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About the Bureau of Transportation Statistics

The Bureau of Transportation Statistics (BTS) was established by the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. As the newest operating administration of the US Department of Transportation, the BTS mission is to compile, analyze, and make accessible information about the nation's transportation systems; collect information on intermodal transportation and other areas as needed; and enhance the quality and effectiveness of the Department's programs through research, the development of guidelines, and the promotion of improvements in data acquisition and use.

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Letter from the Director of the Bureau of Transportation Statistics

Transportation is the lifeblood of our economy, entering the production of every good and service and accounting for the high level of mobility that is an essential ingredient of our daily life. The President and Congress, in establishing the Bureau of Transportation Statistics (BTS) as a modal administration within the U.S. Department of Transportation (DOT) in 1991, recognized the critical need for accurate, reliable, timely information and a knowledge base to support a safe, efficient, dependable, and environmentally benign transportation system that serves all Americans. With that in mind, we are creating and making available transportation information to support improved decisionmaking and public policy formation, in addition to facilitating the transition of the broader transportation community into the rapidly emerging Information Age. Taking advantage of state-of-the-art information technologies and organizational opportunities in this era of government reform, which stresses accountability and performance, BTS is organized to respond to the current and emerging needs of its customers.

As a statistical agency, BTS addresses its missions from three perspectives. First, are we measuring the *right things?* This is particularly crucial in a world where transportation services and the socioeconomic, technological, and institutional context in which transportation operates are changing rapidly. Second, are we measuring things *rightly?* This pertains to our work on statistical quality and our research to develop improved measures of such concepts as costs, benefits, etc. Third, what does the information *mean?* The *Transportation Statistics Annual Report* and *National Transportation Statistics,* along with other BTS reports are our interpretive efforts in this area.

In creating the *Journal of Transportation and Statistics (JTS),* I seek to provide an instrument for open, scientific, and scholarly exchanges that hopefully will aid us in the above missions and in advancing the state of knowledge about transportation in a free society. The purpose of this new journal is to advance the art and science of transportation information to better serve society's common goals. But the *JTS* will not engage in policy advocacy. Strive as we may to present information and analysis objectively and to steer clear of policy positions, it is inevitable that information will occasionally attract political controversy. To ensure the impartiality of the *JTS*, I have selected an editor-in-chief and distinguished editorial board largely from outside of the U.S. government. Of course, DOT is well represented on the editorial board, and the active participation of the various Department administrations will be essential if the journal is to achieve its goals. I have deliberately chosen the vast majority of the editorial board members from among the most eminent scholars in transportation outside of government in the United States and abroad, in the hope that they will keep the *JTS* on a true course regardless of how the political winds may shift about them.

We will publish the *JTS* biannually at first, with the intention of producing a quarterly journal if the volume and caliber of research papers submitted will support it. The *JTS* will be priced affordably to serve a broad spectrum of members of the transportation community. We will encourage participation from government, academia, and industry. All articles will be peer-reviewed by highly qualified scholars, and the decision to publish will be based on technical merit and contribution to the goals of the journal.

I intend the *JTS* to serve BTS's core responsibilities of compiling, analyzing, and making accessible information on the nation's transportation systems, while at the same time developing the understanding necessary to ensure that the information developed is relevant and meaningful, and that it is efficiently and effectively obtained and disseminated. The *JTS* will serve as a forum for the latest developments in transportation information and data, theory, concepts, and methods of analysis relevant to transportation systems and their roles in society, the economy, and the environment. It will provide a unique venue for studies that: 1) present new sources of transportation information, 2) deal with the science of collecting, evaluating, managing, and disseminating transportation information, 3) analyze information to provide insights for public and private decisionmaking, and 4) advance theory and methods relevant to all three subject areas. The *JTS* will also include methodological and empirical studies analyzing trends, measuring the performance of transportation systems, or developing key indicators.

Like many BTS undertakings over its first few years, the *Journal of Transportation and Statistics* is to some extent an experiment. Developing the information needed to make just and effective decisions about transportation is an enormously important duty. I recognize that there are and will be threats to the continued existence of the *Journal* and to its success. I am counting on the diligence and integrity of the editorial board to guide and protect it. I am asking the community of transportation researchers to support it.

T.R. Lakshmanan

Meta-Analysis for Explaining the Variance in Public Transport Demand Elasticities in Europe

PETER NIJKAMP
GERARD PEPPING
Free University

ABSTRACT

Results from past studies on transport demand elasticities show a large variance. This paper assesses key factors that influence the sensitivity of public transport users to transport costs in Europe, by carrying out a comparative analysis of the different elasticity values of demand for transport that are being used in some of the different Member States. Our empirical base is elasticity studies in Norway, Finland, the Netherlands and the United Kingdom. The paper identifies a set of potential factors causing variances between results of different studies. An indepth rough set analysis of causes of variances between elasticity values across the four countries is presented. Our analysis supports the literature, which indicates that the difference between aggregated, empirical-based research methods and the use of disaggregated choice models, as well as model assumptions, explain the variance in elasticity values across studies. It also appears that the country involved, the number of competitive modes, and type of data collected are important factors in accounting for the size of elasticities.

Professor Peter Nijkamp, Department of Regional Economics, Free University, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands. Email: pnijkamp @econ.vu.nl.

INTRODUCTION

Public authorities in many countries have an increasing interest in the financial side of the transport system. Various agencies involved with the provision of transport infrastructure are faced with a mismatch between supply and demand. On the one hand, we observe endless traffic jams on main arteries and in urban areas, but on the other hand we also witness empty motorways in more peripheral areas. It is increasingly recognized that the price mechanism is not properly used to ensure a balance between supply and demand. However, the introduction of market principles in transport policy does not mean an automatic panacea for all friction in the transport systems under all circumstances, as we have different types of travelers, different (competing and complementary) modes, different travel motives, different goods, different time horizons, different distances to be bridged, and different (site-specific) travel conditions. So we need to have more insight into behavioral responses.

Easily the most important parameter for understanding how pricing policies will affect transport demand is the price elasticity of demand. This elasticity expresses the change in demand induced by a change in price. More precisely, it is defined as the ratio of the relative change in demand and the relative change in price. Public transport operators use price elasticities to assess the behavioral implications of a change in the fare system. It is also used by fiscal authorities to estimate the financial revenue consequences of a rise of gasoline taxes in the private transport sector. Furthermore, it is used to make assessments of the sensitivity of car drivers to a toll system (bridges, tunnels, toll roads). More recently, price elasticity has gained much popularity in the context of road pricing proposals in many countries, through which not only the private but also the social costs of surface transport might be incorporated in the travelers' decisions.

In the past years, several studies in European countries have assessed price elasticities of demand in the transport sector. There is a great diversity of empirical results. Clearly, most investigations have been made on a noncontrolled basis, so that the comparability of the results of these studies is rather feeble. Nevertheless, it makes sense to analyze the differences in statistical results more carefully, in order to identify commonalities and site-specific differences more precisely. This would also allow for more transferability of results under certain conditions.

In this context, meta-analysis may play an important role. Meta-analysis has been developed as a tool for comparing and synthesizing results from different studies with a similar goal in the natural sciences, and has increasingly found its position in the social sciences (e.g., experimental psychology and economics). (For more details, see Van den Bergh et al 1997.) This methodological tool offers opportunities for comparing different findings and will hence also be used for a comparative statistical exercise on cost elasticities in the transport sector in different European countries.

The aim of this paper is to assess key factors that influence the sensitivity of public transport travelers to transport costs in Europe, by carrying out a comparative analysis of the different elasticity values of demand for transport that are being used in some of the different Member States.[1] This comparative analysis is based on a meta-approach called rough set analysis.

The paper is organized as follows. The next section covers earlier reviews of elasticity studies and their main results. These reviews tell us the extent of the knowledge on elasticity values for European countries. Next, an indepth analysis of possible causes of variances between elasticity values across four European countries (Norway, Finland, the Netherlands and the UK) is presented. This section is followed by an introduction to the meta-analytic method used in our study, rough set analysis. The application of this technique to our European database takes place in the next section. Finally, the main conclusions and recommendations following from our analysis are presented.

EXISTING ELASTICITY REVIEWS

In the past, numerous studies have been carried out that aimed to assess values of transport elasticities. Many methods have been used in these studies. The European Commission (1996) provides the

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[1] The data used for this empirical application have been obtained from the EXTRA research project (1996–97) in the Transport Programme of the European Commission.

following list of the different sources where elasticity values can be found, or the different methodologies for the estimation of elasticity values.

- Before and after surveys: assessment of elasticities by comparing demand before and after a price change.
- *Aggregated time series analysis:* use of econometric models based on monthly, quarterly, or annual data.
- *Aggregated cross-sectional data:* use of data collected for a single time period.
- *Aggregated time series and cross-sectional analysis:* use of pooled time series and cross-sectional data.
- *Disaggregated cross-sectional analysis:* use of data collected from economic subjects like households and individuals.
- *Hypothetical market research:* inference of elasticities from expressed travel behavior.
- *Model-based elasticities:* derivation of elasticities from (computer) models of travel behavior with respect to price change.

Extensive literature reviews have been undertaken by Goodwin (1988, 1992) and Oum et al (1990, 1992). Between them they probably cover most of the work up until the time of their reviews. Two other important literature reviews are a report commissioned by the Department of Transport in Britain (Halcrow Fox 1993) and a report of the European Commission (1996). Also, Luk and Hepburn (1993) provided a useful addition, while a more recent review is Espey (1996). Although none of these review studies explicitly focus on public transport, they face the same problem as in the underlying study.

In these historical reviews, elasticities have been summarized in various ways, generally without discussing the different ways the elasticities have been estimated, although the authors of the reviews cited here are aware of these problems. For example, Goodwin (1988, 1992) lumps various estimates of the same mode to calculate a total mean fairly uncritically, taking all results by equal merit, apart from a few studies that were omitted due to "incomprehensibility or absurdity." He then subdivides the elasticities according to data type and length of period. Oum et al (1990, 1992) do not calculate means of elasticities, but list the whole range of estimates. In their World Bank working paper, they present subjective "most likely" ranges of elasticity values of demand for various travel modes.

Across the studies, there is much diversity in modes included, type of data, and methods of estimation. In addition, there is great variety in the geographical diversity. In view of the discussion in Oum et al, the estimated elasticities are not directly comparable. Even though mode choice elasticities may be distinguished from market demand elasticities, the various mode choice elasticities may not be comparable due to the inclusion of different alternative modes. For example, bus as an alternative to car may be different according to frequency, comfort, and speed. Estimated mode choice elasticities would then differ.

Therefore, generalizing the value of an estimated elasticity to different circumstances is a dubious practice. The same can be said about calculating the mean of elasticities from different studies.

On the other hand, when numerous studies are carried out with different data, and models give similar values for an elasticity, the result may be regarded as robust. The conclusion of Oum et al (1992) that the demand for car usage and urban transit are unambiguously inelastic is therefore strongly supported. If, however, the choice of policy in a particular situation is dependent on precise estimates of elasticities, estimation of elasticities should be undertaken.

Oum et al (1992) identify a number of issues that can cause different elasticity estimates, which they believe warrant attention. The most important of these are the presence of intermodal competition, the use of different functional forms, and different locations. It is concluded that: "While some generalisations, particularly on demand elasticities of car usage and public transit are possible, across-the-board generalisations about transport demand elasticities are impossible."

Most of the elasticities in these reviews are derived from empirical studies. An alternative way of estimating elasticities is by using disaggregated travel demand models, which is the case for some of the surveys in the applied meta-analysis presented in this paper. Such models can produce estimate of elasticities for not only mode-specific elasticities for different purposes but also for different segments of the population. However, it should be noted that values from travel demand models are often very different from those in empirical studies.

Halcrow Fox (1993) concludes that those literature values, i.e., based on empirical studies, are 50% to 200% higher than model elasticities. The main reason for this is that the results from models depend on a limited number of variables and thus do not allow for all the many causes of variation that exist in reality. Empirical values, however, are more likely to include the system effects, within a specific timeframe. This leads Halcrow Fox to conclude that model elasticities should be treated as minimum values.

POTENTIAL CAUSES OF VARIANCE BETWEEN ELASTICITIES IN DIFFERENT REGIONS

In this section, we focus on the fact that choices regarding different aspects of research on transport demand elasticities may have impacts on the size of the estimated elasticities. From theory, we can derive criteria that can be used to evaluate the results of different elasticity studies. Such a checklist of criteria can be used to evaluate the differences between similar elasticities by means of meta-analysis. In this section, these criteria are systematically described. But first we turn to the fundamental issues that determine the definition of the elasticity.

Definition of the Elasticity

This criterion relates to the type of elasticity measured. Various types of transport elasticities exist. The most important distinctions are own-price versus cross-price elasticities, regular versus mode-choice elasticities, and the definitions of the dependent and the independent variables.

- *Own- versus cross-price elasticities.* Instead of a demand for travel in general, demand for specific modes may be studied. Mode-specific demand leads to mode-specific elasticity values. The elasticity of one mode of transport with respect to its own price is called own-price elasticity. The elasticity of one mode of transport with respect to the price of another is called cross-price elasticity. Since a price increase for a mode will tend to reduce demand, the own-price elasticity values are negative. The cross-price elasticity values are normally positive. An increase in the price of one mode of transport will transfer some of the demand to the other modes.
- *Regular versus mode-choice elasticities.* For mode-specific elasticities, it is important to distinguish between mode-choice and regular demand elasticities. Mode-choice elasticities express the change in demand for one mode given a fixed demand of traffic for all modes. They do not take into account the change in price on the aggregated volume of traffic. Mode-choice elasticities are therefore a lower limit to regular demand elasticities.
- *The dependent variable.* Travel demand may be defined as travel volume (e.g., number of trips), modal choice, route choice, etc.
- *The independent variable.* In principle, three explaining variables can be used on the basis of which elasticities can be calculated: travel cost, travel time, and income. These variables show a high level of heterogeneity (e.g., perceived travel time in a bus is different from waiting at a bus stop; the issue of generalised costs).

In this paper, we restrict ourselves to own-price regular elasticities, where the dependent variable is travel volume and the independent variable is travel cost.

Nature of the Elasticity

Important aspects of the nature of the elasticity are:

- *Ordinary versus compensated elasticities.* Of theoretical interest is the difference between Marshallian or ordinary and Hicksian or compensated elasticities. In the first case, no compensation is given for a price rise. In the case of compensated elasticities, compensation is given so that the utility level is constant. No direct compensation is usually given in real life, though in the case of tax increases, indirect compensation can take place in the shape of better roads, etc.
- *Demand measurement unit.* A distinction must be made between measurement of demand in number of trips, distance traveled, etc.
- *The specific market segment.* The transport demand market can be segmented to different

population classes with different sensitivities to policy measures. Also, a distinction can be made between travel motives. The purpose of travel may have an influence on elasticities. Travel to work is expected to be less elastic than travel for leisure purposes, since the latter can be canceled more easily. Elasticities for rush-hour travel (peak) should ideally therefore be distinguished from off-peak elasticities.

Size of Choice Possibilities

In general, the level to which substitution is possible is an important potential factor influencing the size of a given type of elasticity. Substitution can be defined as a change in choice behavior (e.g., modal choice and route choice) in order to maintain the existing activity pattern as much as possible. If substitution is possible, it may be expected that the resulting elasticities are higher than when no substitution is possible. Important aspects are:

- *Level of aggregation over alternatives.* The level of aggregation over alternatives is important for the evaluation of the size of the elasticities. The higher the level of aggregation, the less the number of substitutes. We then expect a lower elasticity. In addition, aggregation will lead to averaging out the underlying variation in the elasticities, as no allowance is made for the heterogeneity of the alternatives to be chosen. For example, price elasticities may differ between the train and bus modes. For an effective differentiated price policy, it is necessary to have insight into the underlying elasticities.
- *Time horizon.* The possibilities to react to changing transport conditions will in general be larger in the long run than in the short run, because in the long run variations in location choice and asset holding resulting from changing transport conditions may also take place. Therefore, long-term elasticities are expected to be higher than short-term elasticities.
- *Travel distance*. It is plausible that there are differences in the sensitivities to price change between short trips and long-distance trips. Therefore, the geographical coverage of mobility surveys is an important factor.
- *Choice possibilities.* An important reason for the existence of low elasticity values in various studies is that many people do not have a choice possibility, implying that the share of these travelers in the sample investigated co-determines the size of the elasticities.
- *Other factors.* From economic theory we may derive several other factors that influence the estimated size of elasticities. For example, there is the hypothesis that travelers often have incomplete information on the real costs and travel times. These uncertainties imply that people not only react on the basis of true travel costs and travel times, but also on expected travel costs and travel times, and the associated risk that their expectation is wrong.

Model Specification

From the type of research methodology, we may derive criteria for the evaluation of elasticities. The important ones are:

- *Point versus arc elasticities.* The elasticity defined by the product of the derivative and the ratio of price demand at a point on the demand function is called a point elasticity. An elasticity can also be estimated by the change in demand induced by a finite change in price. This is an arc elasticity. Both elasticities may differ from each other when the demand curve shows a changing elasticity value. In general, arc elasticities are more suitable when one wants to know the consequences of a relatively large change in price.
- *Aggregated and disaggregated models.* The most important criterion is likely to be whether the model used is an aggregated or a disaggregated model. Aggregated models do not make an allowance for individuals who make choices based on specific circumstances. Therefore, problems related to methods of aggregation may cause significant biases in the elasticities. In most cases, this will lead to lower elasticities resulting from aggregated models in comparison with disaggregated models. In addition, aggregated models do not make an allowance for the large variation in mobility behavior of individuals, even within groups with similar characteristics. In other words, the use of aggregated models is based on a low level of variation in (aggregated) behavior, which causes a less precise estimation of model parameters.

- *Number of competitive modes taken up in the model.* In addition to real-world choice possibilities, the number of modes included in (choice) models when they are estimated can have an influence on the elasticity values. Of course, this is a matter of proper modeling, but usually there are discrepancies between real-world choice possibilities and those represented in a model.
- *Control for other factors.* In many cases, two situations are compared and it is concluded that a policy measure has led to a certain change in mobility behavior. However, other (external) developments may have had an impact on the dependent variables, and it is, therefore, important to verify this.
- *The functional form of the model.* The functional form of the model used can, in a number of respects, influence the size of elasticities. Different model types may also generate different elasticity types. A model may allow for a distinction between generation and substitution effects (gross and net substitution). Some models yield higher elasticities when changes in the independent variables, like transport price, are higher. Dynamic models allow for an explicit modeling of short-term and long-term effects.

Criteria Derived from the Data

- *Type of data source.* Various data types exist: cross-section, time series, panel, and stated preference data. The use of these data has different consequences for the size of the estimated elasticities. For example, it appears that elasticities based on cross-section data are often higher than elasticities based on time series data. Also, it appears that elasticities based on stated preference data are higher than cross-section data, unless they are re-scaled. Therefore, a proper recording of the data source from which elasticities are calculated is of great importance. In addition, other aspects related to the data source are important.
- *The operationalization of the variables.* Even slight differences in definitions of income, transport price, and travel times (e.g., monetary or generalized travel costs) may cause significant differences in the estimated elasticities.
- *Actual level of travel costs.* As already mentioned, the level of travel demand may show a relationship to travel cost with a changing elasticity value on this curve. It is plausible that travel demand becomes more sensitive to changes in transport costs when these costs are already relatively high.
- *General problems with the data source.* If there are general problems related to the data source, this should be properly recorded. For instance, results from panel data may be influenced by selectivity in panel attrition.
- *Year of collection of the data.* In general, the sensitivity to price change is likely to vary over time, especially when there are large time periods between measurements (more than 10 years). In past decades, the role of transport has rapidly increased in the whole society.

QUALITY OF RESEARCH

In addition to the theory used, the model specification, and the data used, it is important that the research from which elasticities are derived meets some quality standards. We take into consideration here:

- *Statistical techniques used.* It is important to verify that appropriate methods of estimation, given the nature of the data and model structure, have been used for the determination of parameter values, and whether chosen techniques are correctly applied.
- *Sample size.* The size of the sample determines the level of representativeness of the results of the study for the population investigated.

From the considerations set out above, it should be clear that elasticities estimated with different methods under different circumstances are not necessarily comparable. We may formulate from this a list of items on the basis of which we will apply a meta-analysis. The aim is to assess the most important aspects responsible for the variation of elasticity estimates between the different studies in the countries investigated.

META-ANALYSIS IN THE CONTEXT OF COMPARING EUROPEAN DEMAND ELASTICITIES

We have noted in the previous sections that results from past studies on transport elasticities vary strongly, and we have explored potential factors that may cause these differences. Knowledge of these factors may be useful for harmonization of (future) international research on the sensitivity of transport demand to prices.

Our empirical data come from 12 elasticity studies in 4 European countries: Norway, Finland, the Netherlands, and the United Kingdom. We are dealing here with a data set consisting of a limited number of observations (i.e., elasticity study results), thus we are facing a high level of uncertainty. Therefore, our indepth analysis of these causes of variance is based on a meta-analytic approach. Such an approach can be used to extract lessons from a limited set of different research studies.

Meta-analysis is a statistical procedure for combining and comparing research findings from different studies focusing on similar phenomena (see Hedges and Olkin 1985; Light and Pillemer 1984; and Wolf 1986). Meta-analysis is particularly suitable in cases where research outcomes are to be judged or compared (or even transferred to other situations) when there are no controlled conditions. In the past, a variety of meta-analytical methods were developed (see e.g., Hunter et al 1982; Rosenthal 1991). Most meta-analytical techniques are designed for sufficiently large numbers of case studies, so that statistical probability statements can be inferred (e.g., Espey 1996). In this respect, meta-analysis has demonstrated its validity and usefulness as a methodological tool for comparative study in the social sciences. In conclusion, meta-analysis is not a single technique, but rather an analytical approach to comparative study that may comprise a multiplicity of different methods and techniques, which are often statistical in nature.

Especially in the case of quasi-controlled or non-controlled comparative experimentation, the level of information is often not cardinal, but imprecise (e.g., categorical, qualitative, fuzzy). In recent years, rough set theory has emerged as a suitable analytical tool for dealing with “soft” data. Rough set theory, proposed in the early 1980s by Pawlak (1982; 1991), aims to classify data measured on any information level by manipulating the data in such a way that a range of consistent and feasible cause-effect relationships can be identified, while at the same time eliminating redundant information. It has proven to be a useful tool for a large class of qualitative or fuzzy multi-attribute decision problems, and can deal with problems of explanation and prescription of a decision situation where knowledge is imperfect.

ROUGH SET ANALYSIS

Rough set analysis is essentially a nonparametric statistical method that is able to handle a diverse and less immediately tangible set of factors. It provides a formal tool for transforming a data set, such as a collection of past examples or a record of experience, into structured knowledge, in the sense that it can classify objects having distinctive patterns of attributes. Using such an approach, it is not always possible to distinguish objects on the basis of available information (descriptors). This imperfect information causes indiscernibility of objects through the values of the attributes describing them and prevents them from being unambiguously assigned to a given single set. In this case, the only sets that can be precisely characterized in terms of values of ranges of such attributes are lower and upper approximations of the set of objects. We will now set out the basic principles of this method (for more details, see also Pawlak 1991; Van den Bergh et al 1997; Slowinski and Stefanowski 1994; and Greco et al 1995).

With reference to a certain finite set of objects U, it is assumed possible to perceive the differences existing between them by observing some information associated with each of them. A finite set Q of *attributes* is identified, which serves to identify and characterize these objects. As the rough set theory aims to classify and distinguish data on the basis of different values their attributes assume with reference to each object, each attribute $q \in Q$ must be able to assume different values in its domain U_q. There must be, therefore, at least two of these values in order for the attribute to be a significant basis for the required characterization. If an attribute is quantitative, its domain is, in practice, partitioned into a suitable number of sub-intervals, which give a good description of the phenomenon studied, so as to avoid ending up with a distribution of values with a high number of modalities, which would not be useful for the analysis intended. The difficult choice of the bounds (called *norms*) used to define these sub-intervals is important to ensure a correct application of this approach and that too much information is not lost in the translation of original quantitative attribute-values into qualitative coded values.

At this point, to every object $x \in U$ may be associated a vector whose components are the distinct evaluations of x with respect to every attribute of Q and called *description* of x in terms of attribute-values from set Q. The table containing the descriptions of every $x \in U$ by means of the attributes of the set Q is known as the *information table.* It is also possible to obtain a description of $x \in U$ in terms of any one subset of attributes $P \subseteq Q$.

A fundamental concept of rough set theory is that of the binary relation of *indiscernibility*, denoted I_P. Two objects $x, y \in U$ are said to be P-indiscernible by means of the set of attributes $P \subseteq Q$ if and only if they have the same description. Naturally, the binary relation I_P is reflexive, symmetric, and transitive (equivalence relation); its classes, that is, the subsets of U containing all the objects having the same description in terms of the attributes from subset P, and only these, are called *P-elementary sets.* If all the attributes of Q are considered, the Q-elementary sets are called atoms. The P-elementary sets, $P \subseteq Q$, generate a partition of U, in that every object $x \in U$ belongs to one and only one P-elementary set.

For the definition of rough set, it is necessary to introduce two other key concepts. Let $P \subseteq Q$ be a subset of attributes and $X \subseteq U$ a subset of objects of U. We define as *P-lower approximation* of X, denoted with P_LX, the subset of U having as its elements all the objects belonging to the P-elementary sets contained in the set X, and only these. In other words, the elements of P_LX are all the elements of U belonging to all the classes generated by the indiscernibility relation I_P and contained in X, and only these.

We define as the *P-upper approximation* of X, denoted with P_UX, the subset of U having as its elements all the objects belonging to the P-elementary sets having at least one element in common with the set X, and only these. In other words, the elements of P_UX are all the elements of U belonging to all the classes generated by the indiscernibility relation I_P that have at least one representative belonging to X, and only these.

The difference between these sets is known as *P-boundary* of X, denoted with $Bn_P(X) = P_UX - P_LX$. Therefore, $P_LX \subseteq X \subseteq P_UX$ results and, consequently, if an object x belongs to P_LX, it is also an element of X; if x belongs to P_UX, it may belong to the set X; $Bn_P(X)$, therefore, constitutes the "doubtful region" (with reference to its elements, nothing can be said with certainty about its belonging to the set X). The indiscernibility classes generated by I_P, therefore, constitute the basic instrument of the rough set theory used to obtain a better knowledge of reality. This knowledge is intended as a family of partitions of U, generated by the indiscernibility relation I_P on U, $P \subseteq Q$.

A *P-rough set* is the family of all subsets of U that have the same lower and upper P-approximations. The intention is thus to approximate a set X, $X \subseteq U$, by means of a pair of sets associated with it, called lower approximation, P_LX, and upper approximation P_UX, of X, that can be then considered as a particular case of interval set. Only if $P_UX = P_LX$ does X prove to be equal to the union of a certain number of P-elementary sets and is called *P-definable*. Clearly, in this case (and only in this case), it is possible to affirm with certainty whether x, $x \in U$, belongs to X, $X \subseteq U$, using the set of attributes P. Moreover the *accuracy* of the approximation of X, equal to

$$\frac{\text{card }(P_LX)}{\text{card }(P_UX)}$$

will be at the maximum value (i.e., equal to 1). In general, therefore, the aim of the rough set analysis is to establish whether x is an element of X on the basis of the lower and upper approximations of X, rather than directly by means of a specific characteristic function.

Let $\mathbf{Y} = (Y_1, Y_2, ..., Y_n)$ be a certain classification of U. With reference to the classification **Y**, we denote as P-lower approximation and P-upper approximation respectively, the sets having as their elements the P-lower and P-upper approximations of its classes, that is $P_L\mathbf{Y} = (P_LY_1, P_LY_2, ..., P_LY_n)$ and $P_U\mathbf{Y} = (P_UY_1, P_UY_2, ..., P_UY_n)$. An indicator of the quality of the approximation of the partition **Y** by means of the set of attributes P, notation $\gamma_P(\mathbf{Y})$, is given by the ratio between the total number of P-correctly classified objects (i.e., belonging to the P-lower approximations of Y_i, i = 1, 2, ..., n), and the total number of objects considered. This is called the *quality of the classification*. This index will assume its maximum value (equal to one) if, and only if, each of the classes Y_i of Y prove P-definable, that is, if each of them is given by the union of P-elementary sets.

Another fundamental concept is that of attribute *reduction* (i.e., given a classification **Y** of the objects of U, the search for a minimal set of (independent) attributes R that supplies the same quality of classification as the original set of attributes P). The minimal subset $R \subseteq P \subseteq Q$ such that $\gamma_R(\mathbf{Y}) = \gamma_P(\mathbf{Y})$ is called **Y**-reduct of P and denoted $RED_Y(P)$. (Note that a single information table may have more than one reduct.) The intersection of all the **Y**-reducts is known as **Y**-core of P, that is, $CORE_Y(P) = \cap RED_Y(P)$. Naturally the *core* contains all the attributes from P which are considered of greatest importance in the information table (i.e., the most relevant for a correct classification of the objects of U).

In other words, in order to analyze the information table, it is sufficient to use any one of the attribute reducts $R \subseteq Q$, that is, the classification **Y** of the objects of U may be characterized without losing any information using only the attributes from R, while the information supplied by the attributes of Q–R prove redundant for this purpose. On the other hand, none of the attributes belonging to the core may be neglected without deteriorating the quality of the classification considered, that is, if any one attribute belonging to the core is eliminated from the information table, it will not be possible to obtain the highest quality of approximation with the remaining attributes.

APPLICATION OF ROUGH SET ANALYSIS

As mentioned in the previous section, rough set theory is essentially a classification method devised for non-stochastic information. This also means that ordinal or categorical information (including dummies) may be taken into consideration. This makes rough set analysis particularly useful as a meta-analytical tool in the case of incomplete, imprecise, or fuzzy information. We can expect the following results from the rough set analysis:

- evaluation of the relevance of particular condition attributes;
- construction of a minimal subset of variables ensuring the same quality of description as the whole set (i.e., reducts of the set of attributes);
- intersection of those reducts giving a core of attributes that cannot be eliminated without disturbing the quality of description of the set of attributes; and
- elimination of irrelevant attributes.

The application of rough set analysis on transport elasticity values in different countries proceeds in two successive steps: the construction of an information survey, and the classification of information contained in the survey.

Information survey. In our case, the information survey consists of a series of public transport elasticity studies based on surveys in four European countries. Included are both aggregated and disaggregated elasticity studies. The total number of studies considered is limited, in order to eliminate, as much as possible, differences in definitions of transport costs and elasticities. The information survey contains site- and study-specific characteristics (attributes) of these studies. Because of the limited number of observations, we selected variables from the criteria listed in the previous section. The set of chosen variables is based on maximizing the extent to which elements of other variables are captured in these. Details of the information survey are in table 1.[2]

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[2] It should be stated that the combination of 12 observations (in casu, studies/surveys) with 8 explaining attributes leaves us only few degrees of freedom.

TABLE 1 Concise Survey Table for Meta-Analysis of Transport Elasticities for Public Transport in Four European Countries

		1 Country	2 Year of data collection	3 Level of aggregation	4 Indicator of transport demand	5 Geographical coverage	6 Number of competitive modes	7 Data type	8 Model type	Elasticity value
1	Helsinki	Finland	1988	Bus, tram, metro, train	Trips	Urban	2	Cross-section	Nested logit	–0.48
2	Helsinki	Finland	1995	Bus, tram, metro, train	Trips	Urban	3	Cross-section	Logit	–0.56
3	Sullström, 1995	Finland	1966–90	Bus, tram, metro, train	Person-km	Urban, interurban	1	Repeated cross-section	Linear demand OLS	–0.75
4	Netherlands	Netherlands	1984–85	Bus, tram, metro	Trips	Urban, semi-urban	2	Panel	Linear demand OLS	–0.35/ –0.40
5	BGC, 1988	Netherlands	1980–86	Bus, tram, metro	Trips	Urban, semi-urban	2	Time series	Linear demand OLS	–0.35/ –0.40
6	Roodenburg, 1983	Netherlands	1950–80	Bus, tram, metro	Person-km	Urban, semi-urban	1	Time series	Linear demand OLS	–0.51
7	Fase, 1986	Netherlands	1965–81	Bus, tram, metro	Person-km	Urban	1	Time series	Linear demand OLS	–0.53/ –0.80
8	Gunn, 1987	Netherlands	1986	Train	Person-km	Semi-urban	2	Cross-section	Discrete choice	–0.77
9	Oum, 1992	Netherlands	1977–91	Bus, tram, metro	Person-km	Urban, semi-urban	2	Time series	Translog utility function	–0.74
10	Oslo	Norway	1990–91	Bus, tram, metro, train	Trips	Urban	3	Cross-section	Multinomial logit	–0.40
11	Norway	Norway	1991–92	Bus	Trips	Interurban	5	Cross-section	Multinomial logit	–0.63
12	UK	UK	1991	Bus, tram, metro, train	Trips	Urban, interurban	4	Cross-section	Nested logit	–0.15

Note: Studies referred to by a city or country name were part of the EXTRA project. The other studies result from a literature review.

Classification of Information

The rough set approach can effectively handle quantitative data, but this data must first be converted into qualitative or categorical data by means of an adequate codification. This is done by means of a set of thresholds called norms, which discretize the measurement scales by which the quantitative data are expressed. This applies to both categorical and ratio information. The observations or objects are classified into various categories for each attribute separately. From the researcher's viewpoint, the introduction of the thresholds could mean a methodological advantage, because the discretization of the measurement scale for quantitative attributes should represent the researcher's perception of the analyzed phenomenon that can be represented and analyzed in a form that is understandable to the researcher. However, this step is one of the most problematic issues in the application of rough set analysis.

First, the use of thresholds implies some loss of information. Second, thresholds are chosen subjectively. For example, the thresholds are often those that produce some satisfactory approximation of the considered categories. This is the case in our survey, for both the attribute variables and the elasticity value range. In general, some sensitivity analysis on the classification used is meaningful, as a balance needs to be found between homogeneity and class size. This classification exercise leads then to a decision table, in which all objects are subdivided into distinct categories for each relevant attribute. The categories used are listed in table 2.

The resulting coded information table is in table 3. (When we speak of respectively high or low values of the elasticity size, we refer to the *absolute* value of the elasticity.)

TABLE 2 Categorization of Variables Investigated

Elasticity value	
1	Lower than –0.40
2	–0.40 to –0.50
3	–0.50 to –0.60
4	Higher than -0.60
Explanatory variables	
1	**Country (COU)**
1	Finland
2	Norway
3	Netherlands
4	UK
2	**Year of data collection (YEA)**
1	1985 and before (including studies using data periods over 10 years of which the median year was before 1986)
2	1986 and after (including studies using data periods over 10 years of which the median year was after 1986)
3	**Level of aggregation (AGG)**
1	Bus, tram, metro, train
2	Bus, tram, metro
3	Bus
4	Train
4	**Indicator of transport demand (IND)**
1	Number of trips
2	Number of person-km
5	**Geographical coverage (GEO)**
1	Urban
2	Urban and semi- or interurban
3	Interurban
6	**Number of competitive modes (CMD)**
1	One
2	Two
3	Three
4	Four and more
7	**Data type (DAT)**
1	Time series
2	Survey, cross-section
3	Survey, panel
8	**Model/estimation type (MOD)**
1	Basic OLS (linear demand models)
2	Discrete choice (probit/logit)
3	Other types

TABLE 3 Coded Table for Meta-Analysis of Transport Elasticities for Public Transport

Case/ attribute	COU	YEA	AGG	IND	GEO	CMD	DAT	MOD	Elasticity value
1	1	2	1	1	1	2	2	2	2
2	1	2	1	1	1	3	2	2	3
3	1	1	1	2	2	1	2	1	4
4	3	1	2	1	2	2	3	1	2
5	3	1	2	1	2	2	1	1	2
6	3	1	2	2	2	1	1	1	3
7	3	1	2	2	1	1	1	1	3
8	3	2	4	2	2	2	2	2	4
9	3	1	2	2	2	2	1	3	4
10	2	2	1	1	1	3	2	2	2
11	2	2	3	1	3	4	2	2	4
12	4	2	1	1	2	4	2	2	1

Applying this classification to the samples of elasticity studies within the four investigated European countries, four main sets of indicators and outputs can be calculated.

(1) The *reducts*, that is, all combinations of explanatory or independent variables that can completely determine (or explain) the variation in the dependent variable, without needing other explanatory variables. The reducts are given in table 4. There appear to be, on the basis of the chosen set of characteristics and classification of these characteristics, two competitive theories for explaining the variance in the estimated elasticity values. The first is that this variance is completely determined by the combination of the country of data collection, the number of competitive modes, the type of data collected, and the type of model used. The second theory is that this variance is completely determined by the country, the indicator for transport demand, the number of competitive modes, and the type of data collected.

(2) The *core*, that is, the set of variables that are in all reducts as discussed under (1), or that are part of all theories. The core consists of the country, number of competitive modes, and type of data collected. Without these characteristics, it is impossible to classify the results of the elasticity studies according to the considered categories. This means that these three variables strongly influence the elasticity size. In conclusion, in addition to the practical findings mentioned earlier on the differ-

TABLE 4 Reducts and Core

Reduct	Set no. 1 {COU, CMD, DAT, MOD} Set no. 2 {COU, IND, CMD, DAT}
Core	{COU, CMD, DAT}

TABLE 5 Accuracy and Quality of the Classification of the Elasticity Value

Elasticity value class	Accuracy	Lower approximation	Upper approximation
Lower than –0.40	1	1	1
–0.40 to –0.50	1	4	4
–0.50 to –0.60	1	4	4
Higher than –0.60	1	3	3

Accuracy of classification: 1
Quality of classification: 1

Note: The accuracy for each class is the lower divided by the upper approximation.

ence between empirical-based research methods and the use of disaggregated choice models, country differences also have a major influence on the elasticity value.

