an appropriate location. The diminishing lines appear very effective in stimulating driver awareness to the surroundings and creating an illusion of acceleration. There will be no long-term effect on speeding, however, unless there are valid and obvious reasons for the driver to slow in that particular area. The stronger implied surveillance and threat of enforcement may have contributed to the greater impact of the feedback sign, although more work will have to be done to factor out the respective impact of each.

Once the proper location has been determined for these techniques, they can be complementary to an enforcement program. Both are relatively permanent fixtures and remain active 24 hr a day, therefore being visible to all road users. They are also very effective in reducing inattention, thereby allowing the driver an opportunity to comply with the speed limit on his own accord. Drivers who ignore these devices and speed anyway usually do so intentionally and become suitable candidates for behavior modification through police enforcement. This allows police to concentrate their efforts on those locations and times when drivers are most likely to respond to their influence.

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Excess Travel: Causes, Extent, and Consequences

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The amount of excess travel in the United States is estimated on the basis of past research and new empirical studies. Excess travel is defined as the arithmetic difference between total actual highway use, exclusive of destination-free "pleasure" driving, and the use that would have resulted if all such travel had been made by using the optimum route connecting each individual origin-destination pair. Excess travel is shown to be caused by a number of different factors acting singly or in combination. These include route selection criteria and efficiencies in necessary route-planning information, in the highway information system, and in both route-planning and route-following skills. The synthesis of all available data indicates that excess travel contributes 4 percent of all vehicle miles of travel and 7 percent of all travel time for work-related trips. Corresponding figures for non-work-related trips are 20 and 40 percent, respectively. Applying these proportions to total U.S. travel results in a total of excess travel amounting to 83.5 billion mi and 914,000 person-years per year at a total estimated cost of more than $45 billion.

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It has been estimated that transportation in the United States consumes approximately 27 percent of all energy used and 65 percent of all petroleum products *(1)*. Highway users account for 80 percent of all transportation-related use of petroleum products at an annual cost to the consumer of $40 billion. The total economic cost of highway accidents has been variably estimated to range from $40 billion to $75 billion per year *(2–5)*.

Although the relationships are somewhat complex and not necessarily linear, it has been shown that both fuel consumption and accident frequency are directly related to total vehicle mileage *(6, 7)*. Other adverse effects of personal mobility, including air and noise pollution and wear and tear on the highway system, can also be represented as functions of highway use.

Furthermore, annual total U.S. vehicle miles of travel (VMT) of nearly 1.75 trillion mi (2.8×10^{12} km) *(8)*, at an average occupancy of 1.65 [Nationwide Personal Transportation Study (NPTS) data], implies that a total of approximately 7.5 million person-years, or an average of almost 11.5 days per person, of automobile travel are accumulated each year.

Minimizing energy use, accident involvement, air and noise pollution, wear and tear on the highway system, and unproductive use of time are desirable social, as well as individual, objectives. Without extensive changes in modal split or trip making, or both, this minimization can be approached by optimizing route choice, that is, by ensuring that each motor vehicle trip made uses the optimum route in terms of both distance and time.

For any given trip, many different factors may contribute to a departure from such an optimum routing, and many different remedial measures have been tried or advocated to overcome such departures. In order to select and implement any combination of these and thus optimize highway travel, it is first necessary to develop

- An estimate, disaggregated by driver and trip attributes, of the proportion of all highway travel that is "excessive" or "wasted," and
- An estimate of the economic costs generated by such excess travel.

A recent FHWA research project designed to develop these estimates is summarized here.

EXCESS TRAVEL

The concept of excess travel rests on two assumptions:

1. Highway travel, with minor exceptions, is purposeful. Vehicle trips represent an attempt to go from one point on the highway system to another.
2. Wardrop's first law of traffic *(9)* is valid. Drivers will, if given perfect information, select the route that minimizes travel time (or costs) in traversing a network.

Excess travel is thus defined as the arithmetic difference between total actual highway use, exclusive of destination-free "pleasure" driving, and the use that would have resulted if all such travel had been made by using the optimum route connecting each individual origin-destination pair. In this definition, highway use as well as route optimization, and therefore excess travel, can be based alternatively on distance, time, or some cost function that combines these parameters.

