5.1	6.0	6.0
Work-related business										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	39.8	38.7	48.9	42.9	36.0	45.6	45.3	45.9	39.6	43.0
Bus	4.9	9.9	17.1	n.e.	0.0	14.6	37.2	25.0	20.0	13.0
Train1	n.e.	n.e.	65.6	5.2	39.5	n.e.	8.7	n.e.	n.e.	34.0
Train2	n.e.	4.0	3.5	7.6	7.5	n.e.	n.e.	7.2	14.0	7.1
Walk	4.2	7.5	4.7	2.7	6.2	0.3	7.1	4.8	2.7	3.1
Shopping, school, church, doctor, dentist, other family or personal business										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	28.9	30.5	32.3	33.0	32.4	32.3	33.6	34.8	32.2	32.2
Bus	12.7	29.3	14.3	19.6	12.6	18.9	38.2	23.6	14.9	18.9
Train1	20.2	4.0	27.5	7.2	19.9	69.6	36.1	10.2	10.6	17.1
Train2	9.9	10.0	14.9	12.2	16.6	10.5	10.7	6.2	10.7	11.4
Walk	4.2	5.1	4.2	4.3	4.0	4.1	5.4	4.3	4.6	4.5
Visit friends or relatives, pleasure drive, vacation, other social or recreational trips										
	< 10	*10-20*	*20-30*	*30-40*	*40-50*	*50-60*	*60-80*	*>80*	*n.a.*	***Total***
Car	33.2	37.0	36.1	39.5	40.0	38.5	40.6	42.6	36.3	38.1
Bus	9.5	25.5	12.8	36.6	31.1	3.8	8.9	25.8	27.6	23.6
Train1	n.e.	59.9	6.2	537.6	n.e.	63.1	n.e.	18.2	32.2	60.1
Train2	0.2	23.9	11.6	10.6	36.6	78.4	2.4	16.9	9.0	13.8
Walk	4.6	4.4	4.5	6.6	4.3	4.8	6.0	5.8	5.1	5.1
Sum1	25.9	31.1	31.6	34.3	34.3	34.2	34.7	35.8	31.3	32.6
Sum2	31.3	33.5	33.9	36.0	35.9	35.5	36.5	37.7	33.8	34.9
Sum3	31.2	33.4	33.7	35.8	35.9	35.1	36.2	37.4	33.7	34.7

Notes: see next page

Equal to person-miles (Table 4-3) divided by person-hours (Table 4-2).

[a]Car = auto, station wagon, passenger van, cargo van, pickup truck (with & w/out camper), other truck, motorcycle, moped/motorized bicycle, taxi
Bus = bus (excluding school bus)
Train1 = Amtrak or commuter train
Train2 = streetcar, trolley, elevated rail, or subway
Walk = walk or bicycle
We did not include "school bus" or "other" modes. We distributed "not ascertained", and "refused" proportionately to the other modes.

SUM1 = Average speed, all trip purposes, all modes
SUM2 = Average speed, all trip purposes by car
SUM3 = Average speed, all trip purposes except work-related business, by car

[b]n.a. = not ascertained, or refused to answer.

PDO = property damage only; MAIS = maximum abbreviated injury scale (see the text); all inj. = all injuries;

[a]The unit costs shown under "all injuries" are the calculated injury-weighted averages.

[b]See equation 4-6. Note that a small amount of the potential external cost estimated here actually is paid through liability claims, and therefore is counted as a private monetary cost, not a nonmonetary cost. See Report #19 for details.

TABLE 4-6. SUMMARY OF THE PERSONAL NONMONETARY COSTS OF MOTOR-VEHICLE USE, 1990-91 (BILLION 1991 $).