(3) The *lower and upper approximation*, and derived accuracy of relationships for each value class of the decisional variable. The latter is the lower divided by the upper approximation of each class. Accuracy and quality of classification can also be derived from this (i.e., choice of thresholds). The results are shown in table 5. For all classes of the elasticity value, the accuracy is 1. Also, the accuracy and quality of classification are equal to 1. This value is the maximum value in all these cases. This means that on the basis of the chosen characteristics the studies in our sample are fully discernible regarding the four classes of the elasticity value. This strengthens the conclusions on the other indicators from the rough set analysis.

(4) *Rules*, that is, exact or approximate relationships between explanatory variables and dependent variables. These may be considered "if . . . then . . . " statements. A rule may be exact (or deterministic), or approximate (or non-deterministic). An exact rule guarantees that the values of the decision attributes correspond to the same values of the condition attributes (same conditions, same decisions); an approximate rule, on the other hand, states that more than one value of the decision attributes corresponds to the same values of the condition attributes (same conditions, different decisions). Therefore, only in the case of exact rules, using the information contained in the decision table, is it always possible to state with certainty if an object belongs to a certain class of the decision variable. An exact rule, therefore, offers a sufficient condition of belonging to a decision class; an approximate rule (only) admits the possibility of this. Table 6 shows the rules that can be generated from our data set. The support of rules by cases is also a useful indicator. If a rule is supported by more objects, then it is more important, for instance, in summarizing the different single study results.

We see from the decision algorithm in table 6 that all rules generated in the elasticity study information survey, using the classes of table 3, are deterministic. Some statements may then be derived on the influence of the variables occurring in this algorithm, but we should take into account that some of these rules are supported by only one

TABLE 6 Rules Generated by the Rough Set Analysis

Classes of dependent attributes	Implied class of elasticity size
COU=UK	Lower than −0.40
COU=Finland, IND=trips, CMD=2	−0.40 to −0.50
COU=Norway, IND=trips, CMD=3	−0.40 to −0.50
COU=Netherlands, IND=trips, CMD=2, DAT=panel	−0.40 to −0.50
AGG=bus/tram/metro, CMD=1	−0.50 to −0.60
COU=Finland, AGG=bus/tram/metro/train, CMD=3	−0.50 to −0.60
COU=Netherlands, AGG=bus/tram/metro, IND=trips, CMD=2, DAT=time series	−0.50 to −00.60
IND=person-km, GEO=urban and interurban	Higher than −0.60
AGG=bus	Higher than −0.60

observation (e.g., the case of where the country (UK) implies a relatively low elasticity value). Nevertheless, within the limits of our small data set we may derive some interesting information from these rules. A rule supported by more observations is that when the area covered is a mixture of the urban, semi-urban and interurban level, the elasticity value is relatively high.

With the limitation of having only few degrees of freedom, our analysis leads to some prudent findings. First, conclusions from past elasticity study reviews on the importance of the difference between aggregated, empirical-based research methods and the use of disaggregated choice models, as well as the model assumptions, seem to be to a certain extent supported by this application of meta-analysis. In this analysis, there appear to be, on the basis of a chosen classification of study characteristics, two competitive theories for explaining the variance in the estimated elasticity values. The first is that this variance is completely determined by the combination of the country of data collection, the number of competitive modes, the type of data collected, and the type of model used.

The second theory is that this variance is completely determined by the country, the indicator for transport demand, the number of competitive modes, and the type of data collected. Thus, it appears that the variables of country, number of competitive modes, and type of data collected are important factors in accounting for the elasticity size. The result of the meta-analysis is, therefore, that in addition to the practical findings on the difference between empirical-based research methods and the use of disaggregated choice models, country differences also have a major influence on the elasticity value. *This means that, even when the estimation method is the same in terms of data used and the model specification, the elasticities for the different European countries should be looked at very carefully.* The situations between the countries may differ to a large extent. For example, in the Netherlands bicycles are a relatively important mode in comparison with the other countries, primarily because of the relatively short travel distances, the flat surface, and the good infrastructure provided for the bicycle. The public transport elasticity of those who are dependent on public transport (e.g., young people) is, therefore, quite high in comparison with other countries. The short travel distances in the Netherlands (looking at both urban and interurban trips) also enlarge substitution possibilities between other modes.

Further reasons for the high impact of the country on elasticity values can be found in the cultural differences between the countries. Differences in the infrastructure and the quality of public transport also determine the level of competitiveness between the transport modes.

CONCLUSIONS

The goal of this paper has been to assess the factors that influence the sensitivity of travelers to public transport travel costs in Europe, by carrying out a comparative analysis of elasticity values of transport demand resulting from studies in various countries. We have made use of a rather limited data set containing 12 studies/surveys on demand elasticities with 8 site- and study-specific characteristics. Because of this, we had only a few degrees of freedom. By applying meta-analysis, this comparative study has still led to some interesting conclusions.

The main findings from existing reviews of elasticity studies assessing causes of variances— namely the importance of the difference between aggregated, empirical-based research methods and disaggregated choice models, as well as the model assumptions—seem to be reasonably supported by our indepth analysis of a set of potential factors of influence by means of rough set analysis. It appears that from our set of variables, country, number of competitive modes, and type of data collected have the strongest explanatory power for the elasticity size. The result of our meta-analytic application is that in addition to the practical findings on the difference between empirical-based research methods and the use of disaggregated choice models, country-specific factors also play a large role. This means that care should be taken when comparing elasticities for the different European countries, even when estimation methods are the same (i.e., data used and the model specification). Relevant country-specific characteristics like natural circumstances and travel distances may mean that certain modes are favored (e.g., the bicycle in the Netherlands). Cultural differences and differences in the quality of public transport are also important, as these determine the level of competitiveness between the transport modes.

The findings above on the importance of country-specific factors that determine the price sensitivity of travelers imply that the formulation of a common transport price policy at the European level, in terms of harmonizing prices, is a difficult task, and will probably not lead to a first-best solution to the rising negative transport externalities in Europe. Instead, pricing policies for public transport should be adapted to local situations in order to be able to derive optimal effects.

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A Review of the Literature on the Social Cost of Motor Vehicle Use in the United States

JAMES J. MURPHY
Department of Agricultural and Resource Economics
University of California, Davis

MARK A. DELUCCHI
Institute of Transportation Studies
University of California, Davis

ABSTRACT

Over the past five years, analysts and policymakers have become increasingly interested in the "full social cost" of motor vehicle use. Not surprisingly, there is little agreement about how to estimate the social cost or why, with the result that estimates and interpretations can diverge tremendously. In this situation, policymakers and others who wish to apply estimates of the social cost of motor vehicle use might find it useful to have most of the major estimates summarized and evaluated in one place. Toward this end, we review the purpose, scope, and conclusions of most of the recent major U.S. studies, and summarize the cost estimates by individual category. We also assess the level of detail of each major cost estimate in the studies.

INTRODUCTION

Over the past five years, analysts and policymakers have become increasingly interested in the full social cost of motor vehicle use. Researchers have performed social cost analyses for a variety of

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James J. Murphy, Graduate Student, Department of Agricultural and Resource Economics, University of California, Davis, CA 95616. Email: jjmurphy @ ucdavis.edu.

reasons, and have used them in a variety of ways, to support a wide range of policy positions. Some researchers have used a social cost analysis to argue that motor vehicles and gasoline are terrifically underpriced, while others have used them to downplay the need for drastic policy intervention in the transportation sector. In any case, social cost analyses excite considerable interest, if only because nearly all of us use motor vehicles.

Interest in full social cost accounting and socially efficient pricing has developed relatively recently. From the 1920s to the 1960s, major decisions about building and financing highways were left to "technical experts," chiefly engineers, who rarely if ever performed social cost-benefit analyses. Starting in the late 1960s, however, "a growing awareness of the human and environmental costs of roads, dams, and other infrastructure projects brought the public's faith in experts to an end" (Gifford 1993, 41). It was a short step from awareness to quantification of the costs not normally included in the narrow financial calculations of the technical experts of the past.

Today, discussions of the social costs of transportation are routine. In most accounts, the social costs of transportation include external, nonmarket, or unpriced costs, such as air pollution costs, as well as private or market costs, such as the cost of vehicles themselves. Government expenditures on motor vehicle infrastructure and services usually are included as well.

Purposes and Uses of Social Cost Analyses

By itself, a social cost analysis does not determine whether motor vehicle use on balance is good or bad, or better or worse than some alternative, or whether it is wise to tax gasoline or encourage alternative modes of travel. A social cost analysis can provide cost data, cost functions, and cost estimates, which can help analysts and policymakers evaluate the costs of transportation policies, establish efficient prices for transportation services and commodities, and prioritize research and funding. Let us examine these uses more closely[1]:

Use #1: Evaluate the costs of transportation projects, policies, and long-range scenarios. In cost-benefit analyses, policy evaluations, and scenario analyses, analysts must quantify changes to, and impacts of, transportation systems. The extent to which a generic national social cost analysis can be of use in the evaluation of a specific transportation policy or system depends, of course, on its detail and quality. At a minimum, a detailed, original social cost analysis can be mined as a source of data and methods for cost evaluations of specific projects. Beyond this, if costs are a linear function of quantity, and invariant with respect to location, then estimates of national total or average cost, which any social cost analysis will produce, may be used to estimate the incremental costs for specific projects, policies, or scenarios. Otherwise, analysts must estimate the actual nonlinear cost functions for the project, policy, or scenario at hand.

Use #2: Establish efficient prices for, and ensure efficient use of, those transportation resources or impacts that at present either are not priced but in principle should be (e.g., emissions from motor vehicles) or else are priced but not efficiently (e.g., roads). Again, at a minimum, the data and methods of a detailed social cost analysis might be useful in analyses of marginal cost prices. Beyond this, the average cost results of a social cost analysis might give analysts some idea of the magnitude of the gap between current prices (which might be zero, as in the case of pollution) and theoretically optimal prices, and inform discussions of the types of policies that might narrow the gap and induce people to use transportation resources more efficiently. And to the extent that total cost functions for the pricing problem at hand are thought to be similar to the assumed linear national cost functions of a social cost analysis, the average cost results of the national social cost analysis may be used to approximate prices for the problem at hand.

Use #3: Prioritize efforts to reduce the costs or increase the benefits of transportation. The total cost or average cost results of a social cost analysis can help analysts and policymakers rank costs (e.g., whether road dust is more damaging than ozone), track costs over time (e.g., whether the cost of air pollution is changing), and compare the costs and benefits of pollution control (e.g., whether expenditures on motor vehicle pollution control devices are more or less than the value of the pol-

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[1] See also Lee (1997).

lution eliminated). This information can help people decide how to fund research and development to improve the performance and reduce the costs of transportation.

Overview of the Debate in the Literature

Not surprisingly, there is little agreement about precisely which costs should be counted in a social cost analysis, which costs are the largest, how much the social cost exceeds the market or private cost, or to what extent, if any, motor vehicle use is "underpriced." On the one hand, many recent analyses argue that the "unpaid" costs of motor vehicle use are quite large—perhaps hundreds of billions of dollars per year—and hence that automobile use is heavily "subsidized" and underpriced (e.g., MacKenzie et al 1992; Miller and Moffet 1993; Behrens et al 1992; California Energy Commission 1994; Apogee Research 1994; COWIconsult 1991; KPMG 1993; Ketcham and Komanoff 1992; Litman 1996). Others have argued that this is not true. For example, the National Research Council (NRC), in its review and analysis of automotive fuel economy, claims that "some economists argue that the societal costs of the 'externalities' associated with the use of gasoline (e.g., national security and environmental impacts) are reflected in the price and that no additional efforts to reduce automotive fuel consumption are warranted" (NRC 1992, 25). Green (1995) makes essentially the same argument. Beshers (1994) and Lockyer and Hill (1992) make the narrower claim that road-user tax and fee payments at least equal government expenditures related to motor vehicle use, and Dougher (1995) actually argues that road-user payments exceed related government outlays by a comfortable margin.

We could cite other examples. This extraordinary disagreement exists because of differing accounting systems, analytical methods, assumptions, definitions, and data sources. The root of the problem is that there are few detailed, up-to-date, conceptually sound analyses. With few exceptions, the recent estimates in the literature are based on reviews of old and often superficial cost studies. Moreover, some of the current work confuses the meaning of *externality*, *opportunity cost*, and other economic concepts. And, because there is no single, universally accepted framework for conducting a social cost analysis of motor vehicle use, it is often difficult, if not impossible, to make meaningful comparisons of the results from different studies.

In this situation, policymakers and others who wish to apply estimates of the social cost of motor vehicle use might find it useful to have most of the major estimates summarized in one place. This is the purpose of our paper: to review much of the present literature on the social cost of motor vehicle use in the United States as an aid to those who wish to use the estimates. Although we are not able to provide a simple evaluation of the overall quality of the studies, we do offer, as a partial indicator of quality, an evaluation of the degree of detail of the cost estimates in each study.

Our Review

The studies reviewed are presented in chronological order. Generally, we review the purpose, scope, and conclusions, and summarize the cost estimates by individual category. We also assess the level of detail for each major cost estimate in the studies.

In each review, the definitions and terms are those of the original study. For example, we report as an "external cost" what each study calls an external cost; we do not define external cost ourselves and then categorize estimates of each study with respect to this definition. This of course means that what may appear in different studies to be estimates of the same cost—the external cost of accidents, for example—might actually be estimates of different costs. Because of this, and because of differences in scope, timeframe, and so on, one must be careful when comparing estimates.

The bulk of the paper consists of a set of relatively detailed reviews, with tabulations of the estimates of cost and level of detail of some of the more frequently cited studies. In the main set of detailed reviews, we include only U.S. studies whose primary purpose is to estimate some significant part of the social cost of motor vehicle use. We do not include studies where the use, review, or development of estimates is secondary to application or theoretical discussion. Also, we do not review here studies of a single cost category, such as air pollution or noise (these studies are reviewed in the appropriate report of the social cost series of

Delucchi et al 1996). Although this literature review focuses specifically on U.S. studies, European studies are summarized at the end of the paper.

KEELER AND SMALL (1975)

Keeler and Small is one of the most influential and widely cited studies of the costs associated with automobile use. It was one of the first attempts to quantify the nonmarket costs of automobile use, such as time and pollution, as well as the direct costs, such as operation and maintenance. Although most of the costs in this report are now outdated, and many of the methods have been improved, we summarize Keeler and Small because of its influence on subsequent research.

Goals and Methodology

This report develops estimates of the costs of peak-hour automobile transportation in the San Francisco Bay Area. To facilitate intermodal comparisons, the authors also develop similar cost estimates for bus and rail work trips. They divide automobile trips into three main components, and estimate costs associated with each: 1) residential collection (i.e., going from a residence to the freeway interchange), 2) line-haul trip (i.e., travel by freeway to the edge of the central business district), and 3) downtown distribution. They evaluate two alternative trip lengths: 1) a 6-mile line-haul trip with an average feeder distance of 1 mile, and 2) a 12-mile trip with an average feeder distance of 2 miles. For both trips, the downtown distribution is assumed to be about 0.75 miles in length.

Capital and Maintenance Costs

To estimate highway capacity costs, Keeler and Small develop statistical cost models for construction, land acquisition, and maintenance for 1972. The data used in the three models covers all state-maintained roads in the Bay Area, including expressways, arterials, and rural roads. The construction cost model, which accounts statistically for the effects of urbanization and economies of scale on expressway construction costs, allows them to estimate the cost of a lane-mile of freeway under different degrees of urbanization and road widths. Land acquisition costs are modeled in a similar manner. Finally, maintenance costs per lane-mile are expressed as a function of the average annual vehicles per lane on the relevant stretch of road.

User Benefits and Costs of Speed

Keeler and Small recognize that there is a tradeoff between highway traffic speed and capacity utilization: faster speeds save travel time, but result in lower capacity utilization and increased fuel consumption.[2] This tradeoff is represented by speed-flow curves. They develop a model that calculates optimal tolls and volume-capacity ratios for each period as a function of time values and lane capacity costs. To develop the model, the authors adjusted the results of a study by the Institute of Transportation and Traffic Engineering that estimated speed-flow curves for the Bay Area. On the basis of a literature review, they assume the value of time in the vehicle is $3 per hour per person. Finally, they use data on hourly vehicle flows to determine the peaking characteristics of traffic.

Public Costs

For Keeler and Small, public costs include environmental costs, the costs of police and supporting social services (e.g., city planning, fire department, courts), and any maintenance costs related to the number of vehicles that use the road (as opposed to the capacity of the road). To estimate police and social service costs, the authors cite an earlier, unpublished paper (Keeler et al 1974), in which they estimated the average costs of police and supporting social services was about 4.5 mills[3] per vehicle-mile in the Bay Area. They assume that the marginal and average costs are about the same.

Their estimate of the environmental costs (i.e., noise and pollution) are also drawn from a previous paper (Keeler and Small 1974). They argue that marginal noise costs are likely to be low, no more than one or two mills per vehicle-mile, because costs are high only on quiet residential streets where an extra vehicle is likely to be

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[2] However, fuel consumption is not by any means a simple linear function of speed, and in some cases a increase in the overall average speed reduces fuel consumption.

[3] One mill equals one-tenth of a cent.

noticed. They estimate that composite pollution (the average from all vehicle types) in 1973 cost about 0.92¢ per vehicle-mile. They note that this is a conservative figure, because it assumes that the cost of human illness and death is only equal to hospital bills and foregone wages. On the other hand, they expect that this cost will decline as more rigorous standards come into effect.

Accidents and Parking Costs

To estimate accident costs, Keeler and Small first compute a national average accident cost figure, and then use the results of two earlier studies (May 1955; Kihlberg and Tharp 1968) to allocate costs among the different highway types and locations. Parking costs are derived by combining the results of two engineering cost studies (Meyer et al 1965; Wilbur Smith and Associates 1965). From this, they derive estimates of the annual cost per parking space for five types of facilities (lot on central business district—CBD—fringe, lot in low land value CBD, and garage in low-, medium-, and high-value CBD). They compare the results of these studies with actual rates at privately owned parking facilities in San Francisco and find that they are consistent.

Related Work

The work of Keeler and Small spawned additional work by Small (1977) on air pollution costs. The objective of Small (1977) is "to provide some rough and aggregate measures of the economic costs imposed on society by air pollution from various transport modes in urban areas." Small uses the work of Rice (1966), Lave and Seskin (1970), and the Midwest Research Institute (1970) to estimate the total health and materials costs of air pollution. He then disaggregates the total pollution cost by specific pollutant and geography. Finally, he estimates the motor vehicle contribution to each pollutant and hence to air pollution damages. The result is an estimate of $1.64 billion in air pollution damages by automobiles, and $0.55 billion by trucks, in 1974.

FEDERAL HIGHWAY ADMINISTRATION (1982)

Goals and Methodology

In the introduction, the authors state:

> This report . . . responds to the [congressional] request for: (1) an allocation of Federal highway program costs among the various classes of highway vehicles occasioning such costs; (2) an assessment of the current Federal user charges and recommendations on any more equitable alternatives; and (3) an evaluation of the need for long-term monitoring of roadway deterioration due to traffic and other factors (p. I-1).

Although the primary focus of the report is the allocation of federal highway expenditures, appendix E of the report contains a discussion of some of the social costs and provides estimates of efficient highway user charges for some of these costs in 1981.[4] The authors focus solely on costs that vary with vehicle-miles of travel (VMT). Of 11 cost items mentioned in the report, the authors attempt to estimate costs on a VMT basis for 6: pavement repairs, vibration damages to vehicles, administration, congestion, air pollution, and noise. Costs associated with the first two items are significant for trucks, but negligible for automobiles on a VMT basis. The authors note that of the five costs not estimated in cents per VMT, "accidents looks to be the only category that might lead to a substantial increase in user charges if more were known about causal relationships. Other marginal costs may be large in the aggregate but small in relation to VMT" (p. E-52). In their conclusion, they estimate that "efficient user charges could raise almost $80 billion annually (ignoring collection costs and assuming revenues from different types of charges are additive), in contrast to the $40 billion currently spent on highways by all levels of government or the $22 billion now raised by user fees" (p. E-7). In addition, appendix E also contains a fairly detailed discussion of the standard economic theory on which their analysis is based.

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[4] "Efficient highway user charges are those which will lead to the greatest surplus of benefits over costs, for a given stock of capital facilities" (p. E-17).

KANAFANI (1983)

Kanafani is a review of published estimates of the social costs of motor vehicle noise, air pollution, and accidents. As he puts it:

> the purpose of this report is to review and assess recent attempts at the evaluation of the social costs of road transport. It is intended to provide a comparative evaluation of the economic magnitude of the social costs of road transport in selected countries, particularly as occasioned by the environmental and safety impacts of motor transport" (p. 3).

He defines social costs as "those costs that are incurred by society as a whole, not solely by the users as direct costs, nor those that are incurred solely by the nonusers (pp. 2–3). He discusses the key cost components for each of these categories, and summarizes the results from other studies.

Kanafani reviews studies from several different countries, including the United States, France, and West Germany. Based on a literature review, he estimates that the social cost of noise in the United States is between \$1.3 billion and \$2.6 billion (0.06% to 0.1% of GDP), the social cost of air pollution ranges between \$3.2 billion and \$9.7 billion (0.14% to 0.36% of GDP), and accidents cost between \$33.0 billion and \$37.0 billion (about 2% of GDP). (The year of these estimates varies, because Kanafani reports estimates from the literature without converting or updating the dollars to a base year.)

FULLER ET AL (1983)

Background and Scope

Fuller et al was prepared in conjunction with the Federal Highway Administration (FHWA) Cost Allocation Study (1982). Although the FHWA report discusses external costs, its primary focus is on allocating government outlays. Fuller et al, on the other hand, focuses exclusively on external costs. The costs identified in this report are: congestion or interference (including accidents), air pollution, and noise damages. The analysis was performed using data for 1976 to 1979, with forecasts for 1985.

Although the report "does not undertake to develop new techniques for the measurement of damages," and instead performs "a comprehensive review of the literature and data available for each type of damage" (p. 4), it does in fact use detailed models to estimate marginal and total costs, particularly for noise.

The work of Fuller et al was incorporated into the FHWA study, and has been cited in a number of others.

Congestion and Accident Costs

Fuller et al model traffic interference and marginal accident rates as a function of the volume-to-capacity ratio on several different functional classes of roads (interstates, arterials, collectors, and local roads in rural and urban areas). They combine these functions with estimates of the value of time by functional road class, and the injury, fatality, and property damage costs of accidents, to produce marginal cost curves for the different functional classes of roads.

Air Pollution Costs

Fuller et al estimate air pollution costs in three steps. First, they review and analyze the literature on the health, vegetation, and materials damages of air pollution (e.g., Small 1977; Lave and Seskin 1970) in order to estimate dollar damages per ton of each pollutant. Second, they multiply the dollars per ton estimates by the U.S. Environmental Protection Agency estimates of grams per mile of emissions, for each pollutant, and sum across all of the pollutants, to obtain dollars per VMT. Finally, they "correct" the dollars per VMT estimates for "microscale" differences in exposure, meteorology, and other factors.

Noise Costs

Fuller et al calculate the dollar cost of motor vehicle noise in residential areas as the product of three factors:

1. the number of housing units in each of up to three distance/noise bands along roads: moderate exposure (55 to 65 dBA), significant exposure (65 to 75 dBA), and severe exposure (more than 75 dBA);
2. excess dBA of noise, equal to the noise level at the midpoint of each distance/noise band minus the threshold noise level (assumed to be 55 dBA);

3. the dollar reduction in property value per excess dBA (estimated to be $152 per excess dBA in 1977 dollars).

They use a 1970s-vintage noise generation equation to delineate the distance/noise bands, and national average data on housing density, housing value, and traffic volume. They do not consider noise costs outside of the home.

MACKENZIE ET AL (1992)

Goals and Methodology

The goal of this report is to quantify the costs of motor vehicle use in the United States that are not borne by drivers. Because it is one of the more widely cited studies on the social cost of motor vehicle use in the United States, we provide some additional comments on the derivation of their cost estimates.

Two types of costs are identified in this study: market and external. "Market costs are those that are actually reflected in economic transactions . . . (They) represent the direct, ordinary, expected costs of owning and operating a motor vehicle" (p. 7). Examples of this include vehicle purchase, fuel and maintenance costs, and road construction and repair. External costs, or externalities, are those costs, such as global warming and illnesses resulting from pollution, that are not incorporated into market transactions. Social costs are the sum of market and external costs.

The results of this study are summarized in table 1. MacKenzie et al estimate that the annual market costs not borne by drivers in 1989 was about $174.2 billion, and that the annual external costs not borne by drivers totaled $126.3 billion, for a total of approximately $300 billion.

Most of the cost estimates provided by MacKenzie et al are direct citations from another work or simple extrapolations from someone else's analysis. In the following sections, we discuss some of the estimates derived by MacKenzie et al. The costs in table 1 that we do not discuss below are essentially direct citations from other studies.

TABLE 1 Annual Social Costs of Vehicle Use not Borne by Drivers: 1989
MacKenzie et al 1992

Market costs	$ billion
Highway construction and repair	13.3
Highway maintenance	7.9
Highway services (police, fire, etc.)	68.0
Value of free parking	85.0
Total market costs	*174.2*
External costs	
Air pollution	10.0
Greenhouse gases	27.0
Strategic petroleum reserve	0.3
Military expenditures	25.0
Accidents	55.0
Noise	9.0
Total external costs	*126.3*
Total social costs	*300.5*

Highway Services

In this category, MacKenzie et al mean to include police motorcycle patrols and details for auto theft, parking enforcement, accident aid, fighting garage fires, and various public works expenses, such as traffic and road engineering. Their estimate of the cost of these services is from Hart (1986), which in turn is based on Hart's earlier, more detailed analysis (Hart 1985).

Hart's (1986) estimates of the national cost of highway services is an extrapolation of his detailed estimate for the city of Pasadena. This extrapolation is questionable. Moreover, it appears that some of the costs that Hart (1985; 1986), and hence MacKenzie et al, count as highway service costs are actually highway capital and operating costs in FHWA (1990), and hence are double counted in MacKenzie et al.

Employer-Paid Parking

MacKenzie et al assume that 86% of the workforce commute by car, and that 90% receive free parking, and use this to calculate that 85 million Americans receive free parking at work. Assuming that the average national value of a parking space is $1,000 (Association for Commuter Transportation 1990),[5] MacKenzie et al estimate that the annual parking subsidy for workers is about $85 billion.

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[5] This estimate probably is too high (Delucchi et al 1996).

MacKenzie et al note that their estimate is for the cost of free parking at work, and therefore it does not include the cost of free parking for other kinds of trips. Because commuting to work constitutes only 26% of all vehicle trips, the cost of free parking for nonwork trips is probably not trivial.

Climate Change

Because there is so much uncertainty about the magnitude, effects, and costs of climate change, MacKenzie et al assume that "it is not possible to accurately estimate the actual costs of the current buildup of greenhouse gases" (p. 14). Instead, they develop an "imperfect" estimate, based on Jorgenson and Wilcoxen (1991), that a phased-in carbon tax that reached $60 per ton of carbon emissions (about 20¢ per gallon of gasoline) in the year 2020 would reduce emissions to 80% of the 1990 level by 2005. By assuming that motor vehicle fuel consumption would continue at roughly 1990 levels, MacKenzie et al estimate that a phased-in tax of 20¢ per gallon would eventually cost motorists about $27 billion per year, which they use as an estimate of the cost of climate change. We emphasize that this is not an estimate of the damage cost of global warming at all, but rather an estimate of the aggregate revenue from a somewhat arbitrarily assumed carbon tax on gasoline.

KETCHAM AND KOMANOFF (1992)

Goals and Methodology

Ketcham and Komanoff are concerned about the inefficient use of New York City's transportation infrastructure. They believe that the compactness of New York City creates an opportunity to provide people with a greater variety of transportation alternatives, but that public policies are skewed toward motor vehicle use and prevent these opportunities from materializing. They argue that New York City's "transportation and air pollution problems are solvable, through an approach that systematically charges motorists for a fair share of the fiscal and social costs of driving and invests much of the revenues in transit and other non-motorized modes" (p. 3). Their paper explains this approach, and how it can "benefit the vast majority of residents in the region" (p. 3).

In their report, costs are divided into four categories. 1) The costs that motorists pay when they drive are called "the direct costs of roadway transportation borne by users." Examples of these direct costs include vehicle purchase, fuel, insurance, and maintenance and repair. 2) The costs of building and maintaining roads, net of user fees such as tolls and taxes, are called "the direct costs of roadway transportation borne by non-users." 3) The portion of motor vehicle externalities, such as congestion, noise, and accidents, that is borne by motorists in the act of driving is called "the externality costs borne by users." 4) Finally, environmental damages and other external costs that are borne by society as a whole are called "externalities borne by non-users."

Much of the paper is devoted to public policy issues that focus primarily on New York City. However, a portion of the paper provides an analysis of the social costs of motor vehicle use for the whole United States. Our review focuses on Ketcham and Komanoff's national estimates, most of which they derived from their review of other published studies, particularly FHWA (1982), Eno Foundation (1991), and MacKenzie et al (1992). The results of their study are shown in table 2, and discussed in more detail below.

Direct Costs of Roadway Transportation

Ketcham and Komanoff's estimates of the direct costs borne by drivers—vehicle ownership, taxi services, school bus transport, and freight movement by truck—are from the Eno Foundation (1991). They do not estimate the national costs associated with off-street parking. Their estimates of the direct costs not borne by drivers—costs associated with roadway construction, maintenance, administration and services—are calculated from FHWA data on highway finances (FHWA 1990).

Externalities of Roadway Transportation

Accidents and congestion. In Ketcham and Komanoff, the two largest external costs are congestion ($168 billion) and accidents ($363 billion), which combined represent almost 75% of their total estimated external costs of roadway transport. To estimate congestion costs they use the cost factors in the FHWA Cost Allocation Study (1982), adjusted to

TABLE 2 Costs of Roadway Transportation in the United States: 1990
Ketcham and Komanoff 1992

Direct costs of roadway transportation borne by users	**$ billion**
Personal transportation (auto)	510.8
Taxi/limousine services	7.5
School bus transport	7.5
Freight movement by truck	272.6
Roadway construction and maintenance	48.1
Off-street parking	n.e.
Total direct costs of roadway modes (A)[1]	*798.4*
Direct costs of roadway transport borne by non-users	
Roadway construction, maintenance, admin. services	16.0
Parking	n.e.
Total direct costs not borne by users (B)	*16.0*
Externality costs borne by users	
Congestion costs	142.8
Air pollution: health and property costs	1.5
Accident costs	290.4
Noise costs	1.1
Pavement damage to vehicles	15.0
Total externality costs borne by motorists (C)	*450.8*
Externality costs borne by non-users	
Congestion costs	25.2
Air pollution: health and property costs	28.5
Accident costs	72.6
Noise costs	21.1
Vibration damage to buildings and infrastructure	6.6
Land costs	66.1
Security costs	33.4
Climate change	25.0
Total externality costs borne by non-users (D)	*278.5*
Total cost of roadway transport (A+B+C+D)	*1,544*
Direct cost of roadway transport (A+B)	*814*
External cost of roadway transport (C+D)	*729*
Roadway costs borne by everyone (B+D)	*295*

n.e. = not estimated.

[1] It is unclear why Ketcham and Komanoff did not include the cost of "Roadway construction and maintenance" in this total. It probably was an oversight. In any case, we report the totals as they are shown in the original source.

1990 dollars, but not to 1990 congestion levels. Their estimate of the national cost of motor vehicle accidents is from the Urban Institute (1991). The bulk of these two external costs is borne by users.

Land costs. According to Ketcham and Komanoff, the land cost of motor vehicle use is one of the largest external costs borne by nondrivers. They estimate the land cost nationally by scaling the estimated cost in New York City. They estimate the cost in New York City on the basis of three assumptions: that street space is one-third of the city's land area; that half of the street space is needed for movement of public vehicles, bicycles, and pedestrians (and therefore is not to be assigned to motor vehicle use); and that the value of the land in New York City is 45% of the city's $26 billion budget derived from property taxes. They then estimate the national land cost by scaling up the cost in New York City on the basis of population and labor force.

One can question all three of the assumptions that Ketcham and Komanoff use to estimate the value of land devoted to motor vehicle use in New York City. Certainly, one can question the basis for scaling the result from New York City to the entire country. Beyond that, however, it is not clear to us why they consider all of the estimated land value to be an external cost: FHWA's estimates of the cost of road construction (FHWA 1990), which Ketcham and Komanoff use in their national analysis, include the cost of acquiring rights-of-way for roads. Hence, at least some of the cost of the land is counted as an infrastructure cost, and is partially recovered from users through user fees.

Air pollution and noise. Ketcham and Komanoff derive their estimate of the cost of air pollution ($30 billion) from the estimates in the FHWA Cost Allocation study (1982), which the authors say are consistent with the ranges published in other studies. (Actually, on basis of these other studies, the authors feel that their estimate of $30 billion is conservative.) Noise cost estimates are derived from a 1981 study for FHWA by the Institute of Urban and Regional Research at the University of Iowa (Hokanson et al 1981), which estimates the nationwide costs of noise in 1977. Ketcham and Komanoff make some adjustments to this figure to account for differences between 1977 and 1990.

HANSON (1992)

Goals and Methodology

Hanson's article "delineates the nature and magnitude of automobile subsidies in the United States and considers their significance for transportation and land use policy. The central argument . . . is that the U.S. transportation system, based on and designed largely for the automobile, has been systematically subsidized in a way that produces a more dispersed settlement pattern than would have otherwise evolved" (p. 60).

In Hanson, an automobile subsidy is any direct cost of providing for and using the automobile system that is not paid for privately or through a transportation fee. Hanson uses data provided by the state of Wisconsin, supplemented with a review of existing studies, to estimate these subsidies. Wisconsin is used because it is near the national average for the percentage of state highway user revenues shared with local governments, and because Wisconsin is unique in its extensive reporting requirements.

Direct Costs

Hanson divides direct costs into three major categories. Highway construction includes right-of-way acquisition, engineering, signage, and construction costs for pavement, bridges, culverts, and storm sewers. Highway maintenance includes maintenance of pavements, bridges, culverts, storm sewers, and traffic control devices, and snow plowing. Other highway infrastructure includes machinery and vehicles, buildings, debt service payments, and street lighting. Hanson analyzes government data to make these estimates. After estimating the gross direct costs, Hanson nets out offsetting user revenues to calculate the subsidy to motor vehicle use.

Externalities and Other Indirect Subsidies

Hanson estimates the external costs of air pollution, water pollution resulting from road salt use, personal injury and lost earnings associated with accidents, land-use opportunity costs for land removed from other sources, and petroleum subsidies. Hanson points out that there are a number of other external costs, such as noise and community disruption, that he has not attempted to quantify.

In order to estimate air pollution costs for Madison, Wisconsin, he notes that the midpoint estimate in the studies of national costs that he reviewed was $7 billion. To allocate a share of this to Madison, he multiplied this midpoint figure by the ratio of the population of Madison to the population of the United States.

To estimate the personal injury costs associated with accidents, Hanson multiplies the number of accidents in 1982 (1,628 according to the Wisconsin Department of Transportation, WDOT) by the personal injury cost per accident ($7,700). He also uses a WDOT estimate of the cost of lost earnings, $1.6 million. These estimates do not include a value for fatalities.

Hanson also uses WDOT data to generate an estimate of the value of property damages resulting from accidents. However, in quantifying the amount that should be considered a subsidy, he assumes that "because a substantial portion of property damage is insured by automobile users via separate insurance coverage, and to a lesser degree by direct payments, those costs are mostly internalized and, therefore, not included."

Hanson assumes that "a land opportunity cost occurs when land, used for roads, could have been used for some other purpose." A subsidy will result if more than the "optimal" amount of land is used for highways. To provide a rough estimate of this subsidy, Hanson assumes that one-third of the surface area of highways in Madison is unnecessary. This is based on two assumptions. First, according to Cervero (1989), local roads provide 80% of the lane-miles, but only 15% of the vehicle-miles. Second, he assumes that higher travel costs would reduce travel demand and alter land use in the long run. He uses foregone property tax revenues to estimate the cost of land, and calculates that, with the existing property tax rates, Madison would gain $1 million in revenues if the area of roadways was reduced by one-third.

Hanson notes that air emissions from motor vehicles contribute to water pollution and acid rain, but believes there are few reliable published estimates of the damages. As a result, he focuses only on damages from road salt. He begins with the estimates provided by Murray and Ernst (1976), adjusts their figures to avoid double counting, converts their estimate to 1983 dollars, and finally allocates a portion of the cost to Madison on the basis of the population in the snowbelt "salt zone."

To estimate petroleum subsidies, Hanson uses Hines' (1988) estimates of the depletion allowances and other tax breaks received by the petroleum industry in 1984. This is allocated to Madison by combining gasoline consumption for personal travel in Madison with the subsidy level per British thermal unit (Btu).

CONGRESSIONAL RESEARCH SERVICE (BEHRENS ET AL 1992)

Goals and Methodology

Congress asked the Congressional Research Service (CRS) to summarize for the U.S. Alternative Fuels Council what is known about monetary estimates of the side effects (external costs) of oil used in highway transportation. In its analysis, CRS considers three kinds of costs: economic costs stemming from the dependence on world oil markets, national defense costs, and health and environmental impacts. They review previously published studies, and develop what they believe are reasonable low- to mid-range estimates of the monetary value of these external costs.

The results of this study are summarized in table 3. Note that CRS, like Kanafani (1983), reports estimates directly from the literature without converting or updating the dollars to a base year.

