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JOURNAL OF TRANSPORTATION AND STATISTICS

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Letter from the Deputy Editor-in-Chief

Dear Readers,

This issue inaugurates the third year of the journal. As the new Deputy Editor-in-Chief, I thank all of you for your support and encouragement, and I hope that you will continue your intellectual engagement as we work together to hammer out a new disciplinary area.

First, I want to note with regret that our editorial assistant, Selena Giesecke, has returned to George Mason University. But we are compensated by the full attention of our new Managing Editor, Deborah Moore, a prescriptive grammarian who is nonetheless kind in her corrections.

Another change in Volume 3 is that we are starting to receive submissions in LaTeX, and we are beginning to pressure contributors more aggressively to submit in that format. This conversion will reduce processing time and enable a more professional and contemporary appearance of the layout of equations. We hope the transition poses no inconvenience to researchers, and we will continue to accept articles in Word, WordPerfect, and Excel.

Recently, the Bureau of Transportation statistics undertook a product evaluation survey that included the *Journal of Transportation and Statistics* and allowed readers to rate the journal's perceived performance. Three different aspects were evaluated: topic breadth, research quality, and journal appearance. Across all three areas, the general finding was that about 97% of our readers are satisfied with the journal. Suggestions for improvement include the addition of more articles on aviation, parking management, and transportation and the environment.

Regarding the meat of the journal, I am proud that the statistical content continues to deepen and widen. Steve Fienberg and Pat Hu have joined the editorial board, and their diverse strengths will support our efforts in this direction. As another part of that initiative, Tim Coburn is serving as guest editor for the next issue, which has automobile emissions as its special topic. He is pulling together papers that were presented at two sessions of the Baltimore meeting of the American Statistical Association, and we look forward to future interactions with that society.

Finally, I am delighted to report that the Bureau of Transportation Statistics has launched a new grants program to fund research at the interface of statistics and transportation sciences. Proposals are invited at several times during the year—please check the website (www.bts.gov) for details.

DAVID L. BANKS

Deputy Editor-in-Chief

Bureau of Transportation Statistics

A Statistical Analysis of Induced Travel Effects in the U.S. Mid-Atlantic Region

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ABSTRACT

We investigate the hypothesis of induced travel demand. County level data from Maryland, Virginia, North Carolina, and Washington, DC are used to estimate "fixed-effects" cross-sectional time-series models that relate travel levels, measured as daily vehicle miles of travel, to roadway capacity in lane-miles. This includes analysis of a difference (or growth) model estimated using a two-stage least squares procedure with an instrumental variable to account for simultaneity bias. Individual models for each state, a combined-state model, and a model with data from the Washington, DC/Baltimore metropolitan area are estimated. Results are generally significant and relationships robust across geographic areas and different specifications. Average elasticities of vehicle-miles of travel (VMT) with respect to lane-miles are estimated to be on the order of 0.2 to 0.6. A Granger Causality test indicates that growth in lane-miles precedes growth in VMT. Overall, the results build on recent research in this area by confirming both the range of elasticities found in other studies and the robustness of these estimates by accounting for simultaneity bias.

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INTRODUCTION

Recent work has empirically estimated relationships between lane-miles of highway capacity and vehicle-miles of travel (VMT). Hansen and Huang (1997) estimated elasticities of VMT with respect to lane-miles using data on California counties and metropolitan areas. Noland (forthcoming) estimated nationwide relationships with state level data using a similar approach. Noland and Cowart (2000) also have developed estimates using a database of metropolitan areas. This paper extends these works by estimating models similar to those of Hansen and Huang (1997) using county level data for the Mid-Atlantic region of the country: Maryland, Virginia, and North Carolina, with a separate analysis for the Washington, DC/Baltimore metropolitan area. It also extends previous work by estimating an instrumental variable model using two stage least squares estimation to account for simultaneity bias in the data. Noland and Cowart (2000) also tested possible instrumental variables but with mixed results, given the weakness of the instruments they selected. The analysis presented here provides strong support for the causal nature of the relationship between new highway capacity and increases in VMT.

Recent literature on the relationship between roadway capacity and levels of vehicle travel appears to be coming to a consensus on general effects despite the lack of an explicit accounting for simultaneity bias. Short run elasticities of VMT with respect to lane-miles have commonly been found to be on the order of 0.2 to 0.6, with long run elasticities of 0.6 to 1.0. These elasticities are based on changes in travel with respect to changes in roadway capacity. This research shows results within the lower bound of previous work that has used aggregate data and econometric techniques.

Other literature has been based on observational traffic counts within travel corridors. These studies have generally not accounted for other exogenous effects that could also contribute to growth in VMT. Econometric techniques can account for these effects either explicitly or through the use of fixed-effects models (see Transportation Research Board 1995 for a good review of research dating back to the 1940s). More recently, in a comprehensive study that utilized traffic count data, Goodwin (1996) controlled for exogenous factors that affect VMT growth by selecting comparable control corridors. In general, he found significant increases in traffic due to specific highway improvement projects within these corridors and estimated travel time elasticities of –0.5 to –1.0. Overall, the results of recent econometric studies provide similar coefficient values to those derived in the work presented here.

The following section provides a discussion of the phenomenon known as "induced travel demand" and how this analysis addresses the questions surrounding the issue. Following is a description of the database and methodology used in the analysis. Then we present the results with an interpretation of the econometric analysis. A concluding section discusses implications and how this could affect the planning of road facilities.

INDUCED DEMAND: THE ISSUE AND UNDERLYING ECONOMIC THEORY

The concept of induced demand involves the idea that additions to roadway capacity result in increases in vehicle travel on the roadway (and the network) above the level that occurred before the capacity addition. Whether and to what extent addition of roadway capacity induces additional travel has been a cause of controversy in recent years and is confounded by the fact that other exogenous factors such as increases in population and demographic changes have also driven VMT growth. Planners have historically considered transportation demand as a derived demand for economic activities and have assumed that travelers will change their behavior as their desire to engage in alternative activities changes over time. This leads to the assertion that capacity increases, including increases in transit capacity, will be effective in reducing congestion and are needed to account for exogenous growth in travel. An understanding of the basic economics of induced travel challenges this argument and recognizes that individuals will make both travel and location decisions in response to the generalized cost of travel.

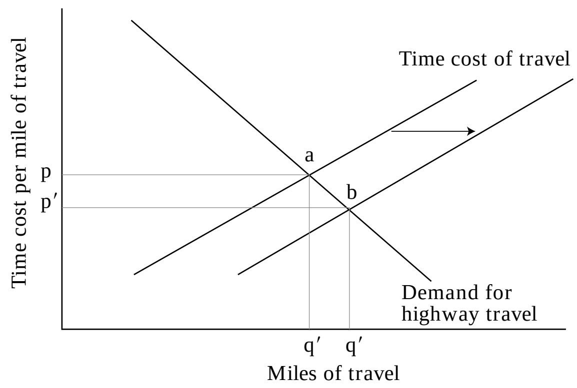
The basic theory underlying the concept of induced travel demand is straightforward. The addition of roadway capacity, either through additional miles of roadway or additional lanes on an existing roadway, reduces the time cost of travel. At some level of congestion, any given driver will choose to avoid dealing with that congestion, either by choosing an alternative route or mode, changing the departure time of the trip, selecting a shorter trip to a similar activity, or avoiding the trip entirely. Hills (1996) outlines and describes these behavioral effects.

The aggregate impact on VMT of these behavioral effects is shown in figure 1. Since each traveler experiences declining utility with each mile traveled, at some point the cost of travel exceeds the benefit to the driver. This increase in generalized cost is primarily the time cost associated with increasing congestion. This is shown as point *a* in the figure. If, however, congestion is relieved through the addition of roadway capacity, the entire cost curve shifts outward, reflecting a shift toward lower travel time cost. This allows higher aggregate levels of travel before a given level of congestion is reached. The effect is shown in the figure as a shift of the time-cost curve and a movement of the equilibrium point along the demand curve from point *a* to point *b*. A reduction in time cost from point p to p' yields an increase in travel from point q to q'. In addition, long term responses to increased access can result in changes in land use patterns, possibly inducing both more and longer trips.

These issues have been hotly debated in the transport literature for many years. Goodwin (1996) cites evidence for this effect in studies dating back to the 1930s. A special report of the Transportation Research Board (1995) assessed the impacts of expanding metropolitan highway capacity on air quality and energy use. While the basic theory of induced travel is extensively outlined and described in the text of the report, the conclusions (and a strong dissenting opinion by one member of the review committee) tended to indicate a lack of consensus on the overall theory. The focus of the report on air quality and energy consumption may have confused the issue somewhat since air quality and energy consumption changes due to changes in the dynamics of traffic flow (associated with capacity increases) are difficult to measure and model.

While the underlying economic relationships of induced travel are conceptually straightforward, there are at least two controversies surrounding the implications for roadway capacity expansion. The first is the specific nature of the relationship between capacity expansion and induced increases in travel. The second is whether the existence of this relationship indicates that roadway capacity expansion provides, on net, costs or benefits to society. This analysis focuses on the first of these questions.

FIGURE 1 Graphic Representation of the Impact of Roadway Expansion on Travel



While this study does not directly address the second issue, it should be noted that the size and nature of the induced travel effect has important implications for whether capacity expansion provides net benefits to society. A large effect indicates that many of the travel-time reduction benefits of highway expansion may be lost to increased traffic volume, over whatever time period the elasticity applies. On the other hand, it could also suggest that there was considerable "pent up" travel demand that was released when the cost of driving was lowered. This effect could be interpreted as providing a benefit of increased mobility. Conversely, a small induced travel effect would indicate that most congestion benefits from capacity expansion are retained and also that there is no significant, latent, unfilled travel demand. The timing of the effects is also important. Long run elasticities that are significantly greater than short run elasticities suggest that initial congestion reduction benefits may ultimately pave the way for increased development and other activities that lead to increased travel levels. While short run congestion reduction benefits may accrue to existing travelers, long run benefits may accrue to both new travelers and to the owners of land that is now more accessible. Cost/benefit analysis of these types of economic interactions are far more complicated to derive than a simple elasticity relationship, but ultimately such considerations are critical to assessing the impact of highway projects. The environmental implications of alternative development patterns that could be triggered by roadway capacity expansion is also an important issue, possibly determining whether a specific project provides, on net, costs or benefits to society.

DATA AND PRELIMINARY ANALYSIS

Following the approaches of Hansen and Huang (1997) and Noland (forthcoming), this study econometrically estimates the relationship between roadway capacity, measured as lane-miles, and vehicle travel, measured as average daily vehicle-miles of travel at the county level. Other key factors that influence travel are also controlled for. The extent of highway travel in an area is a function of many factors, including population, income, car ownership levels, land use, fuel prices (and other variable costs of travel), and availability of alternative modes of travel, such as transit. Any attempt to estimate the impact of additions to roadway capacity on travel levels should account for as many of these factors as possible.

The database for this analysis was originally developed by Energy and Environmental Analysis (EEA) and is fully documented there (1999). It includes county level data for Maryland, Virginia, and North Carolina as well as for the District of Columbia. Virginia does not incorporate a number of its cities into county jurisdictions; data for these cities were unavailable. Many counties in Virginia are highly urbanized and would be considered cities in other states; therefore, this is more of a definitional omission than a real data problem. Some of the cities may contain older, more established neighborhoods that have not had large increases in lane-miles, relative to newly developed areas. The Maryland data exclude Baltimore City, for which data were not readily available.[1]

For each county in each state, the data collected included geographic area, population and population density, income per capita, employment (available as total employment and unemployment rate), and extent of roadway lane-miles in different roadway categories. The time series of lane mileage and VMT data varied by state. Virginia and Maryland had data available back to 1970 and 1969, respectively, while data for North Carolina and the District of Columbia extended back to 1985 and 1984, respectively.

The VMT and lane-mile data that states submit to the Federal Highway Administration (FHWA) for use in the Highway Performance Monitoring System were not available (and in most cases are not kept) on a county-by-county basis. Nevertheless, each of the three states collects and tracks these data at a county level. In most cases, however, the data do not cover all roads or travel within each county, and so the state totals do not match the summary statistics for each state produced by the FHWA. In particular, each of these states only collect data on travel and roadway for roads that are state-maintained. In each of the states included in the analysis, the data included all interstate lane-miles, all state highways, and many (but not all) other primary roads. Data covering some secondary roads were obtained for Maryland and North Carolina but not for Virginia. To maintain consistency, the database used in the analysis contains no secondary road data. There may be some data variation in the percentage of roadway coverage in each state. This is not believed to represent a problem since the primary need is to have the data for VMT match the data for lane-miles with respect to road coverage, which it does.

It should also be noted that the general method of VMT data collection appears to be similar in the three states, although there are some minor differences. In each case, the states collect VMT data primarily through traffic counts on a sample of roadway segments. Each state has a large number of portable "periodic" traffic counting devices, and these are placed on different roadway segments for several days at a time throughout the year in order to obtain the counts. Each state also has some dedicated "continuous" counters kept permanently in one location, but generally there are far fewer of

[1] Data for Baltimore City, separate from Baltimore County, are collected and maintained by the city rather than by the state of Maryland. Historical data were not available from the city.

these than portable counters used for sampling. A special effort is often, but not always, made to collect data on segments that are being considered for or have recently had changes in capacity. VMT samples are aggregated to estimates of total VMT using a fairly standard methodology involving the development of growth factors for each roadway link, based on VMT changes from previous years' sampling data. Although the basic approach to data collection appears similar in each state, the number of traffic counters and the frequency of sampling each roadway segment varies across the states. This is, then, a source of uncertainty in the accuracy and consistency of the VMT data used in the analysis. For this reason, we chose to estimate separate regression models for each state as well as models including all states together.

There are several variables that could be important but were unavailable for this analysis. As discussed in the methodology section below, the effects of these variables are captured by county-specific and year-specific intercept terms when utilizing a fixed-effects econometric specification. Average vehicles per driver by county may have been an important factor determining travel growth over the period but was unavailable for this study. However, it is likely to be highly correlated with the level of population. Fuel prices, although potentially important, were not easily available on a county level, only on a state level. Use of state level data would result in all counties within a state having the same fuel prices for a given year. The effects of this variable are therefore captured in any regression model including an intercept term for each year of data. Finally, transit data were not available for many counties, so they are not included in the analysis. It has been noted by other analysts (e.g., Hansen and Huang 1997) that the availability of transit itself may be influenced by roadway supply and may represent a joint product with highway travel, in which case controlling for it would be inappropriate.

Basic characteristics of the five study areas (and of all areas taken together) are shown in table 1. Several important differences can be seen across the different study areas. While the average geographic area of counties in each study area is quite similar, the average population, and therefore population density, varies considerably. The Washington, DC/Baltimore metropolitan area has about 1,600 persons per square mile; Maryland, about 420 per square mile; Virginia, slightly under 200 per square mile, and North Carolina has less than 150 per square mile. The travel per capita is inversely correlated with population density, with Virginia showing 30 to 40% more daily travel per capita (on interstates and state-maintained primary roads) than North Carolina and Maryland, with the Washington DC/Baltimore metropolitan area about 10% below Maryland. This suggests that the more densely populated areas require fewer and/or shorter car trips, which may be due to the proximity of destinations and/or the greater availability of alternative (non-auto) travel modes.

The average number of lane-miles per capita is also greater in the areas with lower population

TABLE 1 Average Values of Key County Variables in 1995

	Units	Maryland	North Carolina	Virginia	Wash. DC/ Baltimore area	All
Total number of counties	—	23	100	96	16	220
Average geographic area	square miles	421	487	399	417	440
Average population	people	188,699	71,867	45,582	326,878	74,804
Average population density	people/sq. mile	422	148	194	1,155	237
Average daily VMT	miles/day	3,536,397	1,297,601	1,064,583	5,834,860	1,457,690
Average daily VMT per capita	VMT/person	21.62	20.55	29.25	19.77	24.43
Average lane-miles	miles	624.42	364.60	260.28	683.45	349.45
Average lane-miles per capita	lane-miles/person	0.0072	0.0087	0.0117	0.0031	0.0098
Average VMT per lane-mile	VMT/lane-mile	4,357	3,055	3,475	8,224	3,392
Average income per capita	1998$	24,644	19,846	20,891	29,623	20,865
Average total number of jobs	jobs	101,128	43,705	31,481	149,293	47,508

TABLE 2 Percentage Average Annual Growth (by state and area based on years of available data)

	Maryland	North Carolina	Virginia	Washington, DC/ Baltimore area	All
Years of data	1969–96	1984–97	1970–96	1970–96	1985–95
Population	1.72	0.96	1.32	2.66	1.10
Population density	1.72	0.97	1.33	2.66	1.11
VMT	3.46	3.46	3.44	4.16	3.28
Lane-miles	0.38	0.58	0.61	0.87	0.45
Population per lane-mile	1.34	0.38	0.71	1.78	0.65
VMT per lane-mile	3.07	2.86	2.81	3.26	2.82
Income per capita	1.50	1.74	1.87	1.76	1.42
Jobs	2.52	1.74	1.94	2.93	1.93

density, with a higher average in North Carolina and Virginia than in the Washington, DC/ Baltimore metropolitan area or in Maryland. This may reflect the presence of underutilized interstates and major arterials put in place to provide access to the scattered populous of the rural counties in states such as North Carolina. It also may help explain why VMT per capita in densely populated areas is lower: the availability of roadway miles per person is much lower. If true, this would imply that congested conditions limit the VMT of residents in such an area to levels below those of areas with a greater roadway capacity available. These relationships are examined more formally in the following section with a multivariate analysis. Finally, the average daily travel (VMT) per lane-mile of available roadway is indeed much higher in the more densely populated areas, again indicating that there is much less available road capacity in the Washington, DC/Baltimore metropolitan area than in Virginia, with North Carolina and Maryland intermediate.

Table 2 lists average annual growth rates of key variables. The growth rates for several key variables are significantly different across the different areas. While the growth rate in VMT is between 3 and 4% per year in all areas, the growth rate in lane-miles varies significantly, ranging from 0.38% in Maryland to 0.87% in the Washington, DC/Baltimore area. In North Carolina, VMT growth is larger than growth in either population or lane-miles, suggesting that average travel per person has increased significantly. However, the average VMT per lane-mile in North Carolina counties in 1995 (shown in table 2) was still quite low compared to Virginia, Maryland, and the Washington, DC/Baltimore area. Clearly, the rapid growth in travel per person in North Carolina has not yet resulted in roadway usage levels on a par with the other areas.

METHODOLOGY

In all estimated models, a "fixed-effects" specification approach has been used. Fixed-effects models use cross sectional and/or time series intercepts for each unit of observation. This technique has two primary advantages. First, it allows the analyst to use a larger data set (over time) rather than a simple one-year cross section of data. Second, the fixed-effect terms, entered as intercept (or "dummy") variables for the cross-sectional units (one for each county) and for time (one for each year), capture the influence of factors unknown or unmeasured by the analyst (Johnston and DiNardo 1997). Econometrically, a fixed-effects model acknowledges the researcher's lack of information about the unique characteristics of each unit in the data. It can also reduce the bias associated with correlations across units that would normally be captured in the error term. The closer the error term is to being independent and identically distributed, the less bias will be present in the standard errors of the estimates, in this case the relationship between lane-miles and VMT. Since the database used here is a panel database, our fixed-effects models also account for variations across time that might be correlated in the error term for individual counties. The fixed-effects model is thus specified with a separate intercept term for each county and each year of data and is estimated using ordinary least squares regression. For a more detailed discussion of the fixed-effects specification see, for example, Kennedy (1992) and Johnston and DiNardo (1997).

A logarithmic specification of the fixed-effects model can be written as:

$$\log(VMT_{it}) = c + \alpha_i + \beta_t + \sum_k \lambda^k \log(X^k_{it}) + \epsilon_{it} \qquad (1)$$

where:

VMT_{it} is the daily vehicle miles of travel for county i in year t;

α_i is the fixed effect for county i, estimated in the analysis;

β_t is the fixed effect for year t, estimated in the analysis;

c is a constant term;

X^k_{it} is the value of explanatory variable k for county i and year t, one component of which is lane-miles (LM).

λ^k is the coefficient of the kth explanatory variable;

ϵ_{it} is the outcome of a random variable for county i in year t, assumed to be normally distributed with mean zero.

The model is specified with the natural log of the variables to avoid heteroskedasticity and to allow the estimated coefficients λ^k to be read as elasticities.

The issue of simultaneity bias is not explicitly addressed by this model formulation. Given that lane-miles may be a function of forecasted growth in VMT, it is likely that this simultaneous relationship results in an upward bias in the coefficient estimates. Both to assess the importance of this effect and to adjust for it, several additional models are estimated.

A difference (or growth) model is analyzed first. This model essentially correlates annual growth in lane-miles with annual growth in VMT. It has the added feature of eliminating much of the collinearity between independent variables. The specification of this model is as follows:

$$\log(VMT_{it}) - \log(VMT_{i(t-1)}) = c + \alpha_i + \beta_t + \sum_k \lambda^k (\log(X^k_{it}) - \log(X^k_{i(t-1)})) + \epsilon_{it} \qquad (2)$$

with variables as defined above.

This model is used as the basis for a Granger causality test, which examines the precedence of the variables. That is, does lane-mile growth precede VMT growth or is the reverse true?

A two-stage least squares estimate using the lagged growth in lane-miles as an instrument for current growth in lane-miles is formulated as

$$\log(LM_{it}) - \log(LM_{i(t-l)}) = c + \alpha_i + \beta_t + \sum_k \lambda^k (\log(LM^k_{it}) - \log(LM_{i(t-l)})) + \epsilon_{it} \qquad (3)$$

where the lag term, l, is equal to 2 or 3 in the estimates that follow. As will be seen, this model provides a strong correlation between the growth in lane-miles in the current year and the lagged growth in lane-miles over multiple years. The instruments are not correlated with current growth in VMT. The difference specification is also used to avoid strong correlations in the independent variables that could create bias in some of the estimates.

RESULTS OF ECONOMETRIC ANALYSIS

Various econometric models were estimated using VMT as the dependent variable with lane-miles, population, and income per capita as potential explanatory variables. Although the principal results are reported here, additional specifications are reported in EEA (1999). Separate regressions were analyzed for five geographic areas: Maryland, North Carolina, Virginia, the Washington, DC/ Baltimore metropolitan area, and the full database (all three states and DC). The DC/Baltimore metropolitan area is comprised of 16 suburban counties around and between the two cities but does not include the cities themselves.[2] The main reason for excluding the District of Columbia itself was the lack of data before 1985. Excluding the District allows the estimation of a model with a more complete time series extending back to 1970. The city of Washington, DC is included in regressions that include all three states together. These are referred to below and in the tables as the "all states" run.

[2] This area includes the Maryland counties of Anne Arundel, Baltimore, Calvert, Carroll, Charles, Frederick, Harford, Howard, Montgomery, and Prince Georges. Virginia counties are Arlington, Fairfax, Fauquier, Loudon, Prince William, and Stafford. The city of Alexandria, Virginia is not included due to its jurisdictional definition as a city and not a county.

TABLE 3 Base Model Results

Dependent variable	LOG(VMT)									
	All states		Maryland		North Carolina		Virginia		Washington, DC/ Baltimore area	
Years of data	1985–95		1969–96		1985–97		1970–96		1970–96	
Log (lane-miles)	0.587	0.564	0.451	0.451	0.475	0.435	0.506	0.508	0.331	0.327
	(12.4)	(11.9)	(8.01)	(8.00)	(9.79)	(8.02)	(15.5)	(15.6)	(6.17)	(6.10)
Log (population)	0.520	0.569	0.659	0.655	0.560	0.585	0.507	0.504	0.518	0.502
	(13.6)	(14.3)	(24.2)	(22.0)	(10.7)	(9.39)	(25.7)	(25.6)	(17.0)	(16.0)
Log (income per capita)	—	0.195	—	0.026	—	0.057	—	0.110	—	0.167
	—	(4.18)	—	(0.369)	—	(0.958)	—	(3.25)	—	(1.87)
Constant	4.51	2.21	3.38	3.19	4.85	4.24	4.90	3.89	6.09	5.27
	(9.23)	(3.01)	(7.77)	(4.62)	(7.80)	(4.11)	(20.0)	(9.82)	(13.6)	(5.73)
N	2420	2420	644	644	1300	1200	2592	2592	432	432
"*R*-Squared"	0.710	0.713	0.948	0.948	0.856	0.838	0.883	0.884	0.963	0.963

T-stats are in parentheses.
County and time specific constants are omitted for brevity.

Base Model Results

A summary of basic results for individual areas and all areas together is presented in table 3. These are all estimated as ordinary least squares log-linear models with fixed-effects. The results across the five study areas are significant and fairly robust (i.e, consistent coefficients across region and specification). All specifications give statistically significant coefficients for the relationship between lane-miles and VMT. The coefficient values range between about 0.3 and 0.6, consistent with other studies such as Noland (forthcoming). The DC/Baltimore metropolitan area specifications have the lowest values on the lane-mile coefficient. This is a somewhat counterintuitive result since this area represents the most congested subset of the data. This area also has the largest use of alternative modes, such as transit, implying that road expansions could have a larger elasticity effect by drawing travelers from other modes. On the other hand, the lower coefficient could reflect a greater degree of infill development due to more mature land use patterns, relative to more rural counties. Population growth and per capita income coefficients are significant for the Washington DC/ Baltimore metro area (the latter at a 90% level) but are not different in magnitude compared to overall results.

For the all states regressions, utilizing the full three-state and DC database, the lane-mile coefficient is slightly larger than that of the individual study areas. A 10% change in lane-miles correlates with about a 5.6 to 5.9% increase in travel. This could indicate that the cross-sectional variation in the data has a steeper slope than the variation within each state, or, more simply, the result may be due to the shorter time series.

The coefficient on income per capita is more varied and much less significant across the models. The consistently strong significance for population is not especially surprising, since the number of people living in an area is expected to be a principal determinant of the level of vehicle travel in the area. The generally low value and low significance for income per capita suggest that in most areas increases in income do not strongly correlate with increased vehicle travel, at least at the county level of analysis. This may also reflect the fact that, quite often, greater distances must be covered in rural areas, which generally have lower income levels.

These results indicate that after controlling for population and income, a 10% increase in lane-miles correlates with a 3 to 6% increase in daily VMT in the Mid-Atlantic region. Since these models do not include any lag structure, this result should be interpreted as an average response (i.e., combining short run and long run effects). The high *t*-statistics and low variation in results by area suggests that the results are quite robust, especially considering the significant differences in the characteristics of the different study areas, as previously discussed.

Many unmeasured factors have contributed to VMT growth, including demographic changes over the last 40 years. One of the more commonly cited factors is the increased number of women in the workplace. Employment growth and growth in vehicle ownership are also drivers of VMT growth. However, these variables are likely to be highly correlated with population growth and therefore cannot be directly included in the models. Models with total employment (by county) but excluding total population were tested and gave essentially the same results as the models reported here. In any case, the use of a fixed-effects approach controls for the variation in these unmeasured demographic factors both by county and over time.

First Difference Model Results

Specifications also were tested using a first difference model. The additive difference of the logs of variables (year *t* minus year *t*-1) were used, capturing percentage changes through time or the annual growth in the variables. This technique eliminates any problems of multicollinearity present in the base model. Lane-miles and population tend to be highly correlated in the levels model. Table 4 shows that the correlation between lane-miles and population is virtually eliminated when differences are used. A summary of the first difference results is shown in table 5.

TABLE 4 Correlation Between Lane-Miles and Population

	Base model	Difference model
All states	0.816	0.040
Maryland	0.903	0.120
North Carolina	0.821	0.066
Virginia	0.686	0.077
Washington, DC/ Baltimore metropolitan area	0.722	0.058

The results of these regressions are somewhat more varied than the base runs but still significant for lane-miles in every study area (the Washington DC/Baltimore area is significant only at about the 90% confidence level). The coefficient for the change in population was insignificant in most

TABLE 5 First Difference Model Results

Dependent variable	LOG(VMT) difference									
	All states		Maryland		North Carolina		Virginia		Washington, DC/ Baltimore area	
Years of data	1985–95		1970–96		1986–97		1971–96		1971–96	
Log (lane-miles difference)	0.434 (5.84)	0.433 (5.83)	0.517 (3.40)	0.527 (3.47)	0.609 (6.95)	0.612 (6.77)	0.149 (3.56)	0.145 (3.45)	0.153 (1.66)	0.154 (1.66)
Log (population difference)	0.067 (0.485)	0.075 (0.535)	0.114 (0.423)	0.243 (0.877)	0.281 (0.989)	0.372 (1.17)	0.117 (2.21)	0.143 (2.67)	0.347 (1.88)	0.379 (1.92)
Log (income per capita difference)	— —	0.023 (0.334)	— —	0.257 (2.03)	— —	0.095 (1.02)	— —	0.103 (2.73)	— —	0.062 (0.454)
Constant	0.006 (0.275)	0.005 (0.238)	0.058 (3.01)	0.057 (2.95)	–0.020 (–0.874)	–0.027 (–1.11)	0.034 (2.72)	0.031 (2.43)	0.068 (3.97)	0.064 (3.26)
N	2200	2200	621	621	1200	1100	2496	2496	416	416
"*R*-Squared"	0.053	0.055	0.175	0.181	0.129	0.131	0.184	0.186	0.328	0.328

T-stats are in parentheses.
County and time specific constants are omitted for brevity.

areas. The "R-squared" values in these runs are quite low,[3] although this is not uncommon for first difference runs, which tend to draw out the stochastic component of the change in variables from year to year.