Cost item	*Low*	*High*	*Q*[a]
Travel time, excluding travel delay imposed by others, that displaces unpaid (nonmonetary) activities	407.1	632.8	A2
Accidental pain, suffering, death, and lost nonmarket productivity inflicted on oneself	131.7	133.5	A2/B
Personal time spent working on motor vehicles and garages, and refueling motor vehicles	49.3	109.4	A3
Personal time spent buying and selling and disposing of vehicles, excluding dealer costs	0.8	2.6	A3
Motor-vehicle noise inflicted on oneself	included with external noise costs		
Motor-vehicle air pollution inflicted on oneself	included with external pollution costs		
Total	**588.9**	**878.3**	

See the text for details.

[a]Q = Quality of the estimate (see Table 1-3 of Report #1).

APPENDIX 4.A: THE NATIONWIDE PERSONAL TRANSPORTATION SURVEY

This Appendix discusses the characteristics of the data from the Nationwide Personal Transportation Survey (NPTS), delineates our use of the NPTS and other sources of travel data, and compares the results of our analysis of the NPTS data tapes with other analyses of the NPTS data, and with data from other sources. The ultimate aim here is to determine how best to disaggregate and characterize total travel, for the purpose of calculating the amount and cost of time spent in motor vehicles.

4.A.1 CHARACTERISTICS OF THE NPTS DATA

The NPTS is the most comprehensive and useful source of data on personal travel in the U.S. The NPTS collects data on vehicles, drivers, households, trips, and other characteristics of travel. The data of the 1990 NPTS were collected from phone interviews of 47,499 persons in 21,869 households between March 1990 and March 1991 (FHWA, 1991b).

The NPTS focuses mainly on travel for "personal" purposes, which actually includes all travel *except* that done as an "essential" part of one's job. (The NPTS labels driving as an essential part of work "commercial" driving. I will discuss this important distinction between personal and commercial travel more momentarily). Although the 1990 NPTS did, for the first time, ask about "commercial driving," the intent was *not* to provide "statistically robust estimates of commercial travel" (Hu and Young, 1993b), but rather to allow commercial drivers to participate in the NPTS without spending an inordinate amount of time describing their business trips. The FHWA did not intend to measure commercial driving comprehensively, and cautions against using the NPTS estimates of commercial travel (Hu and Young, 1993b). Nevertheless, the NPTS results do include estimates of commercial driving, which I will compare with independent estimates of "business-use" of trucks, from the Truck Inventory and Use Survey (TIUS).

For my purposes, there are five main sources of data in the NPTS: i) estimates by drivers of their "commercial" driving; ii) estimates by drivers of their total mileage; iii) estimates of miles of travel by household vehicles; iv) travel during the designated "travel day;" and v) long trips during the "travel period."

4.A.1.1 Estimates by driver of their "commercial" driving.

Question F-6 of the survey asks drivers how many miles they drive as "part of their work," not counting commuting (FHWA, 1991b). Driving as a "part of work" means driving in a licensed motor vehicle on a daily or regular basis as an "essential" part of work (Question F-3). As an example, the survey lists cab drivers, truck drivers, and delivery people. The responses to question F-6 are tallied to produce an estimate of total "commercial" driving (Table 4-A1 below).

The difficulty with this estimate of commercial driving is that different respondents will interpret "driving as an essential part of work" differently. Hu and Young (1993b) state that "commercial" driving was meant to include any driving by paid drivers, and any other driving that was "central" to the performance of work (such as some driving by sales people), but not regular or occasional trips as part of the work (such as travel to meetings). Regular or occasional trips as part of work were, according to Hu and Young (1993b), supposed to be classified as non-commercial work-related business travel. However, as noted above, the actual published survey gives as examples of commercial drivers *only* cab drivers, truck drivers, and delivery people who must driver to perform their work. Thus, it is not clear if respondents actually were given as much detail about commercial driving as Hu and Young (1993b) believe they were. And even if they were, there still was room for differences in interpretation, as Hu and Young (1993b) properly note.