TABLE 3 Estimated External Costs of Oil Used in Transport
Congressional Research Service
(Behrens et al 1992)
(Billions of dollars)

Cost category	Low	High
Risk of supply disruption	3.2	4.9
Monopsony effects	11.3	13.0
Military expenditures	0.3	5.0
Air pollution—human health	3.6	3.6
Air pollution—crop damages	1.1	1.1
Air pollution—material damages	0.3	0.3
Air pollution—visibility	0.8	0.8
Oil spills	n. e.	n. e.
Total with monopsony effects[1]	*10.5*	*17.0*
Total without monopsony effects[1]	*21.8*	*30.0*

n.e. = not estimated.

[1] The estimates in each category and the totals shown here are those reported in Behrens et al and are based on a review of the literature. The authors did not convert the dollar estimates in the literature to a single dollar base year. The totals are the overall estimates, not the sum of the individual estimates.

Economic Costs of Oil Dependence

CRS considers two effects on the economy due to oil dependency: the risk of a supply disruption, and the market power or monopsony effect. The former is the result of exposure to "possible market manipulation or disruption by exporting nations" (p. 7). Some of the potential adverse impacts include higher inflation and unemployment, as well as possible balance of payments and exchange rate effects. The range of estimates of the costs associated with this are from zero to $10 per barrel. Multiplying the results of a mid-range estimate by U.S. oil imports for 1990, the authors estimate a $6 billion to $9 billion cost to the economy due to the risk of disruption.

According to CRS, "the market power or monopsony component reflects the influence on the world price that a large importer such as the United States causes" (p. 7). The economic cost of this is the failure to transfer wealth to U.S. citizens by reducing U.S. oil imports (which would result in lower world oil prices). Based on a literature review, the authors use a mid-range estimate between $21 billion and $24 billion for not exploiting this power.

National Defense Costs

CRS considers military expenditures that could be avoided if the United States and other industrialized countries did not need to import oil from the Persian Gulf (p. 23). In developing its estimate, CRS reviews the estimates provided by the U.S. General Accounting Office (1991), Ravenal (1991), and Kaufmann and Steinbruner (1991).

CRS discusses at length some of the difficulties of attributing military expenditures to the defense of Persian Gulf oil interests. As a result of these difficulties, cost estimates can range from a few cents to a few hundred dollars per barrel. The authors conclude that attempts to reduce U.S. dependence on imported oil will probably have little effect on the amount spent in the Persian Gulf. They also note that attempts to internalize these costs may not have a significant impact on reducing the costs.

Health and Environmental Impacts

CRS estimates the impacts of motor vehicle pollution on human health, crop yields, certain species in forests, materials, and visibility, but not climate change. The authors acknowledge that there will be damage to ecosystems resulting from oil spills, but believe that there are no "defendable estimates of the monetary value of the external costs associated with oil spills" (p. 55).

CRS emphasizes that "the effects on the environment and health . . . are imperfectly understood. And how these environmental and health damages can be approximated in monetary terms is controversial" (p. 10).

On the basis of a literature review, the authors conclude that a "reasonable estimate of the lower range of health and welfare damages resulting from transportation-related pollution is between $5 and $6 billion per year" (p. 52). We note that this is one of the lower estimates in the literature.

MILLER AND MOFFET (1993)

Through a survey of existing literature, Miller and Moffet attempt to develop estimates of the full cost of transportation in the United States in 1990. In addition to estimating the costs associated with automobile transportation, they also estimate these costs for bus and rail transportation. Table 4 summarizes their estimates of the costs of automobile use.

They consider three categories of costs. "Personal costs," which include the costs to purchase, register, maintain, and operate a car, are borne solely by the vehicle owner. "Government subsidies" include direct construction and maintenance expenditures plus other government expenses directly associated with providing transportation services. Miller and Moffet's estimate of these costs are net of user fees. "Societal costs" include all other indirect costs, or what is often referred to as externalities. Examples of this include energy dependence, pollution, and congestion.

Miller and Moffet estimate that the full annual costs of automobile transportation were between $1.1 trillion and $1.6 trillion in 1990. They estimate that $72 billion of this was government subsidies, between $310 billion and $592 billion were societal costs, and the remaining $775 billion to $930 billion were personal costs incurred by the vehicle owners. However, one must be cautious in interpreting their estimate of the full annual costs of automobile transportation. The bulk of this estimate is comprised of personal costs entirely borne by vehicle users, and it can be somewhat confusing when this figure is added to net government expenditures, rather then gross government expenditures. Total unpaid social costs, that is, net government subsidies plus societal costs, totaled between $378 billion and $660 billion in 1990.

TABLE 4 The Full Cost of Transportation in the United States: 1990
Miller and Moffet 1993

Category	$ billion
Personal costs	
Ownership and maintenance	775–930
Government subsidies	
Capital and operating expenses	64.0
Local government expenses	8.0
Total government subsidies	*72.0*
Societal costs	
Energy dependence	45–150
Congestion	11.0
Parking	25–100
Accidents	98.0
Noise	2.7–4.4
Building damage	0.3
Air pollution	120–220
Water pollution	3.8
Total societal costs	*310–592*
Unquantified costs	
Wetlands lost	n.e.
Agricultural land lost	n.e.
Damage to historic property	n.e.
Changes in property value	n.e.
Equity effects	n.e.
Urban sprawl	n.e.
Total government and societal costs	*378–660*
Total costs	1,153–1,590

n.e. = not estimated.

Note: This table is reproduced directly from Miller and Moffet. Note that both the total government and societal costs and the total costs do not add up, presumably due to rounding.

KPMG PEAT MARWICK, STEVENSON, AND KELLOGG (1993)

As part of a long-range transport planning initiative, the Greater Vancouver Regional District and the Province of British Columbia hired KPMG Peat Marwick, Stevenson, and Kellogg to analyze the full costs of various modes of passenger transportation in British Columbia. The resulting study estimates the total cost of transporting people in the Lower Mainland in 1991, and calculates the average cost "per unit" of travel, by different modes, for urban peak, urban off-peak and suburban travel (p. iii). There are three specific goals of the analysis: 1) estimate the total economic costs of different modes of passenger transport in the region; 2) determine how much is paid by users of different transport modes and how much is paid by non-users; and 3) provide a broad basis for assumptions and recommendations regarding the future levels and methods of pricing the movement of people in the region.

The authors utilize a computer model to estimate these costs for five different modes of private transport (average car, fuel-efficient car, car pool, van pool, and motorcycle), four modes of public transport (diesel bus, trolley bus, SkyTrain, and SeaBus), and three modes of nonmotorized transport (bicycle, walking, and telecommuting). The costs are evaluated for travel in urban areas during peak and off-peak hours, as well as for suburban travel. They find that the total subsidy for automobile transport in 1991 was $2.7 billion Canadian dollars (C$2.7 billion).

The authors estimate that the total cost associated with the transportation in the Lower Mainland of British Columbia in 1991 was approximately C$13.6 billion. The five modes of transport via private motor vehicles accounted for C$11.7 billion (86%) of the total cost, and were subsidized at approximately C$2.7 billion, or 23% of the total cost of private transport.

CALIFORNIA ENERGY COMMISSION (1994)

Purpose

In the aftermath of the 1991 Persian Gulf War, the California legislature passed, and Governor Pete Wilson signed into law, Senate Bill 1214, which provides, in part, that:

> it is the policy of this state to fully evaluate the economic and environmental costs of petroleum use . . . including the costs and value of environmental externalities, and to establish a state transportation energy policy that results in the least environmental and economic cost to the state (CEC 1994, 1).

The task of developing a "least environmental and economic cost scenario," including the costs and values of environmental externalities and energy security, was assigned to the California Energy Commission (CEC), as part of its biennial report. To fulfill this charge, CEC analyzed the social costs and benefits of several state and national energy policies, relative to a base case. The policy measures included increasing fuel taxes, increasing fuel economy standards, and subsidizing the price of alternative fuels and vehicles. For each policy, CEC estimated the differences in travel, emissions, fuel use, and so forth, relative to the base case. The value of the differences was the net social cost or benefit of the policy.

Estimates of Avoidable Costs

CEC quantified several kinds of social costs: travel time, accidents, infrastructure maintenance and repair, governmental services, air pollution, carbon dioxide, petroleum spills, and energy security.

Travel time. CEC used the "Personal Vehicle Model," a demand forecasting model that projects vehicle stock, VMT, and fuel consumption for personal cars and trucks, to estimate that congestion costs, including the disutility of aggravation, are $10.60 per hour (1992$). CEC also estimated the actual net change in travel time in Los Angeles under the various policy scenarios.

Accidents. The cost of accidents is estimated by multiplying the cost per injury or death by the number of injuries or deaths, for several kinds of injuries. Ted Miller, lead author of the much-cited Urban Institute (1991) study of the cost of highway crashes, developed California-specific unit costs for the Commission. CEC uses the Urban Institute study to allocate costs to different vehicle classes.

Air pollution. To calculate the cost per mile of air pollution, CEC multiplied the change in total emissions (estimated using California's mobile source emissions inventory models, EMFAC and

BURDEN), by the dollar-per-ton value of emissions, and then divided by the change in travel. The dollar-per-ton values, estimated for nitrogen oxides, sulfur oxides, reactive organic gases, particulate matter, and carbon monoxide, are from the Air Quality Valuation Model, a damage function model that estimates the cost of air pollution from powerplants in California air basins. CEC acknowledges that damage values for powerplants might not apply to motor vehicles.

Carbon dioxide. Because, according to CEC, "reliable data on damage functions are not available . . . the Energy Commission uses carbon emission control costs alone to represent carbon values" (p. 3G-1). CEC adopted its own control cost estimate of $28 per ton-carbon from its 1990 electricity report. To estimate the total carbon dioxide cost of different policies, CEC multiplied the cost per ton by the change in carbon emissions under the different scenarios. Carbon emissions rates for different fuel cycles were taken from reports by CEC, the U.S. Environmental Protection Agency, and DeLuchi et al (1987).

APOGEE RESEARCH (1994)

The report by Apogee Research, prepared for the Conservation Law Foundation, presents the results of case studies of intraurban passenger transportation in Boston, Massachusetts, and Portland, Maine. The report "attempts to develop a framework for comparing transportation costs and to provide specific quantification of the costs of passenger transportation" in the two regions analyzed. The methodology developed by the authors was constructed such that it could be adapted for other case studies.

The study evaluates nine "sub-modes" of transportation: single-occupancy vehicles (SOVs) on expressways, SOVs off expressways, high-occupancy vehicles (HOVs) on expressways, HOVs off expressways, commuter rail, rail transit, bus, bicycle, and walking. It also distinguishes between high, medium, and low population densities, and between on-peak and off-peak travel. Table 5 summarizes the cost categories used in their report.

Their report is divided into four main sections. The first is a comprehensive literature review that provides background information for the analytic framework. The next section describes the methodology used in the case studies, and defines the costs and travel parameters studied. The analytic framework is then applied to estimate the costs in Portland and Boston. Finally, the report presents the results of the case studies and suggests some policy responses.

Apogee Research focuses primarily on developing original estimates for user and governmental costs, and relies on existing estimates for the societal costs. Wherever possible, they try to use data from the relevant agencies to develop their cost estimates. This is supplemented by literature reviews when data were unavailable. The cost estimates derived from these data are primarily the result of relatively simple, yet intuitively reasonable, analysis, rather than the product of more complex and rigorous statistical models. The authors acknowledge this, stating that "while additional research and analysis on particular costs would undoubtedly lead to more refined results, we believe that these case studies provide a good sense of the magnitude of the various costs of transportation" (p. 59).

The policy recommendations provided in the report are common to most analyses: reduce trip length, favor lower cost modes, increase vehicle occupancy, explore single occupancy vehicle pricing, and educate the public on transportation costs.

LEE (1994)

This draft paper examines the debate about the extent to which drivers pay the costs associated with motor vehicle use. Lee uses a "full cost pricing" approach to analyze this issue. "Full cost pricing is a policy strategy based on the idea that the economy would benefit from imposing the discipline on each enterprise that all its costs should be recovered from consumers, i.e., total user revenues should equal total cost for each activity" (p. 1).

Lee is concerned more with theoretical issues than with estimates of costs. After discussing the fundamental economic issues pertaining to full and marginal cost pricing, Lee outlines a strategy for estimating these costs. His focus is not so much on estimating costs as developing an appropriate analytical structure. He discusses which costs should be included in a social costs analysis, why they

TABLE 5 Transportation Cost Categories
Apogee Research 1994

User costs[1]	**Governmental costs[2]**	**Societal costs[3]**
Vehicle purchase and debt	Capital investment—land, structures, vehicles	Parking—free private
Gas, oil, tires[4]	Operations and maintenance	Pollution—health care, cost of control, productivity loss, environmental harm
Repairs, parts	Driver education and DMV	Private infrastructure repair—vibration damage, etc.
Auto rentals	Police, judicial system, and fire	Accidents—health insurance, productivity loss, pain and suffering
Auto insurance	Parking—public, tax breaks	Energy—trade effects
Tolls[4]	Energy—security	Noise
Transit fares[4]	Accidents—public assistance	Land loss—urban, crop value, wetlands
Registration, licensing and annual taxes[4]	Pollution—public assistance	Property values and aesthetics
Parking—paid		Induced land-use patterns
Parking—housing cost		
Accidents—private expense		
Travel time		

DMV = Department of Motor Vehicles.

[1] User costs are the costs borne by vehicle owners: the direct ownership and operating costs, such as gas, oil and parts; the indirect costs, such as garage parking and accident risks.

[2] Governmental costs include expenditures that are not explicitly for the purpose of transportation, but which nevertheless are necessitated by vehicle travel.

[3] Societal costs of transportation are those paid by neither the traveler nor the government, but rather are spread across the economy.

[4] These items are, or include, dedicated taxes that fund governmental transportation expenditures and must be deducted from costs in

should be estimated, and important theoretical issues on how they should be calculated. However, Lee does make some estimates of unpaid costs, primarily on the basis of a literature review. Table 6 summarizes his estimates.

COHEN (1994)

The goal of this study is to "update and extend the analysis of the external costs of highway operations that was reported in appendix E of the final report on the 1982 Federal Highway Cost Allocation Study" (p. 1). The present report actually is an interim report. It summarizes the literature on estimating external costs, assesses recent efforts to develop national estimates of these costs, and recommends procedures that should be used to develop cost models and estimate the monetary value of external costs.

When the final report is completed, it will contain three primary elements. First, it will provide estimates of the external costs due to congestion delay, highway crashes, noise, and air pollution. Second, the report will include a simple computer model to reproduce these results in future analyses. Third, it will include a detailed discussion of institutional barriers, equity implications, and political consideration that affect marginal cost pricing and other methods to charge highway users for external costs.

For the most part, the literature review in the interim report refers to studies that we have reviewed here. And, because this is an interim report, there are no actual cost estimates for us to report. However, it appears that the authors are in the process of developing a useful framework for making original estimates of these costs. Recent unpublished manuscripts from this project indicate that they are using external cost estimation methods similar to those summarized in Delucchi et al (1996).

TABLE 6 Estimates of Highway Costs not Recovered from Users: 1991
Lee 1994

Cost group	Cost item	$ billion
Highway capital	Land (interest)	74.7
	Construction, capital expenditures	42.5
	Construction, interest	26.3
	Land acquisition and clearance	n.e.
	Relocation of prior uses and residents	n.e.
	Neighborhood disruption	n.e.
	Removal of wetlands, aquifer recharge	n.e.
	Uncontrolled construction noise, dust, runoff	n.e.
	Heat island effect	n.e.
Highway maintenance	Pavement, right-of-way, and structures	20.4
Administration	Administration and research	6.9
	Traffic police	7.8
Parking	Commuting	52.9
	Shopping, recreation, services	14.9
	Environmental degradation	n.e.
Vehicle ownership	Disposal of scrapped or abandoned vehicles	0.7
Vehicle operation	Pollution from tires	3.0
	Pollution from used oil and lubricants	0.5
	Pollution from toxic materials	0.0
Fuel and oil	Strategic petroleum reserve	4.4
	Tax subsidies to production	9.0
Accidental loss	Government compensation for natural disaster	n.e.
	Public medical costs	8.5
	Uncompensated losses	5.9
Pollution	Air	43.4
	Water	10.9
	Noise and vibration	6.4
	Noise barriers	5.1
Social overhead	Local fuel tax exemptions	4.3
	Federal gasohol exemption	1.2
	Federal corporate income tax	3.4
	State government sales taxes	13.2
	Local government property taxes	16.0
	Total cost	*382.1*
	Current user revenues	*52.1*
	Profit (loss)	*(330.0)*

n.e. = not estimated.

LITMAN (1996)

The purpose of Litman's analysis is to establish a foundation for analyzing transportation costs. After estimating the costs for the United States in 1994, primarily through an extensive literature review, he discusses the implications of these costs with respect to efficiency, equity, land use, stakeholder perspectives, and future policy options.

Litman classifies transportation costs into three dichotomies, as shown in table 7: internal (users) or external (social) costs, market or nonmarket costs, and fixed or variable costs. He estimates these costs for 11 different modes of transportation. In order to estimate the costs, Litman conducted a literature review, and from this information, generates his "best guess" at the true cost.

TABLE 7 Motor Vehicle Transportation Costs
Litman 1996

		Variable	Fixed
Internal	*Market*	Fuel Short-term parking Vehicle maintenance (part)	Vehicle purchase Vehicle registration Insurance payments Long-term parking facilities Vehicle maintenance (part)
	Nonmarket	User time and stress User accident risk	
External	*Market*	Road maintenance Traffic law enforcement Insurance disbursements	Road construction "Free" or subsidized parking Traffic planning Street lighting
	Nonmarket	Congestion delays Environmental impacts Uncompensated accident risk	Land-use impacts Social inequity

His estimates of costs for motor vehicles are summarized in table 8. In 1994, internal costs were about $1.6 trillion, and accounted for about two-thirds of the total costs. External costs amounted to about $0.8 trillion.

In Litman's analysis, the value of user time alone accounts for over 20% of the total cost of the average automobile used during peak times in urban areas. As a basis for deriving the costs, Litman uses a 1992 value of time schedule for British Columbia because it is "current and comprehensive." That study assumes that the value of the personal vehicle driver's time is 50% of the current average wage, which Litman assumes to be $12 per hour. He calculates total costs assuming average speeds of 30 mph (urban peak), 35 mph (urban off-peak), and 40 mph (rural), and an hourly cost premium of 16.5% in congestion.

In Litman's analysis, land-use impacts and parking costs are the largest external costs associated with an average car. On the basis of a review of the literature, Litman assumes that the average automobile off-street parking cost is around $3 per day.

TABLE 8 Motor Vehicle Costs in the United States: 1994
Litman 1996
(Billions of 1994 dollars)

	Internal costs	External costs	Total costs
Urban peak	327	281	607
Urban off-peak	653	313	966
Rural	589	184	773
Total	*1,569*	*778*	*2,347*

According to Litman, "a primary conclusion of this research is that a major portion of transportation costs are external, fixed, or non-market . . . This underpricing leads to transportation patterns that are economically inefficient and inequitable . . ." (p. vi).

LEVINSON ET AL (1996)[6]

Goals and Methodology

The goal of this report is to compare the costs of intercity passenger travel by air, automobile, and high-speed rail in the California Corridor (i.e., between San Francisco and Los Angeles). The policy question they address is whether the full costs of developing a high-speed rail line are comparable to the costs of expanding the air or highway transportation systems. To accomplish this, they develop long- and short-run average and marginal cost functions for each of the three modes of travel. Our discussion of this report will be limited to their analysis of the highway costs.

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[6] In this review, we refer to the pair of 1996 papers by Levinson et al (1996a and 1996b) as Levinson et al (1996). The later paper, 1996b, is a condensed journal article that summarizes the more detailed research report, 1996a.

TABLE 9 Long-Run Full Costs of the Highway System
Levinson et al 1996
(Dollars per vehicle-kilometer)

	Short-run costs		Long-run costs	
Cost category	**Marginal**	**Average**	**Marginal**	**Average**
Infrastructure costs				
Construction and maintenance	0.0055	0.0008	0.0180	0.0174
External costs				
Accidents	0.0350	0.0310	0.0350	0.0310
Congestion	0.0330	0.0680	0.0330	0.0068
Noise	0.0090	0.0060	0.0090	0.0060
Pollution	0.0046	0.0046	0.0046	0.0046
Total external costs	*0.0816*	*0.1096*	*0.0816*	*0.0484*
User costs				
Fixed + variable	0.0490	0.1300	0.0490	0.1300
Time	0.5000	0.5000	0.1500	0.1500
Total user costs	*0.5490*	*0.6300*	*0.1990*	*0.2800*
Total costs[1]	*0.2861*	*0.3292*	*0.2986*	*0.3458*

[1] This table is reproduced directly from Levinson et al without changes. Note that the total for the short-run costs do not add up properly.

They identify three types of costs associated with automobile use: infrastructure costs, user costs, and social (or external) costs.[7] For the most part, Levinson et al develop their own econometric models to estimate these costs. Each of these is discussed in more detail below. A summary of their estimates of the long-run full costs of the highway system is provided in table 9.

Infrastructure Costs

Infrastructure costs include the capital costs of infrastructure construction and debt servicing, and operations and maintenance costs. Levinson et al develop an econometric model that predicts total expenditures as a function of the price of inputs (interest rates, wage rates, and material costs), outputs (miles traveled per passenger vehicle, single unit truck, and combination truck), and network variables (the length of the network and the average width of the links). The data used for the model come from a variety of sources, such as FHWA data on maintenance and operating costs, and Gillen et al (1994) data on capital stock, among others. Costs are allocated among the different vehicle classes on the basis of an engineering analysis of the amount of damage caused by each vehicle type.

User Costs

Levinson et al estimate the cost of gas, oil, maintenance, tires, and depreciation for an intermediate-size automobile, the most popular vehicle type in 1995. (They omit insurance costs, license and registration fees, and taxes on the grounds that they are transfers.) For most of their estimates, they use data from the American Automobile Association (AAA). However, to estimate depreciation, they regress the posted price (not the actual transaction price) in an Internet classified ad for Ford Taurus and Honda Accord against the age of the vehicle and the distance traveled multiplied by the vehicle age. From this, they estimate depreciation costs of $1,351 per year and 2.3¢ per vehicle-mile of travel, which, assuming 10,000 miles per year, translates to an annual depreciation of about $1,581, as compared with the AAA estimate of $2,883 in 1993. To estimate the cost of user time, the authors assume that travel time costs $10 per hour and vehicles travel at 100 km per hour.

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[7] Note that Levinson et al (1996) use a different definition of social costs than we do in our own analyses (Delucchi et al 1996). In their report, they limit the definition of social costs to negative externalities, or external costs.

External Costs

Levinson et al identify four external costs, which they also refer to as social costs: accidents, congestion, noise, and air pollution. Their estimates for each of these costs are based on simple models and an analysis of existing work.

Accidents. Their estimate of accident costs is developed by combining an accident rate model by Sullivan and Hsu (1988) with the work of the Urban Institute (1991). The accident cost is obtained by determining the value of life, property, and injury per accident, and multiplying this by an equation that represents accident rates. They estimate that a crash on a rural interstate costs about $120,000 (in 1995 dollars), and a crash on an urban interstate costs about $70,000. The disparity is largely attributable to the higher death rate associated with accidents on rural highways due to the higher speed of travel.

Congestion. Assuming a modest average traffic flow of 1,500 vehicles per hour per lane, a $10 per hour value of time, and 1.5 passengers per vehicle, the authors estimate that the average congestion costs are $0.005 per passenger-kilometer of travel. This is based on a simple analysis of the relationship between traffic volumes and time delay.

Noise. For noise costs, they develop a simple analytical framework and use the results of previous research to derive their estimates. Essentially, this involved translating noise production rates into economic damages using total residential property damage costs per linear-kilometer of roadway.

Air pollution. The authors identify four types of air pollution (photochemical smog, acid deposition, ozone depletion, and global warming), which generate three types of damages (health effects, material and vegetation effects, and global effects). Their estimate of the total cost of air pollution is derived by combining the results of a number of other studies.

Costs Excluded from the Analysis

Levinson et al (1996) do not include U.S. defense expenditures in the Middle East or the costs of parking in their analysis. They dispute the notion that a significant share of U.S. defense expenditures are directly related to the transportation sector. They exclude parking on the grounds that it is a local cost that is unlikely to be avoided by switching intercity travel modes.

DELUCCHI ET AL (1996)

In a series of 20 reports, Delucchi et al (1996) estimate the annualized social cost of motor vehicle use, as:

- 1990 to 1991 periodic or "operating" costs, such as fuel, vehicle maintenance, highway maintenance, salaries of police officers, travel time, noise, injuries from accidents, and disease from air pollution;

  plus
- the 1990 to 1991 value of all capital, such as highways, parking lots, and residential garages (items that provide a stream of services), converted (annualized) into an equivalent stream of annual costs over the life of the capital.

This annualization approach essentially is an investment analysis, or project evaluation.

They classify and estimate costs in six general categories: personal nonmonetary costs, motor vehicle goods and services priced in the private sector, motor vehicle goods and services bundled in the private sector, motor vehicle goods and service provided by government, monetary externalities, and nonmonetary externalities.

Personal Nonmonetary Costs

In Delucchi et al, personal nonmonetary costs are those unpriced costs of motor vehicle use that a person imposes on him or herself as a result of the 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. Delucchi et al perform detailed analyses of travel time costs in this category.

Motor Vehicle Goods and Services Priced in the Private Sector

The economic cost of motor vehicle goods and services supplied in private markets is the area under the private supply curve: the dollar value of the resources that a private market allocates to supplying vehicles, fuel, parts, insurance, and so on. To estimate this area, Delucchi et al subtract producer surplus (revenue in excess of economic cost) and taxes and fees (mainly noncost transfers) from total price-times-quantity revenues. The cost items in this category include those in the "transportation" accounts of the Gross National Product (GNP), and several others. For several of these costs, Delucchi et al use the same primary data and methods used in GNP accounting.

Motor Vehicle Goods and Services Bundled in the Private Sector

Some very large costs of motor vehicle use are not explicitly priced separately. Foremost among these are the cost of free nonresidential parking, the cost of home garages, and the cost of local roads provided by private developers. However, all of these costs are included in the price of "packages," such as homes and goods, that are explicitly priced.[8] Delucchi et al use a variety of primary data sources to estimate national parking and garage costs in detail.

Motor Vehicle Goods and Services Provided by the Public Sector

Government provides a wide range of infrastructure and services in support of motor vehicle use. The most costly item is the highway infrastructure. Delucchi et al analyze survey data from FHWA, the Bureau of the Census, the Department of Energy, the Department of Justice, and other government departments to estimate these infrastructure and service costs. They note that, whereas all government expenditures on highways and the highway patrol are a cost of motor vehicle use, only a portion of total government expenditures on local police, fire, corrections, jails, and so on is a cost of motor vehicle use.

Monetary Externalities

Some costs of motor vehicle use are valued monetarily yet are unpriced from the perspective of the responsible motor vehicle user, and hence are external costs. Examples of these are accident costs that are paid for by those *not* responsible for the accident, and congestion that displaces monetarily compensated work. Delucchi et al estimate that the largest monetary externalities are those resulting from travel delay.

Nonmonetary Externalities

Delucchi et al follow Baumol and Oates (1988) and define a nonmonetary externality as a cost or benefit imposed on person A by person B but not accounted for by person B. Environmental pollution, traffic delay, and uncompensated pain and suffering due to accidents are common examples of externalities.

Environmental costs include those related to air pollution, global warming, water pollution, and noise due to motor vehicles. Delucchi et al use damage functions to estimate air pollution and noise costs. They find that by far the largest environmental externality is the cost of particulate air pollution.

The authors' estimates of the total social costs in each of the six cost categories are summarized in table 10.

STUDIES OF THE SOCIAL COSTS OF MOTOR VEHICLE USE IN EUROPE

Although this paper focuses on U.S. studies, there are a number of good studies of the social costs of motor vehicle use in Europe. Quinet (1997) provides the most comprehensive and up-to-date summary of European studies of the external cost of traffic noise. In Quinet, the range of noise cost estimates is between 0.02% and 2.0% of Gross Domestic Product (GDP); the range of local pollution costs, between 0.03% and 1.0% of GDP; and the range of accident costs, between 1.1% and 2.6% of GDP.

Verhoef (1994) also summarizes many estimates of the external cost of noise (0.02% to 0.2% of GDP), air pollution (0.1% to 1.0% of GDP), and accidents (0.5% to 2.5% of GDP) attributable to road traffic, and Kageson (1992) and Ecoplan (1992) summarize estimates of the damage cost of air pollution caused by the transport sector (0.01% to 1.0% of GDP). These ranges indicate that

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[8] Delucchi et al note that this bundling is not necessarily inefficient: in principle, a producer will bundle a cost, and not price it separately, if the administrative, operational, and customer (or employee) cost of collecting a separate price exceed the benefits.

TABLE 10 Summary of the Costs of Motor Vehicle Use: 1990–91
Delucchi et al 1996

Category	Low	High	Low	High
	(billion 1991$)		(percent)	
1. Personal nonmonetary costs of motor vehicle use	$584	$861	30	26
2. Motor vehicle goods and services priced in the private sector (estimated net of producer surplus, taxes, fees)	$761	$918	40	28
3. Motor vehicle goods and services bundled in the private sector	$131	$279	7	8
4. Motor vehicle infrastructure and services provided by the public sector	$122	$201	6	6
5. Monetary externalities of motor vehicle use	$55	$144	3	4
6. Non-monetary externalities of motor vehicle use	$267	$885	14	27
Grand total social costs of highway transportation	*$1,920*	*$3,289*	*100*	*100*
Subtotal: monetary cost only (2+3+4+5)	*$1,069*	*$1,543*		

European estimates of air pollution and accident costs are somewhat lower than recent detailed U.S. estimates (e.g., Delucchi et al 1996).

Several recent, detailed studies are not included in the reviews by Quinet (1997), Verhoef (1994), or Kageson (1992). Eyre et al (1997) estimate the effects of fuel and location on the damage cost of transport emissions. Bickel and Friedrich (1995; 1996) use a damage function approach to estimate the external costs of accidents, air pollution, noise, land use, and “dissociation effects” (e.g., roads as barriers or dividers in communities) of passenger vehicles, freight trucks, passenger rail, and freight rail in Germany in 1990. Otterström (1995) uses a detailed damage function approach, similar to the method of Delucchi et al (1996, Report #9), to estimate the external cost of the effect of traffic emissions on health, crops, materials, forests, and global warming in Finland in 1990. Maddison et al (1996; summarized in Maddison 1996) use a variety of methods to estimate the marginal external costs of global warming, air pollution, noise, congestion, road damage, and accidents attributable to road transport in the United Kingdom in 1993. Mayeres et al (1996) develop marginal cost functions, again similar to those of Delucchi et al (1996, Report #9), to estimate the marginal external cost of congestion, accidents, air pollution, and noise attributable to cars, buses, trams, metro rail, and trucks in the urban area of Brussels in the year 2005.

SUMMARY AND CONCLUSION

Our Rating of the Level of Detail

A review of the study summaries, in tables 1 to 10, indicates that in most cost categories, there is a very wide range of estimates. These ranges result from differences in every conceivable facet of the analysis: scope, accounting system, analytical methods, assumptions, and data sources. Because of this, it is not possible to give a simple summary of the *overall* quality of each analysis, or of the sources of discrepancies between analyses. However, it is possible and we hope useful to evaluate the studies according to one partial indicator of quality: the level of analytical detail.

Tables 11a to 11d identify some of the major cost categories included in these studies. For each cost category, we give a rating of A through F, which is our assessment of the level of analytical detail underlying each estimate in the studies reviewed. These ratings are explained in more detail in table 12. We emphasize that they are not necessarily assessments of the *overall* quality, because there is more to quality than detail, and a review and analysis of sound and pertinent literature is preferable to a poorly done detailed, original analysis. Nevertheless, it is useful for policymakers to know who has done a detailed original analysis, and who has done a combination of literature review and detailed analysis, and who has simply cited the work of others.

TABLE 11a Summary of Social Cost Items and Level of Detail in the Studies Reviewed[1]

Author	Keeler and Small (1975)	FHWA (1982)	Kanafani (1983)	Fuller et al (1983)
Geographic region	**San Francisco**	**USA**	**USA**	**USA**
Year(s) of estimates	**1972–73**	**1981**	**Varies**	**1976–79**
Primary purpose or objective	**Efficient resource use; compare travel modes**	**Cost allocation**	**Compare estimates for different countries**	**Cost allocation**
Cost categories[2]				
Accidents	B	F	C	A1/B
Air pollution	A1/B	B	C	A1/B
Congestion/time	A1	B		A1/B
Energy dependence[3]				
Equity				
Global warming/climate change				
Military expenditures				
Noise pollution	A1/B	B	C	A1
Parking	C			
Pavement damage to vehicles		E		
Roadway construction	A1/A2			
Roadway maintenance	A1/A2	A2		
Highway services[4]	A1	C		
Strategic petroleum reserve				
Urban sprawl/land use				
Vehicle ownership and operation		F		
Vibration damage to buildings				
Water pollution		F		

FHWA = Federal Highway Administration.

[1] The ratings A through F are defined in table 12.

[2] This list of cost categories is not meant to be all-inclusive. Instead, it represents some of the costs that are commonly estimated in these studies. The category definitions in this table necessarily are generic, because each study uses its own specific definitions. It is possible that some of the studies include other costs that are not identified in this table.

[3] Energy dependence may include such costs as macroeconomic effects of monopsony power, threats of supply disruption, trade effects, and petroleum subsidies.

[4] Highway services include such costs as police services, fire protection services, the judicial system, and paramedics.

Of course, there is a fair bit of judgment in our assessment here. What one person might consider a combination of literature review and detailed analysis of primary data (our “B” rating), another might consider a detailed analysis of the literature (our “C” rating). Although we tried to assess the studies consistently and evenhandedly, we recommend that readers consult the original studies to fully understand their level of detail as well as their overall quality.

Table 11 shows that the range in the level of detail is quite broad. For example, most of the estimates of MacKenzie et al (1992)—one of the most widely cited analyses—are based on a straightforward literature review. Miller and Moffet (1993) provide a significantly more detailed discussion of the issues, but still derive most of their estimates from the literature. Litman (1994) conducts a rather extensive literature review, and uses this as a basis for generating his “best guess” of the costs. By contrast, Levinson et al (1996) derive their estimates of the marginal and average costs from econometric models, and Delucchi et al (1996) primarily use original data analysis for their figures.

Conclusion

This review, and the ratings in tables 11a to 11d, indicate that many of the current estimates are based on literature reviews rather than detailed analysis. Of course, this in itself is not *necessarily* bad. The real problems are: 1) many of the reviews rely on outdated, superficial, nongeneralizable, or otherwise inappropriate studies; and 2) many of the cost-accounting systems are not fully articulated, or else are a mix of economic and equity crite-

TABLE 11b Summary of Social Cost Items and Level of Detail in the Studies Reviewed[1]

Author	**MacKenzie et al (1992)**	**Ketcham and Komanoff (1992)**	**Hanson (1992)**	**Behrens et al (1992)**
Geographic region	**USA**	**USA**	**Madison, WI**	**USA**
Year(s) of estimates	**1989**	**1990**	**1983**	**Varies**
Primary purpose or objective	**Equity; efficient resource use**	**Efficient resource use**	**Equity; efficient resource use**	**Estimate external costs; compare alternative fuels**
Cost categories[2]				
Accidents	D	D	D	
Air pollution	C	D, C	C	C
Congestion/time	C	D		
Energy dependence[3]			D	C
Equity				
Global warming/climate change	C	D		F
Military expenditures	D	D		C
Noise pollution	D	D		
Parking	D			
Pavement damage to vehicles		D		
Roadway construction	A2	D	A2	
Roadway maintenance	A2	D	A2	
Highway services[4]	D/E	D	A2	
Strategic petroleum reserve	D	D		C
Urban sprawl/land use			B	
Vehicle ownership and operation	D	D		
Vibration damage to buildings	E	D		
Water pollution			D	

TABLE 11c Summary of Social Cost Items and Level of Detail in the Studies Reviewed[1]

Author	**Miller and Moffett (1993)**	**KPMG (1993)**	**CEC (1994)**	**Apogee (1994)**	**Lee (1994)**
Geographic region	**USA**	**British Columbia**	**California**	**Boston; Maine**	**USA**
Year of estimates	**1990**	**1990**	**Varies**	**1993**	**1991**
Primary purpose or objective	**Efficient resource use; compare travel modes**	**Efficient resource use; compare travel modes**	**Efficient resource use**	**Efficient resource use; compare travel modes**	**Efficient pricing and resource use**
Cost categories[2]					
Accidents	B/C	A1/B	B	B	C
Air Pollution	B	B	B	B	C
Congestion/time	C	A1/B	A1/B	B/D	F
Energy dependence[3]	C		C	D	
Equity	F				
Global warming/climate change	C	B	D		
Military expenditures	C				
Noise pollution	C	A1/A2		D	C
Parking	C	A1/A2		A1	B
Pavement damage to vehicles					
Roadway construction	A2	A2		A2	A2
Roadway maintenance	A2	A2	A2	A2	A2
Highway services[4]	D	A2/E	D	A2	C
Strategic petroleum reserve	C				B/C
Urban sprawl/land use	F	E			F
Vehicle ownership and operation	D	B		A1/B	C
Vibration damage to buildings	D				
Water pollution	B	D	B/C		C

See the notes in table 11a.

TABLE 11d Summary of Social Cost Items and Level of Detail in the Studies Reviewed[1]

Author	Cohen (1994)[5]	Litman (1996)	Levinson et al (1996)
Geographic region	**USA**	**USA**	**California**
Year(s) of estimates	**1990**	**1990**	**1995–96**
Primary purpose or objective	**Cost allocation**	**Equity; efficient resource use and pricing; compare travel modes**	**Compare travel modes**
Cost categories[2]			
Accidents	F (A1/B)	B/C	A1/B
Air pollution	F (A1/B)	C	B
Congestion/time	F (A1)	B	B
Energy dependence[3]		C	
Equity		E	
Global warming/climate change			
Military expenditures			F
Noise pollution	F (A1)	C	B
Parking		B/C	F
Pavement damage to vehicles			
Roadway construction		C	A1/A2
Roadway maintenance		C	A1/A2
Highway services[4]		C	
Strategic petroleum reserve			
Urban sprawl/land use		E	
Vehicle ownership and operation		C	B
Vibration damage to buildings			
Water pollution		C	

See the notes in table 11a.