Excess travel can be due to any of the following factors or to several acting jointly:

- Use of a route-selection criterion set that does not emphasize route optimization.
- Failure to consider an adequate number of alternative routes.
- Inadequate skills to identify optimum routes.
- Unavailability, inadequacy, or inaccuracy of the information necessary for route selection.
- Failure to follow a planned route because of deficiencies in formulating a route description or in the storage of that description.
- Failure to follow a planned route because of lack of adequate skills or of required a priori knowledge.
- Failure to follow a planned route because of deficiencies in the highway information system.
- Incorrect evaluation of real-time route-choice alternatives.
- Voluntary diversion from a planned route.
- Forced diversion from a planned route followed by selection of a suboptimum detour route.

In addition to the foregoing factors, which affect individual trips, excess travel can also occur as the result of inefficient sequencing of multilink trip chains or failure to aggregate individual trips into such trip chains.

Both the individual causes of excess travel and the excess itself have been the subject of prior studies. These studies, however, did not address all potential instances of excess travel. Furthermore, although these studies clearly indicate the existence of an excess-travel problem in terms of the proportion of times that suboptimum routes were used, existing data are inadequate to quantify the excess so generated or to stratify this excess by driver or trip attributes. Finally, a considerable proportion of the more comprehensive and more recent studies have been made abroad and the generalizability of the quantitative results obtained to U.S. conditions is somewhat questionable. To overcome these problems, a number of empirical studies were carried out. The methodology and results of these studies have been reported elsewhere *(10–12)*.

Considerable research has been done on identifying and, to a lesser extent, quantifying the distribution of route-choice criteria used by motorists. In many instances, motorists were found to apply more than one criterion to a specific route plan. The criteria selected are applied either simultaneously, in the form of an implicitly weighted linear function, or hierarchically. These studies have been summarized elsewhere *(13)*. A taxonomy of more than 50 distinct criteria is included in the summary. The choice of desired route attributes (route-selection criteria) represents largely subjective decisions by individual drivers. Optimization of these decisions probably requires long-term changes in attitudes and in individual value systems. This aspect of the problem will therefore not be considered further.

The results of some major studies oriented specifically toward quantifying the excess-travel problem are given in Table 1 *(14–26)*. Examination of this table shows that

- For nonwork, non-CBD trips, excess travel, in every study, amounted to more than 10 percent of optimum, and
- In every instance in which data on both parameters were obtained, the proportion of excess time is considerably larger than the proportion of excess distance.

No study systematically examined the causality for this excess travel. The literature, however, presents some indication of potential causes without allowing for the evaluation of the quantitative contribution of each of these. For instance, Benshoof *(27)* compared the actual route selected according to a stated criterion with the optimum route for the same criterion for relatively short trips (1.4 to 4.0 mi) to a city center. The results were as follows ($N \approx 1{,}300$):

Criterion	*Proportion Selecting Optimum Route*
Quickest	0.823
Shortest	0.598
Least stops	0.771
Least traffic	0.713

Benshoof explains this relatively poor performance by postulating that

1. Route selection, for many motorists, is a largely irrational process, and
2. Many motorists do not actually measure certain characteristics of their routes.

This second conclusion was also reached in a Swedish study of route choice *(28)*:

> The reason drivers choose different routes is not only that they ascribe different values to the road characteristics but also, to a great extent, that they simply do not accurately measure the characteristics of the routes. The capability of accurate measurement seems to decrease when this length increases.

Similar results and conclusions have been reported from other studies *(16, 29)*.

Quantitative data on failures in route following as contrasted with route planning are less common. It should be pointed out, however, that the relative contributions of route selection and route implementation for some of the studies summarized in Table 1 cannot be disaggregated. Data from a number of studies *(30–32)* show that a significant proportion of drivers reported that they lost their way or were observed at a location or traveling in a direction that could not be part of an optimum route trip plan. None of these studies, however, quantified the excess travel so generated.

Only one empirically based overall estimate of total excess travel could be located in the literature. Jeffery *(33)* synthesized the results of all studies made in Great Britain and concluded that 6.9 percent of all driver costs are due to excess travel. Using conservative estimates that route changes for repeat trips of less than 5 km (3.1 mi) are unlikely and that for a substantial proportion of non-work-related travel drivers do not seek to optimize their routes, he concluded that approximately 2.2 percent of all journey costs represent recoverable excess costs.