The coefficient on lane-miles varies from a low of 0.15 for the Washington DC/Baltimore metropolitan area to a maximum of 0.61 for North Carolina. This range is slightly broader than, but not inconsistent with, the base run results. The lane-mile coefficients for Virginia are similar to those for the Washington DC/Baltimore metropolitan area and much lower than for Maryland and North Carolina. These latter two areas have a coefficient on population that is significant, possibly explaining the difference in the results for lane-miles and also indicating that growth in travel is more population-driven in these areas than in the other states.

Simultaneity Bias and Testing for Causal Relationships

One of the key issues of debate over the existence of induced travel is whether the generation of additional VMT on new or expanded roads merely reflects the response of planners to the forecasted demand for travel. In other words, are planners merely accommodating travel increases that would occur in any case? The analysis presented above is likely to suffer from some degree of simultaneity bias if the causal relationship is reversed; that is, forecasts of VMT result in new road capacity. To assess this relationship and the magnitude of simultaneity bias, we use two alternative methods. First, a Granger Causality test is used to test the time precedence of the relationship: does lane-mile growth precede VMT growth or vice-versa? Second, we estimate an instrumental variable regression using two-stage least squares estimation to test whether lane-miles are truly exogenous.

The long time series of data (30 years) for both Maryland and Virginia allows the use of a Granger Causality test. Maddala (1992) points out that the Granger test is not strictly a test for exogeneity but rather for the time-precedence of the variables. The test is specified by including both a backward and a forward lag in the regression. If the backward lag is statistically significant while the forward lag is not, then this indicates that the independent variable temporally precedes the dependent variable (i.e., lane-miles precede VMT). If the significance is reversed, then the dependent variable precedes the independent variable (i.e., VMT precedes lane-miles).

Results for the Granger test are presented in table 6. A difference model was used due to multicollinearity between the backward and forward lag variables when using a levels model. This is similar to the difference models shown in table 5. Analysis of the data for Maryland and Virginia using a one-year backward and forward lag and also a two-year backward and forward lag is shown. The backward lag terms are statistically significant above the 95% level for 3 of the models but not for the two-year lag for Maryland. In all cases, the forward lag is not statistically significant.

This result suggests that lane-mile growth precedes growth in VMT. However, as mentioned, this is not evidence of causality: increases in lane-miles may not be the cause of increases in VMT since the results can also be explained by planning that correctly anticipates future growth in VMT by building new capacity in advance.

The second and more powerful technique to correct for simultaneity bias is the use of an instrumental variable in a two-stage least squares regression. A good instrument for lane-miles is one that is correlated with lane-miles but not correlated with VMT. It is common to use an instrument that is a lagged value of the variable of interest. Using the growth (or difference) model specified previously, we "instrument" the growth in lane-miles by using growth in lane-miles over two- and three-year periods. That is

$$\log(LM_t) - \log(LM_{t-l}) \qquad (4)$$

where $l = 2$ or 3. This variable is both highly correlated with the growth in lane-miles and not correlated with the growth in VMT, as can be seen in tables 7 through 10 for Maryland, Virginia, North Carolina, and the all states data.

[3] "R-Squared" values, while similar, do not correspond to R^2 as calculated in OLS regressions. See StataCorp (1999) for a discussion of "R-Squared" as defined under the xtreg procedure.

TABLE 6 Results of Granger Test Using Difference Model

Dependent variable	LOG(VMT) difference			
	Maryland	Virginia	Maryland	Virginia
Years of data	1970–96	1971–96	1970–96	1971–96
Log (lane-miles difference)– backward lag one year	0.545 (3.450)	0.143 (3.356)	— —	— —
Log (lane-miles difference) – forward lag one year	–0.097 (–0.613)	–0.039 (–0.876)	— —	— —
Log (lane-miles difference) – backward lag two years	— —	— —	–0.057 (–0.345)	0.123 (2.814)
Log (lane-miles difference) – forward lag two years	— —	— —	0.220 (1.166)	–0.024 (–0.477)
Log (population difference)	0.236 (0.829)	0.156 (2.838)	0.317 (1.010)	0.153 (2.436)
Log (income per capita) difference)	0.257 (1.981)	0.109 (2.861)	0.218 (1.547)	0.111 (2.751)
Constant	0.009 (0.592)	0.038 (6.273)	–0.006 (–0.376)	–0.030 (–4.954)
N	598	2400	552	2208
"*R*-Squared"	0.181	0.190	0.156	0.197

T-Stats are in parentheses.
County and time specific constants are omitted for brevity.

TABLE 7 Correlation Coefficients: All States

All states	Growth in VMT	Growth in lane-miles	Growth in lane-miles over two years	Growth in lane-miles over three years
Growth in VMT	1.000	—	—	—
Growth in lane-miles	0.166	1.000	—	—
Growth in lane-miles over two years	0.128	0.685	1.000	—
Growth in lane-miles over three years	0.113	0.580	0.840	1.000

TABLE 8 Correlation Coefficients: Maryland

Maryland	Growth in VMT	Growth in lane-miles	Growth in lane-miles over two years	Growth in lane-miles over three years
Growth in VMT	1.000	—	—	—
Growth in lane-miles	0.113	1.000	—	—
Growth in lane-miles over two years	0.073	0.755	1.000	—
Growth in lane-miles over three years	0.090	0.615	0.868	1.000

TABLE 9 Correlation Coefficients: North Carolina

North Carolina	Growth in VMT	Growth in lane-miles	Growth in lane-miles over two years	Growth in lane-miles over three years
Growth in VMT	1.000	—	—	—
Growth in lane-miles	0.276	1.000	—	—
Growth in lane-miles over two years	0.201	0.697	1.000	—
Growth in lane-miles over three years	0.136	0.594	0.860	1.000

TABLE 10 Correlation Coefficients: Virginia

Virginia	Growth in VMT	Growth in lane-miles	Growth in lane-miles over two years	Growth in lane-miles over three years
Growth in VMT	1.000	—	—	—
Growth in lane-miles	0.071	1.000	—	—
Growth in lane-miles over two years	0.091	0.702	1.000	—
Growth in lane-miles over three years	0.100	0.589	0.821	1.000

TABLE 11 Fixed Effects Regressions with Lane-Mile Growth as Dependent Variable

Dependent variable state	Growth in lane-miles							
	All states		Maryland		North Carolina		Virginia	
Growth in lane-miles over two years	0.497	—	0.505	—	0.598	—	0.474	—
	(36.698)	—	(28.203)	—	(34.353)	—	(44.251)	—
Growth in lane-miles over three years	—	0.310	—	0.280	—	0.413	—	0.296
	—	(21.077)	—	(16.512)	—	(20.747)	—	(30.500)
Growth in population	–0.025	–0.047	–0.081	–0.149	–0.068	–0.098	0.024	–0.032
	(–0.706)	(–1.118)	(–1.576)	(–2.445)	(–0.810)	(–0.876)	(1.139)	(–1.310)
Growth in per capita income	0.001	0.008	0.007	–0.025	–0.015	0.003	0.025	0.038
	(0.079)	(0.378)	(0.287)	(–0.867)	(–0.624)	(0.107)	(1.860)	(2.556)
Constant	–0.002	–0.000	0.002	0.004	–0.005	0.000	–0.002	–0.003
	(–1.650)	(–0.277)	(0.709)	(1.313)	(–2.205)	(0.157)	(–1.056)	(–1.172)
N	1980	1760	598	575	1000	900	2400	2304
"*R*–Squared"	0.441	0.232	0.622	0.377	0.576	0.362	0.478	0.321

T–stats are in parentheses.
County and time specific constants are omitted for brevity.

Table 11 shows the results of four fixed-effect regressions with growth in lane-miles as the dependent variable. As can be seen, the growth in lane-miles over a two- or three-year period is a highly significant predictor of growth in lane-miles in the current year. Growth in per capita income is not a significant determinant of lane-mile growth, and population growth shows a negative sign and is only relatively strong for Maryland and Virginia.

Table 12 shows the results using the instrumental variable in a two-stage least squares regression. These results should be compared with the coefficient estimates in the first difference model (table 5). The results generally show that the lane-mile coefficient is both positive and significant at or above the 95% confidence level. The lane-mile coefficients are generally similar in magnitude to the results shown in table 5. Results for the all states model are 0.505 and 0.457, compared to

TABLE 12 Instrumental Variable Regressions (with fixed effects)								
Dependent variable growth in VMT	**All states**		**Maryland**		**North Carolina**		**Virginia**	
	Instrument: growth in lane-miles							
	over 2 years	**over 3 years**	**over 2 years**	**over 3 years**	**over 2 years**	**over 3 years**	**over 2 years**	**over 3 years**
Growth in lane-miles	0.505 (4.823)	0.457 (2.796)	0.397 (1.972)	0.290 (0.948)	0.638 (6.491)	0.479 (3.705)	0.288 (4.405)	0.444 (4.958)
Growth in population	0.031 (0.234)	0.031 (0.214)	0.251 (0.864)	0.219 (0.726)	0.166 (0.589)	0.387 (1.293)	0.120 (1.998)	0.114 (1.694)
Growth in per capita income	0.002 (0.037)	–0.028 (–0.372)	0.255 (1.923)	0.292 (2.047)	0.114 (1.423)	0.133 (1.573)	0.088 (2.232)	0.080 (1.959)
Constant	–0.003 (–0.148)	–0.004 (–0.176)	0.009 (0.451)	0.008 (0.396)	0.038 (1.900)	0.038 (1.824)	0.040 (3.098)	0.043 (3.222)
N	1980	1760	598	575	1000	900	2400	2304
Adjusted R^2	0.031	0.024	0.112	0.089	0.060	0.060	0.172	0.199

T-stats are in parentheses.
County and time specific constants are omitted for brevity.

0.433 in the previous model. The coefficients for Maryland are slightly smaller, 0.397 and 0.290, compared to 0.527. North Carolina has coefficient values of 0.638 and 0.479, compared to 0.612, and the coefficient values for Virginia are higher when the instrument is used: 0.288 and 0.444, compared to 0.145. Overall, these results appear to provide a strong indication that growth in lane-miles is exogenous and therefore causes the growth in VMT, with lane-mile elasticities ranging from about 0.2 to 0.6.

CONCLUSIONS

The results presented indicate a significant relationship between the level of highway capacity, as measured by lane-miles, and the level of travel, measured by daily VMT, in the Mid-Atlantic region of the United States. After accounting for other important determinants of travel and for potential simultaneity bias, the estimated elasticity between VMT and lane-miles is estimated at 0.2 to 0.6. This implies that a 10% increase in lane-mileage can result in anywhere from a 2 to 6% increase in total VMT. A Granger test further indicates that changes in lane-miles precede changes in travel.

Although there is some variation in the results across study area and specification, there is a considerable degree of consistency in both the significance and the value of the lane-mile coefficient across all the models that were estimated. This is especially interesting given the significant differences in the geographic and population characteristics of the three states. It should be noted that the elasticity estimates do not account for potential long run impacts, such as ultimate changes in land use, that may generate further growth in VMT. On the other hand, the similar results in urban (DC/Baltimore) and mostly rural (North Carolina) areas suggest that both short run congestion effects and longer run land use/growth effects may be important contributors to induced demand. While it is not possible to disentangle these effects with the data available, it certainly suggests that induced travel from new development, even in uncongested areas, may be significant.

These results add to a growing literature that appears unable to reject the induced travel hypotheses. The implications for those who advocate increased mobility should be reassuring, since the estimated relationship implies that adding roadway capacity reduces the cost of travel and encourages greater overall travel and, therefore, mobility. On the other hand, if congestion reduction is of paramount concern, then induced travel implies that some or even most of the congestion reduction benefits of capacity expansion will be lost over time. Given a desire to both increase mobility and reduce congestion, the key question is whether individual demand for mobility is best served by increases in highway capacity or by alternative means, such as provision of alternative modes of travel, demand management policies, or urban design changes. Environmental costs may also be more significant when induced travel impacts are accounted for, resulting in major differences in the relative social costs and benefits of alternative mobility enhancing projects.

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Four Measures of Transportation's Economic Importance

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ABSTRACT

As a commodity, transportation has a supply side and a demand side. Unlike many other commodities, however, transportation's supply and demand overlap extensively. A significant portion of transportation is provided by consumers for their own use. Therefore, "transportation" means not only transportation industries, those businesses whose primary activity is to provide transportation services for a fee, but also it includes the transportation activities of other business establishments and consumers. Further, transportation can indicate transportation equipment, infrastructure, and other transportation-related goods and services. Differing concepts of transportation make it difficult to produce a single measure of the size of transportation in the economy that is satisfactory to all people for all purposes. Many widely used statistics of the size or importance of transportation in the economy do not correlate with the concepts they are intended to measure. This paper presents four measures of transportation's economic importance, namely, transportation industry's gross domestic product (GDP), transportation final demand, transportation-related GDP, and trans-

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portation-driven GDP. All four of these measures are conceptually consistent with the framework and accounting rules of the Systems of National Accounts and are statistically comparable to the GDP. With each targeted at a different aspect of transportation, together the four measures provide a complete frame of reference for the size and importance of transportation in the U.S. economy.

INTRODUCTION

One tends to associate the importance of transportation with its benefits rather than with its costs. Consequently, "benefits" and "importance" are often used interchangeably in transportation economic analyses. For example, transportation's share in the GDP is frequently cited as a measure of transportation's importance in the economy and also as the benefit of transportation to the economy. Although this interchangeable use of terms may seem reasonable at first, it lacks a valid conceptual basis. Ultimately, the economic importance of transportation should be measured by how many economic resources are required to produce it. On the other hand, the benefit of transportation should be measured by the "willingness to pay" of all transportation users, plus possible net externalities (UKDOE 1999). As progress is made in transportation technology and management, the transportation system is becoming more efficient in that the same benefit is produced at a lesser cost or a greater benefit is produced at the same cost. In other words, transportation services are becoming less and less expensive. As a result, it is quite possible that the importance of transportation in the economy, as measured by transportation's share in the GDP, decreases, while the actual benefits of transportation remain the same or even increase. Historically, this is what has happened to agricultural industries and to many manufacturing industries. Since the cost and the benefit of an economic activity may differ significantly, a large measure of economic importance does not necessarily imply a high benefit/cost ratio or a high rate of return to investments. The economic importance of transportation should reflect how many economic resources are devoted to supporting the nation's transportation needs. Given the level of transportation services, the less spent on transportation and, therefore, the smaller the share of transportation in the GDP, the better. For this reason, the economic importance of transportation should not be used as a criterion for investment decisions. Instead, a benefit/cost ratio and marginal benefit and cost analysis should be used. This paper focuses on the measures of transportation's economic importance, not the benefits of transportation.

It might seem clear that transportation's importance in the U.S. economy should be measured by transportation's share in the GDP. However, very different ideas exist about what the share of transportation in the GDP represents because there exist very different concepts of what transportation entails. For example, some believe transportation is those activities directly involved in transporting people and freight from one place to another. Some equate transportation with transportation industries. Others consider transportation a social function that includes all economic activities that support people's transportation needs, directly or indirectly. These different concepts reflect the various perspectives on transportation, and, therefore, are all valid[1]. Accordingly, transportation's importance has to be measured from these different perspectives as well.

1992 and 1997 estimates of the four different but related measures of the economic importance of transportation presented here are based on data

[1] To consumers, transportation means not only the transportation services but also the commodities and other services they purchase for transportation purposes, such as cars, gas, and auto insurance. For example, in the Consumer Expenditure Survey (USDOL BLS 1997), transportation expenditure includes vehicles, gas, auto insurance, auto repair service, tolls, parking fees, and purchased transportation services. To a government, in addition to all of the above, transportation also means infrastructure investments, traffic control, and law enforcement. For an industry, transportation means a special group of businesses whose primary economic activity is providing transportation services. Therefore, transportation industry output may include not only transportation services but also other services or goods if the transportation establishments have secondary products. From a functional perspective, transportation means all goods and services produced for transportation purposes, including narrowly defined transportation services. From a resource perspective, all economic resources used, directly and indirectly, that support the transportation needs of a society may be considered transportation. Clearly, different definitions describe different aspects of transportation and are useful for different transportation-related analyses.

from U.S. Transportation Satellite Accounts for 1992 (TSA92) (USDOT BTS 1999) and the most recent data from the U.S. National Income and Product Account (USDOC BEA 1993–1999). All four of these measures are consistent with the conceptual framework and accounting rules of the System of National Accounts (Commission of the European Communities 1993). There are six sections in this paper. Following the introduction, the second section discusses transportation industry GDP, the conventional measure of transportation's importance in the economy. Estimates of the contribution of in-house transportation to the U.S. GDP are highlighted. The third section presents transportation final demand, a measure of transportation's importance to the economy from a demand and "function" perspective. The relationship between transportation industry GDP and transportation final demand is also illustrated. The fourth section introduces a new measure, transportation-related GDP, which has the advantage of being consistent with a broad concept of transportation while still being comparable to the GDP. The fifth section introduces another new measure, transportation-driven GDP, which captures the direct and indirect impact of transportation on the economy and presents an input-output method developed by Han and Fang (1997) for the derivation of transportation-driven GDP. The last section presents some concluding remarks.

TRANSPORTATION INDUSTRY GDP

The gross domestic product (GDP) is the sum of the gross value-added of all productive activities taking place within a nation. Transportation GDP is the sum of all the gross value-added created in the process of conducting transportation activities or providing transportation services. However, statistics on transportation GDP are rarely available because the economic census in the United States, which is the primary data source for the U.S. national accounts, is based on establishments (basic productive units) rather than on activities. Because transportation industries are the most important providers of transportation services and represent a large portion of transportation activities in the economy, transportation industry GDP is often used as a surrogate for transportation GDP.

In both the Standard Industrial Classification (SIC) system (U.S. Executive Office of the President 1987) and the newly published North American Industry Classification System (NAICS) (U.S. Executive Office of the President 1997), transportation industries are shown to include establishments that provide passenger and/or freight transportation services. Establishments in transportation industries use transportation equipment and transportation-related facilities as productive assets. Based on the type of equipment used, these establishments are classified into five modes of transportation: air, rail, water, road, and pipeline. Since the GDP is the sum of the gross value-added of all industries in the economy, the importance of transportation industries in the economy can be effectively measured by the share of their gross value-added in the GDP. The gross value-added of transportation industries is the net output of transportation services. Quantitatively, it is the difference between the value of transportation output and the value of intermediate input, such as gasoline and vehicle repair services, that are consumed in the production of transportation services.

While the GDP of transportation industries as defined in the SIC and NAICS systems is a widely used measure, it does not completely measure the importance of transportation from the supply side since transportation services are not only supplied by transportation industries. Based on the SIC system, only establishments providing passenger and freight transportation services to the general public or to other business enterprises for a fee, such as railroad companies, common carrier trucking companies, and pipeline companies, are included as transportation industries in the U.S. national accounts system. Their output is counted as the transportation industry's output, and their gross value-added is counted as the transportation industry's GDP. A considerable amount of in-house transportation activities within nontransportation firms, for which there are no observable market transactions or value, is not separately identified. The output of these activities is not counted as transportation output but rather as output of the industries that host them. For example, transportation activities conducted by a grocery company's truck fleet moving goods from warehouses to the retail outlets are counted not as transportation output but as output of the retail industry. As a result, the magnitude of transportation services has long been underrepresented in national economic statistics; therefore, most estimates of the economic benefits of transportation investments have been low. Clearly, an inclusive supply-side measure of transportation must cover in-house as well as for-hire transportation activities. Only with this broad definition of the transportation industry can transportation industry GDP closely represent transportation GDP.

Because our definition of transportation industry GDP, as a supply-side measure of transportation, includes in-house transportation, it has two major advantages for transportation analyses when compared to traditional national accounts measurements. First, it is more comprehensive in measuring transportation's contribution to the economy. Second, it is not affected by changes in the way transportation is provided and, therefore, offers a more reliable representation of transportation in the economy. For example, when a grocery company contracts out its internal trucking operations to a common carrier trucking company, the national accounts estimates show an increase in the output of transportation industries. When the company switches back to internal operations for its trucking needs, the national accounts estimates show a decrease in the output of transportation industries. In contrast, the estimates of transportation industry GDP as defined here remain unchanged in both cases. Empirical results also indicate the importance of including in-house transportation in a more complete supply-side measurement. According to the TSA92 (USDOT BTS 1999), developed by the Bureau of Transportation Statistics of the U.S. Department of Transportation and the Bureau of Economic Analysis of the U.S. Department of Commerce, in-house transportation activity was significant in the U.S. economy in 1992. It alone contributed $122 billion to the GDP, accounting for 39% of all transportation industry's GDP. In-house transportation was even larger than the agriculture and mining industries. See Fang et al. (1998) for more details on TSA92.

Deriving estimates for transportation industry GDP as defined in this paper requires more statistics than are available from the national accounts. Fortunately, TSA92 provides a set of detailed statistics that can be used as a benchmark. In this paper, data from TSA92 and the 1997 U.S. national accounts (USDOC 1993–1999) are combined to develop estimates for 1997.[2] The results, as well as statistics for 1992 from TSA92, are presented in table 1. Between 1992 and 1997, transportation industry GDP increased from $314 billion to $411 billion in its support of the growth of the U.S. economy. Its share in the U.S. GDP increased from

[2] Specifically, estimates of transportation industry's GDP for 1997 were derived by applying the 1997 U.S. final demand data from U.S. National Income and Product Accounts (USDOC 1993–1999) to TSA 1992 technical coefficient matrices. Since the application assumed that there were no technical changes from 1992 to 1997, the estimates are accurate reflections of the changes in transportation industry's output and value-added caused by economic growth and changes in final demand structure from 1992 to 1997. How close they are to the real changes in transportation industry's output and value-added depends on the magnitude of technical changes in the economy during the same period. The smaller the technical changes, the more accurate the estimates.

TABLE 1 Transportation Industry's GDP: 1992 and 1997

	1992		1997	
Industry	**Value-added**	**Percentage of GDP**	**Value-added**	**Percentage of GDP**
Railroads and related services	34,390	0.55	43,633	0.54
Motor freight and warehousing	83,371	1.34	108,882	1.36
Water transportation	12,796	0.21	17,884	0.22
Air transportation	42,166	0.68	57,367	0.72
Pipeline and related services	19,624	0.31	25,859	0.32
In-house transportation	121,531	1.95	157,765	1.97
Total	**313,886**	**5.04**	**411,391**	**5.13**

5 to 5.1%. Within transportation industries, the share of the air transportation industry in the GDP increased the most, followed by the motor freight and warehousing industries. In-house transportation industry's share also increased. Only railroad industry's share in the GDP decreased slightly.

TRANSPORTATION FINAL DEMAND

The gross domestic product (GDP) at market prices represents the net output of the production activities of resident producer units. Since goods and services are the specific forms of industry output, the GDP is also frequently viewed as a special category of goods and services. In other words, the GDP, in physical terms, is a basket of goods and services produced in the economy not used up in the production process itself. This basket of goods and services is put to final use, as opposed to current period production use. Final use is collectively called final demand. Therefore, the value of final demand is always equal to the GDP.[3]

Goods and services can be classified into categories according to the "purposes" or "objectives" of the product's use. This classification is called "functional classification" in the System of National Accounts. Based on the principles of functional classifications, final demand can be classified into six broad categories: food, housing, health care, education, transportation, and other. Transportation's final demand is the sum of the values of all goods and services in the GDP basket delivered to final users for transportation purposes. Goods and services of transportation's final demand include motor vehicles, motor fuels, highway construction, and auto repair services, among others. (See Han and Fang 1998 for further discussion of this topic.) As part of the GDP, transportation final demand shows how much of the economy's net output is used for transportation purposes. In addition, the share of transportation final demand in GDP is a good indicator of the importance of transportation as a driving force in the economy since, given the manner of production, total output and GDP of an economy go up and down as a function of changes in final demand.

Table 2 shows the size of transportation final demand and its share in the U.S. GDP for 1992 and 1997. Table 3 shows the commodity components of transportation final demand. Measured in current dollars, transportation final demand for the U.S. economy was $669.4 billion in 1992, equivalent to 10.7% of the GDP. Between 1992 and 1997, transportation final demand grew faster than the overall GDP. It reached $904.8 billion in 1997, and its share in the U.S. GDP increased to 11.2%. This means that the importance of transportation final demand increased as a driving force in the economy. Among the six broad functions, transportation was almost as large as food by 1997. It was smaller than housing and health but about twice as large as education.

[3] Final demand is defined in the System of National Accounts as the sum of the value of goods and services delivered to final users, less the value of imports. Final users include personal consumption, government consumption, capital investment, and exports.

TABLE 2 Gross Domestic Product by Major Social Function: 1992 and 1997[1]

	1992		1997	
Major social function	**Billions of current dollars**	**Share in GDP (percent)**	**Billions of current dollars**	**Share in GDP (percent)**
Gross Domestic Product	6,244.4	100	8,110.9	100
Housing	1,468.7	23.5	1,969.1	24.3
Health	880.2	14.1	1,151.1	14.2
Food	803.1	12.9	955.7	11.8
Transport	669.4	10.7	904.8	11.2
Education	427.9	6.9	558.7	6.9
Other	1,995.0	31.9	2,571.5	31.7

[1]Calculated from data published in U.S. Department of Commerce (USDOC), Bureau of Economic Analysis (BEA), *Survey of Current Business*, various issues, 1996–98.

TABLE 3 Components of Transportation Final Demand: 1992 and 1997[1]

Type of final use and commodity	1992 Billions of current dollars	1992 Share in total (percent)	1997 Billions of current dollars	1997 Share in total (percent)
Total final uses for transportation	669.4	100	904.8	100
Personal consumption of transportation	471.6	70.5	636.3	70.3
Motor vehicles and parts	206.9	30.9	269.5	29.8
Gasoline and oil	106.6	15.9	126.5	14.0
Transport services	158.1	23.6	240.3	26.6
Gross private domestic investment	89.9	13.4	158.1	17.5
Transportation structures	3.7	0.6	6.1	0.7
Transportation equipment	86.2	12.9	152.0	16.8
Net exports of goods and services	–15.5	–2.3	–40.7	–4.5
Exports(+)	125.0	18.7	164.2	18.1
Civilian aircraft, engines, and parts	37.7	5.6	41.4	4.6
Automotive vehicles, engines, and parts	47.0	7.0	74.0	8.2
Passenger fares	16.6	2.5	20.9	2.3
Other transportation	23.7	3.5	27.9	3.1
Imports(–)	140.5	21.0	204.9	22.6
Civilian aircraft, engines, and parts	12.6	1.9	16.6	1.8
Automotive vehicles, engines, and parts	91.8	13.7	140.8	15.6
Passenger fares	10.6	1.6	18.2	2.0
Other transportation	25.5	3.8	29.3	3.2
Government transport-related purchases	123.4	18.4	151.0	16.7
Federal purchases	16.8	2.5	19.7	2.2
State and local purchases	95.3	14.2	123.1	13.6
Defense-related purchases	11.3	1.7	8.2	0.9

[1]Sources: US Department of Commerce (USDOC), Bureau of Economic Analysis (BEA), NIPA tables in the *Survey of Current Business*, various issues, 1996–98.

In 1992, about 70% of transportation final demand was personal consumption demand for motor vehicles, gasoline and oil, and transportation services. Private, domestic investment in transportation equipment and structures added another 13%. Government transportation-related purchases, such as purchases of transportation equipment and transportation services, investment in public roads, and expenditures in transportation programs, accounted for about 18%. U.S. exports of aircraft, automobiles, and transportation services also contributed to transportation final demand. However, its effect was completely offset by U.S. imports of similar goods and services. The net effect of international trade on U.S. transportation final demand was –$15.5 billion. In other words, the United States imported $15.5 billion more of transportation goods and services than it exported of the same in 1992.