[5] Cohen (1994) is an interim report; the ratings in parentheses refer to expected level of detail of the final estimates when the research is completed.

ria. Thus, with a few exceptions, the recent literature on national social costs in the United States, taken at face value, is of limited use.

There is, however, a good deal of excellent work focusing on particular costs or localities, and it is to these, rather than generic summaries, that analysts and policymakers should turn. For example, there now are at least three detailed, original, and conceptually sound analyses of air pollution costs in the United States (Delucchi et al 1996, Report #9; Krupnick et al 1997; Small and Kazimi 1995, for Los Angeles), and several good European analyses (see discussion above). These analyses supersede previous work. Similarly, the noise cost estimates of Delucchi et al (1996, Report #14) supersede the older and heretofore widely cited estimates of Fuller et al (1983). The recent volume edited by Greene et al (1997) summarizes state-of-the-art estimates of accident costs, congestion costs, travel time costs, air pollution costs, and parking costs. As analysts continue to develop detailed marginal social cost models and sound cost-benefit evaluation tools, policymakers will begin to have more reliable cost information to consider in the complex task of making transportation policy.

TABLE 12 The Level of Detail Rating System

A1: ESTIMATE BASED ON DETAILED ANALYSIS OF PRIMARY DATA

This designation was used if the author performed a detailed, original analysis based mainly on primary data, or developed detailed cost models, such as damage-function models of the cost of air pollution. Primary data include, but are not limited to: original censuses and surveys of population, employment and wages, government expenditures, manufacturing, production and consumption of goods and services, travel, energy use, and crime; financial statistics collected by government agencies, such as the Internal Revenue Service and state motor vehicle departments; measured environmental data, such as of ambient air quality and visibility; surveys and inventories of physical infrastructure, such as housing stock and roads; and the results of empirical statistical analyses, such as epidemiological analyses of air pollution and health.

A2: ESTIMATE BASED ON STRAIGHTFORWARD ANALYSIS OF PRIMARY DATA

This designation was used if the author made relatively straightforward use of primary (or “raw”) data published (typically) by a government agency. An example of this that appears in many studies is the use of Federal Highway Administration data (e.g., FHWA 1990) to estimate highway construction and maintenance costs. (See above for other examples of primary data).

Difference between A1 and A2 ratings: A1 work is more detailed and extensive than A2 work.

B: ESTIMATE BASED ON A COMBINATION OF ORIGINAL DATA ANALYSIS AND LITERATURE REVIEW

This designation was used if the author took published estimates and then adjusted them by changing some of the variables used to derive the estimates, or if the author combined published results from various sources to develop his own estimate. For example, in the FHWA Cost Allocation Study (FHWA 1982), the authors estimate the costs of air pollution by combining vehicle pollutant emissions rates published by the U.S. Environmental Protection Agency with an estimate of air pollution damage cost rates for each pollutant.

Difference between A2 and B ratings: A2 work is based mainly on primary data, such as from government surveys or data series or physical measurements; whereas B work is more dependent on the secondary literature. However, the calculations in B work can be more extensive than those in A2 work, which can involve direct use of relevant primary data.

C: ESTIMATE BASED ON A REVIEW AND ANALYSIS OF THE LITERATURE

This designation was used if estimates were based on a review and analysis of literature, with perhaps some simple calculations. Some studies, such as Kanafani (1983), simply provide tables listing the results of other studies. Other studies, such as Behrens et al (1992) and Litman (1996), conduct a literature review and then make their own estimate on the basis of the review.

Difference between B and C ratings: B work involves some primary data (e.g., data from government surveys, from physical measurements, or primary economic analyses), whereas C work by and large does not; correspondingly, B work requires more calculation than C work.

D: ESTIMATE IS A SIMPLE EXTRAPOLATION, ADJUSTMENT, OR CITATION FROM ANOTHER STUDY

This designation was used if the author did some simple manipulation or update of a previously published result. For example, in estimating congestion costs, Ketcham and Komanoff (1992) adjusted FHWA’s (1982) congestion factors to reflect 1990 data. Similarly, MacKenzie et al (1992) cite the results of a study by the Urban Institute (1991). They adjust the constant dollar year to 1989, but make no significant adjustment to the published estimate.

Difference between C and D ratings: C work involves more sources and analysis than D work.

E: ESTIMATE IS BASED MAINLY ON SUPPOSITION OR JUDGMENT

This designation was used for estimates or simple, illustrative calculations based ultimately on supposition or judgment. For example, Ketcham and Komanoff’s (1992) found no reliable estimates of vibration damage to buildings, and so used their judgment to develop their own.

Difference between D and E ratings: D work cites a substantive analysis or estimate of the cost under consideration; E work is based on judgment without reference to any direct estimate of the cost or its major components.

F: COST ITEM IS DISCUSSED, BUT NOT ESTIMATED

This designation was used for those costs that the authors acknowledge as important, but do not attempt to quantify. For example, Lee (1994) discusses, but does not estimate, the costs of vehicle use. Miller and Moffet (1993) provide estimates for most costs, but do not estimate others due to insufficient data.

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Establishing Fare Elasticity Regimes for Urban Passenger Transport: Time-Based Fares for Concession and Non-Concession Markets Segmented by Trip Length

DAVID A. HENSHER
JENNY KING
Institute of Transport Studies
The University of Sydney and Monash University

ABSTRACT

A missing element in public transport patronage prediction is often a matrix of direct and cross fare elasticities for specific fare classes. This paper employs a combined stated preference and revealed preference data set to obtain this type of matrix, reflecting the market environment for concession and non-concession travelers using public transport for short and long trips. A heteroskedastic extreme value choice model relaxes the constant variance assumption of the multinomial logit model so that empirically realistic cross elasticities can be obtained. The elasticities obtained from the study indicate the level of switching between ticket types and between the car and bus modes for any given change in fare levels or types.

INTRODUCTION

Public transport operators increasingly use yield management techniques in establishing mixtures of ticket types and fare levels. In predicting the response of the market to specific fare classes, a knowledge of how various market segments respond to both the choice of ticket type within a

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Professor David A. Hensher, Institute of Transport Studies, C37, The University of Sydney, NSW 2006, Sydney, Australia. Email: Davidh@its.usyd.edu.au.

public transport mode and the choice between modes is crucial to the outcome. In some circumstances, the interest is in evaluating the patronage and revenue implications of variations in offered prices for the existing regime of fare classes; in other circumstances, the interest is in changes in the fare class offerings either through deletions and/or additions of classes.

A missing ingredient in many operational studies is a matrix of appropriate direct and cross fare elasticities that relates to specific fare classes within a choice set of fare class opportunities. Surprisingly, the research literature is relatively barren of empirical evidence that is rich enough to distinguish sensitivities to particular fare class offerings within a predefined choice set of offerings. Although there is a plethora of empirical evidence offered on direct elasticities (Oum et al 1992; Goodwin 1992), primarily treated as unweighted or weighted average fares within each public transport mode, there is limited evidence on cross elasticities (see Hensher (Forthcoming) for a brief review of the literature). Elasticities related to specific ticket types are generally absent from the literature, and non-existent in Australia.

This article departs from the reliance on average fares, distinguishing between fare classes for bus travel for concessionary and non-concessionary travel in the Newcastle metropolitan area (approximately 160 kilometers north of Sydney). Non-concessionary travel refers to all discounted travel, excepting pensioners who are excluded from this study. Full matrices of direct and cross share elasticities are derived for two future scenarios: Scenario I where the current Single and TravelPass/TravelTen tickets are eliminated and replaced with four timed tickets: one-hour, four-hour, one-day, and weekly tickets; and Scenario II where the four timed tickets are introduced with the retention of the current single fare. A TravelTen ticket entitles the user to 10 one-way trips over an agreed number of sections; a TravelPass entitles the purchaser to an unlimited number of one-way trips over a seven-day period over sections identified by the color coded ticket purchased. The only other major mode in the Newcastle area is the car. Taxis and trains (long distance) are excluded since they compete very little with the bus system, the major modal focus of this study.

To evaluate sizeable variations in the levels of fares in each ticket class so that operators have extended policy intelligence beyond market experience, stated choice responses are combined with a knowledge of current modal attributes from revealed preference data to assess the ticket and mode choices made.

The motivation for such disaggregation is twofold. First, public transport operators have little interest in empirical approaches that treat all fare classes as an equivalent one-way average fare—this is not a useful operational framework within which to make decisions on fare setting. Secondly, empirical measurement of indicators of behavioral response to specific ticket types, given the set of ticket types available, will enable bus operators to identify the impact of these various ticket type (and level) scenarios on overall patronage and revenue. The incorporation of these elasticities into a Decision Support System (DSS) allows an operator to evaluate the implications of various fare policies on patronage, revenue, market share, and the net social benefit per dollar of "subsidy" or community service obligation (CSO) payment provided.

The paper is organized as follows. The next section introduces a discrete choice model associated with the family of random utility models—heteroskedastic extreme value logit (HEVL)—which relaxes the strong assumption of constant variance in the unobserved effects to allow the cross elasticities to break away from the equality constraint imposed in the multinomial logit model and within partitions of the popular nested logit model. The following section outlines the empirical context in which we source revealed and stated preference data to provide an enriched utility space for assessing behavioral responses to fare scenarios extending beyond the range observed in real markets. The next section presents the empirical evidence, including a full matrix of direct and cross share elasticities for concession and non-concession travel over short and long distances. A set of conclusions highlights the major contribution of this study.

SPECIFYING A CHOICE MODEL

The ticket type and mode choice model is based on the utility maximization hypothesis, which assumes that an individual's choice of ticket type is conditional on mode. The individual's choice of mode is a reflection of the preferences for each of the available alternatives, and the alternative with the highest utility is selected. The utility that an individual associates with an alternative is specified as the sum of a deterministic component (which depends on observed attributes of the alternative and the individual) and a random component (which represents the effects of unobserved attributes of the individual and unobserved characteristics of the alternative).

In the majority of mode choice models, the random components of the utilities of the different alternatives are assumed to be independent and identically distributed (IID) with a type I extreme value distribution. This results in the multinomial logit (MNL) model of mode choice (McFadden 1981). The multinomial logit model has a simple and elegant closed-form mathematical structure, making it easy to estimate and interpret. However, it is saddled with the "independence of irrelevant alternatives" (IIA) property at the individual level (Hensher and Johnson 1981; Ben-Akiva and Lerman 1985); that is, the MNL model imposes the restriction of equal cross elasticities due to a change in an attribute affecting only the utility of an alternative i for all alternatives j≠i. This property of equal proportionate change is unlikely to represent actual choice behavior in many situations. Such misrepresentation of choice behavior can lead to misleading projections of mode share on a new or upgraded service and of diversion from existing modes. The nested logit model is a variant of the MNL model, relaxing the constant variance assumption between branches while preserving it within a branch of the nested structure (McFadden 1981; Hensher 1991).

The model developed herein assumes independent, but non-identical random terms distributed with a type I extreme value distribution. Unequal variances of the random components are likely to occur when the variance of an unobserved variable that affects choice is different for different alternatives. For example, in a mode choice model, if comfort is an unobserved variable whose values vary considerably for the bus mode (based on, say, the degree of crowding on different bus routes) but little for the automobile, then the random components for the automobile and bus will have different variances (Horowitz 1981). We apply this model in the current study. Once we relax the constant variance assumption, we have to distinguish scale and taste, to which we now turn.

The Inseparability of Taste and Scale

It has been well known for some time that a fundamental link exists between the scale of the estimated parameters and the magnitude of the random component in all choice models based on Random Utility Theory (RUT, see McFadden 1981). Let

$$U_{iq} = V_{iq} + \epsilon_{iq}, \tag{1}$$

where U_{iq} is the unobserved, latent utility individual q associates with alternative i; V_{iq} is the systematic, quantifiable proportion of utility that can be expressed in terms of observables of alternatives and consumers; and the ϵ_{iq}'s are the random or unobservable effects associated with the utility of alternative i and individual q. All RUT-based choice models are derived by making some assumptions about the distribution of the random effects; regardless of the particular assumption adopted, there is an embedded scale parameter, which is inversely related to the magnitude of the random component that cannot be separately identified from the taste parameters.

For example, to derive the MNL choice model from (1), we assume that the ϵ_{iq}'s are IID Type I Extreme Value (or Gumbel) distributed. The scale parameter $\lambda \geqslant 0$ of the Gumbel distribution is inversely proportional to the standard deviation of the error component, thus,

$$\sigma^2_{iq} = \pi^2 / 6\lambda^2.$$

The identification problem of RUT-based choice models shows itself in the MNL model through the fact that the vector of parameters actually estimated from any given source of RUT-conformable preference data is $(\lambda\beta)$, where β is the vector of taste parameters. This is seen in the full expression of the MNL choice probability:

$$P_{iq} = \frac{\exp(\lambda V_{iq})}{\sum\limits_{j \epsilon C_n} \exp(\lambda V_{jq})} = \frac{\exp(\lambda \beta X_{iq})}{\sum\limits_{j \epsilon C_q} \exp(\lambda \beta X_{jq})}, \qquad (2)$$

where P_{iq} is the choice probability of alternative i for individual q, and the systematic utility $V_{iq} = \beta X_{iq}$. Since a given set of data is characterized by some value of λ, this constant is normalized to some value (say, 1), and analysis proceeds as if $(\lambda\beta)$ were the taste parameters.

The reason for the pervasiveness of the identification problem is that choice models are specifying a structural relationship between a categorical response and a latent variable (i.e., utility). As in structural equation models involving latent variables, it is necessary to specify both origin *and* variance (read "scale") for the latent variable(s) to permit identification of utility function parameters (Hensher et al Forthcoming).

Recognition of the role of the scale parameter in the estimation and interpretation of choice models came somewhat late in the game, but was triggered by the desire to combine sources of preference data, especially revealed preference (RP) and stated preference (SP) data. Morikawa (1989) noted that the fundamental identification problem was confined to a single preference data source, and that the ratio of λ's in two or more sources of data could be identified.

The estimation problem amounts to placing an equality restriction on the taste parameters of K preference data sources to be combined (i.e., $\beta_1 = \ldots = \beta_K = \beta$) and estimating K additional scale parameters $(\beta_1,\ldots, \beta_K)$. One of these scale parameters must be fixed, say $\lambda_1 = 1$. The remaining scale parameters are then interpreted as inverse variance ratios with respect to the referent data source. The corresponding unrestricted model frees the taste parameters and the scale factors for the K data sources by estimating $(\lambda_k\beta_k)$, k = 1,…,K. The null hypothesis of interest is that of taste invariance across data sources, after permitting variance/reliability differences such an hypothesis can be tested using a likelihood ratio statistic.

The existing studies with the exception of Hensher (Forthcoming) using data from multiple sources have all adopted a constant variance assumption within the set of alternatives associated with each data set. They have set the scale parameter to 1.0 for one data set and rescaled the other data set by a scale parameter that is constant (but possibly not equal to 1.0) across the set of alternatives. The cross elasticities remain subject to the IID assumption and hence are potentially ill conditioned. We relax the constant variance assumption and allow all scale parameters to differ within and between two data sets. We do this by a procedure known as a heteroskedastic extreme value (HEV) random utility model (Bhat 1995). Joint estimation is essential to enable direct comparability in rescaling between the RP and SP choice models, since only one alternative across both data sets has its variance on the unobserved effects arbitrarily set to 1.0.

Random Effects Heteroskedastic Extreme Value Model

Allenby and Ginter (1995), Bhat (1995), and Hensher (In press) have implemented the HEV model on a single data source. Hensher (Forthcoming) has applied the HEV model to joint estimation of SP and RP data. The indirect utility function (1) is defined as:

$$U_{iq} = \lambda_{iq}\alpha + \lambda_{iq}\beta X_{iq} + \epsilon_{iq.} \qquad (3)$$

The MNL model assumes IID, that is, $\lambda_i = \lambda_j \; \forall \; j \epsilon J, i \neq j$, and $\epsilon_{iq} = \epsilon_{jq} = \epsilon$. Now assume that the λ_{iq} are equal to λ_l for all individuals q; in addition, assume they are independently, but not identically, distributed across alternatives according to the Type I Extreme Value density function

f(t) = exp(-t)*exp(-exp(-t)) = -F(t)*log(F(t)),

where F(.) is the corresponding cumulative distribution function. If the decision rule is maximal utility, then the choice probabilities are given by

$$P_{iq} = \int_{-\infty}^{\infty} \prod_{j \neq i} \mathrm{F}(\lambda_j)[V_{iq} - V_{jq} + \epsilon_{iq}]\lambda_i f(\lambda_i \epsilon_{iq}) d\epsilon_{iq}. \quad (4)$$

The probabilities are evaluated numerically, as there is no closed-form solution for this single dimensional integral. The integral can be approximated, for example, using Gauss-Laguerre quadrature (Press et al 1986). Computational experience has shown that a 68-point approximation is sufficient to reproduce taste parameter estimates (see Greene 1996). Selecting appropriate starting values is critical to the search for an optimal solution since, unlike MNL, there is no unique optimum log-likelihood at convergence; local optima exist as well as the global optimum. Experience suggests that MNL starting values are highly recommended.

The heteroskedastic extreme value model nests the restrictive MNL and is flexible enough to allow differential cross elasticities among all pairs of alternatives. It avoids the *a priori* identification of mutually exclusive market partitions of a nested MNL structure, and is thus preferable to the nested MNL model in which cross elasticities are behaviorally meaningful between alternatives within a branch of a nest but not between branches. The MNL model is of no interest here since it cannot reveal the cross elasticities that are required to establish the extent to which travelers may switch between fare classes within a mode and between modes. In contrast, the nested MNL model may be of value provided one can identify the best tree structure, consistent with global utility maximization. Selecting the best nested structure where particular cross elasticities can be ignored can involve the search across a large number of tree structures. The HEV model can assist in revealing a preferred nested structure through the distribution of the scale parameters across the alternatives.

THE EMPIRICAL CONTEXT

The prime focus is on evaluating new time-based bus tickets in the presence and absence of existing ticket offerings of a sample of non-concessioners and concession/non-pensioners in the Newcastle Bus Operations Area. Given the interest in evaluating sizeable variations in the levels of existing fares as well as the introduction of new fare categories, we use stated choice methods in combination with a knowledge of current modal/ticket attributes from revealed preference data to assess the ticket and mode choices made by a sample of residents (either car or bus users).

In the survey, respondents are asked to think about the last trip they made, where they went, how they traveled, how much it cost, etc., then are asked to describe another way they could have made that trip if their current mode were not available. Recognizing that the major forms of transport in Newcastle are car and bus, the survey limited the choice of current and alternative modes for all respondents to either bus or car. The stated preference component of the survey varies the new time-based tickets under a series of different pricing scenarios while assuming that the costs of the respondents' current form of travel is the same (see figure 1). Their responses to these different scenarios are recorded in terms of whether they choose to use their current mode/ticket (including car) or one of the new time-based tickets.

Sampling Strategy

A sample was designed that captured a sufficient number of travelers currently choosing bus or car modes and the available current ticket types. Using the distribution in table 1, it was necessary to collapse the bus ticket categories down to those most frequently used; namely, Single and TravelTen/TravelPass.

The sample size is 400 (expanded to 1,600 given 4 replications per person), with half being non-concession holders and half being concession/non-pension holders. Four suburbs in Newcastle, which are typical representations of travel behaviors for all residents in the Newcastle Bus Operations Area, were selected and sampled in roughly equal proportions, as were car users and bus users. Another quota of the sample is to have roughly equal proportions of car and bus users traveling for short and long trips. Through consultation with Newcastle Bus and Ferry Services, a short trip was defined as less than or equal to 5 km by car or less than or equal to 12 minutes by bus. It was also required that roughly equal proportions of bus users traveled on Single tickets and on TravelTen/TravelPass.

A face-to-face home interview was undertaken. Survey start points were generated to specifically target bus routes to obtain a sufficient sample of

FIGURE 1 Example of a Showcard for a Non-Concessioner

Current Form of Travel or New Bus? Call Number–A1

1	2	3	4	5
Current form of travel	**New bus**	**New bus**	**New bus**	**New bus**
Same costs as now	1-hour ticket $1.50 (Includes all transfers)	4-hour ticket $3.00 (Includes all transfers)	Day ticket $4.50 (Includes all transfers)	Weekly ticket $18.00 (Includes all transfers)

bus users. The start points were generated by randomly choosing streets in each of the selected suburbs to be cluster sampled. The sample is "choice-based"; that is, the sampling unit is the mode (ticket type) to ensure there are enough sampled currently choosing each of the alternative modes/ticket types. The revealed preference choice set is corrected in estimation to reproduce the base market shares. This does not apply to the stated choice subset of alternatives.

In addition, all observations are weighted by the distribution of personal income for residents in the Newcastle Bus Operations Area as revealed in the 1991 Census of Population and Housing. Table 2 summarizes the distribution of personal income for the population (Newcastle Bus Operations Area) and for the sample, and the weights used in scaling the data to represent the population.

TABLE 1 Profile of Public Bus Users by Ticket Type

Ticket type	Adult %	Concession %
Cash		
1–2 sections	20.8	9.9
3–9 sections	28.7	13.3
10–15 sections	2.7	1.1
16–21 sections	0.4	0.2
TravelTen		
1–2 sections	15.6	9.1
3–9 sections	22.9	6.6
10–15 sections	1.5	0.2
16–21 sections	0.0	0.0
TravelPass		
Blue	3.5	1.2
Orange	3.3	0.7
Red	0.5	0.2
Pink	0.0	0.0
Yellow	0.0	0.0
Bus Tripper	0.1	0.0
Total	100.0	100.0

Source: Newcastle Buses Ticket Usage: Number of One-Way Bus Trips, 1995.

Developing the Stated Choice Experiment

In a combined RP/SP approach it is important to present individuals with a stated preference experiment that offers realistic scenarios. Fare elasticities are only valid within the bounds of the minimum and maximum fares presented in an SP experiment. A variation of 25% below and 50% above a base fare level was selected (table 3) as the limits believed by Newcastle Buses to be "politically" feasible. The choice experimental design is a one-quarter fraction of a 3^4. This produces nine fare scenarios for each concession and non-concession situation. Each respondent is presented with four randomly assigned scenarios. The experimental

TABLE 2 Annual Personal Income Distribution of Population and Sample and Weights Used

Annual personal income	Population %	Sample %	Weights
$0–$3,000	9.6	16.6	0.58
$3,001–$12,000	37.0	40.5	0.91
$12,001–$30,000	38.6	28.3	1.36
$30,001–$40,000	8.5	8.2	1.04
$40,001–$50,000	3.2	3.2	1.01
$50,001–$60,000	1.6	1.1	1.53
$60,001–$70,000	0.6	0.8	0.77
Over $70,000	0.9	1.3	0.64
Total	100.0	100.0	

Source: 1991 Census of Population and Housing.

TABLE 3 Full Range of Fares Used in Experiments

Ticket type	Low fare	Base fare	High fare
Concession/non-pensioners			
1-hour ticket	$0.75	$1.00	$1.50
4-hour ticket	$1.50	$2.00	$3.00
Day ticket	$2.25	$3.00	$4.50
Weekly ticket	$9.00	$12.00	$18.00
Non-concessioners			
1-hour ticket	$1.50	$2.00	$3.00
4-hour ticket	$3.00	$4.00	$6.00
Day ticket	$4.50	$6.00	$9.00
Weekly ticket	$18.00	$24.00	$36.00

design is limited to the current mode/ticket used and the four proposed time-based ticket types for the bus—one-hour ticket, four-hour ticket, day ticket, and weekly ticket. A respondent is asked to select one of the four offered time-based tickets or their current mode. The fares for concession holders are exactly half that for non-concession holders. The current bus fares paid by respondents are not varied in the experiments.

The full set of alternatives analyzed are shown in figure 2. "Bus with current ticket" was modeled as two mutually exclusive alternatives—bus Single and bus TravelTen/TravelPass.

EMPIRICAL RESULTS

Table 4 provides a detailed breakdown of response rates. It was quite difficult to find respondents, especially those in the quota targets. It was particularly difficult to find respondents who traveled on buses using non-concession Single tickets and TravelTen or TravelPass for short distances (< 5 km or < 12 minutes). There was a high percentage of "non-quota" respondents, partly because those entitled to pensioner concession fares were not part of the sampling frame. Figure 3 gives the breakdown of useable responses by concession/ non concession, by trip length (short/long), and by ticket and mode.

It must be noted that the sample sizes in figure 3 refer to actual interviews; the number of individuals having each RP alternative in their choice set is much higher. In addition, when the RP data is combined with the SP data we expanded the RP data to equivalence the number of SP replications. The decision on how to match the RP data with each SP replication is essentially Bayesian (Keane et al In press)—we have chosen to give them equal weight. The descriptive statistics for the estimation sample are summarized in Appendix A. When SP replications are pooled together with RP data, the possibility for serial correlation and state dependence exists. This issue has been recognized in the extant literature (e.g., Morikawa 1994). Morikawa suggests that inertia dummy variables representing actual RP choices be included in the SP utility expressions to ". . . absorb unobserved factors related to the preference of certain alternatives over others" (p. 164) as a way of approximating the presence of state dependence. We, however, found no statistical significance on the set of inertia dummies. We have not tested for serial correlation, which if it exists may lead to possible biases in the taste weights. We did, however, run a model with only the first SP replication and compared the taste weights and found no statistical significance. This finding is confirmed in unpublished work by Brownstone (1997).

The sample has been scaled using external data to represent the population. The profile of current mode and ticket is largely governed by the sampling strategy, where 33% of respondents are current car users, 33% are bus TravelTen or TravelPass

FIGURE 2 The Universal Choice Set of Modes and Ticket Types

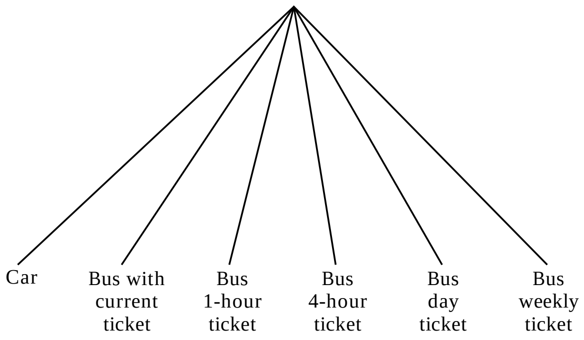
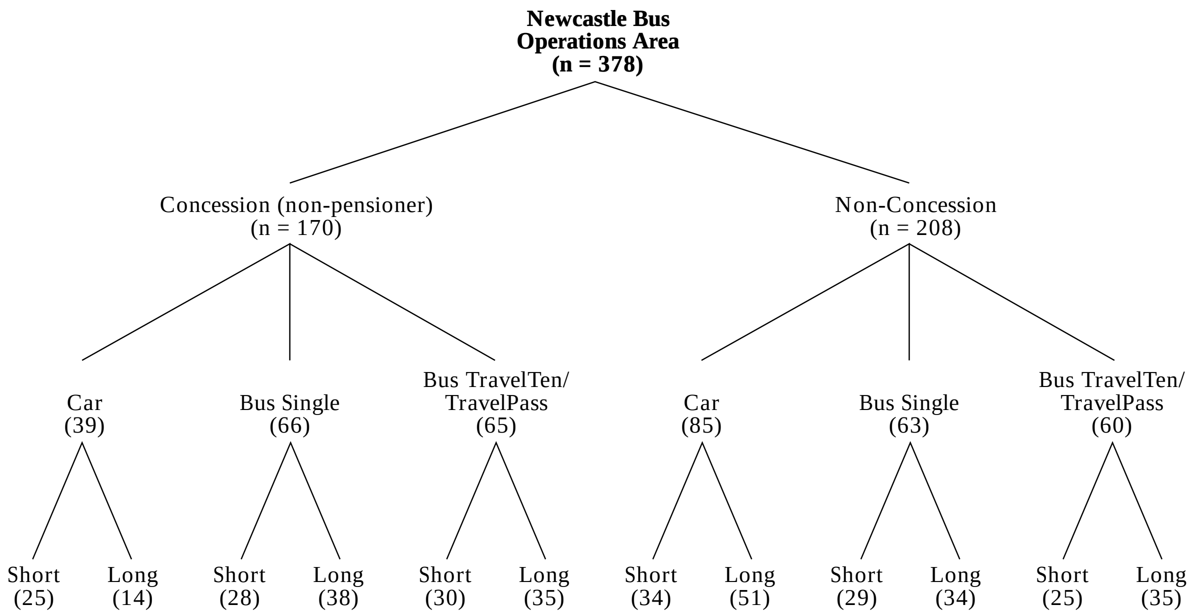


TABLE 4 Response Rates

Response	Number	Percent
Not at home	509	23
Refusals	304	14
Call backs	24	1
Other	28	1
Non-quota	952	43
Interviews	398	18

FIGURE 3 Breakdown of Fully Completed Interviews



users, and 34% are bus Single users. For the current car users, if the car were not available to them, 73% chose the bus Single ticket. Of current bus users, 67% will use the car as an alternative.

Tables 5 and 6 summarize the responses to the experiment. Table 5 shows choices made by respondents across the whole sample, broken down by their current mode/ticket. Of the respondents, 41% (6.5% bus Single, 15.2% bus TravelTen/TravelPass, and 19.3% car) did not switch from their current mode/ticket when presented with the new bus time-based fare options in the SP experiment. The one-hour ticket seems to be the most popular of the time-based bus fares, being the one chosen most by those who did not choose their current mode/ticket in the SP experiment. Of the respondents, 23.7% (i.e., 8.2% current bus Single, 7.3% current bus TravelTen/TravelPass, and 8.2%

TABLE 5 Current Mode/Ticket and Mode Chosen/Ticket in SP Experiment
(Based on weighted data)

	Current mode/ticket (in percent)			
Chosen mode/ ticket (SP)	**Bus Single**	**Bus TravelTen/ TravelPass**	**Car**	**Total**
Bus Single	6.5	0.0	0.0	6.5
Bus TravelTen/ TravelPass	0.0	15.2	0.0	15.2
Car	0.0	0.0	19.3	19.3
1-hour ticket	8.2	7.3	8.2	23.7
4-hour ticket	5.2	2.7	2.7	10.5
Day ticket	7.3	3.4	2.2	13.0
Weekly ticket	5.2	5.1	1.5	11.8
Total	32.5	33.6	33.9	100.0

TABLE 6 Current Mode/Ticket and Mode Chosen/Ticket in SP Experiment
(Based on weighted data)

	Current mode/ticket (in percent)		
Chosen mode/ ticket (SP)	**Bus Single**	**Bus TravelTen/ TravelPass**	**Car**
Bus Single	20.0	0.0	0.0
Bus TravelTen/ TravelPass	0.0	45.1	0.0
Car	0.0	0.0	57.0
1-hour ticket	25.3	21.6	24.1
4-hour ticket	16.0	8.0	7.9
Day ticket	22.6	10.2	6.6
Weekly ticket	16.1	15.1	4.5
Total	100.0	100.0	100.0

TABLE 7a Current Mode/Ticket and Mode/ Ticket Chosen in SP Experiment for Concession: Short Trips
(Based on weighted data)

	Current mode/ticket (in percent)		
Chosen mode/ ticket (SP)	**Bus Single**	**Bus TravelTen/ TravelPass**	**Car**
Bus Single	25.9	0.0	0.0
Bus TravelTen/ TravelPass	0.0	37.9	0.0
Car	0.0	0.0	74.0
1-hour ticket	21.9	15.0	12.3
4-hour ticket	13.2	10.7	5.1
Day ticket	25.0	10.5	7.1
Weekly ticket	14.0	25.8	1.4
Total	100.0	100.0	100.0

TABLE 7b Current Mode/Ticket and Mode/ Ticket Chosen in SP Experiment for Concession: Long Trips
(Based on weighted data)

	Current mode/ticket (in percent)		
Chosen mode/ ticket (SP)	**Bus Single**	**Bus TravelTen/ TravelPass**	**Car**
Bus Single	11.8	0.0	0.0
Bus TravelTen/ TravelPass	0.0	35.6	0.0
Car	0.0	0.0	32.0
1-hour ticket	17.8	33.9	53.8
4-hour ticket	15.5	7.2	0.0
Day ticket	28.7	10.6	7.8
Weekly ticket	26.1	12.6	6.4
Total	100.0	100.0	100.0

current car users) chose to travel by bus using the one-hour ticket.

Table 6 shows the breakdown of the choices made within each group of current mode/ticket classification. It shows that more than half (57%) of the current car users (current car users made up 32.8% of the sample) did not switch to using bus when presented with the new bus ticket options in the SP experiment. However, the remaining 43% of the current car users chose one of the time-based bus fares in the SP experiment. This implies that there is potential to attract current car users to the bus given the right conditions (e.g., fare levels, service level, etc.) since almost half of the current car users have indicated a willingness to switch to or consider traveling by bus using the new time-based fares.

Tables 7 and 8 look at the ticket choice more closely by stratifying into concession and non-concession, and short and long trips. Comparing tables 7 and 8 shows some interesting results. Most people who are using cars for short trips, even though they hold concession passes for public transport, are not willing to change to public transport. In contrast, their counterparts using cars for long trips are more willing to change to public transport. With current car users, the most popular time-based ticket is the one-hour ticket.

TABLE 8a Current Mode/Ticket and Mode/ Ticket Chosen in SP Experiment for Non-Concession (Non-Pensioner): Short Trips
(Based on weighted data)

	Current mode/ticket (in percent)		
Chosen mode/ ticket (SP)	**Bus Single**	**Bus TravelTen/ TravelPass**	**Car**
Bus Single	24.3	0.0	0.0
Bus TravelTen/ TravelPass	0.0	71.3	0.0
Car	0.0	0.0	57.5
1-hour ticket	34.3	8.1	26.0
4-hour ticket	10.8	5.9	9.3
Day ticket	14.9	8.1	4.7
Weekly ticket	15.7	6.6	2.5
Total	100.0	100.0	100.0

TABLE 8b Current Mode/Ticket and Mode/ Ticket Chosen in SP Experiment for Non-Concession (Non-Pensioner): Long Trips
(Based on weighted data)

	Current mode/ticket (in percent)		
Chosen mode/ ticket (SP)	**Bus Single**	**Bus TravelTen/ TravelPass**	**Car**
Bus Single	19.6	0.0	0.0
Bus TravelTen/ TravelPass	0.0	40.2	0.0
Car	0.0	0.0	54.7
1-hour ticket	27.2	25.0	21.2
4-hour ticket	22.9	8.1	10.0
Day ticket	21.6	11.0	7.4
Weekly ticket	8.7	15.6	6.7
Total	100.0	100.0	100.0

Generally, most respondents using bus Singles for both short and long trips, are willing to switch to the time-based tickets offered. A higher proportion of the current bus TravelTen or TravelPass users in comparison to the current bus Singles users chose their current ticket instead of the time-based tickets. The final model results are given in table 9. Summary statistics of the estimation sample are given in Appendix A.

All four choice models have high explanatory power for a non-linear logit model as measured by pseudo r^2 values, varying from 0.550 to 0.598. The scale parameters vary quite a lot across the alternatives for each market, and despite the number of non-statistically significant scale parameters, there are sufficient significant parameters to suggest that a simple MNL model would confound taste and scale. If we look at short non-concession trips, we see similar mean estimates for scale parameters for one-hour bus and bus Single tickets, which is an appealing result given the expectation that there might be common unobserved influences. The same relationship holds in all four markets. However, in the long non-concession market the scale parameters are similar for one- and four-hour tickets, Single, and TravelTens, although the level of statistical significance is below acceptable levels except for a one-hour bus ticket. The ranking of the magnitudes of the scale parameters are very similar across trip lengths within each market of concession and non-concession travelers, but quite different between the two segments. The absolute levels of scale cannot be directly compared because the models are independently estimated.

We investigated the possible role of trip purpose, setting commuting trips as the base (exclude) purpose, and assigning the three trip-purpose dummy variable to all of the bus alternatives. With the exception of shopping trips for long concession trips, which has a significant downward shift effect on the probability of choosing bus (i.e., the probability of car use is higher for shopping trips in this market segment), trip purpose has no significant role.

Travel time and cost were estimated as generic both within each RP and SP data set and between the data sets. There is no microeconomic theoretical reason for treating them as data set specific, which has traditionally been the assumption in both sequential and joint estimation of SP-RP models resulting in a single scale parameter attributed to all alternatives in a specific data set (e.g., Morikawa 1989; Swait et al 1994). However, the joint estimation takes into account possible differences in scale in order to ensure that the final set of taste weights (parameter estimates) in table 9 are not confounded with scale. Differences in measurement error between the RP and SP data are accommodated in the scale parameter when a generic specification across the RP and SP alternatives is imposed.

The four models contain the set of parameter estimates for the RP model enriched by the SP data, to enable estimation of the matrices of direct and cross share price elasticities, reported in the next section. Importantly, the weighted aggregate elasticities (with choice probability weights) are derived from the RP model for the observed tickets types and car, enriched by the new time-based tickets drawn from the SP model system. The elements of an elasticity calculation are the predicted choice probability (which makes little sense in the stand-alone SP subset), the taste weights and scale parameters, and the attribute levels. The attribute levels used in calculating the elasticities reported in tables 10 and 11 are the levels used in model estimation across the sample.