Hu and Young (1993b) present evidence that some respondents who, according to the intent of the survey, should not have called themselves commercial drivers, nevertheless called themselves commercial drivers. They argue that it is likely that some people who did regular but "non-essential" driving as part of work mistakenly considered the driving to be "commercial". I believe that, if this is true, it might have resulted in an overestimate of commercial driving in *automobiles*, because automobiles and not trucks tend to be used for the sort of trips (e.g., to meetings) that might be mistakenly considered to be "commercial." However, as I explain next, there is compelling evidence that the NPTS dramatically underestimated commercial driving in *trucks*[19].

Table 4-A2 compares the NPTS estimates of commercial driving in trucks and vans in 1987 with the TIUS estimates of non-personal driving in trucks and vans in 1987 and 1992. The TIUS, which is based on a much larger sample, estimates considerably more "business-use" (non-personal) mileage in trucks and vans than does the NPTS. The difference in the estimates for pick ups and vans is most striking.

For several reasons, I believe that the TIUS data are more accurate. First, the TIUS sampled 150,000 trucks in 1992, of which more than 30%, or at least 45,000, were used for business (Bureau of the Census, 1995), whereas the NPTS sampled only 4,789 "commercial" drivers in 1990 (FHWA, 1991b). Second, the TIUS asked respondents to estimate how many miles a particular vehicle was driven in a year, rather than how many miles a particular driver has driven, and in general it is easier to estimate mileage by vehicle than by driver, because mileage is recorded by vehicle. Third, the TIUS was a mail survey rather than a phone survey, and in general respondents have more time to

[19]Hu and Young (1993a) probably would agree: they state that it is "highly likely that the estimate of commercial driving in the NPTS is underestimated" (p. 1-10). If overall commercial VMT is underestimated (as per the previous statement), but commercial VMT by LDAs is overestimated (as per the discussion in the text), then commercial VMT by trucks must be greatly underestimated.

fill out a mail survey than answer questions on the phone. Fourth, the TIUS distinguished between business use and personal use more clearly than the NPTS distinguished between commercial use and personal use. Item 18 of the TIUS states that a truck is used for business if it is operated by and for a private business (including self-employers) or a company, and is used in related activities of that business. Moreover, the TIUS asked respondents to identify vehicles that were used both for personal transportation and business, and estimate the percentage of personal use; it turns out that very few trucks were used for both (Tables 2a and 10 of the Bureau of the Census, 1995).

However, none of these advantages of the TIUS data necessarily explain why the TIUS estimated so much *more* non-personal mileage in trucks than did the NPTS. For this, there are four possible explanations.

1). The proportion of commercial drivers in the NPTS sample almost certainly is less than the proportion of commercial drivers in the population, because the NPTS missed some people who were not at home during the time of the survey, and commercial drivers -- especially long-haul operators -- are at home less than are most people. The NPTS started with 73,579 randomly selected telephone numbers, and from this set identified 26,172 households with telephones. This means that 47,407 phone numbers were excluded because they did not positively identify a household, either because the number did not work, or was a business number, or simply was not answered[20]. Thus, the NPTS sample under-represents households that answer their phone less frequently than average. Households with truck drivers probably answer less frequently than average, because the drivers are away so much, and, perhaps, because commercial drivers might tend to be single.

Beyond that, the NPTS identified 54,313 eligible household residents, but was able to complete interviews for only 47,499 of them. Thus, people who tend not to be home -- such as long-distance truck drivers -- were under-represented in the interviews.

These under-representations could explain the difference between the NPTS estimate and the TIUS estimate of commercial miles driven in "other" (mainly heavy-duty) trucks, because operators of heavy-duty trucks often are not home.

2). It is conceivable, albeit unlikely, that in the TIUS, some of the "business-use" mileage by trucks might be the commute to work. It is conceivable simply because some respondents might have believed that a commute to work in a company-owned truck constitutes a business use. However, it is unlikely because the TIUS questionnaire explicitly includes "travel to work" as an example of a *personal* (non-business) use of a vehicle. (The NPTS categories "commercial driving" and "work-related business" also explicitly exclude commuting to work.)