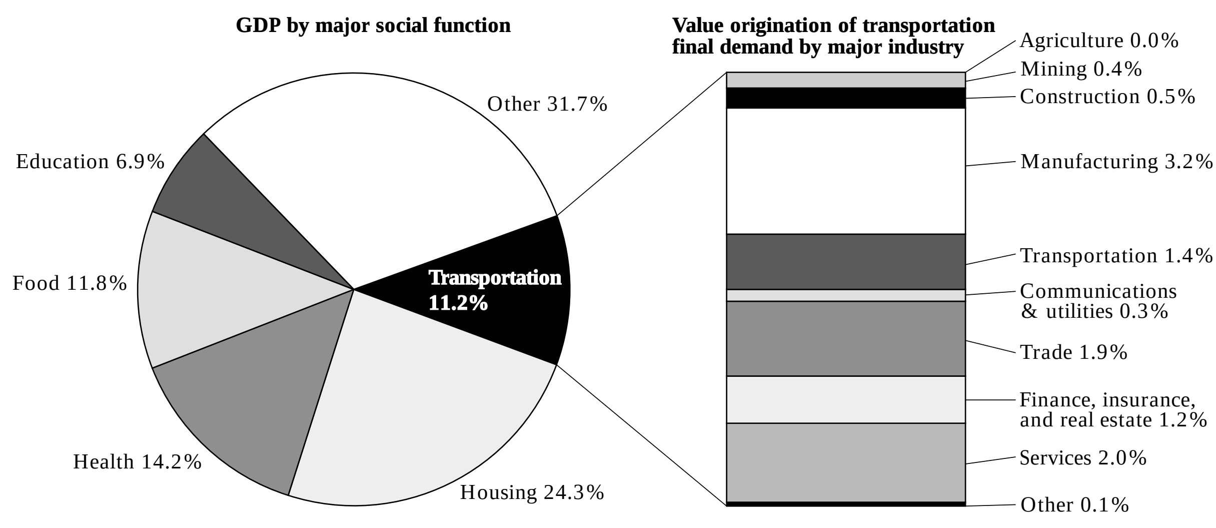
Between 1992 and 1997, U.S. transportation final demand increased about 35% from $669.4 billion to $904.8 billion. Its composition, however, stayed relatively stable. The most noticeable changes were the increased share of private, domestic investment and the decreased share of government purchases in transportation final demand. Private, domestic investment in transportation equipment and structures was $89.9 billion in 1992, accounting for 13.4% of transportation final demand. By 1997, private, domestic investment reached $158 billion, and its share in transportation final demand increased to 17.5%. During the same period, government purchases of transportation-related goods and services grew only 22%, from $123.4 billion to $151 billion. Its share in transportation final demand decreased from 18.4 to 16.7%.

It is worth emphasizing that transportation final demand does not measure the importance of transportation as a value generator. This is because the value embodied in the goods and services delivered to final users for their transportation needs is generated not just by transportation activities but also by other productive activities that directly or indirectly provide input for the production of these goods and services. For example, the value of a car is generated partially by the automobile industry, the steel industry, the tire industry, and all other industries providing input to the automobile industry. For all other goods and services, a similar breakdown of value by origination can be done. Figure 1 shows the value origination of transportation final demand by major industry group in 1997. Out of the 11.2% that transportation final demand accounts for in the GDP, only 1.4% originated from transportation services, including the services of for-hire transportation industries and in-house transportation services of nontransportation industries. The remaining 9.8% originated entirely from nontransportation industries in the economy. The largest portion of the value of transportation final demand was from the manufacturing industry. Following manufacturing were the service industry and the wholesale and trade industry. Together, these three industry groups contributed more than 63% of the value of transportation final demand. It is clear that transportation services were a relatively small source of the value of transportation final demand. At the same time, however, only a small portion of the value generated by transportation services ended up in transportation final demand. In 1997, the value-added of transportation services was $411.4 billion, out of which only $116.1 billion were embodied in transportation final demand. This means that more than 71% of the value-added of transportation services was embodied in goods and services delivered to final users for nontransportation purposes or nontransportation final demand.

TRANSPORTATION-RELATED GDP

As a social function, transportation has a supply side, which includes many transportation and nontransportation industries such as automobile manufacturing, petroleum refining, and highway construction. In order to elucidate the importance of transportation to the economy from a supply perspective, we introduce the concept of transportation-related GDP, defined as value-added (or net value) generated in producing goods and services to satisfy the society's transportation needs. These goods and services include transportation services such as freight and passenger transportation services as well as transportation input such as motor vehicles and gasoline. The difference between transportation-related GDP and transportation industry GDP is that in addition to the value-added generated by transportation services (or transportation industries), transportation-related GDP also includes the value-added generated in the production of direct input for transportation services, such as the production of motor vehicles and gasoline.

FIGURE 1 Transportation Final Demand and its Value Origination: 1997



Transportation-related GDP has several advantages over the previous two measures. First, it has a definitional boundary consistent with that of transportation expenditure. Statistics on transportation expenditures always cover not only the expenses of transportation services but also the expenses of transportation equipment, gasoline, and other operational costs (ENO 1998). In comparison, transportation industry GDP covers only transportation services.[4] Second, transportation-related GDP measures the importance of transportation to both final users and business, while transportation final demand covers final users only. By tracing the quantity of transportation-related goods and services required for business and final use, transportation-related GDP allows separate measures of the importance of transportation to business and final users and separate measures of the role of business transportation demand and final user's transportation demand in stimulating the production of various industries.

We derive transportation-related GDP with input-output methods and data from National Income and Product Accounts (USDOC 1993–1999) and the U.S. Transportation Satellite Accounts for 1992 (USDOT 1999). We first calculate the transportation portion of each industry's output by summing the industry's output delivered to final demand for transportation purpose and its output used by business for providing transportation services. We then estimate the industry's value-added generated in producing the transportation portion of its output by multiplying the output used for transportation with the industry's average value-added rate per one dollar's worth of output. The sum of the transportation portion of every industry's output yields the total transportation-related output of the economy. The sum of every industry's transportation-related value-added yields the transportation-related GDP of the economy.

In 1992, transportation-related GDP for the U.S. economy was $666.6 billion, accounting for 10.7% of the U.S. GDP. In 1997, it increased to $888.3 billion or 11.1% of the U.S. GDP. One point worth noting is that the size of transportation-related GDP was very close to the size of transportation final demand in both 1992 and 1997. However, these phenomena occurred by chance with no intrinsic reason for their seeming correspondence. As we have discussed, transportation final demand measures the value of goods and services delivered to final users to serve their transportation needs. A large portion of this value originated from nontransportation related production activities. For example, the value of the steel embodied in a car that was purchased by a consumer is counted as transportation output, but the value originated with the steel industry. Transportation-related GDP, on the other hand, measures the value generated by business activities that provide either transportation services or direct input to transportation services. The transportation services may be consumed either by businesses as input to production or by final users as final consumption. Therefore, a large portion of the value of transportation services may not be captured by transportation final demand. A good example of this point is the sharp difference between the small final demand for steel and the considerable GDP of the steel industry. Steel is an important input to many industries, but only a small amount of steel becomes final consumption.

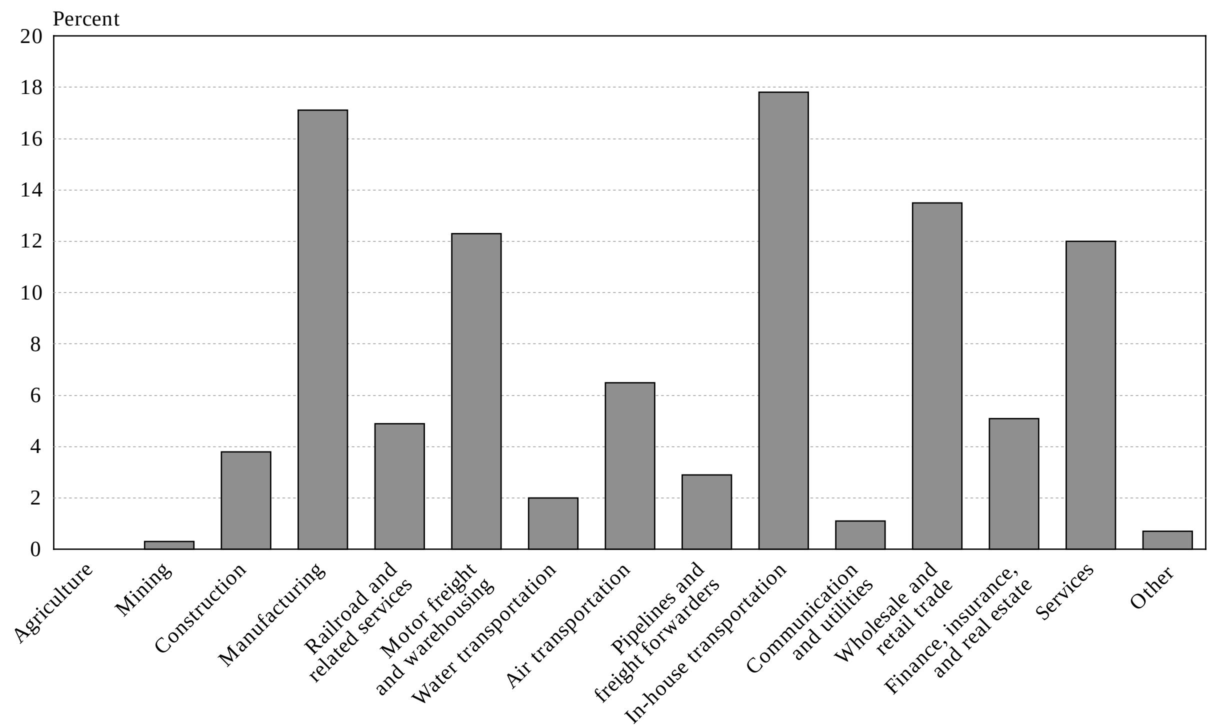
Table 4 and figure 2 show the distribution of transportation-related GDP across major industries. Out of the $888.3 billion transportation-related GDP in 1997, about 46% originated from transportation industries, while the rest originated from the production of direct transportation input by nontransportation industries. If all economic activity is aggregated into 16 industries, the in-house transportation industry ranks number 1 in terms of contribution to transportation-related GDP, accounting for 17.8% of the total. The manufacturing industry ranked number 2 and contributed 17.1%. The largest for-hire industry, motor freight and warehousing, contributed

[4] The consistency between the definitional boundaries of transportation-related GDP and the common measures of transportation expenditure is also important for estimating transportation-related GDP. Transportation expenditures are frequently used as surrogates for transportation-related output. Without expenditure information, it will be very difficult to estimate the transportation portion of the output and value-added of some transportation-related industries, such as petroleum refinery, because their products can be used for both transportation and nontransportation purposes

TABLE 4 Transportation-Related GDP by Major Industry: 1992 and 1997

Industry	1992 Millions of dollars	1992 Share in total (percent)	1997 Millions of dollars	1997 Share in total (percent)
Agriculture	12	0.0	16	0.0
Mining	2,026	0.3	2,522	0.3
Construction	21,786	3.3	33,915	3.8
Manufacturing	122,879	18.4	152,023	17.1
Transportation				
Railroad and related services	343,90	5.2	43,633	4.9
Motor freight and warehousing	83,371	12.5	108,882	12.3
Water transportation	12,796	1.9	17,884	2.0
Air transportation	42,166	6.3	57,367	6.5
Pipelines and freight forwarders	19,624	2.9	25,859	2.9
In-house transportation	121,531	18.2	157,765	17.8
Communication and utilities	7,164	1.1	9,452	1.1
Wholesale and retail trade	90,928	13.6	119,730	13.5
Finance, insurance, and real estate	32,115	4.8	45,660	5.1
Services	70,798	10.6	106,914	12.0
Other	5,009	0.8	6,629	0.7
Total transportation-related GDP	**666,593**	**100**	**888,251**	**100**

FIGURE 2 Industry Share in Total Transportation-Related GDP: 1997



12.3%. However, motor freight and warehousing ranked fourth, after the wholesale and retail industry, which contributed 13.5% to the total. Although this kind of ranking reflects the size of an industry as much as its affinity with transportation, it demonstrates that for-hire transportation industries are only part of the entire transportation system and represent only a small portion of the GDP generated in relation to transportation.

FIGURE 3 Share of Transportation-Related Value-Added in Industry Total Value-Added: 1997

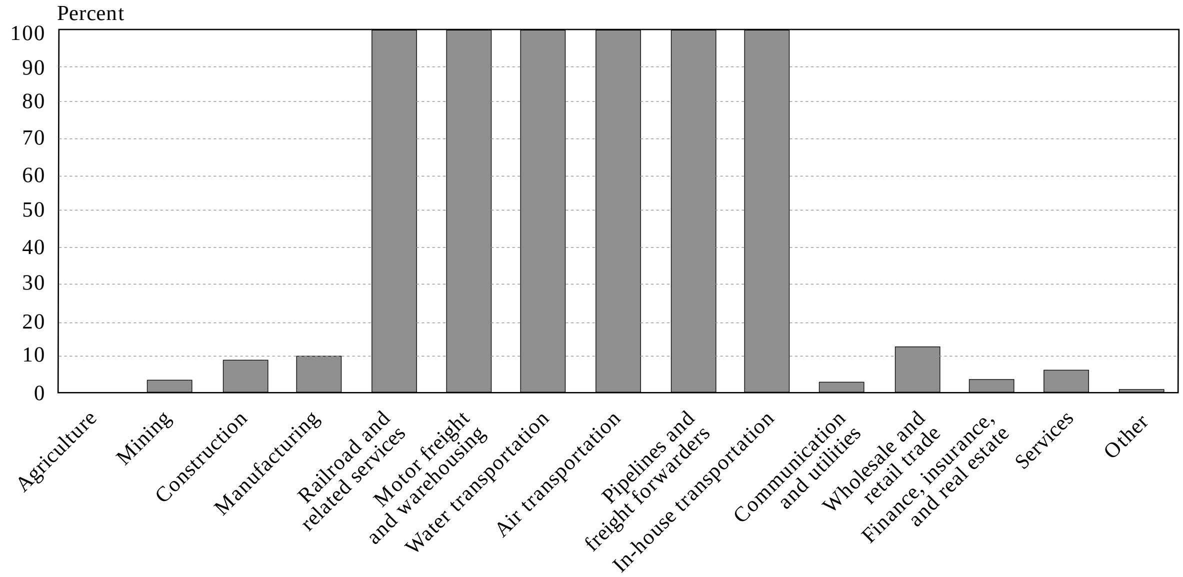
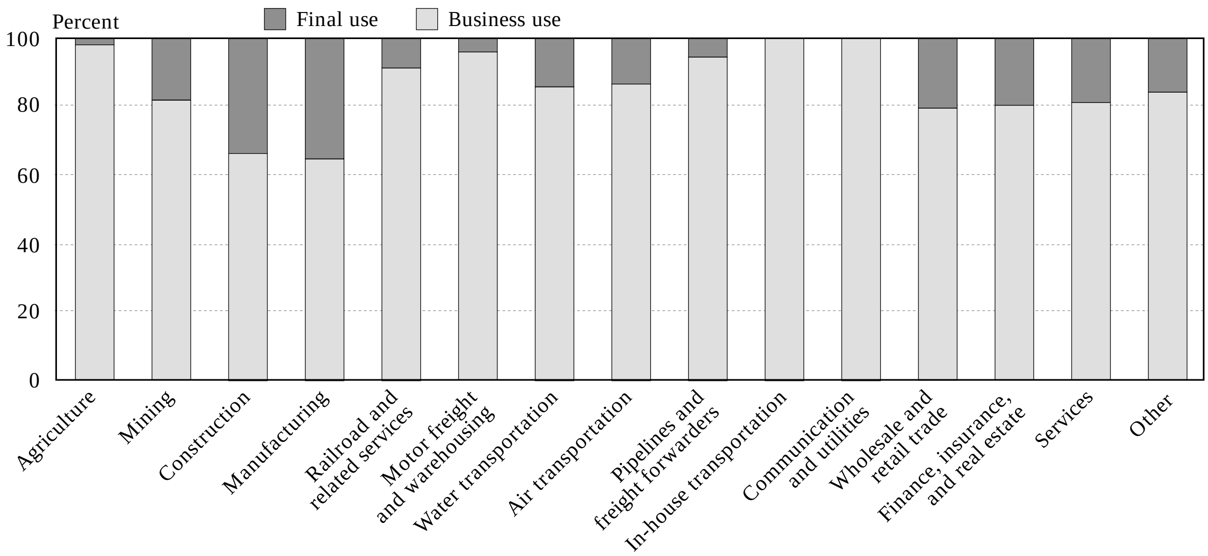


Figure 3 shows the degree of affinity of an industry with transportation using the share of its transportation-related value-added in its total value-added. By definition, all transportation industries, from railroad to in-house transportation, are 100% transportation-related. Among other industries, the share of transportation-related value-added in the total GDP was the highest for the wholesale and retail trade industry, 12.5%. For the manufacturing industry, the share was 11%. Another two industries closely related to transportation were construction and services. Their shares of transportation-related value-added in total value-added were nine percent for the construction industry and six percent for the services industry. Agriculture was the only industry that had almost no relation to transportation by this particular measure.

As mentioned earlier, transportation-related GDP allows separate measures of the importance of business transportation demand and transportation final demand. In 1997, 84% of the $888.3 billion transportation-related GDP was generated by supplying business transportation demand, and 16% was generated by directly supplying the transportation demands of final users. Figure 4 shows the dichotomy of transportation-related GDP by industry between business use and final use. Since the in-house transportation industry is made up of transportation activities conducted by nontransportation firms to meet their own transportation needs, in-house transportation industry's GDP was 100% generated by providing transportation services to business. The communication and utilities industry was another industry whose transportation-related GDP was almost completely driven by business demand. The communication and utilities industry is transportation-related because its output is used by for-hire transportation industries as input in providing transportation services. The industry that had the highest share of final use in total transportation-related GDP among all the industries was the manufacturing industry. About 35% of its transportation-related GDP was generated from supporting final users' transportation needs. Obviously, this was because a great deal of transportation equipment, such as cars, trucks, and boats, were used not only by businesses but also by consumers and governments. The share of final use in total transportation-related GDP was 14% for water transportation and 13% for air transportation, the highest in final use of the five for-hire transportation industries. The motor freight and warehousing industry has the lowest final use orientation. Only four percent of its services was directly consumed by final users. On average, for-hire transportation industries generated 92% of their total GDP by providing transportation services to business and only 8% from services to final users.

FIGURE 4 Dichotomy of Transportation-Related GDP Between Business Use Origin and Final Use Origin, 1997



TRANSPORTATION-DRIVEN GDP

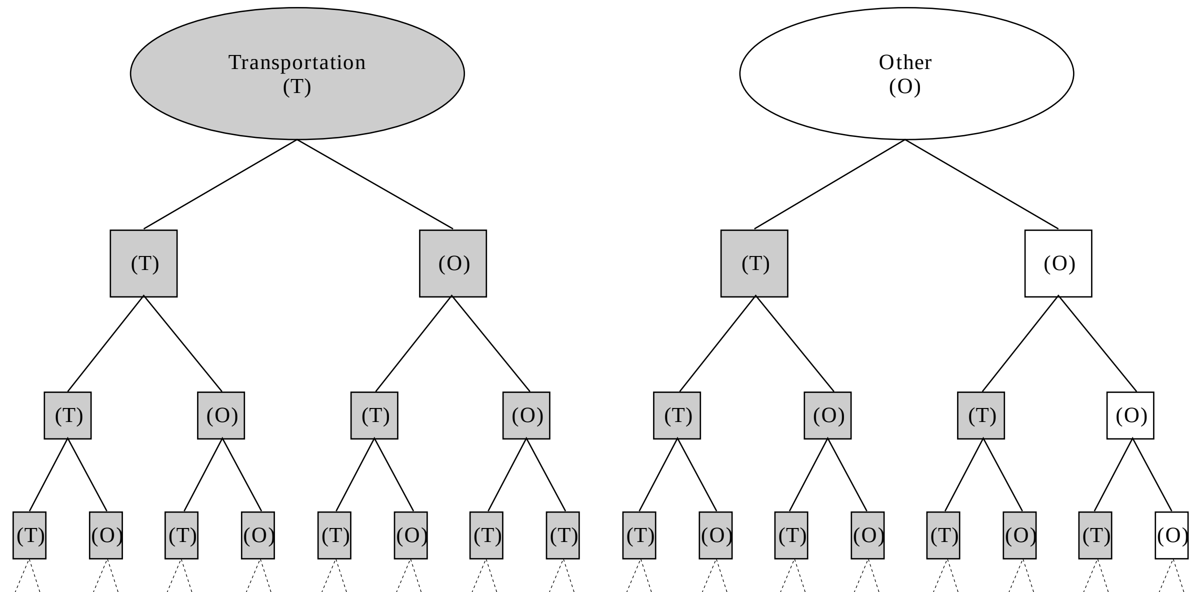
Transportation-related GDP expands transportation industry GDP by including the value of transportation input. To avoid double counting, only the producing industries' value-added embodied in the output which is used as direct input to transportation is included. The value-added embodied in the input used to produce that transportation input is not included. To illustrate this point, we will assume that trucking is the only transportation service and that it takes only labor and trucks to produce trucking service; only labor, steel, and trucking service to produce trucks; and only labor, iron ore, and trucking service to produce steel. In this scenario, transportation industry GDP equals the value of labor used in providing trucking service. Transportation-related GDP is the sum of transportation industry GDP and the value of labor used in producing trucks. The value of labor used in producing the steel needed for producing trucks is not included. Therefore, if asked how much of the GDP would be lost if demand for transportation suddenly dropped to zero, transportation-related GDP would not provide us with the correct answer.[5]

[5] Clearly, many economic activities would not be able to take place if transportation suddenly ceased to exist. However, the impact of transportation's enabling function is not what is of concern here. What we try to measure here is transportation's economic impact from a purely accounting perspective, assuming that other economic activities would be able to continue without transportation services.

To address this question, we introduce the concept of transportation-driven GDP and present a method that allows us to derive an empirical measure that correlates with the concept. We define transportation-driven GDP as the sum of all the value-added generated by productive activities that provide transportation services and that directly or indirectly produce input used by transportation services. Transportation-driven GDP differs from transportation-related GDP by including the value-added generated in productive activities that indirectly support transportation services through an input-output chain. In our previous example, transportation-driven GDP includes the value of the labor used to produce the steel that was used to produce trucks. Since the industries of the economy are interconnected through input-output chains and since transportation services are also used by other industries as input in their production, which support other social functions, transportation-driven GDP and the GDP driven by other social functions will not be mutually exclusive. They will add up to a total larger than the GDP. We emphasize transportation here and use transportation services as the key link to sort out the interconnected input-output chain.

Figure 5 illustrates the concept of transportation-driven output in an interconnected production system. For simplicity, we assume that there are only two types of production in the economy:

FIGURE 5 Transportation-Driven Output



transportation-related (T) and other (O). Each of the two types of production uses the output of the other as input. The ovals represent final demand for the output of each of the two types of production. The boxes represent intermediate demand for output of the two types at each round of production.[6] Since transportation-driven output is defined as the output of all industries used directly and indirectly for transportation purposes, output of transportation-related production, used by either final users or business to meet their transportation needs, is by definition transportation-driven output. Output of nontransportation production is also transportation-driven if it is indirectly used to support the production of transportation-related goods and services. For example, steel is an output of nontransportation-related production because it is not used as a direct input to transportation services. However, some steel is used as an input to produce vehicles used for transportation purposes. Therefore, the steel used for vehicle production indirectly supports the demand for transportation.

Since transportation services are a necessary input to every industry's production, nontransportation final demand also generates demand for output of transportation-related industries. These demands for transportation services will further induce demands for transportation-related output and nontransportation-related output and so on. All the output induced by intermediate demands for transportation-related output are also transportation-driven output, although the initial demand is not transportation-related. Therefore, transportation-driven output is equal to the sum of all the output represented by the darkened areas in figure 5.

The challenge is to quantitatively determine the transportation-driven output at each round in an infinite series of production. Since it is the use of the output of an industry and not who produces it that determines if an output is transportation-driven, we have to start with demand. The input-output approach enables us to go from the demand side to the supply side through the standard equation

$$G = (I\text{–}A)^{-1} f \quad (1)$$

where f is the final demand vector, G is the output vector, and A is the technical coefficient matrix. In other words, output G is driven by final demand f.

[6] In figure 5, the sizes of the ovals and boxes do not represent or imply the size of the output of the two types of production. Nontransportation-related final demand and intermediate demand are much larger than their transportation-related counterparts.

If f takes the value represented by the darkened oval in figure 5, then the equation gives an output G equal to the sum of all darkened areas on the left side of the figure. To calculate G as equal to the sum of the darkened areas on the right side of figure 5, we need an f that is equal to the sum of those darkened boxes that immediately follow the light boxes, the initial intermediate transportation demand. Conceptually, initial intermediate transportation demand is the sum of transportation output that must be produced to satisfy the production of nontransportation output driven by nontransportation demands at each round of an infinite production process. Demand for transportation output to support the production of nontransportation output that, in turn, is needed to support the production of transportation output is not initial intermediate transportation demand. In matrix notation, the initial intermediate transportation demand can be expressed as

$$f = U(I-\tilde{A})^{-1}O \quad (2)$$

where O is nontransportation final demand, U is a direct requirement matrix with goods and services used as input to transportation, and $\tilde{A} \equiv A-U$, a direct requirement matrix with goods and services directly required to meet nontransportation needs. For those goods and services not directly required for transportation needs, the corresponding coefficients in U are zero. For those goods and services directly required for both transportation and nontransportation needs, such as gasoline purchased by a farmer to run his trucks and harvesting machines, the corresponding coefficients in A are split into one part for U and another part for $\tilde{A}$. The detailed mathematical derivation of the equation for initial intermediate demand can be found in Han and Fang (1997).

With initial intermediate transportation demand, the total transportation-driven output can be expressed as the following equation

$$X = (I-A^{-1})[T + U(I-\tilde{A})^{-1}O] \quad (3)$$

where T is transportation final demand and O is nontransportation final demand. The interpretation of the equation is straightforward: $(I-A^{-1})T$ is the output driven by transportation final demand, while $(I-A^{-1})U(I-\tilde{A})^{-1}O$ is the output driven by transportation demand that itself is driven by nontransportation final demand.[7] A simple matrix multiplication of X with the value-added coefficient vector of the economy yields the value-added generated by all industries of the economy in their production to directly and indirectly support all, final and intermediate, transportation demands in the economy. This transportation driven GDP is a comprehensive measure of transportation's economic impact on the economy.

In 1992, transportation-driven GDP was \$988.6 billion, accounting for 15.9% of the U.S. GDP. As the economy grew, transportation-driven GDP also grew (table 5). In 1997, transportation-driven GDP increased to \$1,321.6 billion, accounting for 16.5% of the U.S. GDP. This means that about 16% of the U.S. GDP was generated by economic activities that either provided transportation services or were involved in supporting transportation directly or indirectly. Other things being equal, without transportation final demand and business demand for transportation, the U.S. GDP would be 16% smaller. For-hire transportation industries' GDP was only a small portion of transportation-driven GDP, accounting for about 19% of the total in both 1992 and 1997. Adding in-house transportation GDP to for-hire transportation industries' GDP boosted the share of transportation industry GDP in transportation-driven GDP up to 31%. This means that more than two-thirds of transportation-driven GDP was from economic activities outside the transportation industries. The manufacturing industry alone accounted for 22% of the transportation-driven GDP in 1992 and 21% in 1997.

Transportation relies heavily on nontransportation industries. It is also an important demand that drives many industries' production. In 1997, the share of transportation-driven GDP in the industry's total GDP was 56% for the mining industry, 20% for the manufacturing industry, 18% for the wholesale and retail trade industry, 12% for the construction industry, 11% for the service industry,

[7] $(I-\tilde{A})^{-1}O$ is the nontransportation output driven by nontransportation final demand, and $U(I-\tilde{A})^{-1}O$ is the total initial intermediate transportation demand driven by nontransportation final demand. Initial intermediate transportation demand is equivalent to transportation final demand in terms of driving the economy's production process.