Fare and Mode Elasticities

A number of mode/ticket type choice models were estimated for each travel market segment. The stated choice experiment provided the richness required for testing each market segment's sensitivity to varying levels of fares for each time-based ticket type. The parameter estimates for fares and car costs when transferred to the revealed preference model and rescaled enabled us to derive the appropriate matrix of direct and cross elasticities. Relaxation of the constant variance assumption of the standard multinomial logit model allows the cross elasticities to be alternative specific.

The final (8) sets of recommended direct and cross elasticities, based on the full sample of 378 interviews, are reported in tables 10 and 11. In reporting the results, we recognize that some of the explanatory variables in the models are marginally significant or not at all; however, the cost

TABLE 9 HEV Model: Joint Estimation of SP and RP Choices
a. Non-Concession Short Trips

Attribute	Units	Alternative	SP parameter estimates	t-value	RP parameter estimates	t-value
One-way trip cost	Dollars	All	–0.169098	–1.76	–0.169098	–1.76
Door-to-door time	Mins	All	–0.0052118	–1.54	–0.0052118	–1.54
Social-recreation trips	1,0	Bus	0.1481	0.76	0.1481	0.76
Shopping trips	1,0	Bus	–0.01907	-0.12	-0.01907	–0.12
Student trips	1,0	Bus	–0.16740	-0.94	-0.16740	–0.94
Bus Single constant		BusS	3.1638	9.22	2.3681	7.43
Bus TravelTen/ TravelPass constant		BusTT	3.5776	13.70		
Bus 1-hour constant		Bus1	3.2627	9.26		
Bus 4-hour constant		Bus4	2.9060	5.22		
Bus day ticket constant		BusDay	2.9667	5.41		
Car constant		Car	2.8706	5.27	4.3980	6.43
Scale parameters						
Bus 1-hour ticket (SP)		Bus1	0.194	1.65		
Bus 4-hour ticket (SP)		Bus4	0.341	1.75		
Bus day ticket (SP)		BusDay	0.405	1.98		
Bus weekly ticket (SP)		BusW	1.283	fixed		
Bus Single		BusS	0.181	2.73	0.709	1.54
Bus TravelTen/TravelPass		BusTT	0.289	1.87	0.249	1.04
Car		Car	0.523	1.54	0.536	1.15
Sample size		704				
Log-likelihood at converg.		–675.73				
Pseudo r-squared		0.598				

TABLE 9 HEV Model: Joint Estimation of SP and RP Choices
b. Non-Concession Long Trips

Attribute	Units	Alternative	SP parameter estimates	t-value	RP parameter estimates	t-value
One-way trip cost	Dollars	All	-0.082095	–2.12	–0.082095	–2.12
Door-to-door time	Mins	All	-0.0022177	–1.76	–0.0022177	–1.76
Social-recreation trips	1,0	Bus	-0.11718	–1.04	–0.11718	–1.04
Shopping trips	1,0	Bus	0.32926	1.38	0.32926	1.38
Student trips	1,0	Bus	-0.24737	–1.65	–0.24737	–1.65
Bus Single constant		BusS	3.2019	8.24	2.5887	6.79
Bus TravelTen/ TravelPass constant		BusTT	3.3262	8.65	2.4353	5.45
Bus 1-hour constant		Bus1	3.2378	9.326		
Bus 4-hour constant		Bus4	3.1318	8.49		
Bus day ticket constant		BusDay	3.1905	8.53		
Car constant		Car	2.9742	6.79	4.3219	4.59
Scale parameters						
Bus 1-hour ticket (SP)		Bus1	0.183	2.16		
Bus 4-hour ticket (SP)		Bus4	0.198	1.59		
Bus day ticket (SP)		BusDay	0.207	1.53		
Bus weekly ticket (SP)		BusW	1.283	fixed		
Bus Single		BusS	0.193	1.54	0.358	1.67
Bus TravelTen/TravelPass		BusTT	0.193	1.28	0.661	1.87
Car		Car	0.479	1.75	0.372	1.14
Sample size		960				
Log-likelihood at converg		–1056.8				
Pseudo r-squared		0.550				

TABLE 9 HEV Model: Joint Estimation of SP and RP Choices
c. Concession Short Trips

Attribute	Units	Alternative	SP parameter estimates	t-value	RP parameter estimates	t-value
One-way trip cost	Dollars	All	–0.36005	–1.96	–0.36005	–1.96
Door-to-door time	Mins	All	–0.02896	–1.86	–0.02896	–1.86
Social-recreation trips	1,0	Bus	0.76731	1.67	0.76731	1.67
Shopping trips	1,0	Bus	–0.06571	–0.56	–0.06571	–0.56
Student trips	1,0	Bus	0.3185	1.54	0.3185	1.54
Bus Single constant		BusS	2.7153	11.36	2.7153	11.36
Bus TravelTen/ TravelPass constant		BusTT	2.7793	12.71	2.4388	9.45
Bus 1-hour constant		Bus1	2.6863	10.54		
Bus 4-hour constant		Bus4	2.4675	6.24		
Bus day ticket constant		BusDay	2.8585	12.56		
Car constant		Car	2.5796	8.39	3.0254	4.77
Scale parameters						
Bus 1-hour ticket (SP)		Bus1	0.221	1.54		
Bus 4-hour ticket (SP)		Bus4	0.314	1.53		
Bus day ticket (SP)		BusDay	0.173	1.65		
Bus weekly ticket (SP)		BusW	1.28	fixed		
Bus Single		BusS	0.174	1.32	0.672	1.87
Bus TravelTen/TravelPass		BusTT	0.171	1.96	0.307	1.21
Car		Car	0.529	1.79	0.451	1.55
Sample size		664				
Log-likelihood at converg		–581.78				
Pseudo r-squared		0.588				

TABLE 9 HEV Model: Joint Estimation of SP and RP Choices
d. Concession Long Trips

Attribute	Units	Alternative	SP parameter estimates	t-value	RP parameter estimates	t-value
One-way trip cost	Dollars	All	–0.22005	–2.12	–0.22005	–2.12
Door-to-door time	Mins	All	–0.02135	–1.97	–0.02135	–1.97
Social-recreation trips	1,0	Bus	0.5462	1.67	0.5462	1.67
Shopping trips	1,0	Bus	–0.08761	–.2.1	–0.08761	–0.21
Student trips	1,0	Bus	0.4236	1.74	0.4236	1.74
Bus Single constant		BusS	2.9523	11.36	2.3114	9.42
Bus TravelTen/ TravelPass constant		BusTT	2.3289	12.71	1.8965	7.66
Bus 1-hour constant		Bus1	2.7789	9.43		
Bus 4-hour constant		Bus4	3.1243	5.32		
Bus day ticket constant		BusDay	3.5632	11.29		
Bus weekly constant		BusW	2.3429	7.46	3.0122	6.88
Scale parameters						
Bus 1-hour ticket (SP)		Bus1	0.174	1.43		
Bus 4-hour ticket (SP)		Bus4	0.329	1.87		
Bus day ticket (SP)		BusDay	0.139	1.66		
Bus weekly ticket (SP)		BusW	1.28	fixed		
Bus Single		BusS	0.153	1.73	0.694	1.95
Bus TravelTen/TravelPass		BusTT	0.214	1.90	0.332	1.55
Car		Car	0.631	1.81	0.476	1.73
Sample size	696					
Log-likelihood at converg	–572.78					
Pseudo r-squared	0.593					

taste weights are statistically significant at the 95% level for concession trips and non-concession long trips, and “acceptable” at a t-value of –1.76 for non-concession short trips. The inclusion/exclusion of the non-significant effects has little impact on the derived probabilities or the taste weights for cost, and thus we are confident that the resulting elasticity matrices are minimally affected by the presence of statistically insignificant influences in table 9. The sets of the direct and cross elasticities are for only two scenarios. The first scenario comprises the car and the four time-based tickets: the situation whereby with the introduction of time-based tickets, bus Singles, TravelTens, and TravelPasses are no longer sold. The second scenario is where bus Singles for short trips are still kept but TravelTens and TravelPasses are no longer offered with the introduction of the time-based tickets.

In Table 10, each column provides one direct share elasticity and four cross share elasticities, while in table 11, each column provides one direct share elasticity and five cross share elasticities. A direct or cross elasticity represents the relationship between a percentage change in fare level and a percentage change in the proportion of daily one-way trips by the particular mode or ticket type. For example, the column headed “one-hour ticket” in the Concession Short Trips section for Scenario 1 tells us that a 1% increase in the one-hour ticket fare leads to a 1.153% reduction in the proportion of daily one-way trips by bus on a one-hour ticket. In addition, this 1% single fare increase is “distributed” among the competing alternatives according to the set of cross elasticities, normalized to sum to 1.

These results have many implications, especially for a fares policy. There is very little switching between car and bus options, with most switching occurring within the bus options. Looking at the direct elasticities, it can be seen that in general,

TABLE 10. Scenario 1: Elasticities for Concession and Non-Concession Markets

	Car	1-hour ticket	4-hour ticket	Day ticket	Weekly ticket
a. Concession: short trips					
Car	–0.200	0.296	0.298	0.422	0.370
1-hour ticket	0.047	–1.153	0.278	0.600	0.305
4-hour ticket	0.049	0.269	–1.165	0.434	0.293
Day ticket	0.056	0.297	0.301	–1.825	0.334
Weekly ticket	0.046	0.288	0.287	0.369	–1.301
b. Concession: long trips					
Car	–0.192	0.055	0.091	0.080	0.300
1-hour ticket	0.040	–0.299	0.102	0.330	0.200
4-hour ticket	0.020	0.074	–0.464	0.042	0.278
Day ticket	0.040	0.080	0.105	–0.551	0.240
Weekly ticket	0.088	0.090	0.166	0.102	–1.020
c. Non-concession: short trips					
Car	–0.068	0.280	0.088	0.195	0.270
1-hour ticket	0.024	–1.520	0.420	0.397	0.480
4-hour ticket	0.013	0.420	–1.010	0.321	0.402
Day ticket	0.020	0.390	0.212	–1.239	0.297
Weekly ticket	0.015	0.430	0.290	0.323	–1.450
d. Non-concession: long trips					
Car	–0.600	0.230	0.260	0.350	0.353
1-hour ticket	0.120	–1.200	0.310	0.420	0.396
4-hour ticket	0.170	0.250	–1.290	0.460	0.431
Day ticket	0.140	0.340	0.350	–1.770	0.445
Weekly ticket	0.170	0.380	0.370	0.540	–1.620

Note: Read for mode/ticket as column.

TABLE 11. Scenario 2: Elasticities for Concession and Non-Concession Markets (plus tables 10b and 10c)

	Bus Single	Car	1-hour ticket	4-hour ticket	Day ticket	Weekly ticket
Concession: short trips						
Bus Single	–1.020	0.000	0.300	0.314	0.464	0.364
Car	0.060	–0.099	0.040	0.024	0.042	0.042
1-hour ticket	0.249	0.030	–1.138	0.410	0.520	0.433
4-hour ticket	0.244	0.030	0.320	–1.473	0.532	0.445
Day ticket	0.241	0.022	0.258	0.373	–2.019	0.360
Weekly ticket	0.230	0.022	0.219	0.351	0.460	–1.643
Non-concession: short trips						
Bus Single	–1.501	0.001	0.375	0.254	0.454	0.466
Car	0.059	-0.070	0.189	0.054	0.083	0.096
1-hour ticket	0.431	0.022	–1.145	0.256	0.455	0.497
4-hour ticket	0.274	0.012	0.140	–0.906	0.315	0.331
Day ticket	0.331	0.017	0.201	0.164	–1.690	0.387
Weekly ticket	0.401	0.020	0.241	0.179	0.381	–1.776

Note: Read for mode/ticket as column.

except in the Non Concession Short Trips market, sensitivity increases as time validity of the time-based fares increases. This has interesting implications for a fares policy, as it means that a decrease in the longer time-based fares purchase is quite substantial with a fare increase compared with the shorter time-based fares. Also, increasing the price of the one-hour ticket offers higher revenue growth prospects for smaller losses in patronage than in the case of day and weekly tickets.

The direct elasticities for long concession trips are lower compared with the short trips. This implies that the concession passengers traveling for long trips are less sensitive to fare changes than their counterparts who are doing short trips. For the non-concession market, those undertaking short trips are very sensitive to changes in fares for the one-hour ticket; while the four-hour ticket has the lowest (short trips) and second lowest (long trips) elasticity among the time-based fares. The implication is that the four-hour ticket is perceived as a better value for money; given the flexibility, one buys for the price and the number of trips that can be made while the ticket is valid.

In the case where bus Singles for short trips are still offered with the introduction of the time-based fares, the concession passengers are less sensitive to changes in fare for bus Singles. This shows that the bus Single is still the best value for passengers traveling short distances on concession. The reason may be that they generally undertake outings with shorter elapsed time before returning.

CONCLUSIONS

The results reported here are based on estimation of stated and revealed choice data, where the variances of the unobserved components of the indirect utility expressions associated with each of the modal and ticketing alternatives are different. The taste weights attached to fares in the stated choice model have been rescaled by the ratio of the variances associated with fare for a particular alternative across the two model systems, so that the richness of the fare data in the stated choice experiment enriches the market model. The resulting matrix of direct and cross elasticities reflects the market environment in which concession and non-concession travelers make choices while benefiting by an enhanced understanding of how travelers respond to fare profiles not always observed in real markets, but including timed-fare profiles that are of interest as potential alternatives to the current market offerings.

A better understanding of market sensitivity to classes of tickets is promoted as part of the improvement in management practices designed to improve fare yields. The matrices of elasticities are input as the behavioral base into a decision support system used to evaluate the implications on revenue and patronage of alternative fare scenarios in respect to mixtures of ticket types and levels of fares.

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Appendix A.

Summary Sample Statistics for the Four Market Segments

(Standard deviations in parenthesis)

a. Short Concession Trips

Stated preference sub-sample	**Out-of pocket cost ($)**	**Main mode time (mins)**	**Access+egress time (mins)**	**Car available (proportion)**	**Sample size**
ALTERNATIVE					
Total sample					
Bus 1-hour ticket	1.08 (0.31)	10.42 (5.95)	6.90 (5.69)	0.120	332
Bus 4-hour ticket	1.07 (0.30)	10.42 (5.95)	6.90 (5.69)	0.120	332
Bus day ticket	1.53 (0.36)	10.42 (5.95)	6.90 (5.69)	0.120	332
Bus weekly ticket	1.25 (0.28)	10.42 (5.95)	6.90 (5.69)	0.120	332
Bus Single	0.97 (0.32)	8.68 (2.34)	6.00 (5.40)	0.179	112
Bus TravelTen/TravelPass	0.65 (0.23)	8.70 (2.43)	7.47 (6.36)	0.167	120
Car	0.30 (0.11)	8.00 (3.28)	– –	–	100
Sample who chose that alternative					
Bus 1-hour ticket	0.91 (0.24)	11.85 (7.40)	5.95 (4.32)	0.130	54
Bus 4-hour ticket	0.91 (0.22)	8.56 (2.34)	6.89 (4.08)	0.194	36
Bus day ticket	1.32 (0.27)	10.04 (5.67)	8.74 (7.70)	0.120	50
Bus weekly ticket	1.12 (0.23)	9.43 (5.76)	7.89 (6.81)	0.149	47
Bus Single	0.78 (0.30)	7.82 (2.40)	4.29 (2.85)	0.357	28
Bus TravelTen/TravelPass	0.54 (0.19)	8.05 (2.81)	6.27 (5.15)	0.068	44
Car	0.28 (0.11)	7.70 (3.32)	– –	–	73

Revealed preference sub-sample	**Out-of pocket cost ($)**	**Main mode time (mins)**	**Access+egress time (mins)**	**Car available (proportion)**	**Sample size**
ALTERNATIVE					
Total sample					
Bus Single	1.069 (0.42)	11.20 (6.90)	6.78 (5.3)	0.111	180
Bus TravelTen/TravelPass	0.646 (0.22)	9.50 (4.38)	7.05 (6.13)	0.132	152
Car	0.357 (0.20)	8.05 (4.55)	– –	–	332
Sample who chose that alternative					
Bus Single	0.97 (0.32)	8.68 (2.34)	6.00 (5.4)	0.179	112
Bus TravelTen/TravelPass	0.65 (0.23)	8.70 (2.43)	7.47 (6.4)	0.167	120
Car	0.302 (0.11)	8.00 (3.28)	– –	–	100

b. Long Concession Trips

Stated preference sub-sample	Out-of pocket cost ($)	Main mode time (mins)	Access+egress time (mins)	Car available (proportion)	Sample size
ALTERNATIVE					
Total sample					
Bus 1-hour ticket	1.085 (0.32)	35.60 (21.5)	8.28 (6.23)	0.218	348
Bus 4-hour ticket	1.084 (0.31)	35.60 (21.5)	8.28 (6.23)	0.218	348
Bus day ticket	1.529 (0.36)	35.60 (21.5)	8.28 (6.23)	0.218	348
Bus weekly ticket	1.235 (0.29)	35.60 (21.5)	8.28 (6.23)	0.218	348
Bus Single	1.47 (0.62)	35.26 (20.9)	10.05 (6.6)	0.342	152
Bus TravelTen/TravelPass	1.01 (0.53)	33.51 (22.2)	6.89 (5.9)	0.171	140
Car	1.07 (0.39)	17.14 (6.8)	– –	–	56
Sample who chose that alternative					
Bus 1-hour ticket	0.942 (0.26)	42.08 (24.6)	8.58 (7.09)	0.212	104
Bus 4-hour ticket	0.882 (0.20)	40.00 (18.9)	10.15 (8.13)	0.294	34
Bus day ticket	1.35 (0.30)	38.93 (26.4)	9.59 (6.58)	0.279	61
Bus weekly ticket	1.14 (0.27)	32.46 (18.2)	7.22 (4.56)	0.159	63
Bus Single	1.25 (0.0)	28.22 (9.9)	9.50 (5.9)	0.333	18
Bus TravelTen/TravelPass	0.802 (0.16)	22.78 (9.1)	5.25 (3.9)	0.224	49
Car	0.94 (0.18)	15.53 (2.8)	– –	–	19

Revealed preference sub-sample	Out-of pocket cost ($)	Main mode time (mins)	Access+egress time (mins)	Car available (proportion)	Sample size
ALTERNATIVE					
Total sample					
Bus Single	1.61 (0.81)	35.44 (19.6)	9.24 (6.43)	0.283	184
Bus TravelTen/TravelPass	0.991 (0.55)	35.78 (23.4)	7.20 (5.83)	0.146	164
Car	0.997 (0.51)	16.59 (8.1)	– –	–	348
Sample who chose that alternative					
Bus Single (RP)	1.47 (0.62)	35.26 (20.9)	10.05 (6.60)	0.342	152
Bus TravelTen/TravelPass	1.10 (0.53)	33.51 (22.2)	6.89 (5.93)	0.171	140
Car	1.074 (0.39)	17.14 (6.8)	– –	–	56

c. Short Non-Concession Trips

Stated preference sub-sample	Out-of pocket cost ($)	Main mode time (mins)	Access+egress time (mins)	Car available (proportion)	Sample size
ALTERNATIVE					
Total sample					
Bus 1-hour ticket	2.17 (0.62)	11.67 (5.87)	7.68 (5.91)	0.114	352
Bus 4-hour ticket	2.18 (0.62)	11.67 (5.87)	7.68 (5.91)	0.114	352
Bus day ticket	3.10 (0.74)	11.67 (5.87)	7.68 (5.91)	0.114	352
Bus weekly ticket	2.44 (0.58)	11.67 (5.87)	7.68 (5.91)	0.114	352
Bus Single	1.93 (0.62)	10.38 (2.41)	8.55 (6.14)	0.207	116
Bus TravelTen/TravelPass	1.25 (0.40)	9.88 (2.35)	6.68 (5.35)	0.160	100
Car	0.28 (0.12)	8.09 (4.28)	– –	–	136
Sample who chose that alternative					
Bus 1-hour ticket	1.85 (0.45)	12.41 (7.70)	7.94 (6.33)	0.084	83
Bus 4-hour ticket	1.85 (0.49)	14.12 (7.46)	9.35 (6.29)	0.147	34
Bus day ticket	2.78 (0.64)	11.14 (4.91)	7.27 (6.62)	0.216	37
Bus weekly ticket	2.07 (0.47)	10.85 (2.21)	7.59 (7.63)	0.111	27
Bus Single	1.71 (0.63)	9.30 (2.09)	8.97 (4.67)	0.267	30
Bus TravelTen/TravelPass	1.27 (0.40)	9.85 (2.29)	6.66 (5.09)	0.134	67
Car	0.27 (0.12)	7.74 (4.44)	– –	–	74

Revealed preference sub-sample	Out-of pocket cost ($)	Main mode time (mins)	Access+egress time (mins)	Car available (proportion)	Sample size
ALTERNATIVE					
Total sample					
Bus Single	1.80 (0.76)	12.33 (6.77)	8.16 (6.13)	0.103	232
Bus TravelTen/TravelPass	1.27 (0.42)	10.40 (3.21)	6.77 (5.36)	0.133	120
Car	0.34 (0.16)	8.05 (4.01)	– –	–	352
Sample who chose that alternative					
Bus Single	1.93 (0.62)	10.38 (2.41)	8.55 (6.14)	0.207	116
Bus TravelTen/TravelPass	1.25 (0.40)	9.88 (2.35)	6.68 (5.35)	0.160	100
Car	0.28 (0.12)	8.09 (4.28)	– –	–	136

d. Long Non-Concession Trips

Stated preference sub-sample	Out-of pocket cost ($)	Main mode time (mins)	Access+egress time (mins)	Car available (proportion)	Sample size
ALTERNATIVE					
Total sample					
Bus 1-hour ticket	2.15 (0.62)	38.88 (24.4)	10.68 (10.4)	0.133	480
Bus 4-hour ticket	2.16 (0.63)	38.88 (24.4)	10.68 (10.4)	0.133	480
Bus day ticket	3.11 (0.72)	38.88 (24.4)	10.68 (10.4)	0.133	480
Bus weekly ticket	2.51 (0.58)	38.88 (24.4)	10.68 (10.4)	0.133	480
Bus Single (RP)	2.56 (0.78)	31.91 (18.4)	9.91 (10.1)	0.206	136
Bus TravelTen/TravelPass	1.65 (0.37)	36.66 (23.6)	8.66 (6.2)	0.257	140
Car	1.43 (1.02)	23.24 (13.6)	– –	–	204
Sample who chose that alternative					
Bus 1-hour ticket	1.83 (0.45)	36.34 (23.4)	9.15 (8.4)	0.103	117
Bus 4-hour ticket	1.88 (0.54)	41.54 (24.0)	8.40 (5.8)	0.206	63
Bus day ticket	2.63 (0.57)	43.14 (25.2)	9.31 (9.1)	0.136	59
Bus weekly ticket	2.08 (0.43)	36.40 (18.2)	11.23 (9.3)	0.208	48
Bus Single (RP)	2.49 (0.15)	30.08 (6.5)	7.50 (4.6)	0.231	26
Bus TravelTen/TravelPass	1.58 (0.32)	28.43 (13.9)	8.23 (5.6)	0.268	56
Car	1.47 (1.10)	24.98 (15.2)	– –	–	111

Revealed preference sub-sample	Out-of pocket cost ($)	Main mode time (mins)	Access+egress time (mins)	Car available (proportion)	Sample size
ALTERNATIVE					
Total sample					
Bus Single (RP)	2.76 (0.93)	37.73 (23.7)	11.83 (12.50)	0.101	276
Bus TravelTen/TravelPass	1.54 (0.51)	40.43 (25.3)	9.14 (6.10)	0.176	204
Car	1.22 (0.91)	19.95 (11.8)	– –	–	480
Sample who chose that alternative					
Bus Single	2.60 (0.78)	31.91 (18.4)	9.91 (10.14)	0.206	136
Bus TravelTen/TravelPass	1.65 (0.37)	36.66 (23.6)	8.66 (6.23)	0.257	140
Car	1.43 (1.00)	23.24 (13.6)	– –	–	204

Estimating State-Level Truck Activities in America

SHIH-MIAO CHIN
Oak Ridge National Laboratory

JANET HOPSON
Oak Ridge Institute of Science and Education

HO-LING HWANG
Oak Ridge National Laboratory

ABSTRACT

For freight, the primary function of the nation's highway system is to link the economies of individual states together to form an integrated national economy. Data from the 1993 Commodity Flow Survey, the first comprehensive national survey of freight shipments since 1977, indicate that the shipment of freight by truck in the United States is predominantly an *interstate* phenomenon. In fact, interstate shipments comprise more than 70% of the total ton-miles and nearly 55% of the value of commodities shipped by truck in 1993. In addition, the proportions of truck freight shipments originating from, destined to, passing through, or occurring entirely within a state vary significantly from state to state. While interstate shipments make up the largest portion of shipments nationally, *intrastate* trucking is more significant in large states such as Texas and California, as well as in corner states such as Florida, Maine, and Washington. The proportion of through traffic also varies widely from state to state. These findings

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Dr. Shih-Miao Chin, Oak Ridge National Laboratory, P.O. Box 2008, Building 3156, MS-6073, Oak Ridge, TN 37831-6073. Email: hlc@ornl.gov.

could have important implications for highway revenue allocations, since trucks carrying freight play a significant role in damage to highway pavement and structures.

INTRODUCTION

The nation's transportation system links U.S. businesses, industries, and consumers. More than 12 billion tons of freight were transported by the U.S. transportation system in 1993 (USDOT BTS 1996c). Shipments by truck (including for-hire and private trucks) accounted for more than half (53%) of the total tonnage, more than two-thirds (72%) of the total shipments by value, and nearly one-quarter (24%) of the total ton-miles shipped in 1993. Despite the vital role of freight in the U.S. economy, the 1993 Commodity Flow Survey (CFS) was the first comprehensive survey of the movement of commodities since 1977. This survey was conducted by the Bureau of the Census with funding and technical guidance provided by the Bureau of Transportation Statistics (BTS) (USDOT BTS 1996a).

The major objective of this study was to describe the geography of truck freight shipments in the United States and, in particular, to measure the degree to which highways serve as state and local versus interstate freight systems. This paper presents estimates of ton-miles of commodities shipped by truck within, to, from, and through each state and thereby provides a measure of the extent to which states' economies are linked together. These estimates were determined using CFS data augmented by including farm-based shipments from the 1992 Census of Agriculture (USDOC 1993a). The impact of imports on U.S. truck flows is also addressed using information from the Transborder Surface Freight database and U.S. Waterway Data (USDOT BTS 1996b; USDOT BTS 1994). Through truck shipments as well as all estimates of CFS shipment distances were determined by routing the truck traffic along the minimum impedance paths using the Oak Ridge National Highway Network (Peterson 1997).

DATA SOURCES

The 1993 CFS represents the most comprehensive survey to date of the shipment of commodities in the United States. Approximately 200,000 business establishments were surveyed; these establishments were selected to represent all 50 states and the District of Columbia. Manufacturing, mining, wholesale trade, and selected retail and service industries were included in the survey. Data collected for individual shipments include origin and destination, commodity code, shipment size (value and weight), mode of transportation, as well as indicators of whether the shipment was an export, hazardous material, or containerized. Each establishment reported a sample of shipment information for a two-week period in each of the four quarters of calendar year 1993. The results of the CFS have been published by the Bureau of the Census and are available on CD-ROM and as a series of printed reports (USDOT BTS 1996a). This study is based on zip code-level data from the CFS (USDOC 1994).

The following types of shipments were excluded from the CFS: 1) shipments with a foreign origin and destination that traverse the United States; 2) shipments originating outside of the United States; and 3) shipments from establishments classified as farms, forestry, fisheries, construction, transportation, oil and gas extraction companies, governments, households, and many retail and service businesses.[1]

Imports were included in the CFS only if they were shipped from the importer's domestic location to another location. Although farm-based agricultural shipments (i.e., shipments from the farm site to processing centers or terminal elevators) were excluded, agricultural shipments from processing centers and terminal elevators were included in the scope of the CFS.

In an attempt to account for as many of the shipments missed by the CFS as possible, data

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[1] Considering only those truck types likely to transport commodities, data from the 1992 Truck Inventory and Use Survey indicate that 7% of total truck-miles result from trucks whose major use is retail trade. The retail share of vehicle-miles drops to 12% when only those trucks operated primarily locally within a radius of 50 miles are considered.

from several other sources were considered in this study:

1. the *1992 Census of Agriculture*, which provides statistical information about the nation's agricultural production at the county, state, and national level;
2. the *1992 Truck Inventory and Use Survey* (TIUS) microdata file, which furnishes information on the typical area of operation of trucks carrying agricultural products;
3. *1993 to 1994 Transborder Surface Freight* data, which provide information on the imports shipped by truck from Canada and Mexico;
4. the U.S. Army Corps of Engineers *1993 U.S. Waterway Data*, which include data on the tonnage and commodity code imported via maritime ports; and
5. the Census Bureau's *1993 County Business Patterns*, which provides information about the activity of U.S. businesses (USDOC 1995).

ESTIMATES OF U.S. TRUCK FLOWS

1993 CFS Data

The 1993 CFS data provide information about the value and weight of total shipments between states and National Transportation Analysis Regions (NTAR) by mode (USDOT BTS 1996a). Only freight shipments listing the mode as truck (either private, for-hire, or both) were utilized. Intermodal shipments involving modes other than truck were not considered in this study.[2] State totals for value, tonnage, and ton-miles were determined for four categories: shipments within the state; shipments from the state; shipments to the state; and shipments through the state.

This paper focuses on estimates of ton-miles of freight; estimates of the value of truck shipments by state have been published previously by BTS (USDOT BTS 1997). The tonnage of shipments to, from, within, and through each state as well as the distance estimates used to compute ton-miles were generated by assigning the CFS truck flows to routes predicted using the Oak Ridge National Highway Network, a geographically-based analytical network representing 400,000 miles of major roadways in the United States (Peterson 1997). The Oak Ridge National Highway Network has the same basic structure as the National Highway Planning Network maintained by the Federal Highway Administration (USDOT FHWA 1994), but the Oak Ridge network includes additional roads, attribute detail, and topological adjustments to produce an enhanced analytical network.

Shipments were routed between nodes on the highway network closest to the centroid of the origin and destination zip code. A shortest path algorithm was used to determine the minimum impedance route between the shipment origin and destination over a mathematical representation of the highway network. Impedance is a relative measure of the level of resistance or deterrence to traffic flow on a particular link in the highway network (Bronzini et al 1996). Truck impedance is calculated as a function of travel time and is designed to simulate the most likely choice of route. Each link's impedance is related to the distance, modified by the physical characteristics of the road relevant to truck use (i.e., whether the road is divided, access controlled, subject to congestion, a designated truck route, a toll road, or has truck restrictions). The impedance function is not capable of accounting for all traffic conditions. For example, the algorithm does not split traffic on beltways circling urban areas, but instead always selects the shortest path. In reality, some portion of the truck traffic may elect to take a slightly longer path in order to avoid local congestion problems. Although this may affect the distance calculations and consequently the estimate of ton-miles, it should not significantly affect the relative proportion of shipments to, from, within, and through a given state.

In addition to determining the minimum impedance route, the computer program determines the states traversed by each shipment and accumulates the tonnage and distance traveled in each state.[3]

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[2] Work is currently underway to include the truck portion of intermodal shipments in the estimates of truck flows. Intermodal shipments constitute a relatively small proportion (<1.5%) of all CFS shipment records, thus their exclusion will not significantly impact the findings presented here.

[3] For detailed information on the programs used to generate these truck flow estimates, contact Dr. Chin (see title page of this article).

Ton-miles of shipments to, from, within, and through each state are determined as follows. If the minimum impedance route traverses only one state, the tonnage and ton-miles are accumulated as intrastate (i.e., within state) shipments. The intrastate shipment distance is calculated as the sum of the mileage of each individual link that comprises the minimum impedance path. Intrastate ton-miles are calculated by multiplying the shipment weight in tons by the distance in miles. If the minimum impedance route traverses two or more states (i.e., the shipment is an interstate shipment) the tonnage is accumulated in the origin state as *shipments from the state*, and in the destination state as *shipments to the state*. In addition, for those paths traversing more than two states, the tonnage is accumulated in each of the intermediate states as *shipments through the state*. The mileage of each *shipment from a given state* was determined by summing the mileage of all links along the minimum impedance path between the origin node and the origin state border. The *mileage of a shipment to a given state* was calculated by summing the mileage of links along the minimum impedance path between the destination state border and the destination node. The mileage of each *shipment passing through a particular state* is the sum of the mileage of all links along the minimum impedance path from the node where the shipment enters the state to the node where the shipment exits the state. The shipment weight in tons was multiplied by the distance traveled in a particular state to calculate the ton-miles resulting from that shipment.

Adjustment for Exports

The estimates generated by the methodology outlined above require an adjustment to the distribution of flows in port states, because the destinations listed for these export shipments are the U.S. port of exit locations. In order to correctly account for truck shipments designated as exports in the CFS, the following adjustments were made. Exports that originate in the same state as the port-of-exit state were shifted from the category of *within-state shipments* to the category of *shipments from the state*. Likewise, exports arriving in a port-of-exit state from another state were shifted from the category of *shipments to the state* to the category of *shipments through the state*. These adjustments were only required in the port-of-exit states and do not affect the distribution of truck flows in other states.

Adjustments for Agricultural Shipments

Farm-based agricultural shipments (i.e., products shipped from the farm site to processing centers and terminal elevators), were not included in the scope of the CFS. Although these shipments are generally thought to be short distance and thus primarily within-state shipments, they may represent a significant proportion of the value and tonnage of truck shipments particularly in midwestern states, where farming represents a large portion of the state's industry. Data from the 1992 Census of Agriculture[4] and *Agricultural Statistics, 1994* were used to estimate the value and tonnage of farm-based agricultural shipments. An estimate of the average trip length for farm shipments was made using information from the 1992 TIUS. Ton-miles were calculated by multiplying the average trip length of farm shipments for a particular state by the total agricultural tonnage for that state.

The total value of agricultural products produced in each state is reported in the Census of Agriculture, but no overall estimate of total agricultural tonnage is provided.[5] Data from the agricultural census was used to generate a rough estimate of the total tonnage of agriculture produced at U.S. agricultural establishments. Quantities of specific agricultural products reported in the 1992 Census of Agriculture were converted from a variety of different units (e.g., bushels, pounds, bales) to tons (short tons) using conversion factors provided in the 1992 Census of Agriculture or in *Agricultural Statistics, 1994*.[6] Once all of the quantities were converted to tons, they

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[4] The Census of Agriculture is conducted every five years and provides statistical information about the nation's agricultural production at the county, state, and national level; all agricultural production establishments (i.e., farms, ranches, nurseries, greenhouses, etc.) are included.

[5] This category represents the gross market value before taxes and production expenses of all agricultural products sold or removed from the establishment in 1992.

[6] All of the quantities used in the estimation of total weight (with the exception of those for milk) are from the 1992 Census of Agriculture. The quantities of milk are from estimates for 1992 provided in *Agricultural Statistics, 1994*.

were summed to provide an estimate of the total agricultural tonnage for each state. The following products were not included in the estimate of tons: greenhouse products, specialty livestock, colonies of bees, and packaging materials.

An estimate of the average trip length for farm shipments is required in order to provide an estimate of ton-miles. Data on trucks that listed either farm products or livestock as the principle product carried were extracted from the TIUS microdata file (USDOC 1993b). Information on the typical area of operation of the truck was used to estimate the average distance of a farm-based agricultural shipment in each state. TIUS area of operation distances are grouped into categories ranging from 0 to 50 miles, to more than 500 miles. A *state radius* was calculated by dividing the state area in square miles by π (i.e., 3.1416) and taking the square root. This estimated radius was used to truncate the TIUS distance categories. For example, if the state radius is between 0 and 50 miles, categories greater than 50 miles were eliminated. Using the remaining frequency distribution, a weighted average distance was computed for each state assuming all of the observations are at the midpoint of their respective distance range(s). Estimates of distances of truck shipments for farm-based agricultural products ranged in length from 25 miles for small states (e.g., New Hampshire and Connecticut) to a high of 94 miles for Alaska.

Ton-miles were calculated by multiplying the estimated agricultural tons for a particular state as calculated above by the estimated trip distance for that state. All farm-based agriculture shipments were assumed to be primarily short distance and were considered as intrastate shipments. Therefore, CFS totals were modified by adding the estimated ton-miles of farm-based agricultural shipments to the CFS within-state shipments for each of the corresponding states. Estimates of tons and ton-miles for farm-based agriculture shipments are probably high for four reasons: 1) some agricultural products may never leave the farm (e.g., hay and silage); 2) the assumption that all observations are at the midpoint of their respective distance range may overestimate the average distance traveled, especially for smaller states; 3) all of the shipments are assumed to be intrastate, but some may in fact be interstate; and 4) it was assumed that all farm-based shipments were transported by truck.