All studies discussed so far dealt with single trips from one origin to one destination. However, multistop, multipurpose travel is frequently undertaken. Such a trip chain, or tour, can introduce considerable excess travel if the sequencing of the individual trip segments is not optimized insofar as permitted by external constraints.

In a Canadian study *(34)* the sequencing of stops on a tour and the time used as a function of the possible minimum for tours of from one to five stops were analyzed. For tours with three or more stops the aggregate excess time consumed amounted to 7.5 percent of the total time. Optimality of individual trips within the tour was not investigated.

Excess travel is also generated by accessing activities in single trips rather than combining these into complex automobile tours. In a study in Detroit *(35)* it was estimated that 67.4 percent of all activities were accessed by complex tours and that a net saving of 7 percent of total VMT could be achieved if this proportion was raised to 83.7 percent.

TABLE 1 RESULTS OF PREVIOUS STUDIES

Reference and Year	Location	Method	Trip Purpose	No. of Subjects and Trips
14, 1975	Central London, England	Car following	Not determined	853
15, 1969	Suburban Washington, D.C.	Staged trips	Not applicable	20
16, 1970	Rome, Italy	Route mapping	Not applicable	82, 384
17, 1967	Vasteras, Sweden	Actual trips	Various	878, 1,235
18, 1981	Eindhoven, Netherlands	Actual trips	Work to home	232
19, 1966	San Francisco, Calif.	Actual trips	Work	574
20, 1966	San Francisco	Actual trips	Work	343
21, 1975–1976	England	Staged trips	Not applicable	70
22, 1974	England	Actual trips, en route interviews	Various	4,915
23, 1979	Tokyo, Japan	Simulation	All	–
24, 1972	England	Route mapping	Not applicable	337, 490
25, 1971	England	Route mapping	Not applicable	128
26, 1984	Suburban Washington, D.C.	Induced error	Not applicable	11

[a]Mean value.

FACTORS AFFECTING NAVIGATIONAL WASTE

The proportion of navigational waste is not uniform across all trips made. For any one trip the existence and magnitude of navigational waste is a function of many interrelated factors, including

- Route planner or driver attributes, or both;
- Trip purpose;
- Trip length;
- Highway systems used;
- Destination, route, and area familiarity; and
- Environmental conditions.

Trip-planning and route-following efficiency, like all cognitive activities, is a function of intelligence, skills, and experience. These items are correlated, though not perfectly, with such attributes as age, sex, education, and driving experience. Empirical evidence from past studies indicates that in most cases, the effect of demographic variables on the amount of navigational waste is small, inconsistent, and, usually, insignificant. However, the extent to which these variables have been studied systematically cannot be determined. One major exception is the correlation of ability to use a map with education, training, and especially spatial visualization. The population distribution of these characteristics is, however, not known.

The empirical portions of this research indicated a significant correlation between subject's sex and navigational efficiency. These results were, however, based on small sample sizes and furthermore were extremely inconsistent between the different levels of trip planning (i.e., the relative contributions to navigational waste of route-selection and of route-following failures). No other significant demographic effects were found.

Another class of driver attributes should be mentioned even though its effect cannot be easily quantified. The efficiency of route selection is clearly related to the amount of effort devoted to that task and to the absence of distracting influences. Similarly, the probability of error or of suboptimum decisions in route following is a function of the driver's momentary physiological and psychological state and of the presence of internal or external distracting factors. No empirical studies could be located that address this topic although the adverse effects of fatigue, alcohol, and psychological factors such as preoccupation on other aspects of the driving task have been well documented [e.g., by Shinar *(36)*].

Trip purpose is closely related to trip length and to familiarity, both of which are discussed in the following paragraphs. The major attribute of trip purpose, applying especially to the distinction between work-related trips and other trips, is the frequency with which trips are repeated. The more often a trip is repeated, the greater is the investment it represents in terms of driving costs and time, and therefore the greater is the probability that the trip-planning effort is enhanced and a greater number of alternative routes tried. However, evidence from past studies as well as questionnaire data collected as part of this project *(37)* indicate that, even for frequent trips, an inadequate number of alternative routes is tried. Furthermore, researchers have concluded that many drivers do not properly evaluate the data they obtain by trying alternative routes.