TABLE 5 Transportation-Driven GDP: 1992 and 1997

Millions of dollars Industry	1992 Millions of dollars	1992 Percentage of total	1997 Millions of dollars	1997 Percentage of total
Agriculture	2,113	0.2	2,911	0.2
Mining	36,889	3.7	46,809	3.5
Construction	29,913	3.0	44,682	3.4
Manufacturing	219,403	22.2	281,503	21.3
Transportation				
Railroad and related services	34,390	3.5	43,633	3.3
Motor freight and warehousing	78,450	7.9	102,444	7.8
Water transportation	12,796	1.3	17,884	1.4
Air transportation	42,166	4.3	57,367	4.3
Pipelines and freight forwarders	19,624	2.0	25,859	2.0
In-house transportation	121,531	12.3	157,765	11.9
Communication and utilities	28,171	2.8	37,613	2.8
Wholesale and retail trade	128,266	13.0	170,966	12.9
Finance, insurance, and real estate	87,395	8.8	120,874	9.1
Services	135,546	13.7	195,136	14.8
Other	11,905	1.2	16,202	1.2
Total	**988,558**	**100**	**1,321,649**	**100**

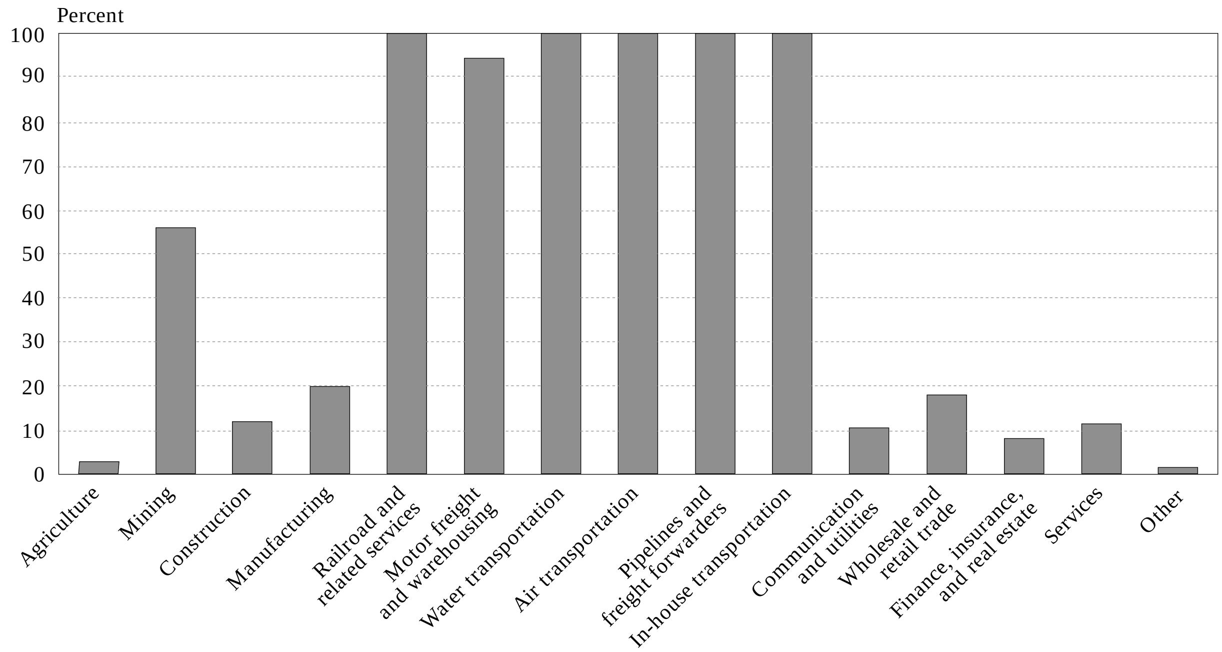
and 10% for the communication and utilities industry (figure 6). Recall that only three percent of the mining industry's GDP was from its output used as input to the production of transportation services. The sizable difference between the share of transportation-related GDP and the share of transportation-driven GDP in the mining industry's total GDP (3% versus 56%) reflects the fact that many industries are involved in supporting transportation services, and a large portion of these industries are themselves intensive users of the products of the mining industry. It also highlights the importance and necessity of measuring transportation-driven GDP in order to understand the impact of transportation on the economy.

CONCLUSION

While all four of the measures of transportation's economic importance presented here have the GDP as the common denominator, the numerators in the different measures characterize transportation from different perspectives: transportation as an industry, as a social function, as the complete supply side of the transportation function, and as the complete impact chain of transportation functions. Transportation industry GDP is the sum of the gross value-added of transportation industries. Traditionally, only the gross value-added of for-hire transportation industries is counted as transportation GDP. The considerable value generated by in-house transportation activities within non-transportation firms has not been explicitly identified in the past and has been implicitly counted as nontransportation GDP. TSA92 reveals that in-house transportation activity was significant in the U.S. economy. Not including the value of in-house transportation services, traditional statistics on transportation GDP in the U.S. national accounts has underestimated the contribution of business transportation services to the GDP. These data may also be misleading if used in analyses of the relationship between transportation and the economy.

Transportation final demand is the sum of the values of all goods and services delivered to final users for meeting their transportation needs. Since it makes up a part of final demand and final demand drives the economy (in the short run), transportation final demand is an indicator of the importance of transportation as a driving force in the economy. The relationship between transportation industry GDP and transportation final demand is a complicated one. Many industries are involved in supporting the economy's transportation final demand, while a sizable portion of transportation

FIGURE 6 Share of Transportation-Driven GDP in Industry GDP: 1997



industry GDP is embodied in (or is used to support) nontransportation final demands. Without statistics on transportation final demand, we would miss a significant portion of the importance of transportation to consumers and, therefore, our understanding of the importance of transportation in the economy would be severely distorted.

Transportation-related GDP is the sum of the value-added generated by all production activities that produce transportation services or transportation input. Transportation-related GDP extends transportation industry GDP by including the value-added generated by producing direct inputs for transportation services, such as motor vehicles and gasoline. Unlike transportation industry GDP, transportation-related GDP covers the complete supply side of transportation. The consistency in coverage between transportation-related GDP and transportation expenditures, which include expenditures on such things as transportation equipment and fuels as well as transportation services, provides a critical link between transportation statistics on the supply side and those on the demand side, beneficial to many types of transportation analyses.

Transportation-driven GDP is the sum of all the value-added generated by production activities providing transportation services or producing input directly or indirectly for transportation services. Transportation-driven GDP extends transportation-related GDP by including the value-added generated in production activities that support transportation services indirectly through an input-output chain. Among the four measures, transportation-driven GDP is the only one that measures the total impact of transportation on the economy and provides a comprehensive description of the intertwined relationship between transportation and other industries in the economy.

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Assessing Data and Modeling Needs for Urban Transport: An Australian Perspective

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ABSTRACT

Managing the transport assets of an urban economy and ensuring that change is in accordance with suitable performance measures requires continuing improvement in analytical power and empirical information. One crucial input for improving planning and policy support in urban transport in an ongoing review of data and modeling capability is a recognition of the role of stakeholders and the impact they can have in supporting the commitment to implementing a state of practice in data and modeling strategy. This paper presents a multistage stakeholder assessment of data and modeling needs in Australia, primarily in the urban passenger context, required to ensure the continuity of appropriate deliverables to a market of diverse stakeholders. The implementation of the framework of inquiry enables data and modeling agencies to remain current and relevant.

BACKGROUND

An important task in the development of a Strategic Travel Information and Model System (STIMS) is to establish efficient and effective links between the needs of stakeholders and STIMS. The details of the specific analytical tools are secondary

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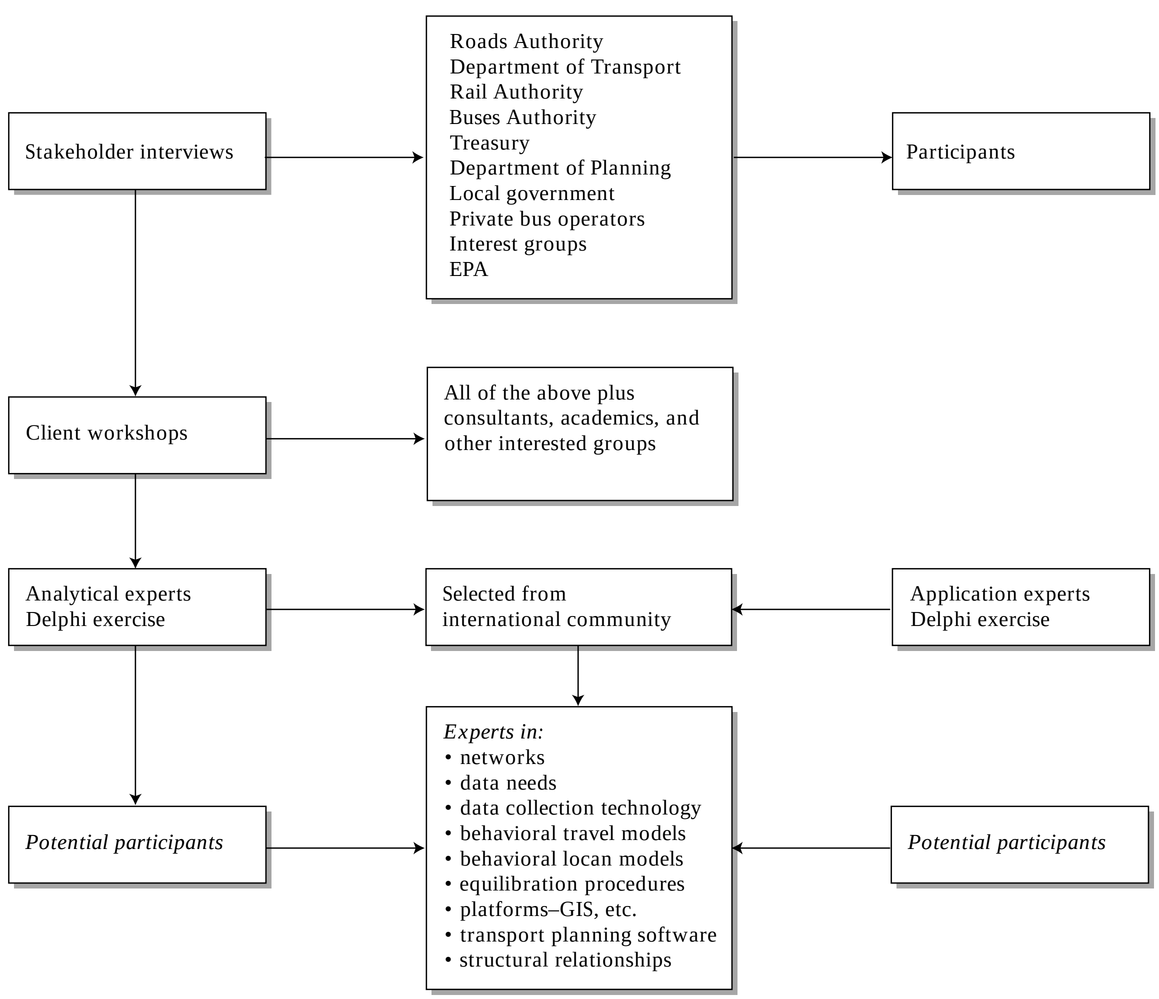
to this objective, representing the translation of needs into relevant models and supporting data. For example, a need may be as simple as data on the number of passenger vehicles, by vehicle type, using tolled motorways in an urban area. This is a descriptive statement of actual vehicle flows, a data need that requires appropriate statistical presentation and supporting documentation. Another need may be more generic, such as an interest in local air pollution and the ability to identify what policy instruments (transport and nontransport related) will have the greatest impact on reducing local air pollution. This may be delivered in a number of ways, including the application of STIMS to produce suitable outputs; alternatively, it may require the simple provision of data to a stakeholder/consultant using his or her own analytical model system.

These examples highlight a main challenge for a strategic travel information and model system. The system must be sufficiently flexible in its architecture to satisfy a diverse set of needs, ranging from the provision of basic descriptive data (e.g., trip tables) to output from a detailed travel forecasting model system. One useful starting point for the process of the development of a data and modeling capability is the design of a consultative process. At least four groups of players should be involved in this process: the stakeholders, the advisers to the stakeholders (e.g., consultants), the clients, and the body of analytical and application expertise. The contribution of these players can be captured by a consultative context as summarized schematically in figure 1. The stakeholders, the wider client base, the analytical experts, and the application experts

FIGURE 1 Consultative Context Design



all bring to the design process necessary perspectives on the state of knowledge and its relevance at various layers of decisionmaking.

Each consultative instrument has a very specific objective:

- Stakeholder interviews: To identify the policy-based obligations of an organization and the role that travel and transport information plays and could contribute to the planning and decisionmaking process.
- Client workshops: To enrich the perspectives of stakeholders and the "experts" by identifying, through debate and discussion, the broader informational needs of stakeholders and other clients in the chain of participation in transport planning and decisionmaking and to identify the most effective way of delivering the products.
- Analytical and application experts activity: To identity the state of the art and practice in areas of information associated with travel models and travel data and to establish the link between the state of play and its relevance to the transport planning and decisionmaking process.

An important distinction exists between analytical and application experts. The latter have often "evolved" from the former, moving away from basic and nonpolicy-directed applied research towards policy-directed, research-oriented applications. In some instances, the application expert is a manager of a team (residing in a government agency, a university, or a consultant firm), directing its activities yet with a wealth of knowledge of the appropriateness of analytical and data tools in servicing the needs of a client base. In contrast, analytical experts include researchers whose primary goal is the advancement of the state of knowledge with a limited commitment to particular applications, at least in the first instance. The analytical experts, however, are well positioned to identify the subsequent contributions of particular pure research activities that define the state of the art in future development of the state of practice.

THE STAKEHOLDER INTERVIEWS

Background

A face to face interview was undertaken in New South Wales (NSW) with 12 key stakeholders drawn primarily from the government sector and major nongovernment users of travel information and models. The selection was based on the historically predominant users of travel data and travel models. To give a minimal structure to the interviews, the following themes were introduced:

1. Definition of transport information and modeling systems,
2. Key research questions your organization is interested in at present and in the last few years,
3. What use you/your organization makes of travel data and models in planning and policy formulation,
4. Information sources for planning and policy advice,
5. Past experience in accessing particular types of information (frustration and satisfaction): what it was, whom you dealt with, how long it took to get the material, and the extent to which the material was suitable,
6. Your views on the preferred means of accessing travel and transport information or models (a wish list of types of information you/your organization would find particularly useful),
7. Particular types of information questions which you cannot get answers for, and
8. General and open discussion; other issues and comments.

A discussion paper for prior circulation to participants of client-based workshops was one output of the stakeholder interviews.

Policy Issues and Links with Travel Information and Model Systems

Stakeholders were asked to identify key policy issues important to their organization today and/or in the future. They were also asked how they would benefit from information produced from travel surveys and enhancements in the form of interpretative analysis of data and the application of calibrated travel models.

Table 1 lists some of the primary data needs for assisting policy development emphasized by stakeholders. They are broadly grouped into five areas.

TABLE 1 Key Policy-Linked and Informtion-Based Issues

Travel information	Specific policy issues (illustrative)
• Travel profiles by OD, trip purpose, time of day, day of week, season, mode, and socioeconomic class for base year (and forecast year)	• Role of public transport (vs. roads) • Likely impact of pricing policies • Public transport route planning • Knowing one's market and reacting • Potential role of mini-buses/hail 'n ride) • Evaluation of traffic on existing road links • Evaluation of major projects (e.g., tollroads, LRT) • Capital works programs • Determine if asset upgrade and/or investment is economically justifiable
• Freight movements (OD) by truck type, cargo type, value, and volume	• Freight route evaluation, traffic density • Health/air, noise, and water issues • Evaluation of traffic on existing road links • Evaluation of major projects (e.g., tollroads) • Economic connectivity and cost • Determination of generating points • Corridor evaluation studies • Plotting freight routes for operators • Influence of constraints (delivery windows, factory hours, etc.)
• Trends in passenger and freight movements Passenger: OD, vkm, trips, vehicle types, by time of day, season, day of week, and household type (life cycle, income, etc.) Freight: OD, truck type, cargo type, value, and volume by time of day, day of week, and season.	• Changing role of public transport • Environmental implications • Impact of changing social patterns on travel (shop opening hours, flexi-time, weekend retailing, etc.) • Impact of changing economic conditions on travel—recession, boom times, etc. • Social equity issues • Regulatory structures • Microeconomic reform directions, monitoring • Understanding past trends to complement the modeling of future trends • Peak spreading and its implications • Development of performance indicators • Setting market share targets in public transport (PT) agencies (e.g., 50% commuter share to CBD) • Impact on and of urban development
• Vehicle kilometers and trips by location (grid square) and vehicle data (age, fuel efficiency), hot and cold starts	• Environmental policy investigations: photochemical smog, greenhouse
• Trends in land-use density by type (residential, commercial, industrial, etc.) and travel patterns by mode and location	• Transport/land-use interaction • Public transport (PT) service planning • Greenfield sites and early role of PT • Implications for the journey to work (where are the jobs by type) • Monitoring urban consolidation and decentralized land use by travel impact

continued on next page

TABLE 1 Key Policy-Linked and Informtion-Based Issues *(continued)*

Travel information	Specific policy issues (illustrative)
• Residential and workplace location, OD activity by time of day and socioeconomic class	• Evaluation of commuter traffic • Spatial/temporal impact of changing work practices • Impact of changed work conditions on travel • Changing employment opportunities
• Activity information to complement trip diaries	• Time spent at shops, at work, at entertainment locations, and implications for parking policy (charges and space)
• What if data (e.g., stated preferences) for many applications (e.g., role of LRT, busways, toll roads, congestion pricing, carbon tax, major changes in level and mix of fare classes, alternative densities of residential and workplace locations, regional center scenarios, job center scenarios)	• City centers policy • Alternative-fuel vehicles • Equity implications of transport policy • Changing patterns of traffic • Efficiency implications (revenue, consumer surplus, user cost, accessibility, emissions, energy, etc.) • Control strategies to effect changes in air quality (road pricing, fuel taxes, parking, restaurants, etc.)
• Understanding past trends to complement the modeling of future trends	• Indicative of urban form and economic activity
• Incorporating policy relevant variables in interlinked location/travel and vehicle models: modeling systems	• Recognition of interdependencies of land use, travel, and environment • To evaluate the complex interrelationships between land use, travel, and the environment (e.g., impact of alternative land release strategies, rail vs. road investment)
• Behavioral understanding of travel/activity patterns (descriptively, interpretation of data, formal modeling of what is and what-ifs) • Attitudinal and opinion surveys	• Wide range of policy investigations • Direct and cross elasticities of alternative fare levels and class policies for public transport (PT) • Competition policy • Deregulation of taxis • What is demand and how do we provide for it

The first area consists of descriptions of the current (base) and historical (trend) profiles of spatial travel patterns in the passenger and freight vehicle markets, disaggregated by trip purpose, mode, vehicle type, time of day, day of week, season, and socioeconomic class. For freight movements, the nature of the cargo by volume and value is added. Multi-way trip tables best describe the output. The second area contains forecast "descriptions" compatible with the base year multi-way trip tables. The third area is interpretative analysis of the descriptive base and trend travel data. The fourth area is an interpretative analysis of "what if . . ." data, and the fifth area is made up of prediction and forecast output of a decision support system driven by a set of travel, location, and vehicle models capable of tracking through the fuller impacts of policies under investigation. The range of output of interest is extensive, although the critical output includes impacts (by origin-destination, mode, trip purpose, time of day) on vehicle-kilometers, vehicle trips, emissions, government revenue, accessibility, income distribution (i.e., equity), and end user costs.

Many stakeholders desire some analysis of trends in transport and travel over time. Almost all indicated an increased interest in understanding the nature of freight movements, especially the origins and destinations of freight vehicles and the main routes used. The environment is a priority policy issue, related to understanding the contribution of the current transport system to air quality, global warming, noise pollution, and damage to property and individuals. Many agencies are increasingly focusing on the relationship between transport policy, movement patterns, and urban form (shape, density), which requires a much richer database of location and travel data than is currently available in transport agencies. Location decisions associated with the supply of jobs and the release of land for residential, commercial, and industrial activity have a profound impact on where people live, where they work, and where the commodity flows must be concentrated and, therefore, on the efficiency of the existing transport system and the needs for further investment.

Theme Discussion Statements emerging from this inquiry:

- TDS11: Data and modeling agencies should develop a wider interpretation of policy-relevant travel data, encompassing the demand-side and supply-side characteristics of activity locations and all transport modes (public and private, passenger, and freight).
- TDS12: Data and modeling agencies should regularly canvas their customer base to ensure that they keep informed about the important policy issues that require transport information and models.
- TDS13: Data and modeling agencies must give significant weight to the tasks of providing base and trend multi-way trip movement tables, offering interpretative analysis and reporting as derivatives of the tabular preparation exercise, developing niche surveys to increase understanding of the impact of policy ("what if . . ." or scenario surveys), and developing a decision support system whose behavioral base is a set of location, travel, and automobile models capable of evaluating the wider set of policy issues represented in table 1.

Data Sources and Requirements

The primary source of travel data (predominantly urban travel data) for NSW is the Department of Transport's (DOT's) travel surveys (1971, 1981, 1991, and 1998–99) as well as supplementary surveys usually undertaken by consultants and universities (Wigan and Groenhout 1990, Taylor et al. 1992b). The Australian Bureau of Statistics census is useful for a very limited set of travel data on modal split for the journey to work by residential and workplace location but is deficient for the growing noncommuting market (Wigan 1990). Despite this, it is one of the most widely used transport data sources by stakeholders because of its ease of access, high quality documentation, and support services. The DOT, through its Transport Data Center (TDC), currently is the only source of travel data with sufficient spatial coverage across all passenger travel and freight movements and is perceived by stakeholders aware of the travel survey activity as the primary source for such detailed travel data.

Desired Future Role for TDC as a Data and Modeling Agency

The diverse policy issues documented in table 1 represent the stakeholders' combined view of the broadening role required of the TDC as the major source of travel data in NSW. Stakeholders would like to see a balance between the responsibility for base travel data collected under the data collection strategy detailed below, interpretative analysis of base data, extensions of base data to incorporate "what if . . ." surveys, and the development of a modeling strategy embedded within a decision support system capable of integrating revealed and stated preference information. This package of capabilities is designed to ensure that a data and modeling agency is policy-useful for the wider set of stakeholders.

An important element of a service delivery strategy is the integrity of any data and modeling agency as a provider of credible information in its various guises. Regardless of the context of service supply, a focus on customers is critical. The stakeholders commented extensively about the need for continual improvement in communication and marketing skills. Tabular data will continue to be a requested form of data; however, the stakeholders proposed a greater flexibility in the way that a data and modeling agency supports requests for a wider range of tables. Tables with more dimensions, as suggested in column 1 of table 1, are needed within a reasonable time period. There is a need to constantly review the structure of data and the relational databases on the computer system to identify ways of minimizing delivery delay. The Internet opens up opportunities for very efficient and effective access to information.

Access to unit record data with confidentiality items removed is seen as essential to expanding the opportunities for stakeholders to determine their own interpretative data needs and to undertake model estimation. This access is also essential as a measure of confidence in the quality of the travel and network data. Any strategy of suppression, by directive or other means, is frequently interpreted by stakeholders as an expression of the lack of integrity of the database and, by inference, of the data and modeling agency (Wigan 1990). Increasingly, metropolitan transport agencies worldwide are making unit record data available to the research community, recognizing that this is a very cost-effective way of gaining knowledge of the transport system through "free" model estimation and application activities. Recent examples include Portland and Miami (USDOT 1996) and the nationwide longitudinal surveys in the United States (Morgan et al. 1974).

Emerging Theme Discussion Statements:

- TDS21: Data and modeling agencies should broaden their obligations to their client base by developing a capability to collect "what if . . ." data to supplement the descriptive "what is. . ." trip data as well as to reorient data to emphasize activities rather than trips per se.
- TDS22: Data and modeling agencies should be prepared to stage release data in both tabular and unit record form.
- TDS23: Data and modeling agencies should complement their development of a broader set of more policy-useful databases with an appropriate information strategy to keep their customers well informed.
- TDS24: Data and modeling agencies must be credible to all so as to avoid disaffected groups developing their own data (plus networks, models, and forecasts). Rival allegiances to alternative sources of data are counterproductive.
- TDS25: Data and modeling agencies should become the recognized repository for agreed travel and network information.

Beyond Basic Travel Data: Other Information Output

In this section we take a closer look at the range of core activities suggested by stakeholders.

Interpretative (Policy) Analysis

Stakeholders often perceive that in addition to collecting and preparing base travel data, data and modeling agencies have historically focused on model development at the expense of undertaking simple and policy-useful interpretative analysis of the base data. Formal quantitative travel models have an important role, but so does more qualitative interpretation of tabular data.

This data analysis activity, called interpretative analysis, was perceived by many stakeholders as the most frequent analysis they would ever require. Many felt that they had enough trouble obtaining quality data on what was happening now, let alone what might happen in the future, so such interpretative analysis skills were initially what was required from data and modeling agencies. This interpretative analysis is not a substitute for all client-interpretative activity. For example, local government often brings an added dimension of interpretation not observed at the center: the "center can provide the spanner, and local government transport planners can wield the spanner," notes one stakeholder.

Projections as a Data Interpretative Analysis

Beyond interpretative analysis is another step before formal modeling, called projection analysis. Some stakeholders see a role for a data and modeling agency in projecting interpretative analysis on the basis of current trends. These projections could become the default set.

Strategic Planning Models

The final step in the information hierarchy is strategic planning models. The view was expressed that many data and modeling agencies have tended to spend too much time estimating and calibrating a very limited set of policy-based travel demand models, outdated by the time they are available and never available in a form useful to the policy process.

Model estimation, calibration, and application is not well-understood by the majority of stakeholders. The historical lack of a demonstration of the value of statistical models in applications has given them a dubious reputation. Some stakeholders would like to see more consideration given to making travel models user-friendly and embedding them within a decision support system. Such a system is designed to show how such models can provide information that may complement tabular data and also to provide another source of information to evaluate the many policy issues not adequately evaluated through interpretative and trend analysis. The following topics represent examples of useful modeling-based application areas.

The stakeholders expressed the strong view that a data and modeling agency should undertake policy-based modeling and applications as a pre-emptive activity so that it is in a good position to contribute to the transport debate in a timely and effective manner. This proactive approach will ensure that the suite of model and data needs is kept up to date and remains policy-useful. Some feel that data and modeling agencies should move away from the very rigid and highly aggregate travel model system typically in place but with little policy relevance. One stakeholder commented that ". . . the current four-step model seems lost in the wilderness with no policy-based motivation." Essential to the new paradigm is a richer specification of the set of dependent variables (i.e., endogenous variables) in the model system as well as a much larger number of explanatory variables that have links to policy. Most metropolitan planning agencies (MPOs) are struggling with this transition, and very few have made the move.

Stakeholders highlighted a need for greater attention to modeling noncommuting travel activity, with a distinction between discretionary and nondiscretionary, noncommuting travel. Modeling urban freight activity was also emphasized as a globally neglected capability. Since externalities (e.g., traffic congestion, traffic noise, air quality, and global warming) now play a central role in transport and land use integration, the need to identify how travel behavior is influenced by strategies to reduce the externalities is critical to an evolving land-use transport strategy.

Conventional travel data is essentially descriptive; it needs to be supplemented by data of a scenario or "what if . . ." nature. Indeed, the whole issue of more innovative data collection strategies that give new meaning to the evaluation of the big issues was cited many times. Armed with enriched advice from the state of the practice tools such as stated preference experiments and revealed preference data-based travel demand models which give confidence not only in explaining "what is . . ." but also in explaining "what if . . . ," stakeholders will feel more confident in their abilities to comment on and/or refute statements made by community and other organizations often based on statistics of dubious interpretation.

Spatial Decision-Support Systems: Bringing it all Together into a Policy-Useful Operational Tool

The comments seem to reveal that what might be required is a set of strategic planning models embedded in a decision support system. It would have to go beyond the traditional four-step travel modeling approach which fixes many land use and behavioral variables to include locational models, vehicle models, and an expanded set of travel models. The need to broaden the definitions of a travel model system to incorporate locational (i.e., land use) and automobile choice models was emphasized. Such a model system, including policy relevant variables, was perceived as being far more useful than the typical agency models because of the ability to address "what if . . ." scenario questions. This would allow for inspection of the wider impacts of decisions, without having expertise in all fields.