3). It is conceivable, albeit unlikely, that NPTS respondents did *not* count as "work-related" trips any business trips that were made in non-household vehicles. This is conceivable because the "vehicle" section of the survey, which comes before the

[20]Hu (1996) states that interviewers tried a phone number at least nine times within a six-day period.

travel-day section, asks respondents to give details about household vehicles *only* (vehicles that are owned by or regularly available to the household). This might have conditioned respondents to presume that the travel-day questions applied only to trips made in household vehicles, in spite of the instruction in the travel-day section to consider all trips except commercial trips.

4). The several disadvantages of the NPTS, discussed above, simply might have happened to result in an underestimate of business driving.

On the basis of the foregoing, I conclude the following:

1) The NPTS might overestimate commercial driving in automobiles
2) The NPTS greatly underestimates commercial driving in pickups and vans
3) The NPTS slightly underestimates commercial driving in large trucks

4.A.1.2 Estimates by drivers of their total mileage

Question F-7 of the survey asks each driver how many miles he or she drove, in all licensed motorized vehicles, and including miles driven as an essential part of work ("commercial driving") during the past 12 months. The VMT tallied from the responses to this question thus should include VMT by *all licensed* vehicles, including heavy trucks, public vehicles, military vehicles, and school buses.

As shown in Table 4-A1, the NPTS estimate of total VMT, based on drivers' estimates of their total mileage, is close to an independent estimate of total VMT by the FHWA. However, this correspondence is to some extent lucky, because the two actually are *not* measuring the same thing. In the first place, the FHWA data include VMT by any type of vehicle that travels on the highways, whether the vehicle is licensed or not. By contrast, the NPTS data apparently exclude travel in unlicensed vehicles, and may exclude travel in certain kinds of military vehicles as well. On the other hand, the NPTS data probably include off-road travel, which the FHWA traffic-count data exclude. Also, the NPTS does not sample people away from home at the time of the survey. To the extent that these people tend to drive differently on average than do the people who were at home, the NPTS will mis-estimate total driving. (For example, as discussed above, commercial drivers, who often are away from home and drive a lot, probably are underrepresented in the NPTS.)

If the two sources actually had the same coverage, then the close agreement in the results would suggest that traffic-count method used by the FHWA and the driver-recollection method used by the NPTS were relatively unbiased. However, given that the agreement may be fortuitous, it is possible that one or both methods are biased.

4.A.1.3 Estimates of miles of travel by household vehicles:

Question B-6 of the NPTS asks the respondent to state the mileage driven on every licensed vehicle owned or, if not owned, then regularly used, by the household (FHWA, 1991b). Thus, the total VMT estimate calculated from the responses to this question apparently excludes:

i) unlicensed vehicles
ii) vehicles that are not owned and not used regularly by the household.

Note that the wording in the "vehicle data" part (B) of the survey does not specifically exclude commercial vehicles, such as heavy trucks, that are "used" regularly by household members. Thus, it is conceivable that a driver of, say, a post-office truck would count the truck among vehicles owned or used regularly by the household. We expect, however, that either most respondents did not even consider such "commercial" or "institutional" vehicles to be covered by the survey, or else, if the question came up, were told to exclude them. This is supported by the Hu and Young's [(1993a]) reference to covered vehicles as "household-based vehicles" (e.g., p. 3-46).

4.A.1.4 Travel during the designated "travel day"

The main body of data in the NPTS are statistics on travel for one whole recent day (4:00 AM to 3:59 AM). Section H of the survey asks respondents about *all* trips, for *all* purposes, by *all* modes, *except* trips made as an "essential" part of work. The travel-day data, then, should include all PMT and VMT (including travel in publicly owned automobiles) except "commercial" travel as defined in the NPTS (see above).