Trip length is obviously correlated with the use of different highway systems and with area familiarity. More directly, the length of a trip is an indication of the number of decision points encountered and hence of the number of error possibilities. The length of a trip is usually also directly correlated with the area covered. Increasing the size of that area increases the demands placed on cognitive mapping ability, which have been shown to be closely connected with navigational efficiency. It should, however, be pointed out that past research results that indicate that a large proportion of total excess travel occurs in the terminal phase of a trip appear to indicate that the total length of the trip may be of less importance.

The type of highway system, or highway functional classification, used for a trip exerts an effect on navigational waste through a number of separate mechanisms.

- The frequency of decision points (e.g., intersections, bifurcations, and interchanges) per unit distance is usually related to highway functional classification.
- The quality and adequacy of the highway information system, including signing, delineation, and other information

	Mean Excess (%)		Extreme Value (%)			
Distance	Distance	Time	Distance	Time	Percentile	Notes
≤7 km	+ 5.5		≅75		95	13.1 percent excess crossings
10.8, 14.3 mi	+ 47.0	+135.2	+89.3	+187.3	90	Two routes
6.25 km	+ 13.2	+ 33.0	+33.2		95	Six routes
Variable, 3.1 km[a]	+ 6.4		+30.0		95	–
4.7 km[a]	+ 7.2	+ 13.2				Least-time criterion
–	+ 3.1	+ 5.3	+10	+ 32	95	–
–	+ 5.7	+ 9.8	+21	+ 36	95	–
24.4, 107.7 km	+ 23.7	+ 29.4				Two routes
18.6 km[a]						Plus 7.2 percent generalized cost
–		+ 6.0				Improvement
–		+ 10.3				–
18 km	+ 18.9			+ 41.4	Max.	–
6.8 km	+150.0					–

sources, are usually better for the higher functional highway classification.

- The penalties associated with navigational errors—that is, excess time and distance to return to the proper route—are different, especially between conventional and limited-access facilities.
- The probability that a given highway link is properly shown on a map, especially one with a relatively large scale, is directly related to that link's classification.
- Choices between alternatives during trip planning often depend on subjectively assigned attributes of different functional classifications. These attributes may not correspond to objective reality.

Little quantitative, empirical data on these items are available except for some rather dated studies on diversion to newly opened freeways and on free versus toll road use. Some data on time-distance tradeoffs were derived from the questionnaire survey *(37)*.

Familiarity with the destination, route, and area obviously has a major effect on the probability that an optimum route will be both selected and followed. Past studies of work-trip routing, however, indicate that familiarity by itself is not a sufficient condition for minimizing navigational waste. Most empirical studies have deliberately excluded subjects familiar with the routes, destinations, or areas used in the experiments. No quantitative data on this topic are therefore available.

Different routes connecting the same O-D pair may be optimum depending on environmental conditions. If these conditions are not properly considered by the driver, if available alternative routes are not known or are avoided for other reasons, or if the environmental conditions are not anticipated, excess travel will be generated.

The preceding brief discussion has indicated the mechanisms by which individual factors may affect the extent of navigational waste. The discussion has also shown that available data are inadequate to completely disaggregate the relative contribution of each of these or assess their interactions. The following discussion of the proportion of total travel that is wasted will therefore be presented in aggregate terms except for those cases (e.g., trip purpose) in which disaggregation is possible.

PROPORTION OF TRAVEL THAT IS WASTED

The two major inputs into a determination of the proportion of all travel that is wasted are the synthesis of prior research studies, as summarized in Table 1, and the empirical data collected for this project. Insofar as past research results are concerned, major emphasis is placed on U.S. studies because the generalizability of foreign quantitative data to U.S. conditions is not known.

Work Trips

Two studies of work-trip routing *(19, 20)* have indicated excess travel of 3.1 and 5.7 percent of distance and 5.3 and 9.8 percent of time, respectively. In both cases the results were obtained by comparing self-reported actual to optimum routes. The subjects also indicated an extremely high rate of repetition of the same route. Under these conditions, it can safely be assumed that the entire excess is due to suboptimum route selection rather than to failures in route following. On the basis of these studies and European studies that indicate results of a similar order of magnitude, an estimate of 4 percent excess distance and 7 percent excess time for work trips can be supported.

Other Trips

On the basis of newly collected empirical data, trips to unfamiliar destinations average 126.5 percent of the optimum distance and 169.6 percent of the optimum time. These data thus indicate that 21 percent (26.5/126.5) of all distance traveled and 41 percent (69.6/169.6) of all time used for these trips represents navigational waste. These figures are somewhat lower than those reported from previous U.S. studies but are comparable to some more recent European results (see Table 1).