Emerging Theme Discussion Statements:

- TDS31: Data and modeling agencies should use the travel information base as a pre-emptive policy tool, not simply to provide information but to interpret it. This is a core value-added activity.
- TDS32: Data and modeling agencies should move from an almost total emphasis on "what is . . ." models to a stronger capability in modeling of "what if. . . ." This reorientation will be more policy-useful.

- TDS33: Data and modeling agencies should develop a strategic-level modeling capability in a proactive mode of policy relevance to assist the debate on the big strategic issues such as rail corridors, the future of urban consolidation vs. decentralization, road pricing, toll roads, etcetera.
- TDS34: A decision support system in which a model system is embedded is an essential tool of the data and modeling agencies and should be available to stakeholders and other clients through advice or on-line.
- TDS35: Data and modeling agencies should develop a staged program of model development, estimation, and application in order to ensure that the model system is both policy-useful and available to the stakeholders in a timely manner.

Travel Surveys: How Often and What Content?

Government transport agencies have historically focussed on the collection of data over a 10-year cycle, designing a geographically stratified, random sample travel survey of a large sample of households (Taylor et al. 1992a; USDOT 1996). In NSW, the 1971 Sydney survey was specialized to the Sydney metropolitan area; the 1981 and 1991 surveys increased their geographic coverage to include Wollongong, the Central Coast, and the Blue Mountains. Commercial vehicle and cordon surveys[1] have complemented the passenger oriented household surveys. The central feature of the latter is a one-day trip diary for each household member and a summary of the socioeconomic characteristics of the household. There is no attitudinal data or "what if . . ." behavioral responses. The survey data is processed and weighted up to the sampled population. Together with updated morning two-hour peak traffic data on network levels of service for the highway and public transport system (with no distinction between types of public transport), a set of traditional travel demand models is estimated and calibrated to the morning peak baseline commuter traffic. In 1981, the modal split model was estimated at the individual traveler level but was adjusted extensively by a number of socioeconomic factors to enable the estimated model to be calibrated at the traffic zone level for input into a traffic assignment package such as EMME/2.

The historical experience with data currency limited to a decade cycle has produced two very strong views: 1) base travel data must be meaningful, long lasting, current, regular, and free of the political process and 2) the 10-year "big bang" survey strategy should be abandoned in favor of a rolling program of travel data collection, both passenger and freight, with a broadening out to accommodate "what is . . ." and "what if . . ." information.

There was a strong view that we need regular core data and a capability to undertake specialized surveys as required. "With all money often in the big 10-year survey, we are fund-strapped," noted one participant. Treasury is always concerned about the currency of data. Credibility requires currency at a level not available from 10-year surveys beyond the early years (up to 3 to 4 years). These issues are explored below. The issue of comparisons of travel activity over time was mentioned many times, with a strong desire to support both the creation of a mix of travel surveys, such as a household panel (e.g., Murakami and Watterson 1990), a firm panel, and a once-off single cross-section on a niche application. These would contain an agreed set of definitions of key data to ensure comparability. Better documentation at the time of a survey would avoid the problems of interpretation often faced by users of earlier travel surveys.

The smaller but regular general travel survey might take a number of forms: it could still contain the detail of earlier 10-year surveys but be administered to a smaller sample, together with other data sources, such as a cordon survey, to obtain suitable trip table data (remembering that the costs of data collection are heavily skewed historically towards the self-administered drop-off and collect/check travel survey). This survey can be repeated every three to five years or, alternatively, it could follow the lead of others surveys such as the VITAL

[1] A cordon survey typically involves distributing a reply post paid survey card to car users stopped at locations throughout the study area. The information sought includes origin and destination of trip, key routes, departure and arrival time, occupancy number, and a few socioeconomic characteristics such as age and gender.

survey in Melbourne, a continuous survey such that each year approximately 6,000 surveys are compiled, giving a rich database both at a point in time and over time. With a knowledge of sampling theory beyond simple random samples and stratified random samples, it is possible to preserve the richness of data through strategies such as activity-based sampling and to weight the observations back to a representative sample of the population prior to aggregation to the population as a whole.

Several stakeholders stressed the need for seasonal data, so a survey such as a rolling 12-month survey should be explored. A popular suggestion was to survey geographical areas in the greatest state of flux more frequently than more stable areas so as to ensure data was as relevant as possible for policy decisions. Table 2 indicates how the timing of such a rolling survey program could be structured. The instrument for such a program would initially be a single cross-section, but such a program would undoubtedly lead to repeated cross-sections, and if desired, panel data. It would be much easier to obtain funding for a continuing small survey program than for a larger survey every 10 years. The NSW Transport Data Centre has since implemented a rolling annual survey program, commencing in 1998. In addition, the use of cordon surveys with a post paid reply card requesting data on origin-destination (OD), mode, purpose, time of day, vehicle type, and travelling party composition is a cost-effective way of securing good spatial data. Doubts were expressed, however, in the workshops about cordon surveys. These few data items are sufficient to generate trip tables for passenger and freight movements.

Emerging Theme Discussion Statements:

- TDS41: Instead of a regular 10-year survey, data and modeling agencies should conduct a rolling program of surveys in which areas of greatest flux and/or where change is not so predictable be surveyed more often than more stable or more predictable areas.
- TDS42: A regular trip-specific cordon survey (post paid reply card) seeking OD data, trip purpose, mode, trip times, etcetera, is the best way of collecting base spatial data for passenger and freight trips. When complemented by a smaller but regularly repeated cross section (RCS) travel survey with "what is. . ." and "what if . . ." questions and a rotated panel off of the RCS, transport agencies will be able to provide the richest form of data.

TABLE 2 Structure of a Rolling Survey Program

	High predictability	Low predictability
Stable area	LEAST OFTEN	
Changing area	MEDIUM FREQUENCY	MOST OFTEN

Information Awareness and Dissemination

Five questions were raised many times throughout the discussions: What data is available? How do I get it? When do I get it? What will it cost? How reliable and credible is it? The most important considerations centered on mechanisms for knowing about the products of a data and modeling agency; how one can access the products and services; the extent, relevance, and quality of documentation; and the mechanisms in place to provide ongoing support. Without an appropriate information communication, distribution, and support strategy in place, all stakeholders see a transport agency as devoid of customer focus.

The discussion on the usefulness of various forms of information (including travel models) highlighted an important point, that the value of travel models in particular is poorly understood for reasons not directly attributed to a transport agency's performance. The issue is much wider and may be an indictment of the modeling community, which seems to have failed to communicate the value of its products. In part, this may be attributable to the poor packaging of model systems, a lack of good documentation of both a technical and lay nature, and the general absence of a series of courses able to handle the widely varying skills and needs of those who might benefit from the use of travel models. One consequence is a "fall back" to simple trip tables for tasks which could be better supported by the application of a travel model system. Decision support systems are seen as an opportunity to correct this situation.

Transport agencies need to develop a number of information series (Wigan 1990). A suggested division is 1) technical documentation explaining the data, sampling, data collection process, response rates, weights, and models and assumptions of a methodological nature which are of current and historical importance; 2) promotional material indicating what is available and how to obtain information; and 3) short travel reports (perhaps 16–20 pages) with many graphs, with a small amount of interpretation, and prepared by an outsourced, professional publication agency.

Emerging Theme Discussion Statements:

- TDS51: Stakeholders who could have benefitted from the information collected by the transport agencies had little or no knowledge of what information was available and, therefore, did not use it. The data and modeling agencies' communications with their client base must improve substantially.
- TDS52: The data and modeling agencies should develop a marketing strategy that specifically addresses the issue of information awareness and retrieval.
- TDS53: Data and modeling agencies should have a custodial role in providing advice to the government but also in assisting others to access information and models.

Institutional Context

Although we tried to avoid the issue of service delivery source, all stakeholders wanted to make a statement on this topic. It was recognized that any data and modeling agency, if constituted within a government department, has a requirement to satisfy the immediate and ongoing needs of the department first and then other government departments. The "closeness" to a department worried many stakeholders who expressed points about 1) access to core data regardless of the current political climate; 2) the extent to which a department might swamp the data and modeling agency with referrals for advice, possibly taking it away from what many believe should be the primary roles of collecting, preparing, and providing core travel data (including networks) and delivering it to all stakeholders and clients in a timely and efficient manner and of undertaking interpretative policy analysis and simple projections of broad stakeholder interest; and 3) the development and application of STIMS embedded in a spatial decision support system.

An important issue is the credibility of information and models. Stakeholders were keen to see some peer review mechanisms to ensure that the products of such a data and modeling agency were relevant, credible, well-documented, and available to all customers in a timely and efficient manner. A common view was that unit record data must be made available to the researchers and practitioners, a normal practice in some countries, notably in the United States (U.S. Bureau of Transportation Statistics 1993). Such an expensive and valuable resource needs to be utilized extensively in order to gain maximum benefit and to minimize duplication of effort. Household data is needed by many stakeholders "to do our own thing." Stakeholders need to access unit records to give flexibility in preparing problem specific data.

Emerging Theme Discussion Statements:

- TDS61: The data and modeling agency should release data at the unit record level and take advantage of the intellectual capital available within the client set to assist the data and modeling agency in studying the travel system. This is an essential requirement for credibility and customer focus.
- TDS62: Data of the data and modeling agency should be seen as a shared resource, jointly financed by key agencies in the transport sector.
- TDS63: The data and modeling agency should not report its activities on an ad hoc basis but instead should produce useful output in a timely manner. A steering committee should review progress regularly.
- TDS64: An advisory committee should be comprised of a mix of stakeholders and experts in the areas of travel data, information, and modeling.

Concluding Comments on Stakeholder Interviews

The stakeholder interviews provided the discussion material for a debate in the STIMS workshops. The issues raised are very similar to those debated in the United States as part of the federal government's ongoing Transport Model Improvement Program (USDOT 1996).

The stakeholders were unanimous in the view that a data and modeling agency must be proactive, develop a commercial sense in the way it runs itself, be policy-useful to the broader client base, and take advantage of the accumulated store of intellectual capital in the wider transport community. The redesign of a strategic travel information and modeling system should accommodate the needs of the wider stakeholder set through the development, application, reporting, and maintenance of the state of practice in travel data collection.

CLIENT-BASED WORKSHOPS

Client-based workshops provide the second step, within which the accumulated contributions of the stakeholders were considered, debated, and enhanced to arrive at a participatory view of STIMS. The emphasis was on both content and context: what should be delivered, over what timeframe and resource commitments, and how might it be best institutionally and managerially delivered.

Essential to the process of the client workshops, preliminary preparation centered on 1) the discussion paper documented in the previous section, 2) the mechanisms for linking the outcomes required by stakeholders, and 3) the way in which the output of this participation process is used in the development of the strategy for a data and modeling agency's model development. A mix of individuals with a strong commitment to the process was invited to participate, including stakeholders themselves and representatives of a broader clientele of stakeholders (see table 3). Three workshops were conducted, and each followed the same daily pattern. After introductions of participants and a background talk from the Department of Transport, a presentation based on the major components of the discussion paper was delivered. Open discussion followed, with some direction to ensure that the three key areas of STIMS were adequately addressed: the data strategy, the modeling strategy, and the information strategy. After lunch, each group was divided into three workshops with the task of developing criteria for a data and modeling strategy. The findings were reported back to the entire workshop, enabling final open discussion.

TABLE 3 Invited Participants in the Client Workshops

Organization type
Community groups
Transport associations
Transport research organizations
Consultants
NSW state government organizations
Academics
International
Interstate government organizations
Local government (NSW)
Other

The major outcome of the workshops can be divided into a reinforcement of the issues raised in the stakeholder interviews and major enhancements to assist in the development of the core components of a revised STIMS. Importantly, the workshops provided an opportunity for the broader set of clients to express their views on the requirements for STIMS to be useful to the client base as a whole. The initial stakeholder interviews closely accorded with the requirements of the broader client base; however, the workshops were essential in order to both confirm this agreement and to refine the issues raised. This reinforcement and clarification provided the confidence to move forward with the advice of the stakeholder set.

TAPPING THE INTERNATIONAL BODY OF EXPERTISE

Background

The analytical and applications experts represent the international body of knowledge on the state of the art and state of practice in travel data, networks, and models. As a group, they provide an important role in both assessing past and present practice as well as the state of the art which will spread into the state of practice over the next 10 years. We surveyed experts in 1995 to synthesize the international state of the art and the state of practice.

The experts' survey involved a first round identification of views of a sample of contributors drawn from mailing lists of various agencies and associations, such as the International Association of Travel Behavior Research, TMIP conference attendees, and members of the editorial advisory boards of the key journals in the field. The views were processed and summarized into key positions that were fed back to the panel in a second round to elicit further commentary. This process can, in principle, continue for a number of rounds, leading to the identification of key consensus and conflict positions. The information sought provides guidance on the seven areas set out in the stakeholder interviews. A formal survey instrument was designed so that there was a common base of information sought. The experts were asked to comment on tools of design and analysis and also to provide views on how to use data and models to improve community commitment to the process and to emergent issues. Issues of response, communication consultation support, and information sharing were also covered.

The first round instrument was faxed out to participants in the last week of July of 1995. Of the 40 forms faxed out, 34 completed forms were returned. Analytic expert goals for the survey included:

1. What can now be achieved?
2. What data is needed to achieve it (and what missing research is required to ensure this is useful)?
3. What are the most vulnerable areas in analytic tools to date?

Application expert goals for the survey included:

1. Where has data helped you?
2. What did you wish you had when it did not help?
3. What forms of models and analysis (if they worked) would be most useful? At what level of detail?
4. How would you suggest making the data collection useful to yourself? To your organization?
5. What do you need data and models for most: consultation, design, strategic planning, consultant use, etcetera?

The second round of the experts' survey provided feedback from both the analytical and application experts' outputs (round 1) to both groups, so that cross-fertilization of the debate evolved. It was hoped that the outcome would then be more balanced between possibilities and practicalities.

Findings of the First Round of the Experts' Survey

The major findings from the first round survey are summarized in a number of tables and figures. One-third of the responses is from Australia, with the United States and the United Kingdom representing 38% of the sample (table 4). There is a good spread of responses from Western Europe and Chile, the latter being very strong on land-use transport modeling. Approximately 50% of the respondents are academics; 25% are government employees, and the balance is composed of consultants (table 5). Figures 2 and 3 summarize the responses to a series of policy questions in which we sought to identify the most important issues in the last five years (figure 2) and the most important issues over the next five years (figure 3). The issues that ought to receive the greatest attention in the next five years are summarized in table 6.

The results are very informative. Road maintenance has been the most important issue in the last five years and is still seen as the number one issue. However, there was very strong support for transport pricing and integrated land-use transport planning as the two areas that ought to receive the greatest attention. These latter two areas have been

TABLE 4 Country in Which Respondents Work

Country	Number of respondents	Percentage of respondents
Australia	12	35.3
Canada	1	2.9
Chile	3	8.8
Germany	1	2.9
Netherlands	3	8.8
Norway	1	2.9
United States	9	26.5
United Kingdom	4	11.8
Total	**34**	**100.0**

TABLE 5 Type of Organization Where Currently Employed

Type of Organization	Number of respondents	Percentage of respondents
University	18	53
Government	9	26
Consultant	7	21
Total	**34**	**100**

FIGURE 2 Priority Issues for the Last Five Years, in Decending Order

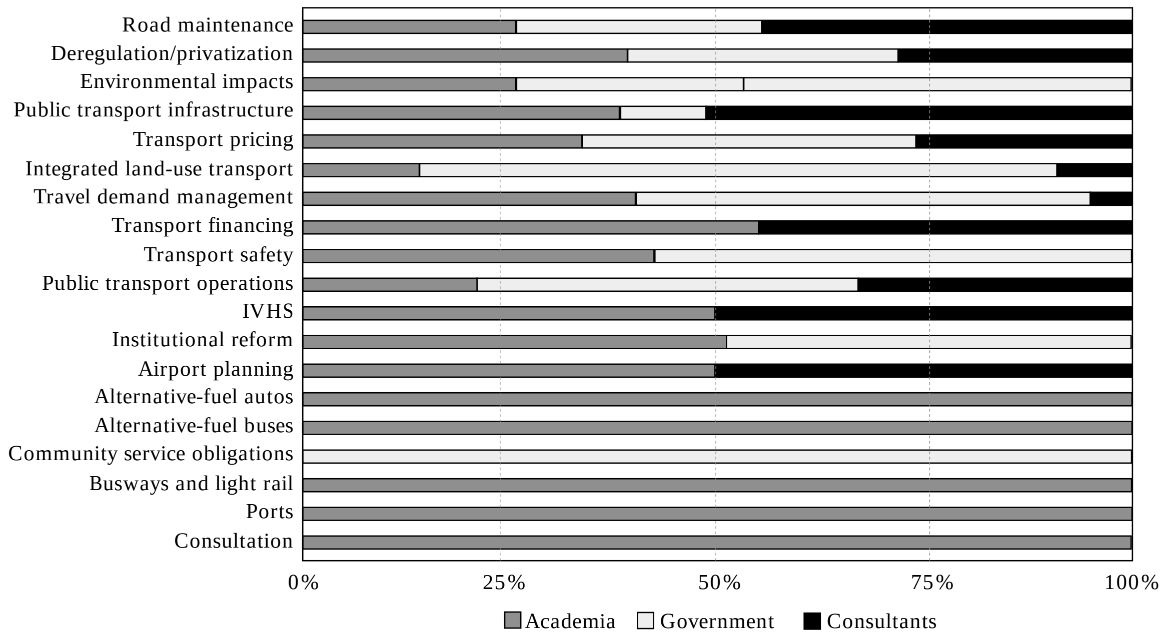
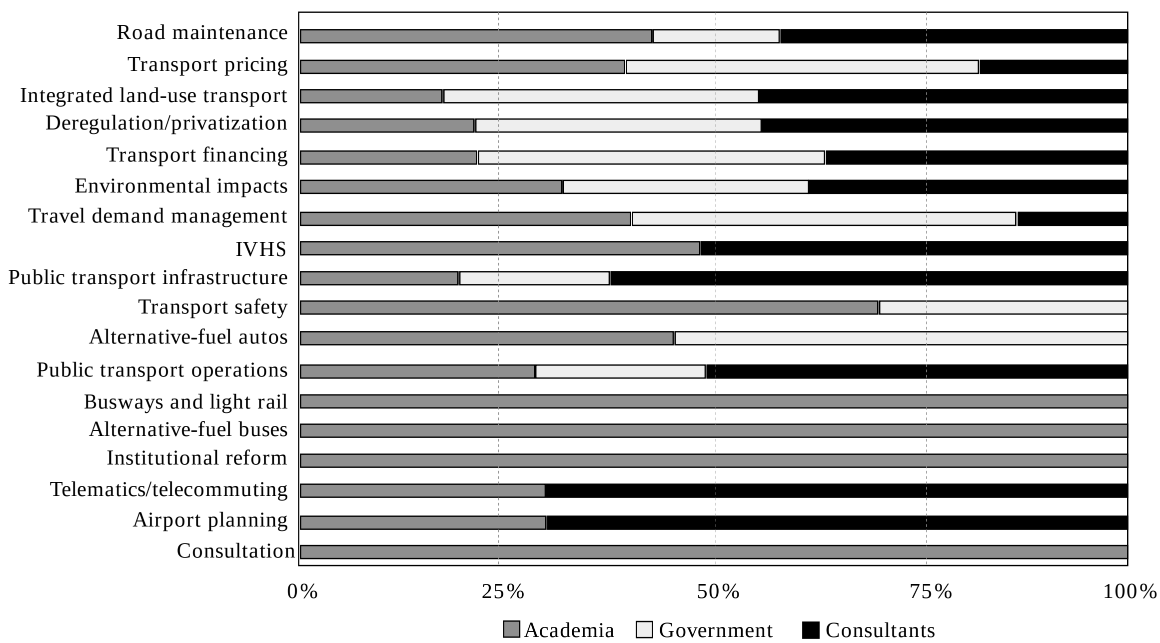


FIGURE 3 Priority Issues for the Next Five Years, in Decending Order



in the top six most important policy areas in the last five years and are likely to continue as high agenda items; the expert panel wishes to elevate them to the top two positions. Economic and environmental considerations have been and are thought to continue to be high agenda areas of policy, although the panel has repositioned environmental impacts somewhat lower in importance for receiving greater attention, implying that it is currently receiving an adequate level of attention, certainly relative to travel demand management and economic issues, such as pricing and deregulation/privatization. Intelligent transport systems is interpreted similarly to environmental impact. It is also seen as best studied by international agencies, as are the broad areas of transport pricing and the

TABLE 6 Priority Shifts Over Time

Priority	Observed in the last five years	Expected to be for the next five years	Ought to be for the next five years
1	Road maintenance	Road maintenance	Transport pricing
2	Deregulation/privatization	Transport pricing	Integrated land-use transport
3	Environmental impacts	Integrated land-use transport	Travel demand management
4	Public transport infrastructure	Deregulation/privatization	Road maintenance
5	Transport pricing	Transport financing	Telematics/telecommuting
6	Integrated land-use transport	Environmental impacts	Deregulation/privatization
7	Travel demand management	Travel demand management	Public transport infrastructure
8	Transport financing	Intelligent transport systems	Transport safety

environment. Telematics and telecommuting moved up substantially, reflecting a growing interest in this policy area.

The dominating role of road maintenance in the last and next five years is being put aside to promote more efforts in pricing, integrated transport and land use, and travel demand management. This reflects a growing interest in a more multimodal approach to transport planning in the past with a stronger emphasis on land use implications. There is a view overall, however, that efforts in the past and in the next five years to improve public transport infrastructure are well established on the policy agenda; what is needed is more emphasis on pricing, land use, and demand management. The same argument applies to transport financing, currently given adequate treatment. Support for greater levels of consultation (as compared to the recent past) is also apparent, even though it is not thought to be as important as the economic issues. Data and modeling agencies are well positioned to contribute to the development of a modeling system that can assist in the debate on alternative land-use transport strategies with a number of alternative scenarios for pricing and travel demand management.

Table 6, showing priority shifts, is complemented by figure 4, which shows the changes in views over time in order of priorities rated by the experts. The themes summarized in the last column in table 6 are the areas where expected priorities are felt to be set too low, and those above where they were (or are expected to be) set too high. The views expressed towards various research and model development areas provide one aspect of the expert opinion consensus but do not clearly indicate the directions where choices are likely to be made. A series of weighted questions were included to

FIGURE 4 Priority Issues in Recent Past

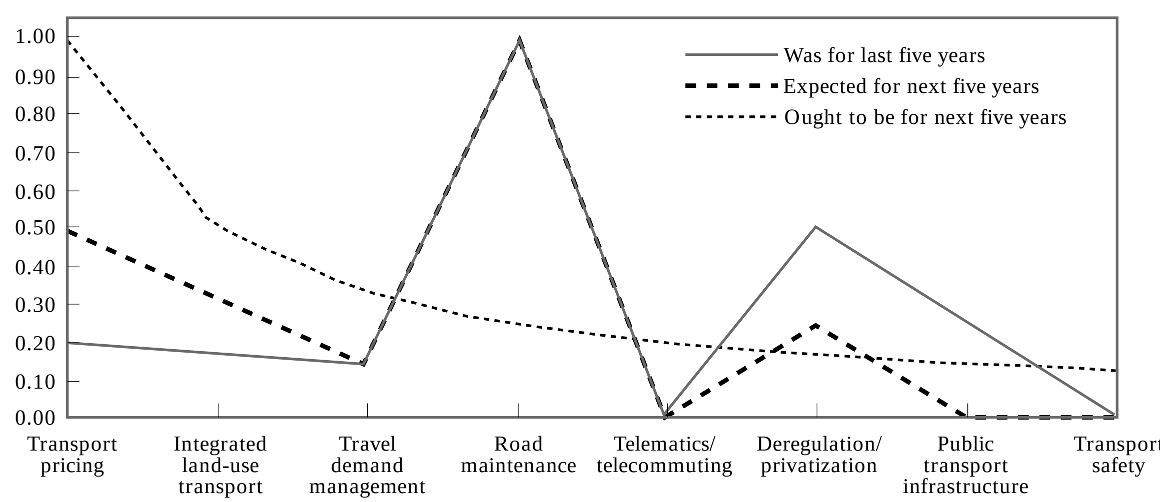
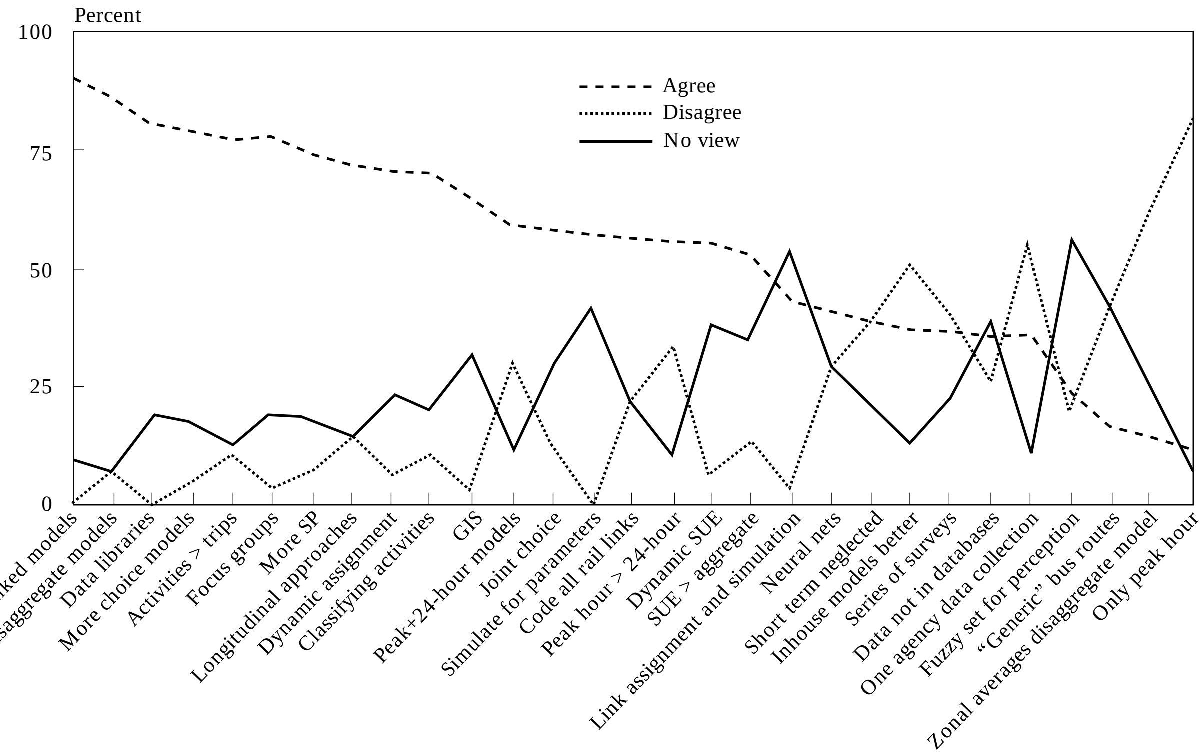


FIGURE 5 Priority Issues for the Near Future



probe further by eliciting opinions of this kind. Initially, it was felt that the survey had only mixed success, but when the responses are arranged in decreasing order of agreement (figure 5), the patterns become clearer.

There is a high degree of agreement on several issues. Traffic and travel demand models need to be more closely linked, and there is a need for greater use of dissagregate choice models and an emphasis on activities rather than trips. Dynamic assignment and classifying activities into mandatory, flexible, and optional categories, as well as an increased use of longitudinal surveys, were also supported. The need for transport data libraries was strongly endorsed, with no recorded disagreements at all. The use of geographical information systems (GIS) for modeling and data management was widely recognized as important. A few respondents were in favor of using only peak hour models, coding only generic bus routes, and keeping data in a simplified format and outside data management systems.

Table 7 summarizes the experts' views on where the expertise lies in each respondent's own country in 20 skill areas. Overall, the perceived expertise in most skill areas is currently seen to lie with consultants and universities, in contrast to any level of government. Highway networks stand out as having a competitive edge in expertise within the state government sector. Table 7 suggests that universities currently have the greatest amount of expertise in the design of surveys, samples, and questionnaires, as well as model estimation, calibration, forecasting, and application. Consultants appear to have an advantage in data collection, editing, entry, preparation, and management, as well as public transport networks. The distinction between survey design, data collection/preparation, and model estimation/application is quite pronounced. The federal government has virtually equal billing with universities and consultants in policy analysis, with state and local government falling behind in this area.