There is an ambiguity regarding travel in publicly owned automobiles. Nothing in the travel-day section of the survey itself excludes non-commercial travel in publicly owned automobiles (for example, occasional travel in a government passenger sedan for government business). However, throughout their discussion of results, Hu and Young (1993a, 1993b) refer to "privately owned vehicles;" which taken literally would exclude publicly owned automobiles. (And there is no other mode category that conceivably could include publicly owned passenger vehicles.) I presume that travel in publicly owned vehicles actually is included in the travel-day statistics, the use of the term "privately owned vehicles" notwithstanding.

4.A.1.5 Long trips during the "travel period."

Section G of the survey asks about trips of 75 miles or more from home, during a recent two-week period.

Note that the travel-day data include any long trips also. In Table 4-A1, the long-trip VMT and PMT recorded for the travel day are shown in parentheses. These values are about 1/3 of the long-trip VMT and PMT estimated on the basis of the travel period reporting. Hu and Young (1993a) assume that the travel-period estimates of long trips are more accurate than the travel-day estimates, and so, when computing grand-total travel (short trips plus long trips) deduct travel-day estimates of long trips from travel-day total, and then add travel-period estimates of long trips.

In principle, however, this procedure will not produce correct estimates of total travel, or for that matter correct estimates of short trips and long trips, because it does not address a fundamental shortcoming of the NPTS: namely, that the NPTS sample was limited to individuals who were at their home, and had a telephone and answered it, at the time of the survey. As discussed above, because of this, long-haul truck drivers, who often are away from home, probably were underrepresented. As regards short trips, long trips, and total travel, the problem is that the NPTS, by design, did not survey people who at the time of the survey were traveling away from home and camping, staying in motels or rest stops, traveling in RVs, or visiting friends. *It is likely that, on average, people who were traveling away from home would have given different responses to the travel-day and even travel period questions than did the persons at home who actually answered the survey.* Some people take more long trips than do others. Those who do are less likely to be at home at any given time, and hence less likely to have answered the NPTS survey. Hence, the NPTS probably underestimated long-trip travel, and, reciprocally, overestimated short-trip travel[21].

The best way to estimate total travel, long trips, and even commercial driving is of course to sample everybody randomly, regardless of where they are at the time of the survey. If one did this, one would have to ask only about the previous day's travel; one would not have to ask about the previous two-week's travel.

4.A.1.6 Conclusions:

As mentioned above, the NPTS is the most comprehensive and useful source of data on personal travel in the U.S. However, as with any survey, there are a number of caveats regarding its use.

1). Most importantly for our purposes, the NPTS is not intended to be a comprehensive estimate of commercial driving in the U. S. Thus, the NPTS estimates of "commercial miles driven" in trucks is substantially less than the amount of miles actually driven by trucks operated by businesses.

Also, the meaning of "commercial driving" in the NPTS is somewhat non-intuitive. In the NPTS, "commercial driving" refers neither to driving in vehicles used exclusively for business or commercial purposes, nor to trips made for commercial or business purposes, but rather to miles driven as a part of work by those who drive regularly as an essential part of their work.

2). The NPTS sample is not representative: people who were away from home, and presumably had traveled a lot recently at the time of the survey, were excluded; hence, their travel behavior was underrepresented.

3). Agreement between the NPTS and the FHWA estimates of total VMT may be fortuitous, because of differences in coverage.

4). Long-trip travel probably is under-represented in the NPTS.

5). Either the term "privately owned vehicle," used throughout the discussion of the NPTS results (Hu and Young, 1993a, 1993b), actually includes publicly owned vehicles, or else travel in publicly owned vehicles actually is excluded from some of the reported results.

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[21]Note that one cannot get around this problem simply by extending the travel period from two weeks to, say, one month or even longer. That merely would give one a more accurate measure of long-trip travel from the unrepresentative sample.