Detailed analysis of the empirical data indicates that the contributions of faulty trip planning and faulty trip plan execution to the proportion of excess travel are almost exactly equal.

Summary

On the basis of the preceding discussion, the following estimate of percent excess travel due to navigational waste can be made.

		Excess (%)	
Trip Purpose	*Causality*	*Distance*	*Time*
Work trips	Route planning	4	7
	Route following	–	–
Other trips (unfamiliar destination)	Route planning	10	10
	Route following	10	30

Further disaggregation of these results would be highly desirable but, as previously indicated, an adequate data base for that purpose is not available.

Because different proportions of excess travel apply to different trip purposes, an assumption concerning the distribution of total travel by purpose must be made. On the basis of an analysis of NPTS data *(38)* made by KLD Associates, Inc., it can be assumed that 40 percent of all VMT is work related. Three other assumptions will be made.

- Automobile travel to unfamiliar destinations, or using unfamiliar routes, amounts to 25 percent of all nonwork travel.
- Nonwork trips to familiar destinations, or using familiar routes, have the same characteristics as work trips.
- The probability of occurrence and magnitude of the consequences of an error in either trip planning or route following are independent of the criteria used for route selection. In other words, there will be a recoverable navigational waste component even in trips previously defined as incurring deliberate waste.

Given these assumptions, the proportion of all automobile travel that falls in the category of recoverable navigational waste can easily be calculated by evaluating

Proportion work travel × proportion waste in work travel + proportion other travel × (proportion unfamiliar × proportion waste in unfamiliar travel + proportion familiar × proportion waste in work travel).

Thus,

Proportion excess distance:
$0.4 \times 0.04 + 0.6 \times (0.25 \times 0.20 + 0.75 \times 0.04) = 0.064$,

Proportion excess time:
$0.4 \times 0.07 + 0.6 \times (0.25 \times 0.40 + 0.75 \times 0.07) = 0.120$.

It must be emphasized that this estimate is restricted to trip planning and route following under essentially steady-state conditions. Excess time occasioned by failures in real-time trip planning—that is, the failure to adjust trip plans to changes in traffic, highway, or environmental conditions—cannot be quantitatively estimated because of the absence of applicable empirical data. Past analyses of this problem, including some simulation studies, indicate that this component of excess travel can be substantial.

No attempt has been made to estimate the proportion of all travel that can be considered deliberate waste because little data are available that would permit evaluating the quantitative effects on travel time and travel distance of the use of "nonoptimizing" criteria in route planning.

ESTIMATED TOTAL EXCESS TRAVEL DUE TO NAVIGATIONAL WASTE IN THE UNITED STATES

Total automobile travel in the United States occurs at an annual rate of 1744.9×10^9 mi *(8)*. The latest available (1983) FHWA data *(39)* indicate that 74.8 percent of this travel is accumulated by personal passenger vehicles. Assuming that this percentage remains unchanged and applying the proportions computed in the preceding section, the total excess travel by noncommercial vehicles in the United States can be estimated as totaling 83.5 billion mi per year.

Estimating the excess time consumed by this navigational waste is somewhat more difficult because reliable data on the amount of time spent in automobile travel are not available. Using NPTS data on vehicle occupancy and representative values of average travel speed for various highway systems, the total time in automobile travel can be estimated as follows.

Work trips:
24.0×10^9 hr = 2.74×10^6 years,

Nonwork trips:
41.5×10^9 hr = 4.73×10^6 years,

All trips:
65.5×10^9 hr = 7.47×10^6 years.

Using previously derived proportions, the excess time due to recoverable navigational waste is as follows.

Work trips:
1.68×10^9 hr = 192,000 years,

Nonwork trips:
6.33×10^9 hr = 723,000 years,

All trips:
8.01×10^9 hr = 914,000 years,

or approximately 34 hr per year for every single person in the United States.

The calculations developed in this section thus indicate that 6.4 percent of all miles driven and 12.2 percent of all time spent can be conservatively assumed to represent recoverable navigational waste.

These estimates apply only to navigational waste under essentially steady-state conditions. The excess travel due to suboptimum real-time route planning—that is, adapting routes to actual traffic, highway, and climatological conditions—has not been addressed.