Overall, the views support the proposed emphasis of a data and modeling agency managing the survey and data aspects of STIMS and outsourcing the survey design and data collection as well as model estimation and calibration. The role of the government as the key data manager is noted. Government respondents showed an emphasis on

TABLE 7 Expertise of Different Organizations[1]

Skill area	Federal government	State government	Local government	Universities	Subsidized research organizations	Consultants
Project management	5.17 (2.69)	4.63 (2.69)	5.04 (1.87)	6.30 (2.49)	4.73 (2.69)	3.13 (1.87)
Survey design	6.14 (3.00)	6.75 (2.91)	7.09 (2.27)	3.00 (2.00)	3.67 (2.32)	3.92 (1.98)
Sample design	6.00 (2.93)	6.88 (2.85)	7.57 (2.09)	3.00 (2.28)	3.47 (2.29)	4.00 (1.98)
Questionnaire design	5.86 (2.98)	6.50 (2.94)	7.09 (2.43)	3.04 (2.24)	3.60 (2.64)	3.87 (2.17)
Data collection	6.10 (2.68)	6.13 (2.85)	6.52 (2.34)	4.48 (2.52)	4.27 (2.74)	3.33 (2.08)
Data editing and entry	6.44 (2.73)	5.93 (2.79)	7.11 (2.25)	4.15 (2.48)	4.27 (2.74)	3.41 (2.06)
Data preparation	6.37 (2.67)	6.00 (2.90)	6.95 (2.12)	4.05 (2.31)	4.13 (2.50)	3.57 (2.02)
Data management	6.48 (3.03)	5.94 (2.92)	6.68 (1.91)	4.24 (2.21)	4.93 (2.46)	3.78 (2.52)
Highway networks	5.57 (2.69)	3.95 (2.09)	5.27 (2.39)	5.24 (2.47)	6.75 (1.96)	4.09 (1.81)
Public transport networks	5.95 (2.82)	5.22 (2.62)	6.24 (2.68)	4.81 (2.29)	7.17 (1.85)	4.30 (2.12)
Model estimation	6.45 (2.65)	6.94 (2.33)	7.82 (2.17)	2.87 (2.38)	4.93 (2.73)	3.88 (1.57)
Model calibration	6.45 (2.76)	6.76 (2.41)	7.55 (2.18)	3.22 (2.66)	5.00 (2.63)	3.75 (1.67)
Travel forecasting	6.13 (2.63)	6.50 (2.22)	7.55 (2.46)	3.50 (1.92)	5.07 (2.40)	3.63 (1.84)
Training	6.15 (2.32)	6.69 (2.60)	7.65 (2.11)	2.84 (2.46)	5.77 (2.01)	4.91 (1.81)
Model application	5.73 (3.10)	5.89 (2.52)	6.45 (1.95)	3.43 (1.43)	4.71 (1.98)	3.46 (1.79)
Transport economics	4.61 (2.19)	6.31 (3.05)	8.05 (1.93)	3.09 (2.43)	4.64 (2.02)	4.45 (2.13)
Consultation	6.85 (2.41)	6.64 (3.00)	5.90 (3.26)	4.76 (2.19)	5.15 (1.91)	3.40 (2.19)
Project evaluation	5.09 (2.50)	5.33 (2.74)	6.55 (2.24)	4.86 (2.48)	6.00 (1.65)	3.61 (1.97)
Policy analysis	4.20 (2.80)	5.22 (2.53)	6.82 (1.74)	4.50 (2.00)	5.47 (2.00)	4.52 (1.83)
Tabular analysis	4.50 (1.86)	4.73 (2.15)	5.93 (1.73)	3.20 (1.61)	4.00 (2.05)	3.29 (2.02)

[1] Figures are mean ratings, with standard deviation in brackets.
1 = very good, 20 = very poor.

land-use transport and transport pricing, probably reflecting concern over the increasing difficulties in financing new infrastructure. They also noted the necessity of having a sound integrated planning framework to maintain control as more partnerships and private financing are used.

Table 8 summarizes the most common sources of frustration in accessing information from each of the three agency types. The items identified in the government sector are echoed in the stakeholder and workshop commentary. The addition of concerns from other participating organizations adds another dimension. Problems do occur outside of the government sector, most notably in the areas of documentation, expense, organization, and property rights.

Participants were asked to rate over 30 areas of research in terms of their potential impact in applications aimed at improving our understanding and forecasting of travel behavior. To enable us to identify the hierarchy of travel models in an integrated model system, the panelists were asked to rate various models in the application contexts of noncommuting, commuting, household activities, firm activities, and freight/commodity movements.

The research areas have a mean rating varying

TABLE 8 Common Frustrations in Accessing Data from Various Agencies (in order of frequency of response)

Government	Private data agencies	Universities
Delays in access	Expense	Lack of documentation
Confidentiality restrictions	Data too specialized	Disorganized approach
Poor staff response	Poor documentation	Inappropriate data
Knowledge of what is available		Uncertain property rights
Expense		

from 3.5 to 7.9 on a 10-point scale. Activity modeling, stated preference methods, location-based choice models, and the implementation of a GIS spatial database lead in relative importance. Stakeholders and participants in the workshops referred to all of these research areas on many occasions. The correspondence between the three consultation instruments is most encouraging. The next research areas were joint modeling of stated and revealed preferences, measuring accessibility, dynamic traffic assignment, and travel market segmentation. Once again, these topic areas reflected a broad view of where the main action should be focussed. Dynamic traffic assignment accords with the interest in trip timing and peak spreading; travel market segmentation reflects the concern expressed in the workshops that we need to develop more useful market segments to reflect the growing complexity of activity and travel behavior.

While not denying the relative importance of other listed topic areas (16 additional areas with an average rating greater than 5.0), the evidence from the experts' survey (round 1) supports a focus on activities rather than trips per se; richer market segments for activity differentiation; the ability to accommodate a much wider set of travel and location choices, as supported by stated preference data, enabling the analyst to enrich the revealed preference data in contexts not readily observed in the market but possibly supportable in future land-use transport strategies; and the need to use GIS as an integrating and presentational tool.

The final section of the experts' survey sought opinions on 29 statements. Respondents were asked to agree, disagree, or express no view on each statement. They were also asked to indicate whether they thought that implementation is feasible today for the approach in each statement and whether they have implemented any of the policies underlying each statement (tables 9, 10, and 11). Agreement with each statement varied from 11 to 90%. The most agreed on statement was "traffic simulation and travel demand models should be linked" (statement 8). The least agreed on statement was "a city only needs a peak hour model." Once again we see evidence to support a trip timing choice model, dynamic traffic assignment, and the integration of travel and traffic models into a spatial decision support system associated with a GIS architecture so that results can be presented at all levels of spatial detail with in respect to traffic movements. The "no view" response was as high as 57% for "fuzzy set theory should be used to model user perceptions" and as low as 7% for "a city only needs a peak hour model" and "models such as mode choice should be disaggregate." A careful assessment of the results in table 9 confirms the support from analytical and applications experts for an approach to modeling that is flexible in the level of disaggregation of data and model estimation, that spawns a widening set of behavioral models to reflect the impacts of peak spreading and noncommuting activity, and that promotes the ideas of longitudinal data, stated preference methods, and activity-based approaches to modeling travel behavior.

In evaluating the feasibility of translating state of the art ideals into practice, much can be achieved. Feasibility across the set of statements varies from a low of 76% to a high of 100%. Indeed, in the areas of interest for the data and modeling agency's strategy highlighted in all dimensions of the consultation process, the level of feasibility as indicated by the expert panelists is in excess of 90%, except for dynamic traffic assignment (87%) and activity data and models compared to trip-based approaches (76%). The activity approach, however, had the fourth highest percentage of "agrees," suggesting that it is an important strategy. The statement combines activity data and activity models, the latter being the true challenge. The support of the consultation participants is essentially in the area of activity diaries with more conventional behavioral model specifications.

Figure 6 summarizes the implementation profile of the participants with respect to the items in the statements. There is a relatively high incidence on nonimplementation (ranging from 100% for fuzzy set theory to 38% for peak hour models). Typically, over 40% of the respondents have implemented, or are in the process of implementing, many of the approaches listed. This question must be handled carefully because many of the participants are specialized researchers not actively undertaking research in many of the areas, though they do have an appreciation of their relevance.

TABLE 9 Experts' Survey Results: Where Should the State-of-Practice Lie?

Statement	Agree	Disagree	No view
Activity data and models more useful than trip-based approaches	77%	10%	13%
Longitudinal data and models should replace static approaches	72%	14%	14%
Focus groups useful to understand household decisionmaking	77%	3%	20%
Should be greater use of SP questions in surveys	74%	7%	19%
GIS should be used for database management and model integration	65%	3%	32%
Data should be held in simple forms rather than databases	35%	26%	39%
Stochastic simulation should replace deterministic aggregate extrapolation	53%	13%	34%
Traffic simulation and travel demand models should be linked	90%	0%	10%
The use of disaggregate choice models should be expanded	79%	4%	17%
Simulations should be used to develop stable travel model parameters	57%	0%	43%
Joint choice decisions should be modeled in preference to sequential models for many travel choices	58%	13%	29%
A city only needs a peak hour model	11%	82%	7%
A city needs both a 24-hour and peak hour model	59%	30%	11%
Models such as mode choice should be disaggregate	86%	7%	7%
Disaggregate models should use zonal averages	14%	62%	24%
Stochastic user equilibrium should be extended to dynamic assignment	55%	6%	39%
Current traffic assignment should be replaced by dynamic assignment processes	71%	6%	23%
Peak hour models are a better option than 24-hour models	56%	33%	11%
Traffic assignment models should be linked with traffic simulation	43%	3%	54%
Every rail line should be coded on the network	57%	21%	22%
Bus routes should be represented as "generic" routes to reflect a corridor	16%	42%	42%
Fuzzy set theory should be used to model user perceptions	23%	20%	57%
Use of neural networks (or similar) should be expanded	41%	29%	30%
Classifying activities into mandatory, flexible, and optional is a behaviorally useful way to recognize possible variability	70%	10%	20%
Developing in-house models rather than purchasing models leads to better forecasting/planning	37%	50%	13%
There should be a transport research data library established in each country which can be accessed worldwide	81%	0%	19%
Core travel data for an urban area should be collected by one agency	35%	55%	10%
Short and medium term forecasting is often neglected in favor of long term forecasting	39%	39%	22%
Travel surveys should evolve from a single large survey to a series of smaller integrated surveys usually with a single goal	37%	40%	23%

The findings from the first round of the experts' survey were fed back to the 34 participants in a second and final round. Each participant was invited to comment on each set of findings by providing an open ended comment on each table and figure. The aim was to elicit any particular view in relation to the contents in order to establish any variation in views which might qualify the interpretations above. The feedback form, mailed out in late September, gave almost unanimous support for the material harnessed in the first round.

CONCLUSIONS AND THE FUTURE

Managing the transport assets of an urban economy and ensuring that change is in accordance with suitable performance measures requires continuing improvement in the support of analytical power and empirical information. One crucial input in any ongoing review of data and modeling capability for improving planning and policy support is a recognition of the role of stakeholders and the impact they can have in supporting the ongoing commitment to implementing a state of practice data and modeling strategy.

The recommendations from this review process have largely been acted on in NSW for passenger transport but remain a challenge for urban freight. There is now an active program of ongoing data collection with approximately 3,000 home interviews undertaken annually in Sydney since 1999. In addition, a new Sydney Travel Model capability

TABLE 10 Experts' Survey Results: Is Implementation Feasible Today?

Statement	Agree	Disagree
Activity data and models more useful than trip-based approaches	76%	24%
Longitudinal data and models should replace static approaches	92%	8%
Focus groups useful to understand household decisionmaking	100%	0%
Should be greater use of SP questions in surveys	96%	4%
GIS should be used for database management and model integration	96%	4%
Data should be held in simple forms rather than databases	100%	0%
Stochastic simulation should replace deterministic aggregate extrapolation	94%	6%
Traffic simulation and travel demand models should be linked	91%	9%
The use of disaggregate choice models should be expanded	100%	0%
Simulations should be used to develop stable travel model parameters	94%	6%
Joint choice decisions should be modeled in preference to sequential models for many travel choices	90%	10%
A city only needs a peak hour model	96%	4%
A city needs both a 24-hour and peak hour model	100%	0%
Models such as mode choice should be disaggregate	96%	4%
Disaggregate models should use zonal averages	95%	5%
Stochastic user equilibrium should be extended to dynamic assignment	80%	20%
Current traffic assignment should be replaced by dynamic assignment processes	87%	13%
Peak hour models are a better option than 24-hour models	100%	0%
Traffic assignment models should be linked with traffic simulation	100%	0%
Every rail line should be coded on the network	100%	0%
Bus routes should be represented as "generic" routes to reflect a corridor	100%	0%
Fuzzy set theory should be used to model user perceptions	78%	22%
Use of neural networks (or similar) should be expanded	93%	7%
Classifying activities into mandatory, flexible, and optional is a behaviorally useful way to recognize possible variability	100%	0%

FIGURE 6 Priority Shifts Over Time

Arranged by leading indicator with 1 as the highest priority

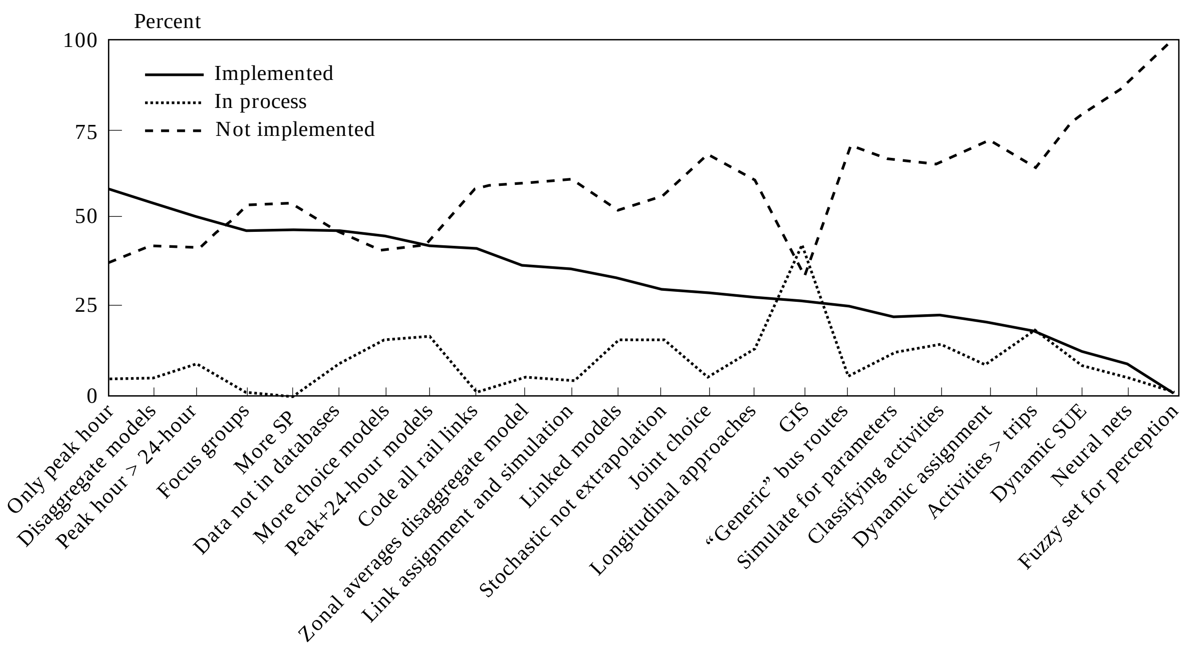


TABLE 11 Experts' Survey Results: Have You Implemented These Policies?

Statement	Implemented	In process of implementation	Not implemented
Activity data and models more useful than trip-based approaches	18%	18%	64%
Longitudinal data and models should replace static approaches	27%	12%	61%
Focus groups useful to understand household decisionmaking	46%	0%	54%
Should be greater use of SP questions in surveys	46%	0%	54%
GIS should be used for database management and model integration	26%	41%	33%
Data should be held in simple forms rather than databases	46%	8%	46%
Stochastic simulation should replace deterministic aggregate extrapolation	29%	15%	56%
Traffic simulation and travel demand models should be linked	33%	15%	52%
The use of disaggregate choice models should be expanded	44%	15%	41%
Simulations should be used to develop stable travel model parameters	22%	11%	67%
Joint choice decisions should be modeled in preference to sequential models for many travel choices	28%	4%	68%
A city only needs a peak hour model	8%	4%	38%
A city needs both a 24-hour and peak hour model	42%	16%	42%
Models such as mode choice should be disaggregate	54%	4%	42%
Disaggregate models should use zonal averages	36%	4%	60%
Stochastic user equilibrium should be extended to dynamic assignment	12%	8%	80%
Current traffic assignment should be replaced by dynamic assignment processes	20%	8%	72%
Peak hour models are a better option than 24-hour models	50%	8%	42%
Traffic assignment models should be linked with traffic simulation	35%	4%	61%
Every rail line should be coded on the network	41%	0%	59%
Bus routes should be represented as "generic" routes to reflect a corridor	25%	5%	70%
Fuzzy set theory should be used to model user perceptions	0%	0%	100%
Use of neural networks (or similar) should be expanded	8%	4%	88%
Classifying activities into mandatory, flexible, and optional is a behaviorally useful way to recognize possible variability	22%	13%	65%

utilizing this new household data and updated highway and public transport networks for five times of day has been designed. Components of the new model system were finalized at the end of 1999, with a focus on car ownership and driving license holdings, as well as trip frequency, trip destination, and mode choice for the journey to work tours. Ongoing implementation of a nonwork travel capability commenced in 2000. To ensure continuous relevance of the data and modeling process, a permanent technical advisory group is in place with representation from key stakeholders.

Good practice in data collection supports an ongoing survey process that guarantees the timeliness and representativity of activity data in general and travel data in particular. The data should be sufficiently rich to capture the diversity of behavioral responses to the transport systems offerings (notably responses to traffic congestion). Such data should include a mixture of description of current activity as well as stated response data that enables analysts to gauge the degree of behavioral sensitivity to policies that offer opportunities and solutions outside the domain of market experience.

Although it might be argued that there is sufficient stability in individual preferences, constraints, and likely behavioral responses to limit data collection to regular periods (e.g., every five years), there are other good reasons for promoting an annual survey process. The most important reason is budgetary and the flow through implications on the resourcing of expertise to maintain its currency of knowledge of data and modeling. It is easier to secure smaller sums of financial support annually than to seek a substantial financial commitment periodically.

With new technologies now available to track activity and travel behavior (e.g., GPS systems and the Internet), the future strategies for data collection per se are likely to be a mixture of direct and indirect methods. In selecting a data collection method, one has to recognize that although one can track actual travel movements of an individual or a vehicle using GPS-linked systems (as in TRANSIMS), essentially replacing paper and pencil cordon surveys, an understanding of behavior and behavioral response requires direct contact with a respondent. The Internet offers real promise in geographical settings where it is widespread, replacing the telephone and fax as the future communication medium. The ability to provide attractive survey forms and real time data capture methods via the Internet makes it the prime contender for ongoing data collection in both passenger and freight activity.

The accumulation of ever-rich data for descriptive interpretative analysis and formal modeling, as well as the growing desire by stakeholders for direct access to outputs (and in some cases to the entire data and modeling process), will require more sophisticated data management systems than we currently have. In particular, the Internet will become a central mechanism for documentation and access to the data systems and models, eventually facilitating the application of the travel model system directly from the Internet, possibly by a subscription service in order to at least recover the value-added element.

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Estimating Statewide Truck Trips Using Commodity Flows and Input-Output Coefficients

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ABSTRACT

This study uses commodity flows from the 1993 Commodity Flow Survey (CFS) together with Input-Output (I-O) coefficients to generate truck flows for the state of Wisconsin. Production and attraction rates in tons, for the heavy truck mode only, were derived at the county level using employment for 28 economic sectors. The CFS, a joint product of the Bureau of Transportation Statistics and the U.S. Bureau of the Census, together with a private database developed for the state, TRANSEARCH, was used to derive the trip production rates. Economic-based I-O software was used to derive the I-O coefficients at the state level in order to develop trip attraction rates. Annual tons at the county level were converted to daily truck trips using an average tons-per-vehicle load and a days-per-year factor. The resulting trips were disaggregated to the Traffic Analysis Zone (TAZ) level using zonal population as a disaggregation factor. Truck trips for four trip types were derived: Internal-to-Internal, Internal-to-External, External-to-Internal, and External-to-External to the state. In order to assess the accuracy of the generation procedure, another more comprehensive study distributed and assigned the estimated trips to

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the state network following the traditional four-stage Urban Transportation Planning modeling process. The results of comparing the estimated truck flows to ground counts for selected network links show that the overall model performed well, indicating that the generation procedure produced a reasonable estimation of statewide truck trips.

INTRODUCTION

This research deals with the forecasting of freight at the statewide level. The forecast of goods in urban areas has been extensively explored, and some forecasts employ computer modeling programs that are relatively well developed. The recently released *Quick Response Freight Manual* (Cambridge Systematics 1996) is a good example of such development in the forecasting of urban truck trips. On the other hand, at the state level many truck forecasting models in the United States were developed by state departments of transportation following state planning proposals, often including passenger forecasting.

Many states use trend line analysis to estimate and forecast statewide truck travel (Park and Smith 1997). These studies will not be fully detailed here because most rely on traffic counts and the base year Annual Average Daily Traffic (AADT) to estimate future traffic growth factors (Huang 1998). It is believed that the demand for freight is better explained when derived from economic activities rather than from traffic counts and projections. In addition, interaction between links is ignored when a trend line approach is applied to statewide truck travel estimations.

To forecast truck flows, other states use standard travel demand models, such as the four-stage and network-based models. These models, however, require costly Origin-Destination (O-D) survey data for calibration. Oregon and Wisconsin have developed network-based models. The TRANSLINKS 21 project developed for Wisconsin (TRANSEARCH 1996) explored commodity flow data to forecast freight demand in an intermodal feasibility study. Growth factors were used to estimate future truck traffic flows.

The problem of the cost of O-D survey data can be mitigated if a direct O-D trip matrix estimation is applied. Models based on the principles of information minimization and entropy maximization (Van Zuylen and Willumsen 1980) can be used to estimate the direct O-D trip matrix from traffic counts. Solution of the entropy maximization model involves, however, a nonlinear programming formulation.

Data availability is the most critical factor in developing a statewide truck demand model. Techniques that can be used as analytical tools also have some drawbacks. The simple trend line analysis and growth factor models are costly and cannot effectively estimate future traffic for long-range planning purposes. Entropy maximization techniques may be useful for small networks but require an initial trip table for estimation of the direct O-D trip matrix, and the forecasting of future travel demand is limited to a simple Fratar expansion. Adapted Urban Transportation Planning models provide the most effective approach for statewide truck forecasting if truck trip productions and attractions can be easily estimated.

The Commodity Flow Survey[1] (USDOC 1996b) shows that local transportation of freight is important to the economy of Wisconsin since in 1993 roughly 35% of the value and 70% of the weight of the total shipments from the state were shipped to destinations within the state. In addition, the survey shows that most commodities originating in Wisconsin were moved specifically by truck: about 84% of the value and 88% of the weight.

Current research in freight relies on a limited source of data for truck forecasting, based mainly on either expensive and time-consuming truck traffic surveys or inefficient truck traffic counts. In the latter case, the studies fail because trend analysis using traffic counts shows little relationship between the growth of truck traffic and possible explanatory variables. The Minnesota Department of Transportation study (MinDOT 1985), the New Mexico Department of Transportation procedure (Albright 1985), the methodology developed for the Maryland Department of Transportation (Sirisonponsilp and Schonfeld 1988), and the comprehensive Michigan Statewide Travel Demand Model (Nellet et al. 1996)

[1] The Commodity Flow Survey is a joint program of the Bureau of Transportation Statistics and the U.S. Bureau of the Census. Additionally, the Federal Highways Association provided financial support for the 1993 edition.

provide examples of methods that use trend line and growth factors based on Annual Average Daily Traffic (AADT) to estimate and to forecast truck travel. A better way to generate truck trips is to use a commodity-based approach together with, for example, Input-Output (I-O) coefficients.

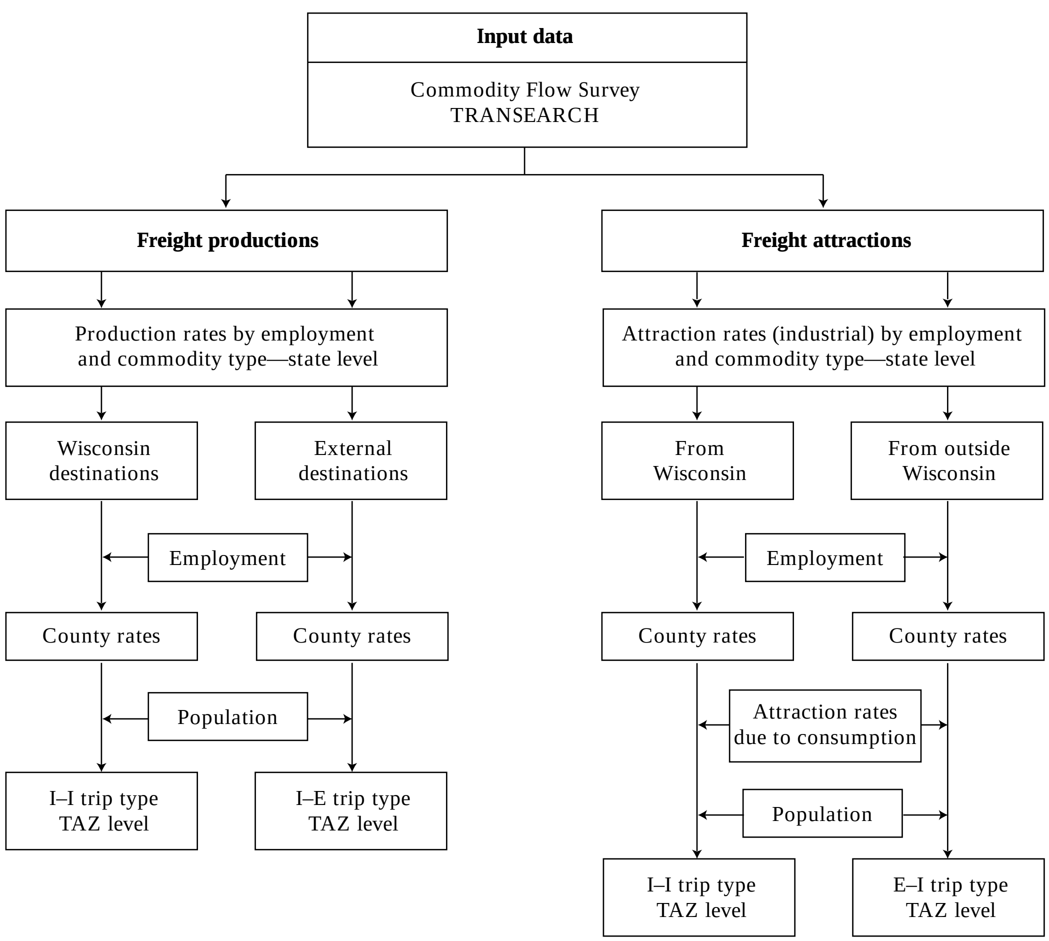
The National Cooperative Highway Research Program (NCHRP 1983) addressed the need for a freight-oriented planning process with one of the main requirements being the preparation of the freight components of statewide master plans. Also, the resulting freight model should use vehicle or commodity flow data as major inputs rather than vehicle count or frequency data alone. Thus, freight traffic projections should be based on economic activity instead of trend extrapolation.

The resulting technique mainly utilizes commodity and employment data together with I-O coefficients in order to improve the truck trip generation process. The procedure was used in the four-stage model. As a result, the state may have a forecasting model that can be applied in the state planning process when heavy truck trips for major commodities need to be estimated. The overall algorithm followed in this study is shown in figure 1.

FREIGHT GENERATION

Freight generation and distribution are normally separate phases when simulation techniques, such as the I-O technique, are used to estimate commodity flow data. In this study, the I-O technique will be used to estimate freight attractions for Wisconsin for 1992. Freight production will be estimated through use of the 1993 Commodity Flow Survey (USDOC 1996c) with complementary data from a private database, TRANSEARCH. TRANSEARCH, which has been produced annually by Reebie Associates since 1980, provides ori-

FIGURE 1 Production and Attractions Rates



gins and destinations of commodity flows for all 72 counties in Wisconsin and for another 70 external zones, including some Canadian zones. The database has been used extensively by the Wisconsin Department of Transportation (WisDOT) since then. Also, the database has a strong relationship with the Commodity Flow Survey in terms of commodity classification and truck type studied. The overall procedure for deriving production and attraction of truck flows is detailed in the following sections.