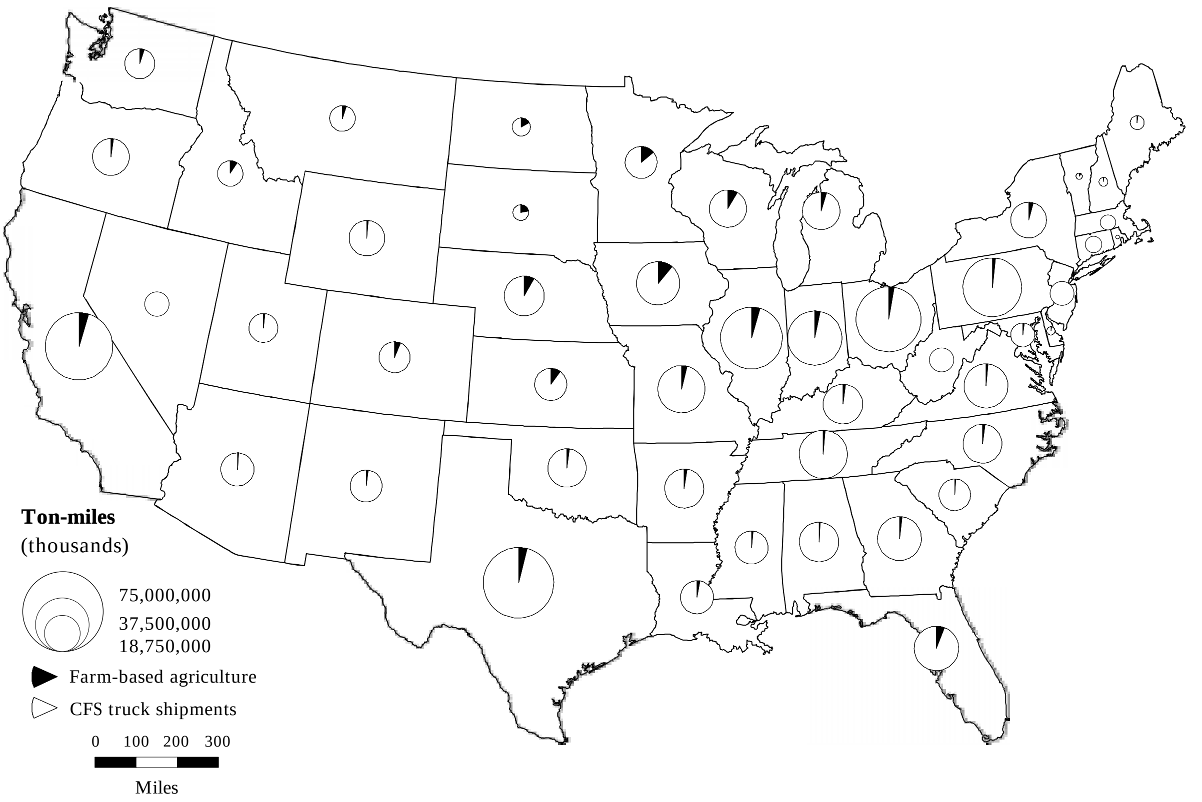
The addition of farm-based agricultural shipments primarily affects truck flows in midwestern states, where agriculture is the major industry in the state (see figure 1). Farm-based agriculture constitutes less than 2% of the total ton-miles in 21 states, but it makes up more than 10% of the ton-miles in seven states (North Dakota, South Dakota, Minnesota, Iowa, Kansas, Hawaii, and Vermont). The majority of these are midwestern states (five of seven). Among these states, the Dakotas have the highest proportion of farm-based agricultural truck flows, with these shipments accounting for roughly one-fifth of the total trucking ton-miles. Although farm-based agriculture results in substantial ton-miles in California and Texas, it constitutes a smaller proportion of the total truck flows (less than 5%) since truck flows resulting from other industries are substantial in these states. Farm-based agricultural ton-miles in Hawaii are probably overestimated, because it was assumed that all observations of average trucking distances from the TIUS were at the midpoint of the reported distance range (i.e., 25 miles for Hawaii).

Summary of Results

The CFS suggests that truck freight transportation on the nation's highway system is primarily between states (see table 1 and figure 2). Truck ton-miles account for 73% of interstate shipments of commodities. In general, the proportion of intrastate traffic is highest in noncentral states (e.g., Alaska, Hawaii, Florida, Maine, Michigan, Minnesota, New Hampshire, and Washington), as well as in large states such as California and Texas. Within-state shipments constitute greater than 50% of the truck ton-miles in only three states: Hawaii, Maine, and New Hampshire. Although this paper focuses on ton-miles of freight, similar patterns are observed if the shipment value is considered (USDOT BTS 1997).

Analysis of data from the CFS clearly demonstrates that the proportions of within, to, from, and through truck shipments vary significantly among states. In terms of ton-miles, through truck shipments account for more than 50% of the ton-

FIGURE 1 State-Level Farm-Based Agriculture Shipments and CFS Shipments



miles in 19 states. States with a high proportion of through traffic are typically those that are either interior states or states that are traversed by Interstates leading to major metropolitan areas in other states. The proportion of through traffic is highest (greater than 70%) in four western states: Nevada, New Mexico, Utah, and Wyoming. Since freight trucks are responsible for much of the damage to the nation's roadway structures, the marked variation in the proportion of ton-miles of through truck traffic among states may have important ramifications for highway revenue allocations.

Estimation of Import Truck Flows

Shipments originating outside the United States were excluded from the CFS. Thus, imports were included in the CFS only if they were shipped from the shipper's domestic location to another location. We relied primarily on foreign trade data from two sources coupled with information from the CFS and the Census Bureau's 1993 *County Business Patterns* to develop estimates of truck flows resulting from imports. The Transborder Surface Freight data from BTS provides information about the U.S. port of entry, destination state, shipment weight, shipment value, as well as the mode of transportation used to enter the U.S. port from Canada and Mexico. The Army Corps of Engineers' 1993 U.S. Waterway Data provides information on the total tonnage through maritime ports, but detailed information regarding the inland destination and mode of transportation is lacking (USDOT BTS 1996b). In order to estimate truck flows resulting from imports through maritime ports, a model was developed to predict the destination and mode split of imports. This model was based on the assumption that the destination and mode of transportation of imports would be similar to that of domestic 1993 CFS shipments.

Estimation of Imports by Truck from Canada and Mexico

Transborder surface freight data collected between April 1993 and March 1994 were analyzed in order to estimate the possible impact of imports by truck from Canada and Mexico on truck flows

TABLE 1 Ton-Miles of Truck Shipments by State: 1993 (In billions)

State	Total	Within	To	From	Through
Alabama	21.61	6.04	2.47	3.97	9.12
Alaska	1.66	0.67	0.20	0.79	—
Arizona	15.82	2.45	2.24	1.47	9.65
Arkansas	21.02	3.19	2.56	3.12	12.15
California	54.76	27.32	12.77	13.28	1.39
Colorado	14.10	3.93	2.16	1.43	6.57
Connecticut	4.79	0.68	0.66	0.48	2.97
Delaware	1.37	0.17	0.27	0.18	0.75
District of Columbia	0.05	0.00	0.02	0.01	0.02
Florida	26.37	13.11	7.77	4.75	0.73
Georgia	25.93	7.49	4.67	5.72	8.05
Hawaii	0.38	0.38	NA	—	NA
Idaho	9.97	2.36	0.93	0.89	5.80
Illinois	47.28	9.32	6.81	8.11	23.05
Indiana	37.51	6.22	4.10	5.12	22.08
Iowa	25.43	6.54	2.68	3.10	13.12
Kansas	14.98	5.11	2.36	2.80	4.71
Kentucky	21.56	4.57	2.58	2.68	11.73
Louisiana	15.79	5.39	2.13	2.50	5.77
Maine	3.45	1.80	0.49	1.15	0.02
Maryland	8.87	1.52	1.86	1.87	3.61
Massachusetts	4.28	1.24	1.22	0.77	1.05
Michigan	19.58	9.07	4.80	4.66	1.05
Minnesota	14.85	6.42	2.95	2.57	2.91
Mississippi	15.78	3.23	1.95	1.93	8.67
Missouri	29.34	5.27	4.47	3.78	15.81
Montana	10.03	2.82	0.86	1.52	4.82
Nebraska	21.90	3.68	1.29	1.74	15.19
Nevada	9.41	1.06	1.11	0.42	6.82
New Hampshire	1.57	0.93	0.23	0.14	0.27
New Jersey	9.19	2.22	1.97	2.22	2.78
New Mexico	14.71	2.33	1.28	0.61	10.49
New York	18.05	5.58	4.02	4.19	4.27
North Carolina	20.89	6.66	4.21	4.60	5.42
North Dakota	5.52	1.89	0.49	0.73	2.41
Ohio	51.34	12.24	7.86	10.34	20.90
Oklahoma	20.45	3.08	3.06	2.48	11.82
Oregon	18.92	5.92	3.78	3.51	5.72
Pennsylvania	42.97	7.99	7.40	7.36	20.21
Rhode Island	0.45	0.09	0.12	0.11	0.13
South Carolina	14.53	3.34	2.15	2.56	6.49
South Dakota	4.23	1.53	0.67	0.85	1.18
Tennessee	30.50	4.10	3.76	6.33	16.31
Texas	59.56	23.97	15.06	11.22	9.31
Utah	12.35	1.48	1.00	1.18	8.69
Vermont	0.88	0.25	0.23	0.20	0.20
Virginia	25.79	4.98	3.30	3.29	14.22
Washington	13.22	6.33	2.83	3.09	0.96
West Virginia	9.30	1.04	0.87	1.27	6.11
Wisconsin	19.42	5.82	3.29	4.14	6.17
Wyoming	17.90	3.59	0.47	0.86	12.98

NA Not applicable; — less than 10 million ton-miles.
Note: These data represent domestic and export shipments by truck from the 1993 Commodity Flow Survey, adjusted to include farm-based agricultural shipments using data from the 1992 Census of Agriculture.

within the United States (USDOT BTS 1994).[7] These data include the value, weight, port of entry, import mode, and destination state of imports from Canada. Data on shipments from Mexico are similar, but shipment weight information was not available until after April 1995. Weight information from the transborder surface freight data for the period of April 1995 to March 1996 was used to estimate 1993 to 1994 shipment weights from Mexico. The weight-to-value ratio for 1995 to 1996 truck shipments from Mexico was determined for each port of entry-destination state pair. The 1993 to 1994 shipment weights were then estimated by applying the 1995 to 1996 ratio to 1993 to 1994 value of shipments from Mexico for the same origin port of entry and destination state pair.

Through traffic and shipment distances were determined by routing the shipments from the port of entry to the destination state on the Oak Ridge National Highway Network. Shipments with either an unspecified or nonborder port of entry, an unknown destination state, or a destination in Hawaii were eliminated. These shipments accounted for less than 4% of the total value. Truck route impedances on the network were modified to "force" import shipments to be routed in the United States. (For example, shipments originating in Maine destined to Minnesota typically would be routed through Canada based on a shortest path algorithm, but the impedance functions were altered to force all of the imports to be routed domestically from the port of entry to the destination state.) Import truck shipments were routed from the port of entry to the centroid of counties in the destination state with the highest percentage of the state's total annual salary as determined from the 1993 Census Bureau's *County Business Patterns*. The number of destination counties varies from state to state, but the sum of the annual salaries of counties selected for each state comprises at least 75% of the total annual salary for that state. Ton-miles for imports to and through each state were then estimated using the methodology as described above for the CFS truck flows.

A number of problems were observed in the

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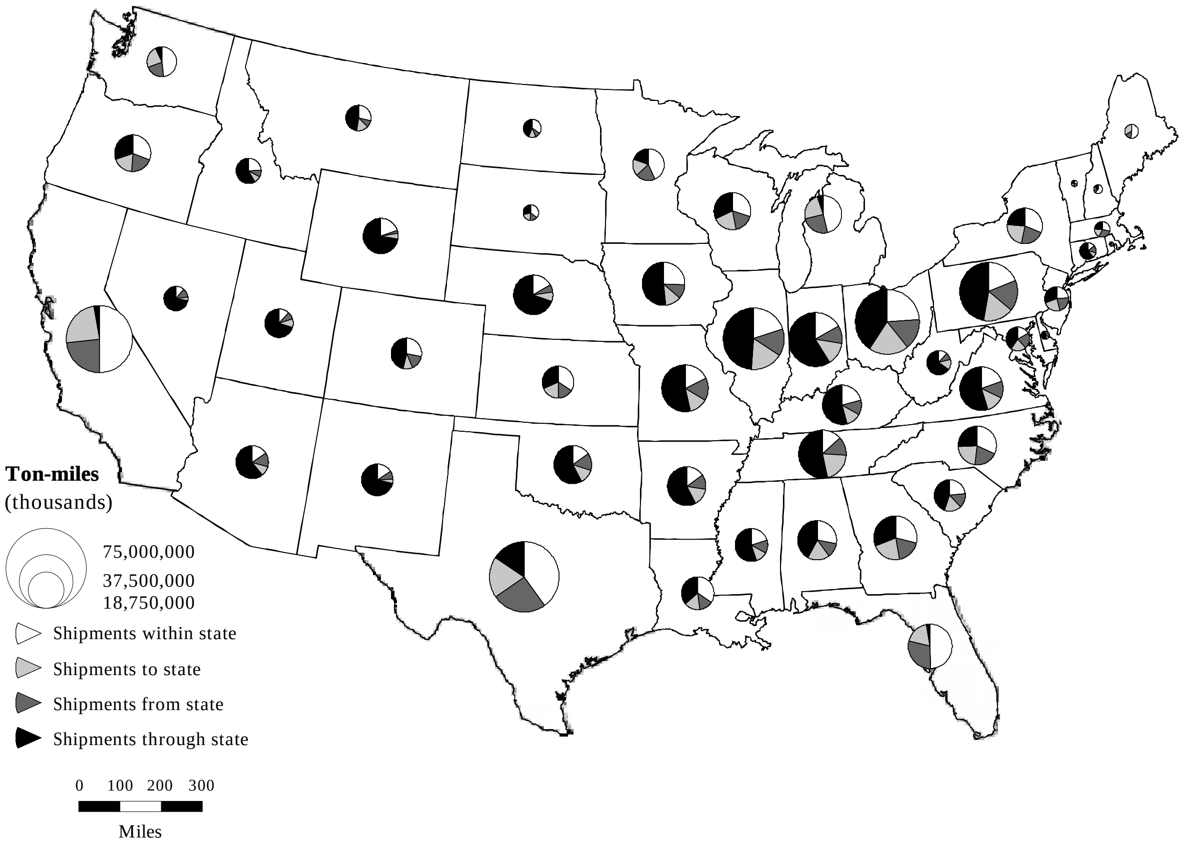
[7] Transborder surface freight data were not available for periods prior to April 1993.

FIGURE 2 State-Level Adjusted CFS and Farm-Based Shipments



transborder data set. In addition to the lack of information on the weight of shipments from Mexico for 1993 to 1994, the weight information on shipments from Canada is incomplete. Since individual shipment records are not provided in the public data set, it is difficult to determine the extent of this problem and how it may affect estimates of truck flows resulting from imports from Canada. Furthermore, no information on the domestic mode is available from these data sets, thus the import mode reported was assumed to be the only mode used (i.e., if the shipments were imported by truck, they were assumed to stay on a truck until these shipments reached their domestic destinations).

Perhaps the most significant problem with the transborder data concerns uncertainties regarding the actual destination of transborder shipments. In order to estimate truck traffic resulting from imports, it was assumed that the destination state listed in the transborder data file was the actual destination of the commodity. In fact, the transborder data tracks the flow of dollars or ownership, rather than the flow of commodities. Only if the "owner" is in the same location as the actual destination of the shipment will the destination reported in the transborder data set coincide with the shipment's destination. It is not possible to precisely ascertain the magnitude of this problem, but a 1996 survey conducted by the Michigan Department of Transportation of freight entering the United States at Ambassador Bridge may shed some light on the issue (Parsons Brinckerhoff Quade & Douglas, Inc. 1997, 65). This survey indicated that only 25% of import shipments entering the U.S. at Ambassador Bridge are destined to Michigan whereas trade flow statistics from Statistics Canada for the same period suggest that 44% of goods are destined to Michigan.

Imports Through Maritime Ports

Data from two sources were used to provide an estimate of truck flows resulting from imports through maritime ports. The total tonnage imported through each U.S. port by commodity is included in the Army Corps of Engineers' 1993 U.S.

Waterway Data. The CFS data were used to predict the destination state of import shipments as well as to estimate the share of imports shipped by truck, as explained below. Truck shipments were routed from the port of entry to the predicted destination using the Oak Ridge National Highway Network. Estimates of ton-miles resulting from imports through maritime ports were determined for each state using the methodology outlined above for the CFS truck shipments.

In order to utilize the Corps' waterway data in this study, a table provided by the Waterborne Commerce Statistics Center was obtained to convert the Lock Performance Management System Commodity Codes to the Standard Transportation Commodity Code used in the CFS data. All petroleum-related commodities were excluded from the import analysis, since most petroleum products are shipped by pipeline. The destination state of CFS shipments originating in counties adjacent to each port was determined for each two-digit commodity group using the CFS data. These data were used to share the import tonnage for a particular commodity group from each port to probable destination states. The truck share (private, for-hire, or both) of domestic shipments for each origin-destination pair was also determined for each two-digit commodity group using the CFS data. This information was used to estimate the truck share of import tonnage for a particular commodity group originating at each port shipped to a particular destination state.

Each port was assigned to the nearest node on the highway network. These nodes were used as the *origin* of import shipments. Shipments were routed from this origin to the centroid of counties within the destination state; the share of imports shipped to particular counties within the destination state was based on the proportion of shipments (by weight) received by that county in the CFS data. Ton-miles for imports to and through each state were then estimated using the method described above for the CFS truck flows.

Impact of Imports on Truck Flows

Despite the limitations of the foreign trade data, this analysis clearly indicates that the inclusion of imports may substantially affect the distribution of truck flows in many border or port states (see table 2 and figure 3). These estimates indicate that imports comprise greater than 10% of the ton-miles in 11 states. These states are primarily along the northern border (e.g., Michigan, North Dakota, Vermont, New York, and Maine), as well as states with large ports (e.g., California and Washington). Imports are estimated to result in nearly 13% of the ton-miles in Michigan with most of these imports from Canada. The transborder data indicate that nearly half of these shipments are destined to Michigan; the remainder of the shipments travel through Michigan to other states. Typically, shipments from Mexico make up a smaller proportion of the shipments to the United States and have less impact on truck freight flows in southern border states. Nonetheless, international trade (imports and exports) results in roughly 14% of truck flows in Texas.

RELIABILITY OF TON-MILE ESTIMATES

Estimates of ton-miles are based on data from three major sources: the 1993 CFS, the 1992 Census of Agriculture, and foreign trade data. Errors in each of these sources and in the estimation methods implemented by this study contribute to errors in the breakdown of ton-miles by inter- or intrastate categories.

The Bureau of the Census has estimated standard errors in CFS's national-level ton-miles transported by truck to be approximately 1.4% (USDOT BTS 1996a). Of course, this estimate was not broken into four categories, which would increase the error. Also, some errors were introduced by the route selection algorithm, although these are believed to be small. Similarly, errors in quantities reported in the Census of Agriculture are typically less than 0.5% (livestock range from 0.02% to 0.29% and crops range from 0.09% to 0.41%). It is believed that the mileage estimates for farm-based agricultural shipments are high (for reasons discussed earlier), but this has not been quantified. Additional errors in translation from reported quantities to tons might also exist. The size of these errors depends on how well categories were matched and the extent of regional variations. In our judgment, these errors are likely to be relatively small. Furthermore, distance (mileage)

TABLE 2 Ton-Miles of Commodities Moved by Truck: 1993

State	Total (billions)	CFS (billions)	Imports (billions)
United States	**973.13**	**909.61**	**63.51**
Alabama	22.44	21.61	0.83
Alaska	1.77	1.66	0.11
Arizona	17.24	15.82	1.43
Arkansas	21.72	21.02	0.70
California	61.84	54.76	7.08
Colorado	14.76	14.10	0.66
Connecticut	5.13	4.79	0.34
Delaware	1.53	1.37	0.16
District of Columbia	0.05	0.05	—
Florida	29.25	26.37	2.88
Georgia	26.97	25.93	1.03
Hawaii	0.39	0.38	0.01
Idaho	10.57	9.97	0.60
Illinois	48.90	47.28	1.62
Indiana	38.73	37.51	1.21
Iowa	26.18	25.43	0.75
Kansas	15.21	14.98	0.22
Kentucky	22.15	21.56	0.59
Louisiana	17.18	15.79	1.39
Maine	4.30	3.45	0.84
Maryland	9.69	8.87	0.83
Massachusetts	4.69	4.28	0.41
Michigan	22.50	19.58	2.93
Minnesota	15.82	14.85	0.97
Mississippi	16.49	15.78	0.71
Missouri	30.14	29.34	0.80
Montana	11.46	10.03	1.43
Nebraska	22.72	21.90	0.82
Nevada	9.91	9.41	0.49
New Hampshire	1.77	1.57	0.20
New Jersey	10.45	9.19	1.26
New Mexico	15.60	14.71	0.89
New York	22.67	18.05	4.62
North Carolina	21.79	20.89	0.90
North Dakota	6.70	5.52	1.18
Ohio	53.93	51.34	2.58
Oklahoma	21.17	20.45	0.73
Oregon	19.95	18.92	1.03
Pennsylvania	46.65	42.97	3.68
Rhode Island	0.49	0.45	0.04
South Carolina	15.39	14.53	0.87
South Dakota	4.41	4.23	0.18
Tennessee	31.48	30.50	0.98
Texas	65.07	59.56	5.50
Utah	13.19	12.35	0.84
Vermont	1.27	0.88	0.39
Virginia	27.28	25.79	1.49
Washington	15.79	13.22	2.57
West Virginia	9.57	9.30	0.27
Wisconsin	20.28	19.42	0.86
Wyoming	18.53	17.90	0.63

— total less than 10 million.

Notes: CFS column includes domestic and export CFS shipments within, to, from, and through each state, as well as farm-based agricultural shipments. Import ton-miles include estimated shipments to and through each state based on data from the Army Corps of Engineers' U.S. Waterway Data, the 1993 CFS, and the Census Bureau's *1993 County Business Patterns.*

estimates for farm-based agriculture shipments within the smallest states (e.g., Hawaii, Rhode Island, and Delaware) could be off by as much as a factor of two. Estimates for farm-based agriculture shipments within larger states are expected to be more accurate.

The transborder import data and import through maritime ports data are based on files compiled from copies of the Customs Service Entry Summary forms. These forms are required to be filed with Customs at the time the merchandise is released to importers. There is no statistical sampling error associated with these import data. Nonsampling errors such as reporting errors, however, might exist.

For the transborder import data, 4% (by value) of the merchandise imported by truck from Canada and Mexico were excluded from this study (for reasons outlined above). More importantly, the mileage estimates associated with the transborder data involve assumptions that are difficult to quantify. All tonnage information associated with imports through maritime ports were included in this study. Truck share and destination distribution for imports through maritime ports were assumed to have similar patterns as found in the CFS. To the extent that modal shares and shipment distances for out-of-scope imports differ from within-scope shipments from a port, there will be errors associated with the ton-mile information for imports through maritime ports that are presently difficult to quantify.

Because this study utilized multiple data sets collected under different methods and in several instances made assumptions of unknown accuracy, there is no way to precisely estimate the total error associated with the overall national ton-miles estimates. However, since imports by truck constitute less than 7% of the total ton-miles and farm-based agricultural shipments account for less than 4% of the total truck ton-miles, errors in these data cannot change the general patterns of U.S. truck freight movements. The total ton-mile error would be less than 7% nationally if 50% errors are assumed to be associated with both the import and farm-based agricultural data.

FIGURE 3 State-Level Domestic, Import, and Export Shipments

CONCLUSIONS

Analysis of recent data on U.S. freight movements reveals that truck freight transportation in the United States is primarily an interstate phenomenon. In terms of ton-miles, 73% of the ton-miles of truck freight were transported between states in 1993. The proportions of within, to, from and through truck shipments vary significantly from state to state. Within-state truck shipments are most important in large states and geographically noncentral states. Through-state shipments account for more than 50% of the truck ton-miles in 19 states. In addition, this study shows that the addition of farm-based agricultural shipments primarily affects truck flows in the midwestern states. The inclusion of imports also substantially alters the distribution of truck flows in states along the northern border and in major port states.

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Truck Accidents at Freeway Ramps: Data Analysis and High-Risk Site Identification

BRUCE N. JANSON
WAEL AWAD
JUAN ROBLES
Department of Civil Engineering
University of Colorado at Denver

JAKE KONONOV
BRIAN PINKERTON
Colorado Department of Transportation

ABSTRACT

To examine the relationship of ramp design to truck accident rates, this paper presents an analysis of truck accidents in Washington State, plus a comparison to limited data from Colorado and California. We group freeway truck accidents by ramp type, accident type, and by four conflict areas of each merge or diverge ramp. We then compare these groups on the basis of truck accidents per location and per truck-mile of travel. We found that truck accident frequencies and rates were not significantly different by ramp type alone, but were significantly different by conflict area and accident type, both between and within ramp types. We also found that high volume ramps had lower rates of truck accidents per truck-mile of travel. Thus, a ramp's safety risk is related to accident type and conflict area, but not directly to truck volumes, which affects assessments of high-risk locations. Specifically, a ramp with few accidents but a high proportion of rollovers in the merge area may have a deficiency, or a ramp with a low accident rate per truck trip due to high truck volumes may still be a

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Professor Bruce N. Janson, Department of Civil Engineering, University of Colorado at Denver, Campus Box 113, PO Box 173364, Denver CO 80217-3364. Email: bjanson@carbon.cudenver.edu.

high-risk site. We describe a straightforward use of the accident data analyzed in this manner to identify accident-prone sites for further investigation.

INTRODUCTION

Nationally, 20% to 30% of freeway truck accidents occur on or near ramps (excluding an additional 10% to 15% that occur at intersections of ramps and surface streets), despite the fact that interchanges account for less than 5% of all freeway lane-miles (Firestine et al 1989). These same percentages hold true for many western states. Of nearly 2,400 truck accidents on Colorado freeways during 1993, 1994, and early 1995, roughly 30% occurred at interchanges, and another 10% occurred at intersections with secondary roads. (We use the term "freeways" in this paper to include all limited access highways; e.g., interstate highways, expressways, turnpikes, and parkways.)

Sullivan (1990) found accidents per vehicle-mile of travel (VMT) to be significantly related to the number of interchange ramps along California freeway sections. In an older study of freeway accidents throughout the United States, Pigman et al (1981) found accidents occurred 33% more often per VMT on freeway sections with bridges or interchanges than on freeway sections without them (see table 1). Both of these findings were for accidents of all vehicle types and severity (fatalities, injuries, and property damage only). However, we also found that truck accident rates were significantly higher on freeway sections in the vicinity of interchanges in our own analysis of truck accident data reported by Goodell-Grivas (1989).

Although most road accidents are precipitated by erroneous driver actions (in both cars and trucks), inadequate interchange designs for large truck operations may contribute to some of them, along with insufficient safety warnings to truck operators at certain locations. Many freeway ramps throughout the United States were designed for older truck configurations and not for longer combination vehicles carrying much greater weights. A study by Ervin et al (1986) found that the American Association of State Highway and Transportation Officials (AASHTO) design standards (at that time) provided a slim margin of safety for operating large trucks through interchanges, although the newer AASHTO (1990) design standards may provide a greater margin of safety for large trucks.

TABLE 1 Accident Rates on Controlled-Access Highway Sections (Pigman 1981)
(Per million vehicle-miles)

	Surrounding area			
Section type	**Rural**	**Suburban**	**Urban**	**Total**
With interchanges	0.57	0.77	3.05	1.22
Without interchanges	0.49	0.61	2.07	0.90

Note: Includes all accidents causing fatalities, injuries, and property damage only.

This paper presents an analysis of truck accidents at freeway ramps in Washington State, plus a comparison to limited data from Colorado and California. We first compare frequencies of truck accidents in four conflict areas of on-ramps and off-ramps by both ramp type and accident type. We briefly summarize findings of truck accident rates per ramp truck volume and ramp truck-mile of travel, which required the estimation of truck percentages at most ramps (see Janson et al 1997). This approach separates the effects of conflict locations, truck volumes, and travel distances. We lastly describe a straightforward use of the data tabulated in this manner to identify accident-prone sites for further investigation.

Although not reported here, we investigated the effects of ramp geometrics (i.e., grade, curvature, and length) on truck accident rates, but did not find any consistent statistical relationships. Traffic accidents are random events with many causal factors such as driver inattention and fatigue, drugs and alcohol, speeding, traffic congestion, lighting, road surface, and weather conditions. The combination of such factors complicates the influence of geometric design features on accident rates as other studies have noted (Miaou et al 1992). Ideally, a study concerned with geometric design effects would limit its analysis to accidents with design as a causal factor. Unfortunately, accident reports do not make that determination, and specific accident factors are not investigated (except for litigation) until an accident-prone site is identified for further analysis.

Difficulties with statistical analyses of truck accidents also arise due to having no information about "non-events." For every accident that does occur, hundreds of "near accidents" are averted by quick and astute driver actions. Thus, characteristics of "near accidents" related to ramp deficiencies are unavailable. A related difficulty is obtaining an adequate measure of exposure, especially at ramps. Few states regularly count ramp volume except where detectors have been installed for ramp control. Where ramp volume is available, truck percentages (let alone truck type classification) are usually not.

This paper does not offer predictive equations of truck accidents based on geometric or traffic characteristics. Instead, we focus on the analysis and use of truck accident data to "flag" accident-prone ramps for further investigation. A well-known difficulty that arises in this context is regression to the mean, whereby some locations (with or without deficiencies) that have relatively few accidents over one period of time may have relatively more accidents over another (Hauer 1997). Deficiencies revealed by a high accident rate over many years may be missed or falsely indicated by the accident rate of fewer years. We revisit this issue later in the paper.

OVERVIEW OF ANALYSIS APPROACH

Taking into account data availability and previous research, our primary objectives in this study were to:

1. Identify requirements of a comprehensive truck accident database to be used for highway improvement studies as part of a state's safety management system.
2. Statistically compare truck accident experiences of four different ramp designs in three states (Colorado, California, and Washington), so as to examine the effects of their design on interchange safety and possibly recommend design improvements.
3. Develop a procedure to identify high-risk locations for remedial action to improve safety using this truck accident database.
4. Include the experiences and observations of truck drivers and fleet managers to identify and assess problem locations, and to develop candidate safety improvements and risk mitigation strategies.

This paper focuses on objectives 1, 2, and 3. Of the states we contacted, we found Washington to have the most comprehensive accident database with which to pursue these objectives. We then created a truck accident database for Washington that included information about "safe travel" through the same interchanges where truck accidents had occurred. We also gathered limited data for Colorado and California to which we make general comparisons. This brief paper highlights the data we compiled and analyzed for Washington, our most complete data source.

Key questions that we investigated regarding truck accidents at ramps were:

1. Do numbers of truck accidents, truck accident rates per truck trip, or truck VMT differ by ramp type, conflict area, or the combination of these two classifications?
2. Do these findings differ significantly by accident type?
3. Do these findings differ significantly by high, medium, or low average daily traffic (ADT) of trucks or all vehicles on the ramps, or in the main freeway lanes due to greater lane-changing difficulties at higher volumes or the risks of greater speeds at lower volumes?
4. Do these findings differ significantly both upstream and downstream of the merge/diverge area?
5. Do these findings differ significantly for different lengths of the accel/decel lanes plus tapers?

To investigate the above questions, we compared accident frequencies and rates by (i) numbers of ramp locations, (ii) ramp truck ADT, and (iii) ramp truck VMT by (a) ramp type, (b) conflict area, and (c) accident type. These multiple comparisons allowed us to examine the separate effects of conflict locations, ramp truck trip, and travel distances. We excluded comparisons per ramp truck trip except in a summary table, but compare accident rates per ramp truck VMT. Comparing truck accidents per ramp truck trip is similar to comparing intersection accidents per "vehicle entered," where types and numbers of conflict points are more important than travel distances. Although ramps involve greater travel distances than intersections, most accidents occur near conflict points, where numbers of vehicles passing may be more critical than VMT, as will be shown by our results.

PREPARATION OF THE WASHINGTON DATABASE

From Washington State Department of Transportation (WSDOT) files, we compiled a database of all truck accidents at all interchanges in Washington over the 27 months from January 1, 1993 to March 31, 1995. All trucks in this study are of at least 10,000 pounds gross vehicle weight. Using each accident's route milepost as a common identifier, we combined data from the following five files into one database: (1) characteristics of truck accidents at interchanges, (2) freeway traffic volumes, (3) ramp traffic volumes, (4) geometric design characteristics, and (5) computer drawings of each interchange with truck accident locations.

Data extracted directly from WSDOT files and coded into our database for each accident were:

1. accident location (route milepost to nearest 1/100 of a mile) and direction of travel;
2. main and secondary route identifiers (perhaps both freeways);
3. accident type (sideswipe, rearend, rollover, other);
4. lane in which accident occurred.

Data that we interpreted from WSDOT files and interchange drawings were:

1. interchange type (diamond, directional, cloverleaf, other);
2. ramp type (diamond, loop, directional, outer connector, other);
3. ramp connection type (freeway-to-freeway, freeway-to-arterial, etc.);
4. conflict area (e.g., ramp, merge/diverge area, upstream, downstream).

Lastly, using a printout of traffic counts and geometric drawings by route milepost, and a supplemental list of 246 ramp counts with truck percentages, we added to our database the additional accident characteristics listed below.

1. length of merge/diverge area from taper to gore (or vice-versa);
2. length of ramp from secondary connection to merge/diverge area;
3. distance of accident upstream from center of merge/diverge area;
4. distance of accident downstream from center of merge/diverge area;
5. main road ADT and truck percentage;
6. secondary road ADT and truck percentage;
7. ramp ADT and truck percentage (if available).

We excluded all accidents at intersections of ramps and secondary roads, but still included all truck accidents on freeway-to-freeway connector ramps. We carefully distinguished accidents on the ramps from accidents on the main freeway lanes near the ramps. We began our classification of ramp types with detailed differences in ramp design, and then simplified our classification to four basic ramp types (diamond, loop, outer connector, and directional), so as to disregard small differences and have sufficient observations in each cross-classification. Depictions of these basic ramp types can be found in many highway engineering textbooks such as Wright (1996).

A paramount concern was to obtain ramp truck ADT for a sufficient number and variety of ramps where truck accidents did not occur so as to not underestimate the truck exposure of any ramp type. There are a total of 2,200 ramps at 465 interchanges in Washington State. We focused our study on 644 ramps at which at least one truck accident occurred during the study period. (A potential bias of this focus is that we disregard the 1,556 ramps at which no truck accidents occurred during this period.) We focused our attention on these ramps for several reasons.

First, the percentage distribution of all ramp types in the state was similar to the 644 ramps in the study, as shown in table 2. The major difference is that diamond ramps used at many lower volume rural interchanges are a larger percentage of total ramps than of the study ramps, and directional ramps used at many higher volume urban interchanges are a larger percentage of study ramps than of total ramps. A second reason for focusing on these 644 ramps is that we could only examine a sample of such ramps in both Colorado and California. Hence, to achieve some limited comparisons between states, we chose a fairly consistent focus in each state.

Third, even to investigate all of the above questions for Washington, we still needed to estimate some data such as ramp lengths and ramp truck

TABLE 2 Distribution of Ramp Types in Washington State

	All ramps		Study ramps	
Ramp type	**Number**	**Percent**	**Number**	**Percent**
Diamond	1,247	56.7	310	48.1
Loop	247	11.2	81	12.6
Outer connector	189	8.6	59	9.2
Directional	407	18.5	152	23.6
Other	110	5.0	42	6.5
Total	2,200	100.0	644	100.0

Note: Study ramps had at least one truck accident in the study period.

ADT (RTADT) in order to compare truck accident rates per truck-mile of travel as a measure of truck exposure at each ramp. Although RTADT is not generally available, WSDOT was able to provide it for the study period at 246 ramps. This allowed us to estimate RTADT for ramps where the data were not available based on the ramp ADT of all vehicles, as explained later. WSDOT had total ADT for most ramps, but not always for the same study period mentioned above. We requested a special tabulation of total ADT for each of the 644 study ramps for the study period. However, it was beyond the resources of this study to obtain total ADT for all 2,200 ramps via a special collection effort.

It was also beyond the resources of this study for us to identify the length of every ramp in Washington based on geometric drawings, and to distinguish the taper-to-gore distance and the accel/decel lane from the ramp itself. Ideally, this data would be collected in a larger study. However, a primary goal of this study was to develop and demonstrate an analysis procedure of stratifying and comparing ramp truck accidents by ramp type, accident type, and ramp location. Finally, we did control to some extent for the potential bias of not including no-accident ramps, since the study ramps for which we did obtain or estimate RTADT also included many conflict areas where accidents did *not* occur as explained later.

DEFINING THE RAMP INFLUENCE ZONE

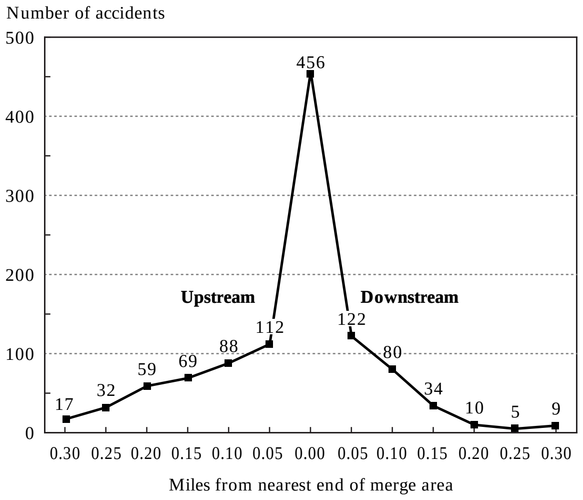
In order to identify truck accidents that were possibly affected by ramp design features, we must first define the area boundaries within which such effects are thought to be significant. We defined this influence zone to (i) exclude intersections with arterials, (ii) be mainly confined to accidents either on the ramp, in the accel/decel lane of the ramp, or in the highway lane adjacent to the accel/decel lane of the ramp, and (iii) be within a certain upstream or downstream distance from the ramp, which we define next.

One research question posed above concerned the effects of upstream and downstream distances on truck accident frequencies. Figure 1 shows numbers of truck accidents both upstream and downstream from merge and diverge ramps in Washington State. Figure 1 includes all freeway lanes, although we later restrict our attention to truck accidents in lane 1 nearest the ramp. Upstream distances are measured in 0.05 mile increments from the tip of the merge gore or from the start of the diverge taper. Downstream distances are also measured in 0.05 mile increments from the tip of the diverge gore or from the end of the merge taper. The center of each figure shows the frequency of accidents in the ramp connection area, which is the accel/decel lane plus taper. (Note that the average length of the ramp connection area for merge ramps was 0.219 miles, but only 0.107 miles for diverge ramps.)