COSTS ASSOCIATED WITH EXCESS TRAVEL

The total costs that can be attributed to excess travel are made up of a number of component parts as follows:

- Vehicle operations,
- Accidents,
- Vehicle occupancy time,
- Maintenance and operation of the highway system, and
- Miscellaneous external costs.

Vehicle Operations

On the basis of a synthesis of published data and estimates *(6, 39, 40)* of vehicle operating costs, a figure of $0.12/mi for variable costs was derived and is used in subsequent calculations. No change in fixed costs is assumed to occur as a consequence of excess travel.

By adjusting published data *(41)* on average vehicle fuel consumption for intervening changes in the composition of the U.S. vehicle fleet, the average energy use for the 1985 fleet can be computed as 0.0400 gal/mi. If it is now further assumed that there is no difference in fuel consumption variables between excess driving and total driving, the net energy impact of nondeliberate excess driving is 3.3 billion gal of gasoline per year.

Accidents

The total cost of motor vehicle accidents to the individuals involved as well as to society as a whole has been estimated as $43.3 billion and $57.2 billion, respectively, by the National Safety Council *(2)* and by NHTSA *(5)*. In a more recent study *(3)* total cost is disaggregated by accident severity. Using these figures and data on the distribution of accidents by severity *(3, 42)* yields a total societal accident cost of $83.3 billion or $0.0484/mi in 1985 dollars.

The accident consequences of excess driving consist of two components. The first of these is the additional exposure due to the additional vehicle miles of travel. To evaluate this component it can be assumed that the distribution of excess travel by highway type is the same as the distribution of total travel.

The second component is much more difficult to quantify. It is the possible additional accident potential due to the joint effect of route unfamiliarity and directional uncertainty. No direct data on these items are available. However, past studies of the relative odds of accident culpability as a function of route familiarity *(43, 44)* and analyses of the driving task *(7)* indicate that it appears safe and conservative to assume that the accident potential during the excess portion of driving is at least 10 percent higher and can thus be estimated to be $0.053/mi. Furthermore, on the basis of the stated assumptions, it can be estimated that excess travel is responsible for 7 percent of all traffic fatalities, or about 3,000 per year.

Time

Quantification of the value of time represents one of the most controversial and conceptually difficult aspects of highway economic analysis. Yucel has made an excellent review of these problems *(45)*.

In the major U.S. research effort on this topic, done by the Stanford Research Institute in 1967 *(46)*, the value of time was found to be highly correlated with gross hourly earnings for private nonagricultural employment. Maintaining this proportion and using the 1985 earning figure of $8.57 *(47)* yields a value of time of $8.72. This is almost identical to the value computed for work trips from project questionnaire data *(37)*.

In deriving an estimate for the value of excess time due to navigational waste, the following, mostly conservative, estimates were made based on past research *(46)* and on the analysis of the questionnaire data *(37)*.

- The unit value per hour of time is $8.50 for work trips and $6.50 for nonwork trips.
- Twenty-five percent of all travel time is accrued on trips that are so short that the excess time per trip is less than 5 min. No value is assigned to this excess.
- One-third of total vehicle occupancy for nonwork trips is contributed by children, whose time has no monetary value.

On the basis of these assumptions, the estimated cost of excess time due to recoverable navigational waste is

Trip Type	*Cost ($ billions)*
Work	10.7
Nonwork	20.6
Total	31.3

As with previous estimates, the excess time effects of deliberate waste have not been estimated. Apart from the impossibility of quantifying the net effects of such deliberate waste, the valuation of the time so consumed introduces a conceptual problem. Because this excess time is the normal result of deliberate action on the part of the driver, it may not be considered "wasted."

Air and Noise Pollution

Air pollution due to vehicular emissions is directly, although not linearly, correlated with VMT. Methodologies exist by which the increase in the amount of pollutants can be approximated. However, no reliable methodology exists by which this pollution level can be translated into incremental costs.

The quantification of noise pollution and especially its conversion into monetary terms represents an even more indeterminate subject. For these reasons, costs associated with increased pollution levels have not been considered in this evaluation.

Highway System Maintenance and Operations

The rate of deterioration of the highway system and the consequent need for maintenance, rehabilitation, or reconstruction are direct results of the physical demands placed on pavement and bridge structures. These demands are a function of axle loading and distance traveled. The relationships between axle loading and wear and tear are not linear. A moderate increase in axle loadings can lead to rapid increases in the rate of deterioration. Because commercial truck traffic was specifically excluded from the scope of this research effort, this topic will not be addressed.