4.A.2 MY USE OF THE NPTS DATA AND OTHER DATA ON TRAVEL

Recall that my ultimate aim here is to determine how best to disaggregate and characterize total travel, for the purpose of calculating the amount and cost of time spent in motor vehicles. For example, I need to determine how best to distinguish business travel from personal travel, because business travel displaces mainly productive work, whereas personal travel displaces mainly leisure, and productive work is worth more than leisure. Beyond that, I need to determine the best source of data on business travel and personal travel.

I use the FHWA (1992) data on total VMT and PMT, because as discussed above the NPTS data on total travel in my view have shortcomings. I then separate business travel, in four different vehicle classes: automobiles, light-duty trucks without paid drivers, light-duty trucks with paid drivers, and heavy-duty trucks. I distinguish between LDTs with paid drivers and those without because the former incur a higher time cost. I use the TIUS data to estimate business travel in HDTs and LDTs, because as discussed above, the TIUS data on business travel in private trucks are more complete and more accurate than the NPTS data on business travel in trucks. I estimate total business travel in private LDAs as a residual: the difference between total travel in all vehicles and total travel except business travel in private LDAs. I use this residual method, rather than use the NPTS data on business travel in autos, because of the problems with the NPTS estimates of commercial travel, and because the NPTS data include business travel in publicly owned autos, which I count separately. I also separate travel in publicly owned (government) vehicles, because travel data are available for several different kinds of publicly owned vehicles (in FHWA, 1992, and other sources; see Table 4-1), and because travel in public vehicles most likely comes at the expense of productive work. Similarly, I separate travel in buses.

However, I use NPTS data on personal household travel, because it is the most detailed and comprehensive source of data on personal travel. In the NPTS data set I distinguish two kinds of personal travel, where “personal” travel excludes commercial and work-related travel as defined in the NPTS: i) all personal travel reported for the travel day, and ii) any *additional* personal ravel reported for the travel period but not the travel day (see the discussion above). That is, I subtract the “overlap” between the travel-day and the travel-period data from the travel-period or “long-trip” results, rather than from the travel-day results, as the NPTS does. The NPTS subtracts the overlap from the travel-day results because it wants a separate, complete estimate of long-trip travel. I do the reverse because I have analyzed the travel-day but not the travel-period data set in detail, and wish to retain all of the detail for all of the trips, including whatever long trips are reported in the travel-day data set. Note, though, that I make no corrections for errors introduced by the unrepresentativeness of the NPTS sample (as discussed above).

A final note: to the extent that individuals drove public vehicles for purely personal reasons (wherein “work-related travel” is *not* a “personal” purpose), and reported such driving in the "travel-day" section of the NPTS, my estimates here will double count mileage in publicly owned vehicles: once as "daily travel in private motor vehicles for personal purposes," and again as mileage recorded for federal or state civilian vehicles. I suspect, though, that few people actually drove public vehicles for purely personal reasons, and that few of those who did reported such mileage as personal mileage in the travel-day section of the NPTS. I assume that all personal travel reported in the travel-day section of the NPTS was in privately owned vehicles.

4.A.3 COMPARISON OF THE RESULTS OF OUR ANALYSIS OF THE NPTS DATA WITH OTHER ANALYSES OF NPTS DATA, AND WITH OTHER SOURCES OF DATA

4.A.3.1 Comparison with other analyses of the NPTS data

Our analysis of the raw NPTS data, the results of which are presented in Tables 4-2, 4-3, and 4-4, is consistent with other published analyses of the NPTS data.

1). Hu and Young (1993a) analyze the NPTS data and report that in 1990, persons 5 years old and older traveled 2,040 billion person miles in autos, vans, pickups, and other private vehicles. Our estimate of total personal travel in cars, excluding travel to public transit modes, is 2,078 billion person-miles (Table 4-3) multiplied by 1.002 (to account for access trips to public transit; see notes to Table 4-3) = 2,082 billion, which is 2% higher than the Hu and Young (1993a) estimate. Part of this minor difference might be due to the difference in coverage: we include trips in taxis, and they do not, but they include trips in recreational vehicles and motor homes, and we do not. It also might be due to a different treatment of non-responses.