We performed a simple test of frequency differences in successive sections of 0.05 miles either upstream or downstream from the ramp connection area for all truck accidents in our database. We found that the truck accident frequencies stopped changing significantly (i.e., leveled off to a similar number per 0.05 mile section) beyond 0.25 miles upstream for both merge and diverge ramps, beyond 0.2 miles downstream for diverge ramps, and beyond 0.15 miles downstream for merge ramps. The shorter downstream distance for merge ramps seems counterintuitive, but when added to the 0.219 mile average length of a merge area, the total length of 0.369 miles exceeds the combined downstream distance of 0.307 miles for diverge ramps (0.107 mile average length of a diverge area plus 0.2 miles). Upstream and downstream accident frequencies by ramp type showed some differences. For example, for both merge and diverge ramps, truck accidents occur most frequently both upstream and downstream of diamond ramps relative to the frequency of accidents in the ramp con-

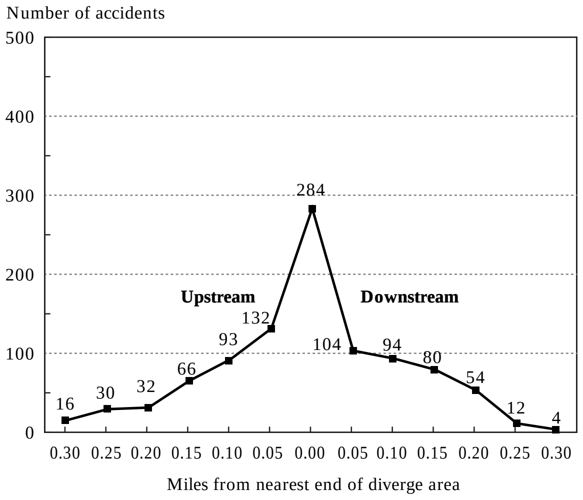
FIGURE 1 Washington State Truck Accidents by Distance from Ramp Area

(a) Number of accidents at merge area



Note: Average length of merge area = 0.219 miles.

(b) Number of accidents at diverge area



Note: Average length of diverge area = 0.107 miles.

nection area. In order to compare accident frequencies among ramp types over equal distances, we defined the same influence zone length for all ramp types as follows:

1. 0.25 miles upstream of the tip of a merge ramp gore;
2. 0.25 miles upstream of the start of a diverge ramp taper;
3. 0.15 miles downstream of the end of a merge ramp taper;
4. 0.20 miles downstream of the tip of a diverge ramp gore.

Figure 2 shows these influence zone distances for both merge and diverge ramps. Figure 2 also shows the four conflict areas that we define later. We show average ramp connection lengths in the figure, but we computed truck VMT for each ramp connection area using its RTADT and its gore-to-taper distance as indicated by its geometric drawing.

ESTIMATING TRUCK EXPOSURE MEASURES

In this section, we compare accident frequencies per location and rates per truck VMT by ramp type, conflict area, and accident type so as to reveal location, volume, and travel distance effects. This required that we estimate ramp truck ADT for ramps where it was not recorded, which we convert to ramp truck VMT for the full study period. WSDOT provided us with ADT and truck percentages at 123 on-ramps and 123 off-ramps. We fitted relationships of RTADT to ramp ADT of all vehicles (RADT) at 84 ramps with at least one truck accident during the study period. Figure 3 shows estimated versus observed RTADT for on-ramps. The figure for off-ramps is very similar. The fitted equations are:

$\text{RTADT} = \text{RADT}^{0.69}$ for on-ramps

$R^2 = 0.826$, parameter's t-statistic = 131.2

$\text{RTADT} = \text{RADT}^{0.71}$ for off-ramps

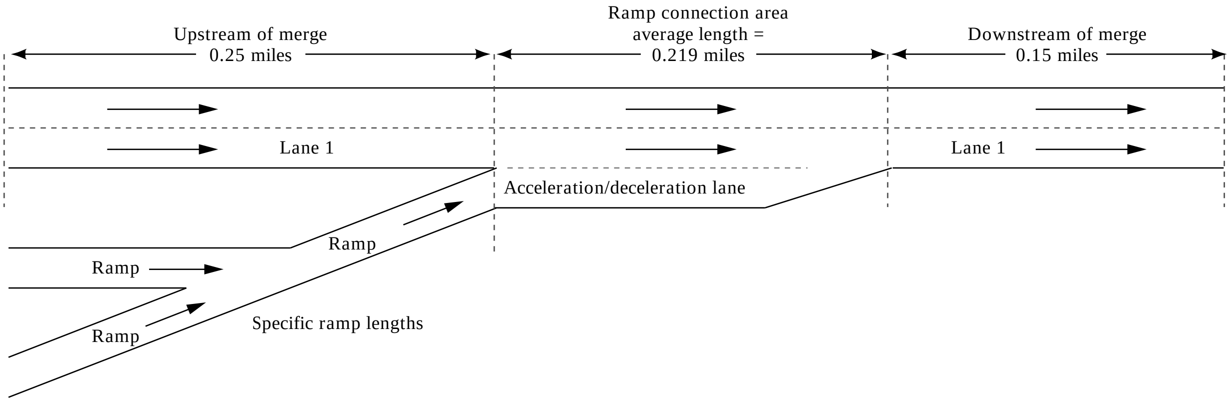
$R^2 = 0.683$, parameter's t-statistic = 106.2

The above equations indicate that RTADT is a decreasing fraction of total ramp ADT as total ramp ADT increases. We fitted several other linear and nonlinear equations to estimate RTADT including (i) a constant, (ii) main road ADT of all vehicles, (iii) truck ADT on the main road, and (iv) secondary road ADT of all vehicles. However, the t-statistics of the other variables were not significant at the 95% confidence level for any of the other models, and the R-squared values were not much improved. Note that two independent data sets (on-ramps versus off-ramps) produced nearly identical fitted parameters (0.69 and 0.71). The fitted equations using all cases (123 on-ramps and 123 off-ramps) also had nearly identical parameters (0.68 and 0.71). Hence, RADT raised to the 0.7 power seems to be a fairly robust predictor for all ramps.

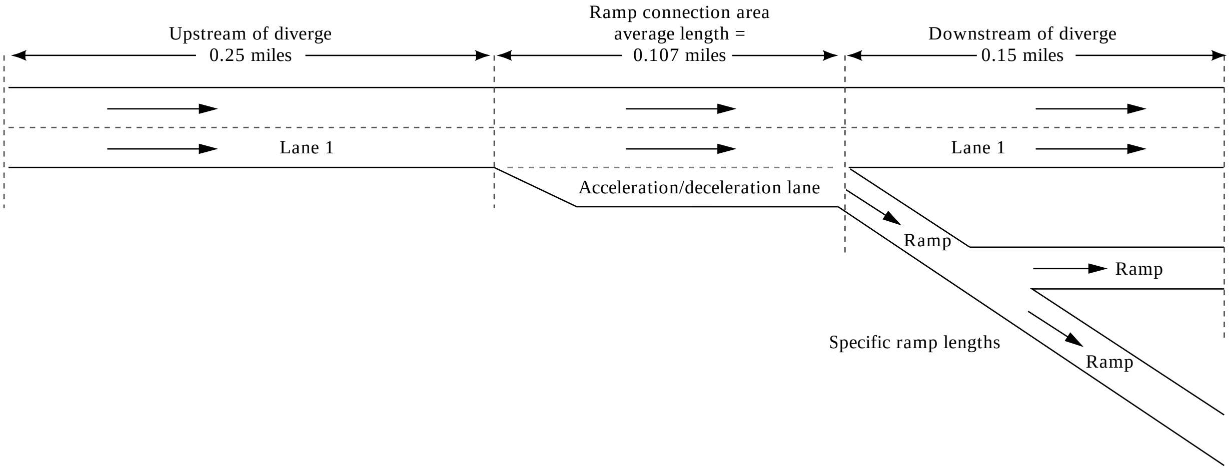
We believe an important predictor of RTADT would be truck ADT on the secondary road, but this data was not available for any interchange

FIGURE 2 Influence Zone Distances in Four Ramp Conflict Areas

(a) Merge ramp



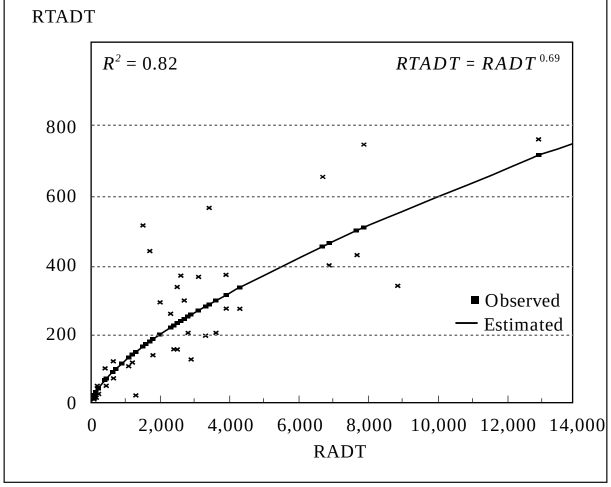
(b) Diverge ramp



location. Certain facilities near an interchange, such as industrial plants, trucking terminals, truck stops, warehouses, and distribution centers will tend to increase RTADT as a proportion of total ADT. Absence of any such facilities, such as an interchange serving mainly residential areas, will tend to decrease RTADT as a proportion of total ADT. Examination of these specific interchange activities would require substantial surveying.

We do not rely heavily on estimated RTADT in this paper, but we emphasize the need for better truck exposure data. Despite their simplicity and lack of accuracy for some specific ramp locations, these equations provide usable estimates of RTADT given the lack of better data. Ideally, state DOTs will sample ADT and truck ADT for a

FIGURE 3 Washington State On-Ramp Truck ADT versus Total On-Ramp ADT



greater proportion of their ramps in the future. Only then will more accurate RTADT be available for truck studies without the need for estimation.

ACCIDENTS PER RAMP IN WASHINGTON STATE

Table 3 shows numbers of ramps and truck accidents per ramp in Washington during the 27 months from January 1, 1993 to March 31, 1995, separated by merge and diverge ramps. The term *ramp* in table 3 refers to the entire ramp area including both the ramp and adjacent freeway lane 1. Part (a) of table 3 shows accidents that occurred on the ramps or in the accel/decel lanes of these ramps, while part (b) shows accidents that occurred on the main line (lane 1) upstream, downstream, or adjacent to these ramps, including shoulder areas. Part (c) shows all accidents combined. Since many ramps had multiple accidents, numbers of accidents by ramp type differ from the numbers of ramps where these accidents occurred. For all 644 ramps combined, 406 (63%) had 1 accident, 141 (22%) had 2 accidents, and the other 97 (15%) had 3 or more accidents, for a total of 1,030 accidents.

Numbers of ramps in parts (a) and (b) of table 3 do not add up to part (c), because many ramps had accidents on both the ramp and main lanes. Numbers of accidents in parts (a) and (b), however, add up to part (c) because every accident is coded to be either on a ramp or on the main line. As explained earlier, we did not record any data for ramps where no accidents occurred. However, these ramps have many conflict areas (i.e., on the ramps, ramp connection areas, upstream areas,

TABLE 3 Washington State Truck Accidents by Ramp Type

Ramp type	Number of on-ramps	Number of off-ramps	Percent of on-ramps	Percent of off-ramps	Number of on-ramp acc	Number of off-ramp acc	Percent of on-ramp acc	Percent of off-ramp acc	Number of acc per on-ramp	Number of acc per off-ramp
(a) Ramp accidents										
Diamond	45	21	37.2	23.1	56	23	33.1	19.0	1.24	1.10
Loop	27	20	22.3	22.0	38	30	22.5	24.8	1.41	1.50
OuterConn	9	10	7.4	11.0	17	12	10.1	9.9	1.89	1.20
Directional	36	34	29.8	37.4	53	48	31.4	39.7	1.47	1.41
Other	4	6	3.3	6.6	5	8	3.0	6.6	1.25	1.33
Total	121	91	100.0	100.0	169	121	100.0	100.0	1.40	1.33
Percent	57.1	42.9			58.3	41.7				
(b) Main line accidents (lane 1)										
Diamond	140	127	57.1	59.3	216	195	54.3	57.0	1.54	1.54
Loop	32	10	13.1	4.7	51	15	12.8	4.4	1.59	1.50
OuterConn	21	22	8.6	10.3	35	36	8.8	10.5	1.67	1.64
Directional	41	49	16.7	22.9	79	89	19.8	26.0	1.93	1.82
Other	11	6	4.5	2.8	17	7	4.3	2.0	1.55	1.17
Total	245	214	100.0	100.0	398	342	100.0	100.0	1.62	1.60
Percent	53.4	46.6			53.8	46.2				
(c) All accidents										
Diamond	168	142	49.6	46.6	272	218	48.0	47.1	1.62	1.54
Loop	53	28	15.6	9.2	89	45	15.7	9.7	1.68	1.61
OuterConn	28	31	8.3	10.2	52	48	9.2	10.4	1.86	1.55
Directional	69	83	20.4	27.2	132	137	23.3	29.6	1.91	1.65
Other	21	21	6.2	6.9	22	15	3.9	3.2	1.05	0.71
Total	339	305	100.0	100.0	567	463	100.0	100.0	1.67	1.52
Percent	52.6	47.4			55.0	45.0				

and downstream areas) where no accidents occurred. Ramps in part (c) minus ramps in part (a) equal ramps where no accidents occurred specifically on the ramps. Ramps in part (c) minus ramps in part (b) equal ramps where no accidents occurred on the main line nearby the ramps. All accidents at intersections of ramps with secondary roads are excluded.

In order to study the effects of ramp geometrics on truck accidents, we separated accidents into four conflict areas, as depicted earlier in figure 2. These four areas are (i) the ramp area away from the main line, (ii) the ramp connection including the accel/decel lane and the adjacent lane 1, (iii) lane 1 upstream of the ramp connection area, and (iv) lane 1 downstream of the ramp connection area. Of the 339 on-ramps and 305 off-ramps listed in table 3(c), only a few merged or diverged on the left side of the freeway.

Average accidents per ramp in table 3 do not account for the volumes and distances of truck travel, but we later examine accident rates per ramp truck trip and per ramp truck VMT. These initial comparisons of average accidents per ramp help to separate out these volume and distance effects. As discussed earlier, there is no "one best" truck exposure measure to use (e.g., RTADT, main line truck ADT, total vehicle ADT). This section compares accident frequencies before introducing an exposure measure. In addition, since truck ADT (both reported and estimated) is not precise, and accident frequencies may be so random or dependent on other factors that no significant relationship to truck ADT is found, an initial inspection of the data without truck ADT is warranted.

Table 4 shows numbers of accidents and average accidents per ramp in the four conflict areas just described. Since numbers of ramps by conflict area include all places where accidents may have occurred even if none did, they generally equal the number of merge or diverge ramps. There are slightly more specific "on-ramps" and "off-ramps" due to collector/distributor connecting ramps for which we did not count upstream and downstream areas. Hence, the average frequencies shown are per all conflict areas regardless of whether any accidents occurred there. Table 4 shows significant differences in the frequencies of accidents per conflict area, which we later examine by ramp and accident type. Accidents occur at significantly lower average frequencies on ramp sections away from freeway lanes (table 4a) than in the upstream, downstream, or ramp connection areas of the freeway (table 4b). Accidents that occur on ramps away from freeway lanes occur more frequently on off-ramps than on on-ramps. Loop off-ramps are a main source of this difference, discussed later in this paper.

Accidents specifically on ramps can occur at junctions of multiple ramps (excluding intersections with arterial roads). Ramp junctions occur most often on directional ramps, and clearly contribute to the frequency of ramp accidents. Among

TABLE 4 Washington State Truck Accidents by Conflict Area

Conflict area	Accidents	Percent	Conflict areas	Accidents per conflict area
(a) On-ramp accidents				
Upstream of merge	151	26.6	331	0.46
Merge ramp	267	47.1	331	0.81
Downstream of merge	74	13.1	331	0.22
On-ramp	75	13.2	339	0.22
Total	567	100.0	1,332	0.43
(b) Off–Ramp Accidents				
Upstream of diverge	119	25.7	294	0.40
Diverge ramp	131	28.3	294	0.45
Downstream of diverge	122	26.3	294	0.41
Off-ramp	91	19.7	305	0.30
Total	463	100.0	1,187	0.39

328 on-ramps containing 94 ramp junctions, 45 truck accidents occurred at junctions (0.644 accidents per junction). Only 40 other truck accidents occurred on the 328 on-ramps (0.122 accidents per ramp). Among 292 off-ramps containing 86 ramp junctions, 25 truck accidents occurred at junctions (0.402 accidents per junction). The 70 other truck accidents on off-ramps occurred away from the junctions (0.240 accidents per ramp). Beyond these comparisons, we did not separately investigate the effects of ramp junctions in this study, and grouped all accidents that occurred on the ramps together, but still separate by merge or diverge ramp.

Table 5 shows a two-way frequency table of accidents by ramp type and conflict area for both merge and diverge ramps. The third line of each cell shows the accident frequency per conflict area, where we see that accidents occur most frequently in ramp connection areas (merge and diverge areas). However, the average frequencies for all on-ramps, all off-ramps, and all ramps combined are not greatly different. Excluding ramp type "other," a two-way analysis of variance showed these average accident frequencies to be significantly different by conflict area at the 95% confidence level, but not by ramp type. This finding suggests the importance of comparing accident histories by conflict area rather than by ramp type alone.

Table 6 shows a two-way frequency table of accidents by conflict area and accident type by aggregating all ramp types together. Note that sideswipe accidents are most prevalent for all ramp types, especially in ramp connection areas. Although not shown here, if separated by ramp type, sideswipe accidents are similarly prevalent at each ramp type, while rollover accidents are most likely to occur at loop off-ramps. Of 50 rollover accidents at all ramps, 19 occurred at loop ramps, of which 11 were at loop off-ramps. Loop ramps are only 12.6% of all study ramps.

Values in the righthand portion of table 6 show the accident frequencies per conflict area. A two-way analysis of variance showed that these average accident frequencies were significantly different by accident type at the 95% confidence level, but not by conflict area, since the values vary highly within conflict areas. One reason the accident frequencies, when grouped by accident type, do not vary significantly by conflict area is that some accident types are so easily affected by driver actions (e.g., a sideswipe may result from the driver attempting to avoid a rearend collision on a short ramp). Thus, frequency variations by conflict area are overshadowed by differences in accident type frequencies. However, two important observations are that sideswipes are most frequent in merge areas, and rollovers are most frequent on ramps themselves.

We next investigate whether stratifying ramps by high, medium, or low ADT of trucks on the ramp shows greater lane-changing difficulties at higher volumes or the risks of greater speeds at lower volumes. In table 7, we grouped conflict areas together by whether RTADT was low, medium, or high. These stratified results, especially from low to middle ADT levels, show accident frequencies on the ramps and in ramp connection areas to increase more consistently with higher ADT than in the upstream or downstream areas, which indicates the effects of traffic volumes on truck accident frequencies on the ramps and in ramp connection areas where most weaving occurs. Results were similar when ramps were stratified by total ADT.

ACCIDENTS PER RAMP TRUCK VMT IN WASHINGTON

This section compares Washington truck accidents per ramp truck VMT (RTVMT). Our final report for this study also makes these comparisons per ramp truck trip. Totals in the rightmost columns of table 8 show numbers of accidents, cumulative RTVMT in millions, and accidents per RTVMT for the four conflict areas. To calculate RTVMT, each RTADT was multiplied by its conflict area length, divided by 1 million, and multiplied by 820 days in the study period (January 1, 1993 to March 31, 1995). We calculated a specific length for each ramp and ramp connection area based on the route milepost data and geometric drawings provided by WSDOT. RTVMT is added once to its sum for each conflict area regardless of whether none or many accidents occurred there.

The upstream and downstream conflict area lengths are the same for each ramp as defined earlier. Hence, the truck VMT of each upstream conflict area equals its RTADT multiplied by 0.25

TABLE 5 Washington State Truck Accidents by Ramp Type and Conflict Area

Conflict Area		Ramp type					Total accidents	Total conflict areas	Accidents per conflict area
		Diamond	Loop	OuterConn	Directional	Other			
On-ramps									
Merge upstream	Accidents	91	7	15	31	7	151		
	Conflict areas	167	50	25	69	20		331	
	Acc/conf area	0.54	0.14	0.60	0.45	0.35			0.46
Merge area	Accidents	116	50	27	63	11	267		
	Conflict areas	167	50	25	69	20		331	
	Acc/conf area	0.69	1.00	1.08	0.91	0.55			0.81
On-ramp	Accidents	21	17	8	28	1	75		
	Conflict areas	168	53	28	69	21		339	
	Acc/conf area	0.13	0.32	0.29	0.41	0.05			0.22
Merge downstream	Accidents	44	15	2	10	3	74		
	Conflict areas	167	50	25	69	20		331	
	Acc/conf area	0.26	0.30	0.08	0.14	0.15			0.22
On-ramps totals	Accidents	272	89	52	132	22	567		
	Conflict areas	669	203	103	276	81		1,332	
	Acc/conf area	0.41	0.44	0.50	0.48	0.27			0.43
Off-ramps									
Diverge upstream	Accidents	67	4	12	32	4	119		
	Conflict areas	142	24	28	80	20		294	
	Acc/conf area	0.47	0.17	0.43	0.40	0.20			0.40
Diverge area	Accidents	54	16	13	42	6	131		
	Conflict areas	142	24	28	80	20		294	
	Acc/conf area	0.38	0.67	0.46	0.53	0.30			0.45
Off-ramp	Accidents	17	23	10	38	3	91		
	Conflict areas	142	28	31	83	21		305	
	Acc/conf area	0.12	0.82	0.32	0.46	0.14			0.30
Diverge downstream	Accidents	80	2	13	25	2	122		
	Conflict areas	142	24	28	80	20		294	
	Acc/conf area	0.56	0.08	0.46	0.31	0.10			0.41
Off-ramp totals	Accidents	218	45	48	137	15	463		
	Conflict areas	568	100	115	323	81		1,187	
	Acc/conf area	0.38	0.45	0.42	0.42	0.19			0.39
Totals for all ramps	Accidents	490	134	100	269	37	1,030		
	Conflict areas	1,237	303	218	599	162		2,519	
	Acc/conf area	0.40	0.44	0.46	0.45	0.23			0.41

miles. The truck VMT in each downstream conflict area equals its RTADT multiplied by 0.15 miles for merge ramps, and by 0.20 miles for diverge ramps. Since ramp lengths and ramp connection lengths (i.e., the accel/decel lane plus taper) vary between ramps, the RTVMT of a ramp or ramp connection area equals its length multiplied by the RTADT. (The length of a ramp is from where it intersects another road to where it joins the ramp connection area.) We also calculated the length of each ramp-to-ramp connection, and added its VMT to the corresponding accident group or ramp type. While drawings from WSDOT fully showed each ramp connection area, they did not always show the full length of every ramp. Hence, the lengths we calculated for some ramps were more approximate than lengths of the ramp connection areas.

Table 8 shows a two-way frequency table of accidents by ramp type and conflict area. Directional ramps have a significantly lower average

TABLE 6 Washington State Truck Accidents by Conflict Area and Accident Type

		Accident type					Accidents per conflict area			
Conflict area	Conflict areas	Side-swipe	Rear-end	Roll-over	Other	Total accidents	Side-swipe	Rear-end	Roll-over	Other
On-ramps										
Merge upstream	331	79	43	4	25	151	0.24	0.13	0.012	0.08
Merge area	331	170	75	3	19	267	0.51	0.23	0.009	0.06
On-ramp	339	36	7	18	14	75	0.11	0.02	0.053	0.04
Merge downstream	331	38	16	1	19	74	0.11	0.05	0.003	0.06
On-ramp totals	1,332	323	141	26	77	567	0.24	0.11	0.020	0.06
Off-ramps										
Diverge upstream	294	58	40	1	20	119	0.20	0.14	0.003	0.07
Diverge area	294	72	39	3	17	131	0.24	0.13	0.010	0.06
Off-ramp	305	33	16	20	22	91	0.11	0.05	0.066	0.07
Diverge downstream	294	70	31	0	21	122	0.24	0.11	0.000	0.07
Off-ramp totals	1,187	233	126	24	80	463	0.20	0.11	0.020	0.07
Totals	2,519	556	267	50	157	1,030	0.22	0.11	0.020	0.06

TABLE 7 Washington State Truck Accidents by Conflict Area and Accident Type Stratified by Ramp Truck ADT

		Ramp truck ADT < 300					300 ≥ Ramp truck ADT < 800					Ramp truck ADT ≥ 800				
		# of loc	Accident type				# of loc	Accident type				# of loc	Accident type			
Conflict area			Sswp	Rend	Rovr	Other		Sswp	Rend	Rovr	Other		Sswp	Rend	Rovr	Other
On-ramps																
Merge upstream	Accidents	114	22	7	2	12	148	39	25	0	8	69	18	11	2	5
	Acc/loc		0.19	0.06	0.02	0.11		0.26	0.17	0.00	0.05		0.26	0.16	0.03	0.07
Merge area	Accidents	114	39	13	2	5	148	87	40	1	10	69	44	22	0	4
	Acc/loc		0.34	0.11	0.02	0.04		0.59	0.27	0.01	0.07		0.64	0.32	0.00	0.06
On-ramp	Accidents	114	2	1	3	3	156	25	3	10	3	69	9	3	5	8
	Acc/loc		0.02	0.01	0.03	0.03		0.16	0.02	0.06	0.02		0.13	0.04	0.07	0.12
Merge downstream	Accidents	114	15	5	1	9	148	16	10	0	5	69	7	1	0	5
	Acc/loc		0.13	0.04	0.01	0.08		0.11	0.07	0.00	0.03		0.10	0.01	0.00	0.07
On-ramp	Totals	456	78	26	8	29	600	167	78	11	26	276	78	37	7	22
	Acc/loc		0.17	0.06	0.02	0.06		0.28	0.13	0.02	0.04		0.28	0.13	0.03	0.08
Off-ramps																
Diverge upstream	Accidents	80	17	11	1	9	172	36	28	0	9	42	5	1	0	2
	Acc/loc		0.21	0.14	0.01	0.11		0.21	0.16	0.00	0.05		0.12	0.02	0.00	0.05
Diverge area	Accidents	80	12	7	1	8	172	49	25	2	8	42	11	7	0	1
	Acc/loc		0.15	0.09	0.01	0.10		0.28	0.15	0.01	0.05		0.26	0.17	0.00	0.02
Off-ramp	Accidents	83	3	2	5	7	180	21	13	14	12	42	9	1	1	3
	Acc/loc		0.04	0.02	0.06	0.08		0.12	0.07	0.08	0.07		0.21	0.02	0.02	0.07
Diverge downstream	Accidents	80	15	7	0	12	172	50	21	0	8	42	5	3	0	1
	Acc/loc		0.19	0.09	0.00	0.15		0.29	0.12	0.00	0.05		0.12	0.07	0.00	0.02
Off-ramp	Totals	323	47	27	7	36	696	156	87	16	37	168	30	12	1	7
	Acc/loc		0.15	0.08	0.02	0.11		0.22	0.13	0.02	0.05		0.18	0.07	0.01	0.04
All ramps	Totals	779	125	53	15	65	1,296	323	165	27	63	444	108	49	8	29
	Acc/loc		0.16	0.07	0.02	0.08		0.25	0.13	0.02	0.05		0.24	0.11	0.02	0.07

Key: ADT = average daily traffic Sswp = sideswipe Rend = rearend Rovr = rollover Loc = location (conflict area)

TABLE 8 Washington State Truck Accidents per Ramp Truck VMT by Ramp Type and Conflict Area

Conflict area		Ramp type					Total accidents	Total RTVMT (millions)	Accidents per RTVMT
		Diamond	Loop	OuterConn	Directional	Other			
On-ramps									
Merge upstream	Accidents	91	7	15	31	7	151		
	RTVMT (millions)	13.66	4.55	2.89	10.88	3.91		35.9	
	Acc/RTVMT	6.66	1.54	5.19	2.85	1.79			4.2
Merge area	Accidents	116	50	27	63	11	267		
	RTVMT (millions)	11.05	3.17	2.84	6.19	3.79		27.0	
	Acc/RTVMT	10.50	15.76	9.49	10.18	2.91			9.9
On-ramp	Accidents	21	17	8	28	1	75		
	RTVMT (millions)	19.81	6.52	4.37	16.02	8.36		55.1	
	Acc/RTVMT	1.06	2.61	1.83	1.75	0.12			1.4
Merge downstream	Accidents	44	15	2	10	3	74		
	RTVMT (millions)	8.20	2.73	1.73	6.57	2.35		21.6	
	Acc/RTVMT	5.37	5.49	1.15	1.52	1.28			3.4
On-ramp totals	Accidents	272	89	52	132	22	567		
	RTVMT (millions)	52.72	16.97	11.84	39.66	18.41		139.6	
	Acc/RTVMT	5.16	5.24	4.39	3.33	1.20			4.1
Off-ramps									
Diverge upstream	Accidents	67	4	12	32	4	119		
	RTVMT (millions)	10.67	2.01	2.59	10.60	3.87		29.7	
	Acc/RTVMT	6.28	1.99	4.63	3.02	1.03			4.0
Diverge area	Accidents	54	16	13	42	6	131		
	RTVMT (millions)	4.67	0.79	1.24	5.49	2.41		14.6	
	Acc/RTVMT	11.57	20.16	10.49	7.65	2.49			9.0
Off-ramp	Accidents	17	23	10	38	3	91		
	RTVMT (millions)	22.89	2.13	2.92	15.80	8.40		52.1	
	Acc/RTVMT	0.74	10.79	3.43	2.40	0.36			1.7
Diverge downstream	Accidents	80	2	13	25	2	122		
	RTVMT (millions)	8.54	1.61	2.07	8.48	3.09		23.8	
	Acc/RTVMT	9.37	1.24	6.27	2.95	0.65			5.1
Off-ramp totals	Accidents	218	45	48	137	15	463		
	RTVMT	46.76	6.55	8.82	40.38	17.77		120.3	
	Acc/RTVMT	4.66	6.87	5.44	3.39	0.84			3.8
Totals for all ramps	Accidents	490	134	100	269	37	1030		
	RTVMT (millions)	99.49	23.52	20.66	80.04	36.17		259.9	
	Acc/RTVMT	4.93	5.70	4.84	3.36	1.02			4.0

Key: RTVMT (ramp truck vehicle-miles of travel) in millions for the study period = ramp truck average daily traffic × conflict area length × 820 ÷ 1,000,000.
Note: Accident rates are per million RTVMT.

accident rate than the other ramp types, and loop off-ramps have the highest average rate. A two-way analysis of variance showed these accident rates per RTVMT to be significantly different by conflict area at the 95% confidence level, but not by ramp type, which is the same test outcome reported for table 5, not taking RTVMT into account. However, these rates differ by conflict area more than for table 5 (i.e., have a higher test power), since lengths of merge and diverge conflict areas and of the ramps themselves are specific to each ramp. When ramp truck volumes and travel distances are taken into account, accident rates per RTVMT are highest in ramp connection areas by a significant margin. While this may be an expected outcome, the finding supports the need to focus ramp improvement efforts on merge and diverge areas.

A final observation from table 8 is that truck accident rates per RTVMT were relatively higher on loop ramps because these ramps are generally shorter, and relatively lower on directional ramps because these ramps tend to serve higher traffic volumes. This finding supports the need to compare the accident rate at a given ramp with similar ramps serving similar traffic volumes.

Table 9 groups conflict areas together by whether RTADT was low, medium, or high. These stratified results show truck accidents per RTVMT to consistently decrease in all conflict areas with higher RTVMT. While truck accidents per location increase with greater truck exposure (as indicated by table 7), the increase is generally much less than the truck VMT increase.

With regard to the accuracy of the RTADT estimates, these equations showed decreasing truck percentages with increasing total ADT. If RTADT were directly proportional to the ramp ADT of all vehicles, then the rates would have the same relative magnitudes as if total ADT were used as the measure of exposure. In that case, the lower accident rates at higher truck volumes would be even lower relative to those for lower truck volumes as seen in table 9.

Table 10 is a summary of Washington truck accident frequencies and rates by conflict area per ramp truck trip and RTVMT. Note that the average accident rates are all nearly equal for merge and diverge ramps when not divided by conflict area, but very different when separated by conflict area. This finding shows the importance of examining the accident histories of ramps by conflict area rather than of entire ramps, in order to identify possible problem spots.

COMPARISON OF ACCIDENTS PER RAMP IN THREE STATES

Since we were not able to obtain RTADT for Colorado or California, we limit our comparisons in this section to accident frequencies per ramp type. Table 11 lists number of ramps and accidents per ramp type for Colorado, California, and Washington. The data in Colorado and California were for 1991 to 1993, while the data for Washington were for 1993 to early 1995. Since our Washington data were for 27 months but our Colorado and California data were for 36 months, all values were converted to a yearly basis. The accident frequencies for Washington State are the weighted means of the frequencies shown in the last two columns of table 3(c). By coincidence, the mean truck accident frequency per ramp for all ramp types was 0.71 per year in each of these states.

The Colorado and California ramps were selected on the basis of a severity index that weighted the number of fatal, injury, and property damage only truck accidents. We also included some sites with lower severity indices in each sample. Thus, the equal mean frequencies for all ramps examined in each state is reasonable. For brevity, we limit our discussion of table 11, but note that the accident frequencies per directional ramp or per loop ramp are very consistent in all three states.

IDENTIFICATION OF HIGH-RISK SITES

Our findings support the need to compare the accident history of a given ramp with similar ramps serving similar traffic volumes. The average accident frequencies did not differ significantly by ramp type, but there was significant variation by conflict area within ramp types. These differences became greater by ramp type and conflict area when accident rates per ramp truck volumes and ADT were examined. These findings led us to propose a straightforward procedure to “flag” potentially high-risk ramps for closer analysis, which can be easily implemented within emerging safety management systems. In states that collect more complete data, the procedure can be made more sophisticated.

Seven comparisons can be made of the accident frequency at a given ramp by one or more of three attributes (accident type, ramp type, and conflict area) to the accident distribution of other ramps in a state. These comparisons are:

1. by accident type for all ramp types and conflict areas;
2. by ramp type for all accident types and conflict areas;
3. by conflict area for all ramp types and accident types;

TABLE 9 Washington State Truck Accidents per RTVMT by Conflict Area and Accident Type Stratified by RTADT

		RTADT < 300					300 ≥ RTADT < 800					RTADT ≥ 800				
		RTVMT	Accident type				RTVMT	Accident type				RTVMT	Accident type			
Conflict area		**(mil)**	**Sswp**	**Rend**	**Rovr**	**Other**	**(mil)**	**Sswp**	**Rend**	**Rovr**	**Other**	**(mil)**	**Sswp**	**Rend**	**Rovr**	**Other**
On-ramps																
Merge	Accidents	3.8	22	8	2	12	16.2	39	25	0	8	15.9	18	10	2	5
upstream	Acc/RTVMT		5.72	2.08	0.52	3.12		2.41	1.55	0.00	0.49		1.13	0.63	0.13	0.32
Merge area	Accidents	3.2	39	13	2	5	12.5	87	40	1	10	11.3	44	22	0	4
	Acc/RTVMT		12.30	4.10	0.63	1.58		6.95	3.20	0.08	0.80		3.88	1.94	0.00	0.35
On-ramp	Accidents	5.9	3	1	3	3	24.3	25	3	10	3	24.9	8	3	5	8
	Acc/RTVMT		0.51	0.17	0.51	0.51		1.03	0.12	0.41	0.12		0.32	0.12	0.20	0.32
Merge	Accidents	2.3	15	5	1	9	9.7	16	10	0	5	9.6	7	1	0	5
downstream	Acc/RTVMT		6.47	2.16	0.43	3.88		1.65	1.03	0.00	0.52		0.73	0.10	0.00	0.52
On-ramp	Totals	15.2	79	27	8	29	62.7	167	78	11	26	61.7	77	36	7	22
	Acc/RTVMT		5.19	1.77	0.53	1.90		2.66	1.24	0.18	0.41		1.25	0.58	0.11	0.36
Off-ramps																
Diverge	Accidents	3.0	17	11	1	9	17.2	36	28	0	9	9.5	5	1	0	2
upstream	Acc/RTVMT		5.68	3.67	0.33	3.01		2.09	1.63	0.00	0.52		0.52	0.10	0.00	0.21
Diverge area	Accidents	1.3	12	7	1	8	7.6	49	25	2	8	5.7	11	7	0	1
	Acc/RTVMT		9.23	5.39	0.77	6.16		6.46	3.29	0.26	1.05		1.93	1.23	0.00	0.18
Off-ramp	Accidents	3.4	3	2	5	7	33.2	21	13	14	12	15.6	9	1	1	3
	Acc/RTVMT		0.88	0.58	1.46	2.04		0.63	0.39	0.42	0.36		0.58	0.06	0.06	0.19
Diverge	Accidents	2.4	15	7	0	12	13.8	50	21	0	8	7.6	5	3	0	1
downstream	Acc/RTVMT		6.26	2.92	0.00	5.01		3.63	1.52	0.00	0.58		0.66	0.39	0.00	0.13
Off-ramp	Totals	10.1	47	27	7	36	71.8	156	87	16	37	38.4	30	12	1	7
	Acc/RTVMT		4.65	2.67	0.69	3.56		2.17	1.21	0.22	0.52		0.78	0.31	0.03	0.18
All ramps	Totals	25.3	126	54	15	65	134.5	323	165	27	63	100.1	107	48	8	29
	Acc/RTVMT		4.97	2.13	0.59	2.56		2.40	1.23	0.20	0.47		1.07	0.48	0.08	0.29

Key: ADT = average daily traffic Sswp = sideswipe Rend = rearend Rovr = rollover

RTVMT (ramp truck vehicle-miles of travel) in millions for the study period = ramp truck average daily traffic × conflict area length × 820 ÷ 1,000,000.