The cost of highway system operations, and especially traffic control, can be directly related to traffic volumes and to their spatial and temporal distribution. Here again the relationship is not linear. A 10 percent increase in traffic volume that raises the volume-capacity ratio from 0.82 to 0.90 can have an enormous effect on the need for traffic management or even on the need for new or improved highway facilities.

However, a valid quantification of these effects would require fine-grained disaggregation of excess travel in terms of its spatial and temporal distribution and the highway systems affected. Such disaggregation is not possible with existing data.

Summary

The total annual cost of navigational waste in noncommercial travel can be estimated, on the basis of the preceding discussions and computations, as follows:

1. Vehicle operating costs, $83.5 \times 10^9 \times \$0.12 = \$10.0 \times 10^9$;
2. Accident costs, $83.5 \times 10^9 \times \$0.053 = \$4.4 \times 10^9$;
3. Cost of time, $\$31.3 \times 10^9$;
4. Total, $\$45.7 \times 10^9$.

These cost figures do not include possibly significant but unquantifiable costs due to air and noise pollution and increased highway maintenance and operations requirements. Furthermore, these costs only cover the quantifiable effects of inadvertent route-planning and route-following failure under steady-state conditions. Costs, especially those associated with excess time due to congestion, occasioned by failures in real-time route planning are not included. Also not included are all costs associated with deliberate waste, that is, excess costs accrued on trips planned with other than optimizing criteria.

CONCLUSIONS

The following conclusions are indicated on the basis of the work accomplished under this project combined with previous analyses and empirical investigations:

- Recoverable navigational waste is made up of 6.4 percent of all miles driven and 12.0 percent of all time spent in non-commercial travel.
- This excess travel accrues costs to individual drivers and to society as a whole that exceed $45 billion per year, not including costs due to increased levels of air and noise pollution or increased demands for highway maintenance and operations.
- Additional costs, unquantifiable with available data but likely to be substantial, are accrued because of failures in real-time trip planning and deliberate waste.
- Approximately half of all recoverable navigational waste can be attributed to deficiencies in trip planning. The other half can be attributed to deficiencies in route following.
- There are no significant differences in the proportion of excess travel, by trip purpose, between day and night driving.
- There are no consistent significant differences in the proportion of excess travel based on driving experience or major demographic variables except that there are some indications that male drivers may perform somewhat better than female drivers.

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Abridgment

A Study of Route Selection from Highway Maps

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An experiment designed to assess the ability of subjects to plan long trips in unfamiliar areas by using only maps is described. The experiment was part of a larger study intended to describe and quantify the excess-travel problem in the United States. Subjects were asked to plan relatively long trips in unfamiliar areas by using only a road atlas. The sample was designed to represent the age and sex distribution of the U.S. driving population. The routes selected by the subjects were compared with the routes recommended by the American Automobile Association (postulated to be "optimum") for both distance and approximate driving time. Analyses of the data indicated that the excess distance of the routes selected by the subjects, on average, increased trip length by 12.1 percent. Age, sex, and geographic location of subjects had little effect on their performance.

Research *(1–3)* has shown that drivers face considerable difficulties in achieving optimum (i.e., in terms of minimum distance or time or both) routes from their origin to their destination. These travel inefficiencies have been shown to generate a considerable aggregate amount of excess travel.

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A comprehensive literature search *(4)* indicated that excess travel may be attributed to one or more of the following trip-making activities:

1. Use of route-selection criteria that do not lead to an optimum route;
2. Trip planning (i.e., application of criteria to route selection), including inadequate trip-planning skills or unavailable, insufficient, or inaccurate information for optimum trip planning;
3. Route following (i.e., implementation of a trip plan), including all aspects of response to, reliance on, and anticipation of highway information systems; and
4. Trip chain sequencing (i.e., ordering of multiple destinations in the absence of sequential or time constraints).

As part of a major FHWA-sponsored study *(5)* of the excess-travel problem and of potential remedial measures, a series of empirical studies of trip planning and route following were implemented. The procedures used and the results obtained for an experiment on trip planning for long trips in unfamiliar areas are described. The purpose of this experiment was to assess the