Hu and Young (1993a) also report PMT by six household income classes. Our estimates of PMT by income class are within 1% to 2% of theirs.

2). Pisarski (1992) analyzes the NPTS data and estimates that commuters spent 19.0 minutes to travel 11.0 miles to work in a "personally-occupied vehicle," making an average speed of 34.7 miles per hour for the journey-to-work trip. The average commute time for all modes was 19.7 minutes[22]. We estimate that commuters by car drove at an average of 34.6 mph to work (Table 4-4). These two estimates are almost identical. The tiny difference most likely is due to the difference between Pisarski's "personally occupied vehicle" and our "car" (see Table 4-4). It also might be due to different definitions of the journey to work trip, although this is unlikely.

In general, our estimated travel speeds, which are equal simply to miles divided by hours in each category, are plausible (Table 4-4). Average speeds by car are between 30 and 40 mph; average speeds by bus, between 10 and 20 mph. Average speeds by car are highest for work-related business trips (which probably include a lot of freeway travel by salesman), second highest for social or recreational trips (which tend either to

[22]Pisarski (1992) also states that the American Housing Survey found a median commute time of 20 minutes in 1989, and that the U. S. Census found an average commute time of 22.4 minutes in 1990.

be relatively long, or else to occur during uncongested times), next highest for work-commute trips, and lowest for shopping and person business trips (which generally are relatively short, and occur on slow surface streets). In fact, our estimated ranking of average speed by trip purpose follows the ranking of average length by trip purpose (Hu and Young, 1993a). This seems reasonable: longer trips involve more higher-speed, freeway driving.

There is one caveat, however. A few of the combinations of trip purpose, income class, and travel mode are quite rare -- so rare that random errors in reporting or estimating travel time or trip distance could have combined to generate inaccurate results. In general, some respondents will overestimate travel time or trip distance, and some will underestimate them. With a large enough sample, the overestimates will roughly cancel the underestimates (unless there is a systematic reporting bias), and the total travel time and distance will be reasonably accurate. However, if for example only a few wealthy people in the survey reported work-related travel by train, then it is possible that the total reported travel time was significantly underestimated, and the reported trip distance significantly overestimated, with the result that the average speed was grossly overestimated. The reverse could have happened, too. This could explain why our calculated range in average speed for train travel varies from 0.2 mph to 537.6 mph. (The other possibilities are errors in data entry or coding in the NPTS data tapes, or errors in our own data-extraction program.) With car travel this problem presumably is avoided, because there were so many responses that it is likely that the average is fairly accurate.

4.A.3.2 Comparison with estimates of time spent in vehicles

The estimated total number of person-hours in Table 4-2 can be translated into minutes per day per person and compared with surveys of how people spend their time each day. In 1975 and 1976, persons 18 and over in the U.S. reported that they spent an average of 83.5 minutes per day in travel (Hummon, 1979). Similarly, in 1985-1987, persons 18 and over in the U.S. spent an average 84 minutes in travel, including riding public transit, but excluding travel during work (Wiley et al., 1991). In 1987 and 1988, teenagers and adults in California spent an average of 111 minutes in travel, including walking and travel during work, of which 91 minutes were in a car or a van (Wiley et al., 1991). Apparently, these estimates does not include the time of commercial drivers, such as drivers of interstate trucks, or others, such as highway patrolman, who in effect work in their vehicles.