FREIGHT PRODUCTION MODEL

Freight production can be inferred from various measures of economic activity, such as monetary measures and employment data by economic sector. Monetary values are converted to physical units, tons, with commodity attributes files (NCHRP 1983), provided that an average value-per-ton of each commodity is known. Employment data from the Census are used to convert state production in tons, stratified by the Standard Transportation Commodity Classification (STCC) (two-digit level in the CFS) first to production rates by sector at the state level (tons per employee) and later to the county level in tons. County tons by sector are further disaggregated to the Traffic Analysis Zone (TAZ) level using population as a disaggregator since at the TAZ level there are no reliable employment data available.

For this study, the 1993 CFS database provided information on 23 economic sectors out of the 28 under study. Table 6 in the CFS report (USDOC 1996c) for Wisconsin provides monetary values, tons, and percentage shipped for the state by private and for-hire truck modes.

Table 1 shows the 28 economic sectors analyzed in this study. The sectors were mainly manufacturing sectors, chosen by data availability, if they were hauled by truck, and if they matched the sectors used by the IMPLAN software in the attraction model. According to the CFS report (USDOC 1996c), sectors 09, 13, 27, and 38 did not meet publication standards, and sector 10 had its figures withheld so as to avoid disclosing data of individual companies. Thus, production tons for these five sectors were borrowed from the TRANSEARCH database.

TABLE 1 Selected Economic Sectors

SIC–STCC[1]	Sector	Tons per truck[2]
01	Farm products	24
08	Forest products	13
09[a]	Fresh fish and other marine products	06
10[a]	Metallic ores	24
13[a]	Crude petroleum, natural gas, and gasoline	14
14	Nonmetallic minerals	19
19	Ordinances and accessories	24
20	Food and kindred products	18
21	Tobacco products, excluding insecticides	05
22	Textile mill products	05
23	Apparel and other finished textile products	03
24	Lumber and wood products, excluding furniture	15
25	Furniture and fixtures	03
26	Pulp, paper, and allied products	16
27[a]	Printed matter	09
28	Chemicals and allied products	22
29	Petroleum and coal products	19
30	Rubber and miscellaneous plastic products	04
31	Leather and leather products	03
32	Clay, concrete, glass, and stone products	23
33	Primary metal products	19
34	Fabricated metal products	24
35	Machinery, excluding electrical	09
36	Electrical machinery, equipments, and supplies	08
37	Transportation equipment	12
38[a]	Instruments, photographic and optical goods	05
39	Miscellaneous products of manufacturing	02
40	Waste and scrap materials	16

[1] SIC = Standard Industrial Classification
STCC = Standard Transportation Commodity Classification
[2] Source: TRANSEARCH database (TRANSEARCH 1996)
[a] Sectors with production tons from the TRANSEARCH database (TRANSEARCH 1996)

Table 2, column 3, shows the total freight production rates in tons per employee for the state of Wisconsin. Annual tonnage shipped by the private and for-hire truck modes by the 28 sectors for 1992 was obtained from the CFS and the TRANSEARCH database. Employment data by sector, column 2, were provided by the *County Business Patterns* (USDOC 1994) from the Census.

The CFS CD-ROM (USDOC 1996c) gives information on commodities transported from state of origin to state of destination for all 50 U.S. states. Tons are stratified by commodity type and by all modes of transportation, including truck, rail, air, water, and pipeline. The truck share from the CFS (USDOC 1996c), table 6, was applied to derive truck tons. In a later step, this procedure was used to derive the freight production table for

TABLE 2 Freight Production Table for the State of Wisconsin

STCC	(1) Employment (1992)	(2) Total production (tons/employee)	(3) Destination inside state (tons/employee)	(4) Destination outside state (tons/employee)
01	67,959[a]	104.95	59.12	45.82
08	149	7,159.53	7,159.53	0.00
09	11	13.27	0.00	13.27
10	90	5.12	0.00	5.12
13	90	0.51	0.00	0.51
14	2,749	13,050.93	12,337.73	713.20
19	1,005[b]	5.17	0.00	5.17
20	53,244	476.15	241.85	234.30
21	1,109[c]	15.90	15.04	0.86
22	2,965	50.25	26.74	23.51
23	6,404	36.70	10.43	26.26
24	26,751	461.07	347.22	113.85
25	14,468	28.13	5.70	22.43
26	44,677	212.03	92.37	119.67
27	49,717	13.29	8.89	4.40
28	11,119	402.91	230.26	172.65
29	297	65,343.43	54,190.82	11,152.62
30	25,927	44.97	15.04	29.93
31	7,106	22.09	4.48	17.62
32	9,072	1,451.83	1,254.88	196.94
33	22,997	163.28	78.04	85.24
34	52,700	40.65	17.20	23.45
35	94,271	16.43	4.16	12.27
36	40,447	22.84	7.15	15.69
37	27,725	78.09	7.52	70.56
38	16,351	3.68	0.61	3.07
39	11,005	33.08	6.63	26.44
40	2,490[d]	1,022.49	698.26	324.23
Sum	**592,895**			

[a] Farms from Census of Agriculture (USDOC 1996a)
[b] SIC 348
[c] From wholesale trade (SIC 5194)
[d] From wholesale trade (SIC 5093)

the state with destinations within the state, the Internal-to-Internal trip type (I-I), and for external destinations, the Internal-to-External trip type (I-E). Table 2, column 4 shows freight production rates in tons per employee for Wisconsin, with only Wisconsin destinations which was used to derive the I-I trip type. Table 2, column 5 shows freight production rates in tons per employee for Wisconsin with only destinations outside the state used, to derive the I-E trip type.

Employment data from the *County Business Patterns* report (USDOC 1994) were used to derive and disaggregate the tons produced from the state level to the county level. Production rates in table 2 multiplied by the number of employees for each sector in each county produced 72 tables, one for each county in Wisconsin.

Table 3 shows the 1993 production tons with destinations internal and external to Wisconsin. The county figures in table 3 do not match the state figures in table 2 because the employment data for counties are not added to the state total in the *County Business Patterns* report. This is because much of the employment information for counties is presented in ranges of employees (e.g., B = from 20 to 99 employees) to avoid the identification of individual firms. For this reason, an average value was applied in this study. The tonnages in table 3, however, are close to the state total.

The next step is to disaggregate the production tons from the county level to the TAZ level so that the estimated truck flows can be compared to ground counts. Employment is a more reliable factor for the disaggregation, but there is no information available on employment by economic sector

TABLE 3 County Production Table (Wisconsin Internal and External Destinations)

STCC	Internal destinations (tons)	External destinations (tons)
01	4,017,881	3,114,119
08	2,641,867	0
09	0	1,062
10	0	359
13	0	36
14	35,273,562	2,039,040
19	0	4,320
20	12,844,193	12,443,527
21	17,088	980
22	77,798	68,387
23	66,825	168,175
24	9,297,398	3,048,590
25	81,573	320,982
26	4,059,096	5,258,696
27	443,712	219,870
28	2,621,081	1,965,288
29	18,208,115	3,747,279
30	386,842	770,028
31	32,572	128,118
32	11,001,576	1,726,616
33	1,823,547	1,991,868
34	930,246	1,268,536
35	392,229	1,157,461
36	289,247	634,479
37	209,308	1,963,111
38	9,764	49,257
39	72,617	289,399
40	1,967,009	913,345
Sum	**106,765,145**	**43,292,928**

at the TAZ level. Consequently, population was used as the disaggregation factor. After the disaggregation, 624 tables resulted, showing the tons produced by each of the 28 sectors at each of the 624 TAZs in the state.

The TRANSEARCH database has information on tons per truck by commodity type. The annual tons at each TAZ divided by the tons per truck from TRANSEARCH resulted in the annual truck trips generated at each TAZ. Yearly truckloads were then divided by 312 (6 days per week multiplied by 52 weeks per year) to estimate daily truck trips. Tons per truck by commodity for the 28 two-digit STCC code sectors are shown in table 1.

DERIVATION OF FREIGHT ATTRACTIONS

Deriving freight attractions is not as straightforward as deriving freight productions. Considered final demand, the consumption of commodities by processing industries and by consumers equals freight attractions. Freight is also attracted by physical distribution centers. This study used the Input-Output analysis to derive the industrial and consumption attractions. The procedure for deriving I-O coefficients, county level attractions, and TAZ level attractions follows.

THE BASICS OF INPUT-OUTPUT ANALYSIS

The Input-Output (I-O) model has had a substantial theoretical and empirical appeal as a tool for national and regional economic analysis since its development in 1936 by Wassily Leontief. Input-Output analysis attempts to quantify, at a point in time, the economic interdependencies in an economy, such as a nation, state, or county. All economic activity is assigned to one of two types of sectors: production or final demand. Production sectors (e.g., agriculture, manufacturing, services, trade, etc.) represent all establishments in the region producing a specific product or service. Final demand may include households, government, foreign trade, or inventory. These are sectors where the level of activity is assumed to be determined by forces external to the model, such as a government policy (Otto and Johnson 1993).

The most important assumption made in I-O analysis is that the inputs used in production are proportional to the output. The amount of a product (good or service) produced by a given sector in the economy is determined by the amount of that product purchased by all users of the product. Users include other industrial sectors using the product as input in the production of their own products, collectively referred to as intermediate demand, as well as sectors that use the product in its final form, collectively referred to as final demand. The flow of products between sectors is measured in monetary values and referred to as transactions between the various sectors (Otto and Johnson 1993).

It is necessary to establish an I-O model specific to the region in order to use the I-O framework for regional analysis. Three prescribed tables (or matrices) form an I-O model: the transactions table, the direct requirements table, and the total (direct, indirect, and induced) requirements table. The transactions table shows the interaction between the various sectors in an economy, providing a snapshot of all the economic activity in the economy at a point in time. The data from the transactions table can be used to derive the direct requirements table, which shows how much of each input is required to produce one monetary value of output. From the direct requirements table, a table of total requirements can be determined, showing the impact of a change in any particular sector or combination of sectors on the entire economy.

Industries producing goods and services for final users (final demand) purchase goods and services (direct purchases) from other producers. These other producers, in turn, purchase goods and services as well (indirect purchases). The induced effects are due to the effects of household expenditures, and they can be obtained from a set of multipliers as a result in the total requirements table. This buying of goods and services continues until leakages from the region (imports) stop the cycle. Therefore, purchases for final use drive the I-O model.

A tremendous amount of data is required to create regional I-O models. The cost of surveying industries within each region to obtain the list of commodities purchased in order to derive the production function of the model is often prohibitive. However, since many times we are only interested in a specific economic sector or industry, the data requirement problem is mitigated. In addition, computer software packages, such as the IMPLAN Professional, provide a database for the development of I-O models at the national, state, and county levels. Therefore, given the necessary amount of data, the I-O models can be used for both forecasting and economic impact analysis. Figure 2 shows the I-O production functions.

The basic Leontief production function can be represented analytically as in equation (1):

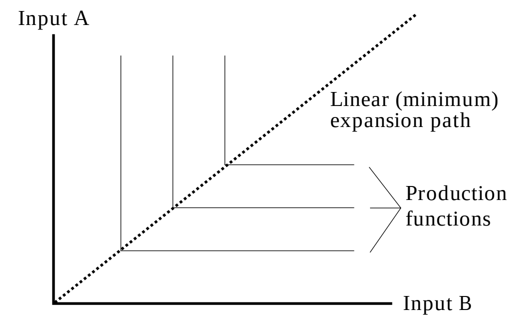
$$Z_{ij} = a_{ij} X_j \tag{1}$$

where:

Z_{ij} = interindustry sales from sector i to sector j,
a_{ij} = technical coefficients, and
X_j = total output of sector j in monetary value terms.

The model revised in matrix format is shown in equation (2):

FIGURE 2: Input-Output (Leontief) Production Function



$$X = AX + Y \tag{2}$$

where:

X = output matrix,
A = technical coefficients matrix, and
Y = final demand vector.

A change in percentage in final demand creates changes in other sectors. Other sectors change their output through increases in input, creating further changes of a diminishing magnitude. The revised final matrix format representing the changes follows:

$$\Delta X = (I–A)^{-1} \Delta Y \tag{3}$$

where:

I is the identity matrix.

DERIVATION OF THE INPUT-OUTPUT TABLES

The IMPLAN Professional software package was used to derive the transactions, direct, and total requirements tables for the state of Wisconsin using the 1994 database, the year closest to the 1992 base year of this study. The model initially had 528 sectors to be aggregated by sector of interest (see table 1). In this study, the final number of sectors, aggregated at the two-digit Standard Industrial Classification (SIC) codes, was 41, with 38 having data available for the state. A type II multiplier[1] option was chosen in order to obtain

[1] When households are included in a closed I-O model, output multipliers include induced, as well as direct and indirect, effects. Output multipliers, which include induced effects, are termed type II multipliers, in distinction to type I multipliers, which include only direct and indirect effects.

the direct, indirect, and induced effects, and this default multiplier was chosen as a requirement to run the IMPLAN software. In this study, only the direct coefficients were computed when deriving freight attractions.

The model must be run first with the 528 IMPLAN sectors. These sectors are enumerated with the SIC codes. A bridge with the four-digit 1987 SIC codes is provided in the software manual, facilitating future aggregation. Only 28 sectors, out of the 38 sectors with available data, were selected because not all the sectors generate commodity movement. In addition, sectors such as coal (SIC 11) do not have information on the value or tons of commodities shipped by truck in the 1993 CFS and, for this reason, were not selected. Most of the 28 sectors selected for the analysis were manufacturing sectors, with the exception of sectors such as farm and forest products.

Components of the IMPLAN database are part of the social accounts of the region under study. Social accounts show the flow of commodities to industry from producers and institutional consumers (household, government). Also shown is the consumption of factors of production, that is, workers, owners of capital, and imports from outside the region. From the social accounts, the model is converted to the industry-by-industry formulation of I-O accounts and ultimately to the predictive multipliers.

The I-O accounts use two classification systems: one for industries and the other for commodities. In the industry classification system, output represents the total output of establishments (defined as a single, physical location), regardless of whether the commodities produced are primary (composing the largest proportion of the output of the establishment) or secondary (primary to another industry) to the industry. In the commodity classification system, output represents the total output of the product or service, regardless of the classification of the establishment where it is produced (USDOC 1991).

In order to create a regional I-O model, the regional database is combined with the national structural matrices to form the regional multipliers. The initial data set is the "use" of commodity by industry and the "make" of commodities by industry, which are flows from the national I-O table. The regional study area file is created by combining the states or counties selected by the user. From the initial study area, the national structural matrices are regionalized by eliminating industries that do not exist in the region.

Imports are then estimated through the Regional Purchase Coefficients (RPC). An RPC represents the proportion of the total supply of a good or service not locally produced that is required to meet a particular demand of an industry. For example, an RPC value of 0.80 for the commodity fish means that 80% of the demand for fish is provided by local fishermen. The remaining 20% is imported. IMPLAN generates RPCs automatically with a set of econometric equations.

The regional final demands and use matrices are multiplied by the resulting RPC coefficients, creating a set of matrices and final demands free of imports. The regional use matrix and final demands are converted from a commodity to an industry basis, providing for the development of the I-O accounts. The subsequent inversion of the I-O accounts provides an import-free matrix of multipliers.

The direct requirement matrix derived in this study was generated from the regional transactions table and is import-free, meaning that it will be used to derive attractions for the Internal-to-Internal (I-I) trip type. In this matrix, the direct coefficients for each sector are added to the value-added and to imports in order to have a total direct coefficient close to one for the state. Imports and value-added were provided by the industry summary report in the IMPLAN social accounts.

Another regional industry-by-industry coefficient matrix, including imports by sector, was also generated by adding imports from outside the state. The import coefficients were derived from the industry balance sheet report from the IMPLAN Social Accounts by subtracting the regional inputs from the gross inputs for each sector and dividing the results by the total industry output.

The total consumption of a commodity is composed of two parts: industrial and personal. Industrial consumption is simply the amount purchased by an industry in order to produce its own goods. Personal consumption is the amount purchased by consumers, both household and government. The final demand report from IMPLAN provides the monetary values spent by households and government for each sector under analysis. Households tend to buy little directly from industries, other than via retail trade. However, in an I-O table purchases made by individuals for final consumption are shown as payments made directly to the industry producing the goods. Government expenditures are made up of federal, state, and local government. Federal purchases are divided by military and nonmilitary use, whereas state and local government are divided by public education and noneducation. RPC coefficients were applied to provide the proportion of consumption used to purchase goods from inside and from outside the state as imports. Then, a final regional industry-by-industry coefficient matrix includes purchases by industries and consumption, since a type II multiplier was selected when the model was run.

DERIVATION OF INDUSTRIAL FREIGHT ATTRACTIONS

Input-Output direct coefficients for the state of Wisconsin were used to derive freight attractions. These coefficients are defined as the monetary amount of one product used in making one monetary unit's worth of another product. In other words, it is the amount and type of commodity purchased by each industry in order to produce its output. Thus, it is necessary to derive a table for each of the 28 sectors that shows all the inputs required to produce the output of that particular sector. Table 4 shows the annual industrial attrac-

TABLE 4 Industrial Freight Attractions Table for Sector 1—Farm Products

(1) Input commodity STCC	(2) I–O direct coefficient	(3) Input ($)	(4) 1992 value ($/ton)	(5) Total tons 1992
01	0.2360000	1,211,328,034	1,270	953,802
08	0.0010800	5,545,249	4,075	1,361
09	0.00E+00	0	3,415	0
10	2.32E-09	12	17,605	0
13	1.79E-06	9,171	224	41
14	0.0007610	3,897,274	98	39,768
19	1.38E-07	707	192,046	0
20	0.0726000	372,235,275	1,442	258,138
21	2.10E-10	1	19,268	0
22	0.0004440	2,273,687	5,385	422
23	0.0003020	1,547,682	16,655	93
24	0.0017800	9,130,461	1,123	8,130
25	3.08E-06	15,781	5,132	3
26	0.0025700	13,177,619	2,406	5,477
27	0.0003710	1,898,400	5,414	351
28	0.0279000	142,904,539	3,869	36,936
29	0.0031600	16,205,274	838	19,338
30	0.0017300	8,887,548	4,652	1,910
31	0.0001490	761,983	12,704	60
32	0.0001130	576,655	1,751	329
33	0.0001640	837,971	4,201	199
34	0.0008770	4,493,804	7,612	590
35	0.0043300	22,176,516	14,660	1,513
36	0.0018000	9,199,189	14,403	639
37	0.0012100	6,191,039	62,439	99
38	0.0001120	573,855	80,036	7
39	0.0001530	785,237	21,035	37
40	0.00E+00	0	514	0

(1) Standard Transportation Commodity Classification—STCC code
(2) I-O direct coefficient from the I-O direct requirements table
(3) = (2) × $5,123,703,613 (farm products output from IMPLAN)
(4) 1992 value per ton. From 1977 MIT research inflated to 1992 using Producer Price Indices (NCHRP 1983)
(5) = (3) ÷ (4)

TABLE 5 Total Industrial Freight Attractions for the State of Wisconsin

(1) Input commodity STCC	(2) Total tons	(3) Truck tons	(4) Employment (1992)	(5) Tons/ employee
01	4,784,196	3,382,426	67,959	49.77
08	93,917	82,459	149	553.42
09	25,215	22,138	11	2,012.59
10	9,267	8,136	90	90.40
13	879,696	772,373	90	8,581.92
14	1,431,163	1,379,641	2,749	501.87
19	28	18	1,005	0.02
20	2,539,964	2,207,229	53,244	41.45
21	19	17	1,109	0.02
22	126,360	119,284	2,965	40.23
23	14,099	11,632	6,404	1.82
24	1,680,314	1,529,086	26,751	57.16
25	35,108	33,669	14,468	2.33
26	1,798,056	1,454,627	44,677	32.56
27	136,524	119,868	49,717	2.41
28	1,018,087	869,446	11,119	78.19
29	233,900	201,388	297	678.07
30	497,706	465,355	25,927	17.95
31	13,411	12,553	7,106	1.77
32	399,471	363,119	9,072	40.03
33	1,117,205	1,081,455	22,997	47.03
34	422,650	406,167	52,700	7.71
35	246,185	218,366	94,271	2.32
36	217,216	197,015	40,447	4.87
37	28,555	4,793	27,725	0.17
38	4,357	2,963	16,351	0.18
39	5,308	4,560	11,005	0.41
40	196,400	147,890	2,490	59.39
Total	**17,954,377**	**15,097,672**	**592,895**	

(1) STCC code
(2) Total freight inputs for all modes of transportation
(3) Truck tons obtained by applying the truck proportion from the CFS (USDOC 1996c)
(4) Total state employment from the County Business Patterns Table 1b (USDOC 1994)
(5) = (3) ÷ (4)

tions for farm products (sector 01) for the state of Wisconsin. Industrial attractions for the other 27 sectors are derived with the same procedure. Direct I-O coefficients for imports-only were used to derive the freight attractions table for inputs from outside the state. Similarly, coefficients without imports were used to derive the freight attractions table for inputs coming inside the state (domestic attractions).

Adding the inputs from all sectors produces the total freight attractions table for the state of Wisconsin together with the import-only and the internal attraction tables. Results are in tons per employee, which can be disaggregated from the state to the county level using employment for each sector. Table 5 shows the total industrial freight attractions table for the state of Wisconsin.

Freight attractions are disaggregated from the state to the county level using employment data as a disaggregation factor. It is assumed that all counties in the state will have the same state productivity in tons per employee. This assumption may be relaxed if an I-O direct table is derived for each of the 72 counties in the state through the use of the IMPLAN county database. However, application at this level of detail is beyond the scope of this study and should be a topic of future research. Also, counties with no employment in a specific sector do not have tons attracted to that sector. Table 6 shows the total industrial freight attractions in tons for Dane county. Industrial attractions for the other 71 state counties were derived with the same procedure.

TABLE 6 Total Industrial Attractions Table for Dane County

(1) STCC	(2) Employment (1992)	(3) Tons/ employee	(4) Tons
01	2,639	49.77	131,347
08	0	553.42	0
09	0	2,012.59	0
10	0	90.40	0
13	10	8,581.92	85,819
14	156	501.87	78,292
19	14	0.02	0
20	3,698	41.45	153,300
21	156	0.02	2
22	156	40.23	6,276
23	58	1.82	105
24	411	57.16	23,493
25	2,088	2.33	4,859
26	417	32.56	13,577
27	3,758	2.41	9,061
28	845	78.19	66,074
29	0	678.07	0
30	2,188	17.95	39,272
31	0	1.77	0
32	540	40.03	21,614
33	606	47.03	28,498
34	1,412	7.71	10,882
35	2,005	2.32	4,644
36	1,078	4.87	5,251
37	1,101	0.17	190
38	2,545	0.18	461
39	337	0.41	140
40	155	59.39	9,206
Total	**26,373**		**692,365**

(1) STCC code
(2) County employment from the County Business Patterns Table 1b (USDOC 1994)
(3) Tons per employee from table 5, column (5)
(4) = (2) x (3)

CONSUMPTION DERIVATION

Consumption by each sector was derived in the same way as industrial derivation, although in this case the disaggregation factor used was population instead of employment. The IMPLAN final demand report provides the monetary value expenditure for households and the government. First, tons per inhabitant must be derived for the truck mode at the state level. Then, disaggregation to the county level is done using county population. Table 7 shows the derivation for the total consumption attractions for the state of Wisconsin.

Regional Purchase Coefficients (RPCs) for each sector from IMPLAN were used to derive the consumption from inside the state (domestic consumption) and from outside the state (imports). The results are tons per inhabitant for the state by sector.

Disaggregation to the county level is done using county population. Tons per population from the state is applied to the county population. Again, it is assumed that all the counties will follow the same pattern in terms of consumption per inhabitant. This assumption could be relaxed if RPCs were derived for each of the 72 Wisconsin counties using the IMPLAN model, also an issue for future research. Table 8 shows the disaggregation of the total freight attractions due to consumption from the state to the county level for Dane County.

Adding freight attractions from the industrial and the consumption derivation gives the total freight attractions for each county by economic sector. The next step will be to disaggregate the total attraction tons from the county level to the TAZ level. Again, employment is a more reliable factor for the disaggregation of industrial attractions, but there is no information available on employment by economic sector at the TAZ level. Consequently, population was used as a disaggregation factor. After the disaggregation, 624 tables resulted showing the tons attracted by each of the 28 sectors at each TAZ in the state.

The TRANSEARCH database provides information on tons per truck by commodity type. The annual tons at each TAZ divided by the tons per truck from TRANSEARCH resulted in the annual truck trips generated in each zone. Yearly truckloads were then divided by 312 (6 days per week, multiplied by 52 weeks per year) to estimate daily truck trips.

MODEL EVALUATION

The Gravity Model (GM) function in TRANPLAN was used to distribute the three trip types: Internal-to-Internal (I-I), Internal-to-External (I-E), and External-to-Internal. The Fratar Growth Factor model was applied for distributing the External-to-External (E-E) trip type. Huang's trip length frequency distributions (1998) were used in the GM calibration.

The four trip types were merged and assigned to the state highway network. A Selected Link Analysis (SLA) iteration procedure in TRANPLAN must be undertaken in order to calibrate the trip

TABLE 7 Total Freight Attractions for the State of Wisconsin Due to Consumption

(1) Input STCC	(2) PCE commodity million $)	(3) Government expense (million $)	(4) Total consumption (million $)	(5) 1992 value ($/ton)	(6) Total tons 1992	(7) Truck tons 1992	(8) Tons/ inhabitant 1992
01	387.2	13.9	401.1	1,270	315,839	223,298	0.04565
08	168.4	10.8	179.2	4,075	43,976	38,611	0.00789
09	58.7	0.8	59.4	3,415	17,401	15,278	0.00312
10	0	0	0	17,605	0	0	0.00000
13	0	0	0	224	0	0	0.00000
14	1.9	8.5	10.4	98	106,526	102,691	0.02099
19	32.6	43.1	75.7	192,046	394	256	0.00005
20	5,441.6	311.5	5,753.1	1,442	3,989,675	3,467,028	0.70875
21	469.9	0	469.9	19,268	24,390	21,414	0.00438
22	211.4	8.0	219.4	5,385	40,744	38,462	0.00786
23	1,758.5	98.2	1,856.7	16,655	111,478	91,969	0.01880
24	52.7	5.4	58.1	1,123	51,740	47,084	0.00963
25	415.3	95.7	510.9	5,132	99,554	95,473	0.01952
26	254.4	123.4	377.9	2,406	157,058	127,060	0.02597
27	629.9	186.2	816.1	5,414	150,742	132,351	0.02706
28	1,786.2	298.9	2,085.1	3,869	538,934	460,250	0.09409
29	1,495.2	280.3	1,775.5	838	2,118,769	1,824,260	0.37292
30	323.3	62.1	385.4	4,652	82,841	77,456	0.01583
31	324.5	5.2	329.7	12,704	25,950	24,289	0.00497
32	124.0	18.2	142.2	1,751	81,219	73,828	0.01509
33	2.1	6.2	8.3	4,201	1,970	1,907	0.00039
34	160.9	94.8	255.7	7,612	33,591	32,281	0.00660
35	142.1	227.6	369.7	14,660	25,221	22,371	0.00457
36	1,129.3	140.7	1,270.0	14,403	88,176	79,975	0.01635
37	2,712.7	1,275.9	3,988.7	62,439	63,881	35,564	0.00727
38	271.2	320.0	591.2	80,036	7,387	5,023	0.00103
39	762.1	66.4	828.5	21,035	39,385	33,831	0.00692
40	527.0	0	528.0	514	1,027,201	773,482	0.15812
Total	**19,644.2**	**3,701.8**	**23,346.0**		**9,244,041**	**7,845,493**	

(1) STCC code
(2) PCE—Personal Consumption Expenditure from IMPLAN Final Demand report
(3) Government expenditures (federal + state & local) from IMPLAN Final Demand report
(4) = (2) + (3)
(5) Value/ton from table 4, column (4)
(6) = (4) ÷ (5)
(7) Truck tons obtained by applying the truck proportion from the CFS (USDOC 1996c)
(8) = (7) ÷ 4,891,769 (state population from 1990 Census of Population and Housing (Census of Population 1991))

table so that the assigned truck trips provide a reasonable match to the actual truck volumes. Evaluation of the SLA is accomplished by checking if the ratio between actual truck volumes and estimated volume approaches 1.0 for most of the 40 selected links in the state network. Adjustment factors for productions and attractions are also checked in each iteration to see if they approach 1.0, indicating that TAZ productions and attractions do not need further adjustments.