Note: Accident rates are per million RTVMT.

4. by accident type and ramp type for all conflict areas;
5. by accident type and conflict area for all ramp types;
6. by ramp type and conflict area for all accident types; and
7. by accident type, ramp type, and conflict area.

Each additional attribute by which accidents are grouped reduces the sample size of accidents and ramps to which a given ramp is compared. Moreover, the likelihood (or ease) of obtaining data to classify accidents by these attributes is greatest for accident type, less for ramp type, and least for conflict area. With those considerations, we recommend performing comparisons 1, 2, 4, 6, and 7 (in that order) as numbered above. Comparisons 1, 2, and 4 do not require identifying the conflict area, the least obtainable data. Comparisons 6 and 7 require identifying the conflict area, but these comparisons are not necessary to warrant a site inspection and design evaluation. If a ramp is found to have a high frequency of accidents (1) overall, (2) by accident type, and (4) by accident and ramp type, then it probably warrants closer examination. Accident reports for that ramp would be studied, and accidents classified by conflict area and several other attributes such as vehicle type, weather, lighting, road condition, and driver actions. This information would then be used to determine whether improvements to geometric design, signage, or traffic controls are warranted considering various alternatives and their costs.

Thus, the high-risk site identification procedure is as follows:

1. For a given ramp (all conflict areas combined), compare its frequency of *all accident types* over a multiyear analysis period to the frequency distribution of *all accident types in all conflict areas*

TABLE 10 Summary of Washington Truck Accident Rates by Conflict Area

Conflict area	Number of accidents	Number of conflict areas	RTT	RTVMT	Accidents per conflict area	Accidents per RTT	Accidents per RTVMT
On-ramps							
Merge upstream	151	331	143.6	35.9	0.5	1.1	4.2
Merge area	267	331	143.6	27.0	0.8	1.9	9.9
On-ramp	75	339	147.0	55.1	0.2	0.5	1.4
Merge downstream	74	331	143.6	21.6	0.2	0.5	3.4
Total	567	1,332	577.8	139.6	0.4	1.0	4.1
Off-ramps							
Diverge upstream	119	294	119.0	29.7	0.4	1.0	4.0
Diverge area	131	294	119.0	14.6	0.4	1.1	9.0
Off-ramp	91	305	122.7	52.1	0.3	0.7	1.7
Diverge downstream	122	294	119.0	23.8	0.4	1.0	5.1
Total	463	1,187	479.6	120.3	0.4	1.0	3.8
Totals	1,030	2,519	1,057.4	259.9	0.4	1.0	4.0

Key: RTT = ramp truck trips; RTVMT = ramp truck vehicle-miles of travel.

Note: Accident rates are per million RTT and million RTVMT.

at all other ramps of a state. If the accident frequency at a given ramp lies above a given threshold (discussed below), an initial flag is raised.

2. For a given ramp (all conflict areas combined), compare its frequency of *each accident type* over a multiyear analysis period to the frequency distribution of *each accident type in all conflict areas at all other ramps of a state.* If any accident type frequency at a given ramp lies above a given threshold, a second flag is raised.
3. For a given ramp (all conflict areas combined), compare its frequency of *each accident type* over a multiyear analysis period to the frequency distribution of *each accident type in all conflict areas at all similar type ramps within a broadly similar range of RTADT in a state.* If any accident type frequency at a given ramp lies above a given threshold, a third flag is raised.

The first comparison indicates whether the ramp has an unusual overall accident history in comparison to all other statewide ramps, and requires minimal information. The second comparison indicates whether the ramp has an unusual accident history for any particular accident type, knowing that data on conflict area and ramp type may not be available. The third comparison (number 4 in the prior list) indicates whether the ramp has an unusual accident history for any particular accident type in comparison to similar ramps, knowing that data on conflict area may still not be available. Note that RTADT as used here indicates that ramps being compared have similar truck exposure. If all comparisons point to a potential problem, then further evaluation is recommended, leading to comparisons 6 and 7 if conflict area data is available for many other ramps of similar design in the state. If only one or two comparisons indicate a potential problem, then further evaluation may be considered depending on available resources.

As for the appropriate threshold, the 75th percentile is suggested by Basha and Ramsey (1993) as an "initial check" to identify locations that may warrant further investigation. A higher or lower percentile might be considered after experience shows whether this percentile flags too many or too few locations that do or do not warrant further attention. If we assume accidents per year at any ramp to be Poisson distributed (for which the variance equals the mean), then the threshold might be set to the number of accidents for which the average "peer" site would have a probability of 5% of exceeding. Note that the accident distribution among ramp locations on which these thresholds are based should ideally include or control for the prevalence of "no accident" locations.

TABLE 11 Comparison of Yearly Truck Accidents per Ramp in Three States

Ramp type	Ramps	Percent	Accidents per year	Percent	Average accident frequency
Colorado accidents					
Diamond	27	30.3	16	25.9	0.60
Loop	12	13.5	9	14.8	0.78
OuterConn	11	12.4	6	9.0	0.52
Directional	39	43.8	32	50.3	0.81
Other	0	0.0	0	0.0	0.00
Total	89	100.0	63	100.0	0.71
California accidents					
Diamond	19	3.9	20	5.6	1.04
Loop	25	5.1	19	5.4	0.76
OuterConn	23	4.7	11	3.1	0.48
Directional	324	65.9	266	75.8	0.82
Other	101	20.5	35	10.1	0.35
Total	492	100.0	351	100.0	0.71
Washington accidents					
Diamond	310	48.1	218	47.5	0.70
Loop	81	12.6	60	13.0	0.74
OuterConn	59	9.2	44	9.7	0.75
Directional	152	23.6	120	26.1	0.79
Other	42	6.5	16	3.6	0.39
Total	644	100.0	458	100.0	0.71

To reduce regression-to-the-mean effects, Bayesian estimates of accident expectancies can also be developed if there are reliable prediction equations of accidents based on explanatory variables, and if reliable data for these explanatory variables is available (see Higle and Witkowski 1988; Higle and Hecht 1989; Miaou et al 1992; and Hauer 1997). We fitted both regression and neural network models of many forms to this data including geometric features and did not obtain reliable prediction equations of ramp truck accidents (see Awad and Janson 1997). Thresholds based on Poisson distributions of accidents per year may be sufficient, however.

The following is an example of applying the above procedure to the interchange of Interstate 25 and State Highway 34 in Colorado, which serves the cities of Greeley and Loveland. This interchange is a full cloverleaf, with four loop ramps and four outer connectors. The entire interchange had experienced 11 truck accidents in the years 1991 to 1993, of which 6 were overturns and 4 were overturns on the loop ramp leading from westbound SH-34 to southbound I-25.

Four truck accidents on one ramp in a three-year period suggested a problem simply according to the first overall test. Four overturns on one ramp in a three-year period more strongly indicated a problem according to the second test. Finally, even compared with other loop ramps, four truck accidents of any type in a three-year period gave justification for a site inspection and design evaluation. Actions were taken to improve the lane markings and speed warning signs at this interchange, and the interchange continues to be monitored.

CONCLUDING REMARKS

Truck accidents per ramp location or per RTVMT can vary by type of ramp, conflict location, and accident type. Based on the data shown, loop ramps in particular have generally higher accident rates, particularly rollovers. One implication of this finding is that a given loop ramp may have a high accident rate compared to all ramp types, but not comparable to loop ramps. Short of total reconstruction, low-cost measures to reduce the accident rate at a loop ramp to be in line with non-loop ramps may be limited. Thus, evaluations of accident mitigation effectiveness should be done within ramp types.

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Measuring Transportation in the U.S. Economy

XIAOLI HAN
BINGSONG FANG
Bureau of Transportation Statistics
US Department of Transportation

ABSTRACT

This paper argues that the System of National Accounts (SNA) is the most appropriate framework for comparable economic measures of national transportation, and shows that within the SNA transportation can be represented as an industry, as a component of Gross Domestic Product (GDP) measured from the demand side and as a component of Gross Domestic Demand (GDD). Two measures of transportation comparable to GDP and one comparable to GDD are presented. Transportation-related final demand is the measure of transportation as a component of GDP, which includes the value of all goods and services delivered to final users for transportation purposes regardless of which industry produced them. In contrast, transportation industry GDP is the measure of transportation as an industry, which comprises value-added created in the provision of transportation services by the industry. Transportation domestic demand measures the U.S. domestic final demand for transportation regard-

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Dr. Xiaoli Han, Bureau of Transportation Statistics, U.S. Department of Transportation, 400 Seventh Street, SW, Room 3430, Washington, DC 20590. Email: charlie.han@bts.gov.

less of who supplies the demand, domestic producers or imports. It differs from transportation-related final demand in that it excludes the balance of trade in transportation goods and services.

INTRODUCTION

Transportation exists in every phase and facet of life today. For those living in an industrialized economy, transportation's importance should be too obvious to warrant lengthy elaboration. Measuring transportation's economic importance, however, is not as obvious, even for transportation experts.

Historically, the most widely used measure of transportation's role in the economy has been the "Transportation Bill" (Eno 1996). The Transportation Bill is constructed from statistics on revenues and expenditures, and attempts to measure the sum total of economic transactions for transportation services, equipment, and so forth. While this reflects how much is spent on transportation throughout the economy, it does not measure how much the transportation industry contributes to the total economy nor does it measure the final demand for transportation in a way that is consistent with other established economic measures, such as GDP. By using a framework that is consistent with the System of National Accounts one can measure transportation's share of the economy in a way that is directly comparable to GDP.

After a summary discussion of aggregate measures of the economy in the SNA, we discuss measuring transportation in the SNA from two perspectives, production and final demand. Following that, we present the three measures of transportation based on actual data from the U.S. National Income and Product Accounts (NIPA).

TRANSPORTATION IN THE SNA

> The System of National Accounts consists of a coherent, consistent and integrated set of macroeconomic accounts, balance sheets and tables based on a set of internationally agreed concepts, definitions, classifications and accounting rules. It provides a comprehensive accounting framework within which economic data can be compiled and presented in a format that is designed for purposes of economic analysis, decision-taking and policy-making. (UN et al 1993, 1, para. 1.1.)

One key statistic of the SNA is GDP, which is widely used as a summary indicator of the size of economic activity and the welfare of a nation. GDP is the sum of gross value-added by resident producer units (institutional sectors or industries). From the demand perspective, GDP is equal to the sum of the final uses of goods and services, measured in terms of purchasers' prices. The major components of GDP viewed from both the supply side and the demand side and their relationship to output are shown in figure 1.

From the demand perspective, the major components of GDP are consumer expenditures, government expenditures, capital investment, and net exports. These components are also often referred to as final demand, as distinguished from intermediate demand.[1] From the supply perspective, GDP consists of every industry's value-added, which includes labor compensation (wage and salary), business taxes, corporate profits, and depreciation of fixed capital. GDP measured as total value-added and as total final demand (or expenditures) are identical.[2] This identity can be easily derived from the following relations:

$$\text{Intermediate demand} + \text{Final demand} = \text{Output}$$
$$= \text{Intermediate demand} + \text{Value-added}$$

$$\text{Final demand} = \text{GDP} = \text{Value-added}$$

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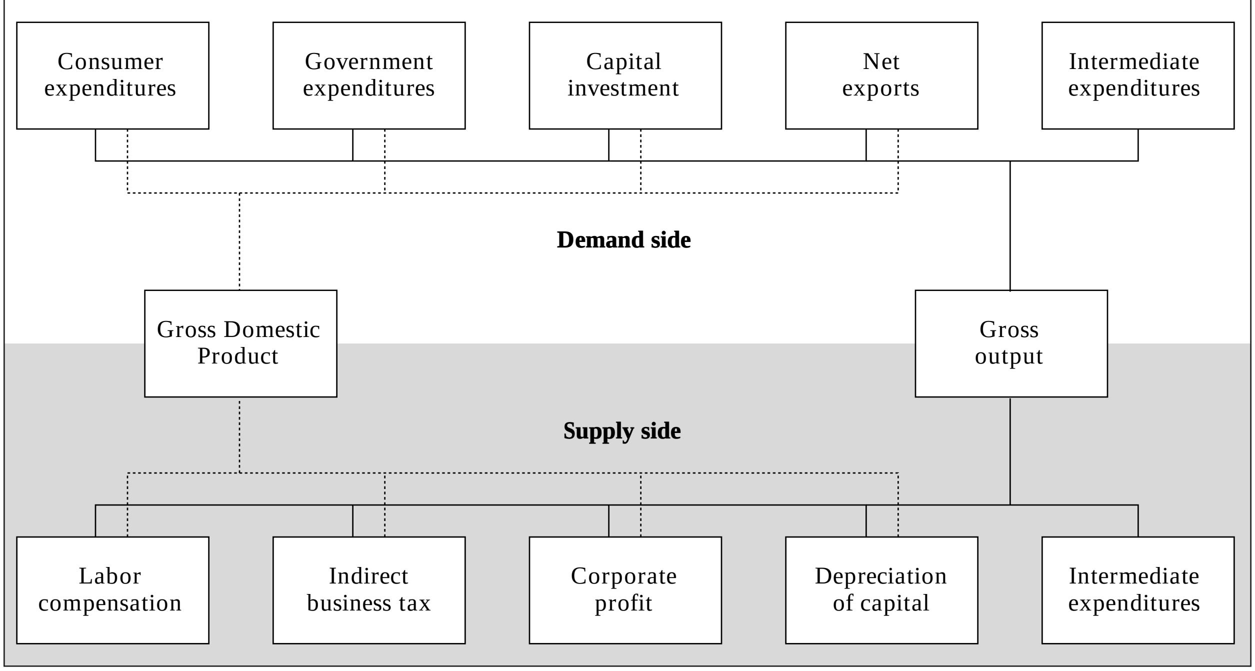
[1] While final demand consists of goods and services delivered to the consumers of economic output, intermediate demand, which is not counted in GDP consists of inputs into processes of production that are used up within the accounting period. A good deal of transportation is produced for intermediate consumption. Normally, households, governments, and foreign consumers and foreign producers are considered final users. In addition, capital formation (or private investment) is also considered as final demand.

[2] This identity between value-added and final demand exists only at the national level, however, and breaks down at the industry level. As an example, there is no final demand for pig iron, but the steel and iron industry generates value-added in producing pig iron. Through the input-output chain of production (e.g., pig iron is used as an input to produce steel, and steel is further used as an input to produce automobiles), the value-added generated by the steel and iron industry will eventually be embodied in the products delivered to final demand. Final expenditures on a product reflect the total value-added embodied in the product, which is the sum of the value-added generated in its production and all the value-added of the inputs used in the production.

FIGURE 1 Major Components of an Economy



These identities give a comprehensive picture of the magnitude of an economy that remains the same when looked at from any angle.

Transportation appears on both the demand and supply sides of GDP. On the supply side, the output of transportation as an industry is measured. In both the Standard Industrial Classification system and the newly developed North American Industrial Classification System, transportation is identified as a separate industry group.

On the demand side, transportation appears as one of many distinct purposes for which households, governments, and others purchase goods and services. Within each broad expenditure category on the demand side in the SNA (see figure 1), expenditure items can be identified as transportation-related. Some obvious components include purchases of automobiles and gasoline, government expenditures on highways, and business expenditures on railway construction.

Because GDP measures the total amount of goods and services for final uses, as opposed to intermediate uses in production, transportation-related final demand measures how much of those goods and services were used for transportation purposes. But GDP also measures total value-added. Transportation as an industry on the supply side measures how much of the total value-added was created in transportation industries. These two measures are qualitatively and quantitatively different. The measure of transportation as final demand includes the value of gasoline produced by the petroleum refinery industry and cement produced by the cement industry to the extent that they are part of final demand and used for transportation purposes. The measure of transportation as an industry would include value-added generated in transporting food from producer to consumer, although the food is not part of transportation final demand.

MEASURING TRANSPORTATION AS FINAL DEMAND

In the NIPA, GDP calculated from the final demand perspective is the sum of four components: personal (household) consumption expenditures, gross private domestic investment, net exports of goods and services, and government consumption expenditures and gross investment. (Various detailed breakdowns of these four components are presented in the NIPA tables. USDOC 1993–96)

PERSONAL CONSUMPTION EXPENDITURES

Personal consumption expenditures are broken down into 12 functional categories of which transportation is one. Expenditures included in the transportation function are:

1. User-operated transportation
   a. New autos
   b. Net purchases of used autos
   c. Other motor vehicles
   d. Tires, tubes, accessories, and other parts
   e. Repair, greasing, washing, parking, storage, rental, and leasing
   f. Gasoline and oil
   g. Bridge, tunnel, ferry, and road tolls
   h. Insurance
2. Purchased local transportation
   a. Mass transit systems
   b. Taxicabs
3. Purchased intercity transportation
   a. Railway
   b. Bus
   c. Airline
   d. Other

Gross Private Domestic Investment

Gross private domestic investment is the sum of fixed investment and the change in business inventories. Change in business inventories is typically very small relative to fixed investment and may be positive in one year and negative in the next. In the NIPA, fixed investment is divided into two broad categories: structures and producers' durable equipment. Private purchases of producers' durable equipment comprise five subcategories, one of which is transportation and related equipment. Transportation and related equipment is further broken into:

1. Trucks, buses, and truck trailers
2. Autos
3. Aircraft
4. Ships and boats
5. Railroad equipment

Net Exports of Goods and Services

Net exports of goods and services in the NIPA are calculated as exports of goods and services less imports of goods and services. "Exports and Imports of Merchandise by End-use Category" comprises six categories, one of which is automotive vehicles, engines, and parts.

U.S. exports and imports of transportation services are found in the NIPA tables on "U.S. International Transactions" and "Private Service Transactions" under four categories:

1. Passenger fares
2. Freight transportation services
3. Port services
4. Other transportation services

Government Consumption Expenditures and Gross Investment

The NIPA records information about federal government consumption and state and local government consumption separately, but transportation is a category in both tables. Within transportation, there are five subcategories: highways, water, air, railroads, and transit. Government investment in transportation concentrates primarily on infrastructure, more specifically, on highways and streets. (Expenditures on highways and streets are also listed in the NIPA table on "Purchases of Structures by Type," and should not be counted twice.) Expenditures under transportation in the two tables exclude defense transportation demand. Statistics on defense transportation expenditures are contained in the NIPA table "National Defense Purchases of Goods and Services" under "transportation of materials" and "travel of military persons."

Transportation-Related Final Demand

The summation of all the transportation-related components in each of the four categories gives the measure of *transportation-related final demand*. Transportation-related final demand is directly comparable to GDP, and its ratio to GDP can be used as an indicator of transportation's importance as a component of GDP. Table 1 presents the components of transportation-related final demand and its relationship to GDP.

In current dollars, transportation-related final demand totaled $847 billion in 1996, equivalent to 11% of GDP. Personal consumption is the dominant component of transportation-related final demand. Its share in the total was 71% in 1996. Gross private domestic investment and govern-

TABLE 1 U.S. Gross Domestic Product Attributed to Transportation-Related Final Demand
(Billions of current dollars)

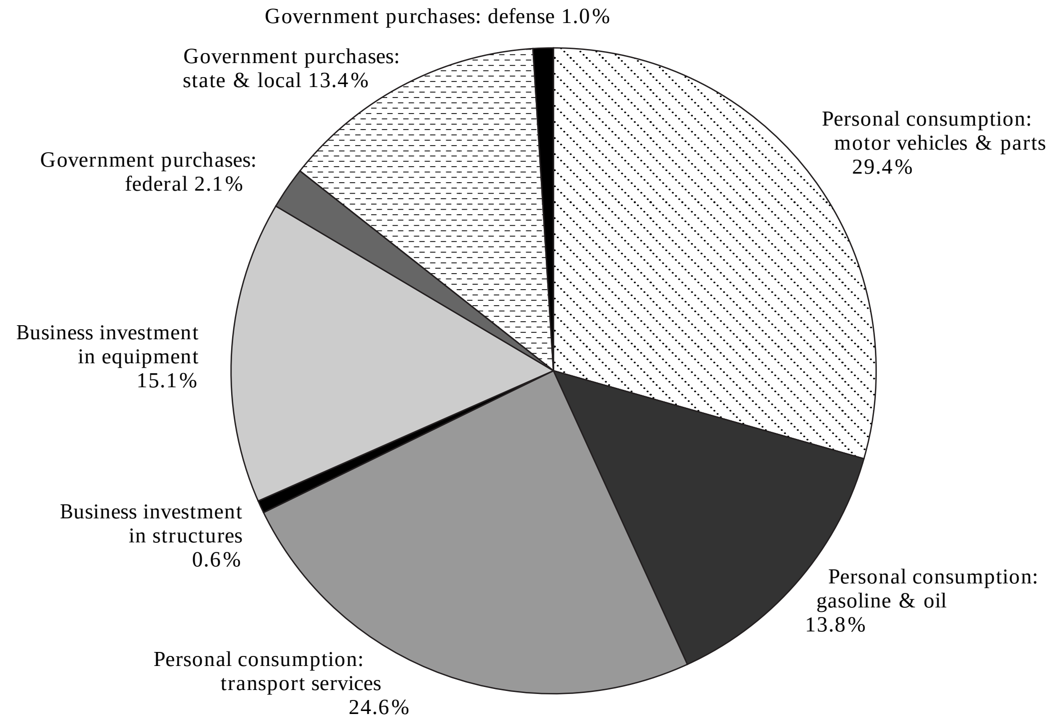
	1991	1992	1993	1994	1995	1996
Personal consumption of transportation	**436.8**	**471.6**	**504**	**542.2**	**572.3**	**602.3**
Motor vehicles and parts	187.6	206.9	226.2	246.6	254.8	261.3
Gasoline and oil	103.9	106.6	107.6	109.4	114.4	122.6
Transportation services	145.3	158.1	170.2	186.2	203.1	218.4
Gross private domestic investment	**82.7**	**89.9**	**104**	**122.9**	**130.1**	**140.1**
Transportation structures	3.2	3.7	4.1	4.3	4.4	5.6
Transportation equipment	79.5	86.2	99.9	118.6	125.7	134.5
Net trade of goods and services	**–16.8**	**–15.5**	**–25.8**	**–38.5**	**–42.8**	**–42.3**
Exports (+)	**115.8**	**125**	**124.9**	**131.3**	**134.4**	**143.6**
Civilian aircraft, engines, and parts	36.6	37.7	32.7	31.5	26.1	30.8
Automotive vehicles, engines, and parts	40	47	52.5	57.8	61.8	65
Passenger fares	15.9	16.6	16.6	17.1	19.1	20.6
Other transportation	23.3	23.7	23.1	24.9	27.4	27.2
Imports (–)	**132.6**	**140.5**	**150.7**	**169.8**	**177.2**	**185.9**
Civilian aircraft, engines, and parts	11.7	12.6	11.3	11.3	10.7	12.7
Automotive vehicles, engines, and parts	85.7	91.8	102.4	118.3	123.8	128.9
Passenger fares	10	10.6	11.3	12.9	14.4	15.8
Other transportation	25.2	25.5	25.7	27.3	28.3	28.5
Government transportation-related purchases	**121.2**	**123.4**	**126.9**	**133.6**	**139.1**	**146.5**
Federal purchases	16.2	16.8	17.6	18.8	17.9	18.7
State and local purchases	89.2	95.3	99.8	106.5	112.4	118.8
Defense-related purchases	15.8	11.3	9.5	8.2	8.8	9.0
Transportation-related final demand	**623.9**	**669.4**	**709.1**	**760.2**	**798.7**	**846.6**
Gross Domestic Product (GDP)	5,916.7	6,244.4	6,558.1	6,947	7,265.4	7,636
Transportation-related final demand in GDP	10.5%	10.7%	10.8%	10.9%	11.0%	11.1%
Transportation domestic demand	**640.7**	**684.9**	**734.9**	**798.7**	**841.5**	**888.9**
Gross Domestic Demand (GDD)	5,937.2	6,273.9	6,618.8	7,037.9	7,351.4	7,730.8
Transportation domestic demand in GDD	10.8%	10.9%	11.1%	11.3%	11.4%	11.5%

SOURCE: Calculated from data published in U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business,* various issues, 1996–97.

ment transportation-related purchases accounted respectively for another 16.5% and 17.3% of transportation-related final demand. The sum of the shares of personal consumption, gross private investment, and government purchases in transportation-related final demand was greater than 100%, because U.S. net exports of transportation-related goods and services were negative. International trade in transportation-related goods and services consistently ran a deficit over the six-year period from 1991 to 1996, primarily as a result of the automobile and parts trade deficit. In contrast, trade of civilian aircraft and parts ran a surplus, with exports consistently about three times imports.

If there were no international trade, the production of an economy would equal its consumption, and transportation-related final demand would be a good measure of the importance of transportation in the economy's final consumption. With international trade, what is produced by an economy and what is consumed by the economy may differ significantly. In the national accounts, a country's domestic final demand is called Gross Domestic Demand (GDD), to distinguish it from final demand for the products of the economy. In 1996, U.S. transportation-related final demand was $846.6 billion, while U.S. gross domestic demand for transportation was $888.9 billion, the difference being the net trade of transportation-related goods and services. Transportation GDD can be directly compared with total U.S. GDD to measure the importance of transportation in U.S. domestic

FIGURE 2 Components of Transportation Domestic Demand: 1996



demand. Figure 2 presents the component structure of U.S. transportation GDD in 1996.

While transportation-related final demand is comparable to GDP, it is not a full and perfect indicator of the importance of transportation to society. First, a great deal of transportation is consumed as an intermediate demand and is not measured in transportation-related final demand. Second, transportation-related final demand covers only transportation services purchased in the market, and does not cover transportation services provided by consumers to themselves. For example, if a person rides a bus to work the fare he or she pays is counted as transportation-related final demand. But if he or she drives to work, the value of the driving service provided is not counted, because there is no market transaction. This kind of "household production" is not only important to measuring transportation, but is also a fundamental issue in the estimation of GDP in general. Although a full discussion of these issues is beyond the scope of this paper, they deserve our attention and demand future research.

Comparison of Transportation with Other Functions

The 11% share of transportation-related final demand in GDP provides a useful measure of the role that transportation plays in the economy. In order to see the relative importance of transportation compared with other major socioeconomic activities, we break GDP into six major categories according to the purposes for which goods and services are produced: housing, health care, food, transportation, education, and "other." Their values and shares in GDP are presented in table 2. Housing is the largest component of U.S. final demand, health care is second, food is third, and transportation is fourth.

Between 1991 and 1996, as the economy grew, the expenditures for all six functions increased, with transportation leading the growth. Transportation, housing, health care, and education grew faster than GDP, while food and "other" grew more slowly. The increase in the shares of health care and transportation in GDP and the decrease in the share of food reflected a general trend of economic development: as incomes

TABLE 2 Gross Domestic Product by Major Social Function: 1991–96

	1991	1992	1993	1994	1995	1996
	Billions of current dollars					
Gross Domestic Product	**5,916.7**	**6,244.4**	**6,558.1**	**6,947.0**	**7,265.4**	**7,636.0**
Housing	1,375.1	1,470.3	1,568.4	1,695.9	1,768.0	1,870.6
Health	806.9	881.2	945.8	1,002.9	1,052.7	1,105.4
Food	781.4	804.0	834.9	872.5	901.8	931.7
Transport	607.9	658.7	701.8	758.6	793.2	840.3
Education	409.0	428.4	447.2	472.7	498.0	525.2
Other	1,936.4	2,001.7	2,060.0	2,144.3	2,251.8	2,362.6
	Share in GDP (%)					
Gross Domestic Product	100.0	100.0	100.0	100.0	100.0	100.0
Housing	23.2	23.5	23.9	24.4	24.3	24.5
Health	13.6	14.1	14.4	14.4	14.5	14.5
Food	13.2	12.9	12.7	12.6	12.4	12.2
Transport	10.3	10.5	10.7	10.9	10.9	11.0
Education	6.9	6.9	6.8	6.8	6.9	6.9
Other	32.7	32.1	31.4	30.9	31.0	30.9

SOURCE: Calculated from data published in U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business*, various issues, 1996–97.

increase, demands shift away from basic needs to services that improve the quality of life, such as health care and personalized transportation.

MEASURING TRANSPORTATION AS AN INDUSTRY

Transportation is considered a service industry, because its outputs cannot be traded separately from its production. In the NIPA, the value of the market output of the transportation industry is calculated as the sum of the values of the following items within a year:

1. The total value of transportation services sold (at economically significant prices[3]).
2. The total value of transportation services bartered.
3. The total value of transportation services used for payments in kind, including compensation in kind.
4. The total value of transportation services supplied by one transportation establishment to another belonging to the same transportation company to be used as intermediate inputs.

The difference between the value of intermediate inputs to the transportation industry (goods and services such as gasoline and vehicle repair services) and the value of transportation outputs is the gross value-added of the transportation industry. Since GDP is made up of the gross value-added of all industries in the economy, gross value-added of the transportation industry is the conceptually correct measure of the contribution of the transportation industry to GDP.[4]

Transportation Industry GDP

Table 3 presents the breakdown of U.S. GDP by major industries in the 1990 to 1994 period. The formal transportation industry, or for-hire transportation industry, contributed $223 billion to the U.S. GDP in 1994. Between 1990 and 1994, trans-

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[3] "Market output is output that is sold at prices that are economically significant or otherwise disposed on the market, or intended for sale or disposal on the market. Prices are said to be economically significant when they have a significant influence on the amount the producers are willing to supply and the amounts purchasers wish to buy." (UN et al 1993, 128, para. 6.45)

[4] Statistics on the gross value-added of each industry in the U.S. economy are annually compiled by the Bureau of Economic Analysis and published in the "Gross Domestic Product by Industry" table in the *Survey of Current Business.*

TABLE 3 Gross Domestic Product by Industry: 1990–94
(Current dollars)

	1990		1991		1992		1993		1994	
	Billion $	%	Billion $	%	Billion $	%	Billion $	%	Billion $	%
Gross Domestic Product (GDP)	**5,744**	100.0	**5,917**	100.0	**6,244**	100.0	**6,550**	100.0	**6,913**	100.0
Agriculture, forestry, and fishing	109	1.9	103	1.7	112	1.8	105	1.6	118	1.7
Mining	112	2.0	101	1.7	92	1.5	89	1.4	90	1.3
Construction	245	4.3	229	3.9	230	3.7	244	3.7	269	3.9
Manufacturing	1,031	18.0	1,028	17.4	1064	17.0	1,117	17.0	1,197	17.3
Transportation	176	3.1	186	3.1	193	3.1	208	3.2	223	3.2
Communications	147	2.6	154	2.6	161	2.6	173	2.6	188	2.7
Electric, gas, and sanitary services	159	2.8	172	2.9	175	2.8	185	2.8	195	2.8
Wholesale trade	367	6.4	388	6.6	407	6.5	423	6.5	462	6.7
Retail trade	504	8.8	517	8.7	544	8.7	571	8.7	610	8.8
Finance, insurance, and real estate	1,025	17.8	1,083	18.3	1,149	18.4	1,214	18.5	1,274	18.4
Health services	308	5.4	338	5.7	369	5.9	385	5.9	408	5.9
Educational services	40	0.7	44	0.7	46	0.7	49	0.7	51	0.7
Other services	712	12.4	726	12.3	785	12.6	833	12.7	883	12.8
Government	793	13.8	840	14.2	874	14.0	900	13.7	931	13.5
Statistical discrepancy[1]	16	0.3	9	0.1	44	0.7	55	0.8	31	0.5

[1] Equals GDP measured as the sum of expenditures less gross domestic income.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business,* August 1996, p. 150. 1994 is the most recent year for which GDP data by industry are available.

portation industry value-added grew 26%, with an average annual growth rate of 6%. During the same period, GDP increased 20%, with an average annual growth rate of 5%. As a result, the share of the transportation industry in GDP increased from 3.1% in 1991 to 3.2% in 1994. On a comparable level of classification and in terms of shares in GDP, the transportation industry is smaller than the health service and the construction industries, but larger than the communications, mining, and agriculture industries.

Based on the technology employed in providing transportation services, the transportation industry can be further broken down into seven sub-industries (see table 4). Among the seven transportation industries, trucking, including warehousing, is the largest. In 1994, the gross value-added of trucking was $95 billion, accounting for 43% of the overall transportation industry. Air transportation ranks second at 23% in 1994. During the past half century, the mode structure of the transportation industry changed drastically. These changes can be summarized as increasing shares of trucking and air transportation, and decreasing shares of rail (see figure 3).

Future Improvement in Measuring Transportation

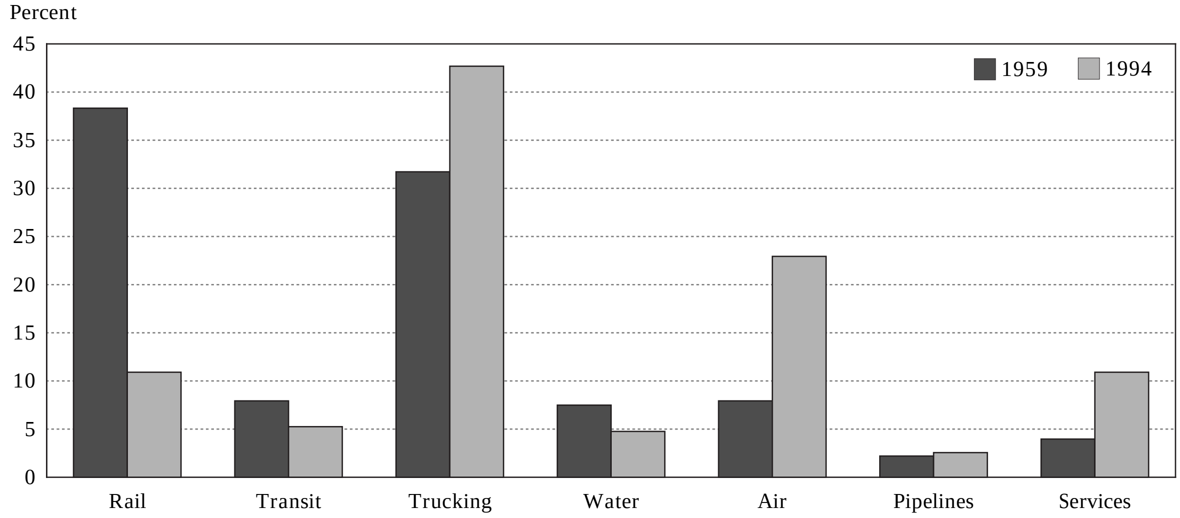
The transportation industry as covered in current national account statistics represents only a part, though the most important part, of all the commercial transportation activities in the U.S. economy. In addition to the transportation activities of the for-hire transportation industry, significant in-house transportation activities are produced by nontransportation industries. For example, a supermarket chain may own a truck fleet and use it to deliver groceries from central warehouses to individual stores. Such an in-house transportation activity is not counted as the output of the transportation industry in the NIPA, because the transportation industry is limited to only those establishments primarily providing for-hire transportation services according to the U.S. Standard Industrial Classification system. Even if all transportation produced by firms were accounted for, this would still fall short of the total value of transportation produced by society. Household-produced transportation is not a commercial activity and its value-added is not counted in GDP,

TABLE 4 Gross Domestic Product by Transportation Industries: 1990–94
(Current dollars)

	1990		1991		1992		1993		1994	
	Billion $	%	Billion $	%	Billion $	%	Billion $	%	Billion $	%
Transportation	**176.4**	100.0	**185.8**	100.0	**192.8**	100.0	**207.6**	100.0	**222.8**	100.0
Trucking	75.8	43.0	77.9	41.9	82.2	42.6	88.4	42.6	95.1	42.7
Air	39.4	22.3	40.8	22.0	43.0	22.3	48.6	23.4	51.1	22.9
Railroad	19.6	11.1	21.9	11.8	22.1	11.5	23.0	11.1	24.3	10.9
Transit	9.0	5.1	10.2	5.5	10.9	5.7	11.3	5.4	11.7	5.3
Water	9.7	5.5	10.7	5.8	10.3	5.3	10.3	5.0	10.6	4.8
Pipelines	5.0	2.8	5.0	2.7	4.9	2.5	5.2	2.5	5.7	2.6
Services	17.8	10.1	19.4	10.4	19.6	10.2	20.8	10.0	24.3	10.9

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business*, August 1996, p. 150. 1994 is the most recent year for which GDP data by industry are available.

FIGURE 3 Mode Structure of Transportation GDP: 1959 and 1994



SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business*, August 1996.

although it is certainly a part of society's transportation activities.

To develop more comprehensive measures than can be obtained from the current national accounts system, the Bureau of Transportation Statistics (BTS) of the U.S. Department of Transportation and the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce are conducting research to estimate the size of in-house transportation activity in each industry of the economy. BEA's input-output account database provides the core of the data required for this project, and the resulting data from the project will be put into a format that is consistent with U.S. input-output accounts. Once this project is completed, BTS and BEA will be able to provide more accurate estimates of the contribution of productive transportation activities to U.S. GDP and conduct more comprehensive analyses of the role of transportation in the economy.

SUMMARY

Based on the SNA classification and accounting principles, this paper presents three alternative monetary measures of transportation: transportation-related final demand, transportation domestic demand, and transportation industry GDP. Each measures transportation in a different way and is useful for different analytical purposes. An advantage all three measures share is their comparability with other economic measures available in the NIPA, most especially GDP. Transportation-related final demand and transportation industry GDP are both directly comparable to GDP. The former measures transportation from the demand side, the latter measures it from the supply side. Transportation domestic demand measures the importance of transportation in total U.S. domestic final demand. While none of the three is a perfect measure of the overall importance of transportation in the economy, each, properly understood, is a useful indicator of the significance of transportation in the economy.

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