Our estimated travel time per person is lower than the time per person results from these surveys. If we sum the annual person-hours in “uncompensated personal” travel, “compensated work” travel, “Federal civilian” travel, and “state and local civilian” travel, from Table 4-1, divide by 365 day/year, multiply by 60 minutes/hour, multiply by 0.90 adult-hours/person-hour (Hu and Young, 1993a)[23], divide by 186

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[23]The data of Table 4-2 pertain to all persons 5 years of age and older. Data in Hu and Young (1993a) indicate that travel by persons 18 and older is 90% of travel by persons 5 and older.

million persons 18 or older in the U.S. in 1990 (Bureau of the Census, *Statistical Abstract of the United States, 1992*, 1992), we get 63 minutes per adult per day in non-commercial motor vehicles, which is lower than the results from the time-budget surveys. If we add about 13 billion person-hours in public transit, we get about 73 minutes per person per day. I cannot explain the discrepancy between this figure, and the figures reported from time-budget surveys.

TABLE 4-A1. SUMMARY STATISTICS FROM THE NPTS, AND FROM FHWA, FOR 1990

	NPTS travel-day adjusted (section H)	NPTS travel-period (section G)	NPTS commercial driving	NPTS total	NPTS driver data (section F)	NPTS vehicle data (section B)	FHWA (1992) data:
PMT	2,315,273 – 333,205[c] = 1,982,068 adjusted	886,235	n.e.	2,868,303[a]	n.e.	n.e.	3,295,298[b]
VMT	1,409,513 – 133,784[c] = 1,275,729 adjusted	337,332	302,824	1,915,948	2,139,703[d]	2,058,323[e]	2,144,362[f]

[a]Person-miles of travel by car, motorcycle, truck, bus, walking, train, or bicycle; equal to adjusted travel-day PMT plus travel-period PMT.

[b]This is based on data from the NPTS, the *Truck Inventory and Use Survey,* and the *National Transportation Statistics* annual report. Hence, it is not completely independent of the NPTS estimates. It includes PMT in highway vehicles only: cars, motorcycles, buses, and trucks, but not trains.

[c]This is the amount of PMT or VMT that originally is included in both the travel-period and the travel-day results. To avoid double counting, Hu and Young (1993b) subtract this amount from the raw or unadjusted travel-day totals, to arrive at the adjusted totals. See the discussion in the appendix text above.

[d]Total miles driven in any licensed motorized vehicle.

[e]Total VMT by licensed motor vehicles owned or used regularly by households.

[f]Total miles of travel by highway vehicles: cars, motorcycles, buses, and trucks. The estimate is based primarily on traffic counts reported by the states, and hence is completely independent of the NPTS estimates.

TABLE 4-A2. BUSINESS AND COMMERCIAL USE OF HIGHWAY VEHICLES: THE NPTS VERSUS THE TIUS (10^6 MILES)

	1990 NPTS[a]			1987 TIUS[b]	1992 TIUS[c]	1990 TIUS l.i.[d]
	Commercial driving	*Work-related travel*	*Total*	*Non-personal uses*	*Non-personal uses*	*Non-personal uses*
Automobile	110,605	33,204	143,809	n.i.	n.i.	n.i.
Pick-up truck	58,660	4,951	63,611	93,267	129,128	114,784
Van[e]	28,005	2,794	30,799	48,424	77,592	65,925
Other truck	90,981	1,375	92,356	100,668	115,583	109,617
Other vehicle[f]	14,573	12	14,585	n.i.	n.i.	n.i.
All trucks[g]	*177,646*	*9,120*	*186,766*	*242,359*	*322,303*	*290,326*

NPTS = Nationwide Personal Transportation Survey; TIUS = Truck Inventory and Use Survey; n.i. = not included in survey; l.i. = linearly interpolated. Note that the TIUS excludes mileage in publicly owned vehicles; the NPTS does not.

[a]From Hu and Young (1993b).

[b]From the Bureau of the Census (1990).

[c]From the Bureau of the Census (1995).

[d]Linear interpolation (l.i.): values are equal to 1987 values plus 3/5 of the difference between 1992 and 1987.

[e]Passenger van and cargo van in the NPTS; minivan, panel truck, van, utility truck, or station wagon in the TIUS.

[f]Other private vehicle, bus, school bus, other, and vehicle-type-not reported, in the NPTS.

[g]Pick-up trucks plus vans plus other trucks.