Evaluation measures are needed to determine if the GM is calibrated and to what extent improvements are obtained from the SLA. The overall performance of the truck travel demand model is measured by the Root Mean Squared Error (RMSE) by comparing the model-generated link volumes with single-day ground counts collected by WisDOT. A percentage RMSE (%RMSE) by aggregation volume group is also computed by dividing the RMSE by the ground count. Changes in the RMSE and the %RMSE from the initial GM through the second iteration of the SLA are shown in table 9 for the 40 selected links in this research.

The RMSE declines between the initial GM and the second iteration. The overall performance of the SLA was good, with the overall %RMSE declining from 65% to 42%. The first iteration produced a 22.4% reduction in the RMSE, and for

TABLE 8 Total Freight Attractions for Dane County Due to Consumption

(1) Input commodity STCC	(2) Tons/inhabitant 1992	(3) Total tons 1992
01	0.04565	16,757
08	0.00789	2,897
09	0.00312	1,146
10	0.00000	0
13	0.00000	0
14	0.02099	7,706
19	0.00005	19
20	0.70875	260,170
21	0.00438	1,607
22	0.00786	2,886
23	0.01880	6,901
24	0.00963	3,533
25	0.01952	7,164
26	0.02597	9,535
27	0.02706	9,932
28	0.09409	34,538
29	0.37292	136,895
30	0.01583	5,812
31	0.00497	1,823
32	0.01509	5,540
33	0.00039	143
34	0.00660	2,422
35	0.00457	1,679
36	0.01635	6,001
37	0.00727	2,669
38	0.00103	377
39	0.00692	2,539
40	0.15812	58,043
Total		**588,736**

(1) STCC code
(2) Tons per inhabitant from table 7, column (8)
(3) = (2) x 367,085 (county population from the 1990 Census of Population and Housing [Census of Population 1991])

the second iteration the reduction was 16.8%, less than the 20% threshold used in this research.

Regional volume biases were also checked through screenlines and functional highway classes, as measured by the link volume-ground count comparison and by the RMSE measure. Table 10 shows the five screenlines created to identify any bias in the estimation of truck trips moving across different sections of the state.

Some biases exist, as shown in table 10, with overestimation of 25% for the Eastern screenline and underestimation of 23% for the Western screenline. However, the model estimated truck trips very well for the other three screenlines, where the link volume almost matched the ground count.

For the functional highway class evaluation, 4 interstate highways with a total of 32 checkpoints, U.S. highways with 34 checkpoints, and 38 state highway checkpoints were analyzed. The results showed that underestimation occurred for the link volume-ground ratios, ranging from 0.69 for state highways, 0.89 for interstate highways, and 0.95 for U.S. highways.

A final overall measure of the goodness of fit of the truck travel demand model is provided by calculating vehicle-miles of travel (VMT) for the model and comparing that single number with the independent estimate of VMT for heavy trucks computed annually by WisDOT. This research produced an estimated 2.814 billion VMT, close to the 2.954 billion from the TRANSLINKS 21 report (TRANSEARCH 1996). The estimated VMT was 23% less than WisDOT's estimate.

SUMMARY AND CONCLUSIONS

This study derived freight productions and attractions for the state of Wisconsin using commodity flow data and Input-Output coefficients. The derivation process forms part of the trip generation

TABLE 9 RMSE and %RMSE by Iteration and by Volume Group for 40 Selected Links

			Volume group			
Initial data and iteration	RMSE [1]	Total	Under 1,000	1,001–2,000	2,001–5,000	Over 5,000
Links		40	18	8	6	8
Average GC[2]		2,495	363	1,490	3,369	7,641
Initial GM[3]	1,609	65%	61%	52%	32%	44%
1st iteration	1,247	50%	60%	38%	33%	33%
2nd iteration	1,038	42%	57%	36%	27%	27%

[1] Root Mean Squared Error
[2] Average ground count truck volume for 40 selected links
[3] Initial gravity model results

TABLE 10 Goodness of Fit Summary for Screenline

Goodness of fit measure	Screenline: Eastern	Western	Southern	Central	Northern
Ave. GC[1]	1,237	1,213	4,306	3,055	782
LV/GC[2]	1.25	0.77	0.97	1.01	1.00
%RMSE[3]	71	55	41	19	37

[1] Average ground count truck volume
[2] Link volume to ground county ratio
[3] Percent Root Mean Squared Error

stage when traditional four-stage Urban Travel Demand Model is adapted to the statewide level. It was found in the full study (Sorratini 1999) to provide improvements in the estimation of daily truck trips. Compared with two other studies developed in the University of Wisconsin—Madison, Park 1995 and Huang 1998, the full study was found to provide a better match between the estimated truck traffic counts and the ground counts than the other studies. It is believed that commodity flow data from the most recent commodity flow survey (USDOC 1996b), applied with insights from an Input-Output model developed for the state, produce better estimates of truck flows.

Daily truck trips for four trip types, Internal-to-Internal, Internal-to-External, External-to-Internal, and External-to-External, were derived first at the county level and later at the Traffic Analysis Zone (TAZ) level. The disaggregation to the TAZ level was done in order to compare the estimated truck flows to the actual ground counts. The four trip types were analyzed in an attempt to study all the trips separately since they have different characteristics in terms of trip length frequency.

Productions and attractions developed in this study were used as inputs to a more comprehensive research (Sorratini 1999). In that research, trips generated were later distributed and assigned to the state network using the TRANPLAN transportation planning software package. Link volumes estimated for the heavy truck mode were compared to actual ground counts at five screenlines and multiple links for three functional classes of highways in order to test the accuracy of the generation process. Performance measures, such as the Root Mean Squared Error, were used to evaluate the model's ability to forecast heavy truck trips at the state level.

The first results showed that productions and attractions derived in this study were underestimated when compared to truck traffic counts and had to be adjusted to better match the actual ground count volumes. This was expected since not all truck movement was accounted for in this research; empty truck movement serves as one example. This study analyzed the heavy and the private and for-hire truck types only, which also contributed to the underestimation. Also, sectors beyond the 28 considered in this study could generate some truck flows. However, an iterative process, through the use of the selected link analysis in TRANPLAN, was applied when adjusting productions and attractions, helping to mitigate the underestimation of flows. The overall performance of the models was found to be reasonable, when compared with previous, similar studies, thanks to a better derivation of productions and attractions, such as the one proposed in this study.

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Assessing the Determinants of Safety in the Trucking Industry

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ABSTRACT

Using data from the 1997 Survey of Drivers conducted by the University of Michigan Trucking Industry Program, we identify the factors which substantially affect three safety measures: accidents, moving violations, and hours of service violations. The variables used include both operational characteristics (firm size, trailer type) and personal characteristics (age, race, union status). Using both basic descriptive statistics and probit estimation, we find that the variables that have the most impact on the three safety measures are operational in nature, not individual characteristics.

INTRODUCTION

There can be little doubt that safety in the trucking industry is one of the most contentious issues in transportation. With headlines that read, "America's Most Dangerous?" and "They Drive by Night," articles on trucking safety appear more and more frequently in the popular press. One recent example appeared in the *Denver Post* titled "Truck Crashes Claim Thousands: Safety Agency Ripped for Shoddy Oversight" (Alonso-Saldivar 1999) with a passage that read, "Spewing gravel

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on windshields and careening across crowded freeway lanes, trucks are the staple of local news video of chain-reaction death on the highway."

Up from 4,755 in 1996, the number of trucks involved in fatal accidents, the most often-cited measure of safety, was 4,871 in 1997, with the total number of fatalities stemming from these accidents at 5,355. However, more trucks were involved in driving more miles in 1997 than in 1996. The rate of fatal accidents was 2.5 per 100 million miles traveled in 1997, down from 2.6 the year before (Schulz 1998c).

Truck accidents are much less likely than passenger car accidents to involve illegal alcohol content: 1.4% versus 19.4% (Schulz 1998b). Though there has been concern in the past with drug use by truck drivers, especially amphetamines, in 1996 less than 0.2% of truck drivers tested positive for drug use.The purpose of this paper is to assess the characteristics which influence driver safety. To this end, we employ data obtained by the University of Michigan Trucking Industry Program in its 1997 Survey of Drivers.[1] These data have the advantage of being comprehensive since they include questions on individual and firm characteristics, hours of service regulations, and safety, and of having been collected from a nongovernmental source, perhaps ensuring more confidence from the drivers and thus more reliable and honest responses to sensitive questions.

[1] The data are from a survey of over-the-road and local drivers in the motor freight industry conducted by the University of Michigan Trucking Industry Program (UMTIP) in the late summer and fall of 1997. The survey used a two-stage, stratified sampling procedure in which interview sites, truck stops, were randomly selected within state and establishment size categories. Interviewers approached entrants to the selected truck stops using a random selection scheme. Sixty-three percent of eligible participants, 573 drivers, agreed to take the survey, which took forty minutes. The survey collected information on topics including respondents' work history; the characteristics of their job and the structure of compensation on the job; time spent working, waiting and resting in the last 24 hours and on the last completed trip; the use of technology; respondents' characteristics, education, and job training; their use and attitudes toward log books and the hours of service regulations; and their views about the current employer and unions.

Using these data, we first use descriptive statistics to assess the factors, both operational and personal, which influence driver safety. We then employ probit estimation techniques to assess what impact the significant variables have on driver safety, all else remaining constant. Our results indicate that variables such as hours of sleep and miles driven, as well as method and rate of pay, play major roles in driver safety.

RELEVANT LITERATURE

There were 151,000 trucks involved in traffic accidents in the United States in 1994, resulting in 5,501 fatalities and 110,000 nonfatal injuries (Center for National Truck Statistics 1996). The 1996 fatality rate for commercial motor vehicles was 2.8 per million miles traveled, versus 2.0 per million miles traveled for passenger cars (Schulz 1998b).

Many studies have attempted to explain the factors in these accidents and the relative likelihood that a commercial motor vehicle will be involved in a traffic accident. Explanatory variables used include, among others, driver fatigue, driver hours of service, driver age and experience, driving conditions, driving under the influence of alcohol, and deregulation of the trucking industry. Human error is cited more often than mechanical defects in truck-related fatalities, emphasizing the need to study variables such as and similar to the aforementioned (Schulz 1998b).

Perhaps the most visible safety hazard in the trucking industry is driver fatigue. At the 1995 National Truck and Bus Safety Summit, driver fatigue was identified as the leading safety issue in the industry (USDOT FHWA 1998). The National Transportation Safety Board estimated 31% of all truck-driver fatalities and 58% of all single-truck crashes are fatigue related (Schulz 1998a).

According to the NASA/Ames Fatigue Countermeasures Group, fatigue is caused by two physiological phenomena: sleep loss and circadian rhythm disruption. As little as two hours of sleep loss, which over several days can accumulate into a "sleep debt," can negatively affect performance and alertness. The disruption of circadian rhythms occurs with schedule changes, such as crossing time zones or shift changes. Truck drivers, especially long-haul drivers, are unusually vulnerable to both types of fatigue.

In 1988, Congress directed the Federal Highway Administration to study driver fatigue and its implications with respect to the hours of service rules. The FHWA concluded in the "Commercial Motor Vehicle Driver Fatigue and Alertness Study"(USDOT FHWA 1996) that "drivers in the study did not get enough sleep" and "were not very good at assessing their own levels of alertness." A publication in the *New England Journal of Medicine* (Mitler et al. 1997) presents the results of electrophysiologic and performance monitoring of drivers. The drivers averaged only 4.78 hours of electrophysiologically verified sleep per day. Forty-five of the drivers (56%) had a least 1 six-minute interval of drowsiness while driving, and 2 drivers had 1 episode each of stage 1 sleep (the lightest stage of sleep) while driving.

The hours of service rules were implemented in the 1930s to protect drivers from being forced to work long and unsafe hours and have changed little since that time. These rules prescribe the maximum hours that a driver may spend on-duty or driving. On-duty time includes all time that the driver is responsible for the truck, including passive activities such as waiting to load or unload. Ten hours of driving is permitted after 8 consecutive hours off-duty, and driving is not permitted after 15 hours on-duty. During any seven-day period, a maximum of 60 hours of driving is permitted. Or, a maximum of 70 hours of driving is permitted during any eight-day period.

Braver et al. (1992) present the results of a study in which 1,249 tractor trailer drivers were interviewed at various locations in Connecticut, Florida, Oklahoma, and Oregon about their usual hours of work and driving. They found that 73% of the drivers were classified as hours of service violators. Significant risk factors for being a violator included the following: low pay rates per mile, high annual miles driven, employment with a for-hire firm, irregular route schedules, having received an unrealistic delivery deadline within the past month, carrying a perishable commodity, and frequent difficulties finding parking in rest areas or truck stops.

Beilock (1995) reports the results of a survey of 500 drivers exiting the Florida peninsula on January 25 and 26, 1998. Depending on average speeds, between 17% and 30% of the drivers surveyed had violation-suspect schedules; between 14% and 26% of the schedules were judged as violation-inducing. Factors that contributed to a tight schedule included the following: solo driving, full loads, refrigerated loads, regular-route schedules, and current trip lengths over 1,000 miles.

Kaneko and Jovanis (1992) developed a method to estimate the relative accident risk or different driving patterns over a multiday period. Nine distinct driving patterns were identified from a data set of over 1,000 drivers. Additional models Kaneko and Jovanis developed considered the driver's age, the driver's experience with the employing firm, the driver's number of hours off-duty prior to the last trip, and the hours driving on the last trip. They concluded that, with marginal statistical significance, early and late morning driving over multiple days was associated with the highest accident risk. Driver age and the number of hours off-duty immediately prior to a trip did not appear to significantly affect accident risk, but driver experience and the number of consecutive hours driven were significant. Drivers with one to five years of experience comprised the highest risk group, while drivers with less than one year of experience comprised the second highest risk group. The lowest risk associated with the number of consecutive hours driven was during the first four hours, and the highest risk was beyond nine hours driven.

Jones and Stein (1987) conducted a case-control study of crashes in the state of Washington from June 1984 to July 1986. They concluded that drivers who drive in excess of hours of service regulations, young drivers, and interstate drivers were likely to have an increased relative risk of crash involvement.

Traynor and McCarthy (1993), using data from California, examined whether the Motor Carrier Act of 1980, which deregulated the trucking industry, affected the probability that a truck would be involved in an accident or that a truck would be at fault in an accident. They concluded that economic deregulation, which essentially allowed the trucking industry to become nearly perfectly competitive, had a "statistically insignificant (positive) effect on highway safety." Alexander (1992) determined that Traynor and McCarthy's conclusion about deregulation in California was not different from what occurred in other states.

DESCRIPTIVE STATISTICS

Using the findings of previous studies as a foundation and incorporating some of our own hypotheses on the factors which may play a significant role in driver safety, we generated descriptive statistics using the UMTIP 1997 data sets, and these factors were related to three safety measures. The three safety measures are: first, whether the driver reported having been involved in an accident reported to the police while on duty in the 12 months prior to the interview (this includes all accidents, not the subset of fatal accidents); second, whether the driver had been cited for a moving violation while on duty in the 12 months prior to the interview; and, third, whether the driver had reported working more than he/she had logged in the last 30 days. All of these are binary variables that take a value of one if the respondent replied in the affirmative to any of the questions and zero otherwise. In the sample, 15.01% reported that they had been involved in an accident; 29.87% reported having received a moving violation; and 57.8% reported having worked more than was logged in the last 30 days.[2] (Interestingly, 82.58% of all drivers reported that, in general, they thought logbooks were inaccurate.) The relatively high rates of affirmative response for each of the three safety measures lead us to believe that any underreporting due to the sensitive nature of the questions is rather low.

Descriptive statistics were compiled on driver characteristics such as race, age, experience, education, mileage, and sleep. Operational characteristics were also examined, including firm size, method of payment, employment status, and type of commodity hauled. Basic descriptive statistics on the sample used are presented in table 1.

[2] One might assume that these three measures are highly correlated; however, this is not the case. The simple correlation coefficient between accidents and moving violations is –0.05, 0.03 between accidents and logbook violations, and 0.14 between moving violations and logbook violations.

TABLE 1 Descriptive Statistics on the Driver Survey Sample Used for Estimation

Earnings and Miles	
1996 annual earnings	$35,758
1996 annual miles	114,269
Collective bargaining	
Union member	10.4%
Human capital	
Age	42.1 years
Occupational experience	15.3 years
Less than high school education	19.3%
High school diploma	45.8%
Vocational or technical degree	5.1%
Some college	21.0%
Associate of arts	4.2%
College degree or higher	4.7%
Race and ethnicity	
African American	9.0%
Native American	1.7%
Hispanic	2.4%
Caucasian	86.9%
Other characteristics	
Local driver	12.1%
Owner-operator	25.9%
Private carriage	18.3%
Paid by the hour	15.3%
Paid by percentage of revenue	34.2%
Firm size	
25 employees or less	21.5%
25 to 99 employees	20.4%
100 to 249 employees	14.5%
250 to 499 employees	11.3%
500 to 999 employees	10.4%
1,000 to 4,999 employees	11.7%
5,000 employees or more	3.8%
Last 24 hours	
Sleep	8.21 hours (std. dev. = 3.14)
Miles driven	404.5 miles (std. dev. = 268)
Safety characteristics	
Accident in last 12 months	15.0%
Moving violation in last 12 months	29.9%
Worked more than logged in last month	57.8%

Race

Whites reported the highest percentage of accidents (16.11%) and logbook violations (58.29%). The most interesting results of linking race to safety measures are the statistics on the subgroup of African-American drivers. African-Americans reported the lowest percentage of logbook violations (32.19%) and accidents (10.02%), but, of the three specific races, African-Americans reported the highest percentage of moving violations (35.73%).

Age

The relationship between age and safety measures is generally a U-shaped function but has significant fluctuation, as can be seen in table 2. Initially, the percentage of reported accidents and violations is high but decreases as age increases. The percentage then turns upward once again as age increases. The U-shaped function tends to hold for accidents as well. Only 10.19% of the age group 51 to 60 reported involvement in an accident in the past year, while age group 61 and older reported the highest, at 31.23%. Although the youngest group (18 to 25) did not consistently report the highest percentage of violations or accidents, the 26 to 35 group, comprising 22% of the total sample, reported the second highest percentage of accidents and moving violations (18.06% and 38.03%, respectively), and almost 70% reported violating their logbook in the past 3 months.

TABLE 2 Statistics on Safety Characteristics by Age Group

Age group (in years)	Percentage of accidents	Percentage of moving violations	Percentage of logbook violations
18 to 25	14.72	45.02	62.86
26 to 35	18.06	38.03	69.35
36 to 50	14.27	26.19	57.83
51 to 60	10.19	28.02	37.26
61 and older	31.23	28.55	44.57

Firm Size

The initial statistics indicate an inverse relationship for accidents and moving violations and firm size, as is presented in table 3. As the size of the firm increases, the percentage of reported accidents and moving violations decreases. Only 8.01% of drivers employed at firms of 500 to 999 employees, 5.45% of drivers at firms with 1,000 to 4,999 employees, and 11.11% at firms with 5,000 or more employees reported involvement in an accident in the previous year, compared with roughly 20% of drivers at firms with less than 25 or with 25 to 99 employees. Approximately 40% of drivers employed at firms with less than 25 employees reported a moving violation, compared with 8.40% of drivers employed at firms of 500 to 999 employees and 12.27% of drivers at firms with 5,000 or more employees.

TABLE 3 Statistics on Safety Characteristics by Firm Size

Firm size (in employees)	Percentage of accidents	Percentage of moving violations	Percentage of logbook violations
25 or fewer	18.81	40.36	54.47
25 to 99	20.83	34.13	55.73
100 to 249	16.18	24.72	61.74
250 to 499	15.09	31.38	59.47
500 to 999	8.01	12.87	68.19
1,000 to 4,999	5.45	21.82	37.59
5,000 or more	11.11	12.27	27.62

For most categories of firm size, about one half of the respondents reported violating their logbook. At the high end, 68% of the drivers employed at firms with 500 to 999 employees reported violating their logbooks, even though they reported at or near the lowest percentile for accidents and moving violations. The figures drop markedly for the largest firms, with 37.6% of drivers at firms with 1,000 to 4,999 employees and 27.6% of drivers at firms with 5,000 or more employees reporting logbook violations in the last 30 days.

TABLE 4 Statistics on Safety Characteristics by Occupational Experience

Occupational experience (in years)	Percentage of accidents	Percentage of moving violations	Percentage of logbook violations
1	27.55	36.52	15.30
2	8.03	39.20	59.73
3	20.54	23.64	68.37
4 to 5	13.35	23.35	74.06
6 to 8	10.48	28.77	53.08
9 to 12	12.45	47.51	75.33
13 to 15	13.10	19.40	55.52
16 or more	16.48	27.91	48.71

Occupational Experience

Experience seems to have a positive effect on the safety measures but is undoubtedly skewed somewhat because of its high correlation with age. As table 4 indicates, drivers with 1 year of experience reported the highest percentage of accidents, at almost 28%. As the drivers gain experience, the accident rate declines, with some fluctuation, and bottoms out around 11% for drivers with 6 to 8 years of experience. The rate then begins a slow incline to 16.48% for drivers with 16 or more years of experience.

The relationship between experience and moving violations is not as clear. With the highest percentage, nearly 48% of drivers with 9 to 12 years of experience reported a moving violation, while only 36.52% of drivers with 1 year of experience reported a moving violation. Drivers with 13 to 15 years of experience reported the lowest, at just under 20%. Those with 16 or more years reported at almost 28%.There is no clear relationship between experience and logbook violations. Around 50 to 75% of the drivers reported they had worked more than they logged in the last 30 days, with one exception. Only 15.30% of the drivers with less than 1 year of experience reported violating their logbook in the last 30 days.

Method of Payment

Drivers paid by percentage of revenue reported a higher percentage of accidents, moving violations, and logbook violations (18%, 38%, and 63%, respectively) than those paid by the mile (13%, 27%, and 55%, respectively). This is not surprising because a driver who is paid by the mile typically gets paid the same amount per mile regardless of the revenue generated by the load (exceptions being premiums paid for hazardous materials, etc.). Drivers who are paid a percentage of revenue, primarily owner-operators, tend to drive more miles and run more loads in order to compensate for any empty or low-revenue loads.

Owner-Operators versus Employees

The rates of accidents and logbook violations are remarkably similar across employment status, with roughly 15% of those in each group reporting an accident in the 12 months prior to the interview and nearly 60% of drivers in each group reporting that they had worked more than they logged in the last 30 days. Moving violations, however, varied across employment status, with 38% of owner-operators reporting a moving violation in the last 12 months versus 30% for employee drivers.

When comparing those in the for-hire segment to drivers in the private carriage segment, we find that safety characteristics are again similar. Approximately 55% of drivers in each group admit to violating the hours of service regulation in the past 30 days, and roughly 30% report receiving a moving violation in the last year. The accident rate, however, varies significantly between the groups, with private carriage drivers (23%) more likely than for-hire drivers (13%) to have been involved in an accident in the past year.

Van Type

It is indicated that drivers pulling a drybox are somewhat safer than drivers with other trailer configurations. There is little difference between drybox and other trailer configurations for accidents and moving violations, but there is a large discrepancy for logbook violations within the past 30 days. For all trailer configurations, around 15% of drivers reported an accident within the past year, while roughly 30% reported a moving violation. As for logbook violations within the past 30 days, just under 50% of drybox drivers reported violating their logbook, while 63% of drivers of other trailer configurations reported the same violation.

Annual Mileage

It is not surprising that as annual miles driven increases, so does the percentage of reported accidents, moving violations, and logbook violations. Of those drivers reporting 50,000 miles or less driven in the past year, 10% reported being involved in an accident; 20% received a moving violation; and 35% reported violating their logbooks. These figures increase as annual mileage increases and are 20%, 30%, and 67%, respectively, for those drivers reporting over 160,000 miles in the last year. This positive relationship is expected since it is likely that those driving more miles are violating hours of service regulations and, therefore, are more likely to be involved in an accident or receive a moving violation. The more miles driven, the more likely a driver is to be cited for a moving violation, and the more hours they have to falsify their logbooks to make up for the obtainable, but probably illegal, miles driven. It may well be noted, however, that the percentage involved in accidents increases with miles driven at a decreasing rate, which may indicate that those drivers who drive more miles may be safer when compared on a per-mile basis.

Sleep in the Last 24 Hours

To examine preliminarily the effect of sleep on safety, we considered our three safety measures across hours of sleep in the last 24 hours. This is a rough proxy for sleep patterns, since sleep in the past 24 hours may have been atypical of usual sleep patterns, but the results are interesting from a fatigue perspective.

Not surprisingly, those who report zero hours of sleep in the last 24 hours are most likely to have also reported an accident in the past year (28% versus roughly 15% for the rest of the sample). These drivers are also most likely to have violated the hours of service regulation in the last 30 days; 68% of those with no sleep reported logbook violations, as did 93% of those with 5.5 hours or less. These figures are significantly higher than the average of 50% for the rest of the driver sample.

Education

The pattern of the relationship between education and safety is seemingly contradictory. College graduates stand out from the other education categories. This group is by far the most likely to violate the hours of service regulations (84% versus roughly 55% for the rest of the sample) and is also the most likely to have reported an accident in the past year (22%). However, this group is the least likely to have received a moving violation (17% versus 30% for the remainder of the sample).

THE MODEL

A regression model is used to explain the rates of accident, moving violation, and logbook violations. A probit model specifically is used because of the dichotomous nature of the response variables.[3] A driver either has an accident or moving violation or logbook violation or not; the factors which affect the probability of these events occurring are what is of interest. The probit model allows us to estimate the effects of key variables while holding all other variables constant. The coefficients presented are the derivatives of the probit function evaluated at the mean, allowing us to interpret the coefficients as "marginal effects."

Three separate models were estimated using identical explanatory variables and a dependent response variable of accident, moving violation, or logbook violation. The explanatory variables include dummy or continuous variables of basic demographic variables and industry related variables. The variables include gender, education level, race, ethnicity, veteran status, union status, marital status, job tenure, occupational experience and its square, driver training, trailer configuration, mileage in the last 24 hours, sleep in the last 24 hours, and a calculated mileage pay rate.[4] The explanatory variables differ somewhat from the variables viewed in the initial descriptive statistics.

First, education is split into four categories: less than high school, high school graduates, those with degrees from vocational or technical schools or associate's degrees, and those who completed some or all of college. High school is the omitted reference group in the model, since most drivers reported a high school degree as their terminal education.

Continuous variables for occupational experience and its square are included and age omitted because of the high correlation between the variables. Occupational experience and its square are desired to reflect the possibility of a learning curve that may increase at a decreasing rate. As experience increases, the probability of the three events occurring is likely to decrease but only to a certain point, at which other factors may have greater influence on safety.

Experience is a strong determinant in driver safety, but the next logical step is to question the method of driver training. Will a driver who goes through weeks of classroom and on-the-road training be a safer driver than one who learns "on-the-job," all

[3] The choice of a probit model over logit is somewhat arbitrary, however, assuming a normal distribution over a logistic distribution affects estimates little in our model. According to Greene (1997), we would expect very different predictions from the two models if there were very few responses or non-responses in the data set or if there were a wide variation in a key explanatory variable. Neither of these applies to our data set. Logit estimates are available from the authors.

[4] Correlation coefficients indicate little problem with multicollinearity in the model. A full set of correlation coefficients is available from the authors.

else being equal? Dummy variables for different types of training were included, with on-the-job omitted as the reference group. The included dummies are private school, public or technical school, courses offered by a trucking company, the military, or other (mainly learned from family or friends).

Different trailer configurations often present different schedules that drivers must abide by, thereby creating an indirect safety variable via this schedule variance. For example, a driver hauling livestock or a tanker of milk in August is more likely to be constrained by a strict delivery schedule than a driver pulling pallets of salt in a drybox. Drybox is the configuration taking a value of one for this variable, with all other configurations at zero.

Continuous variables for mileage and sleep in the last 24 hours are included to capture a driver's "normal" driving habits. A driver may report mileage or hours different from his or her norm, but it is assumed that drivers' pictures of the last 24 hours represent, on average, a typical scenario. These are important variables because of the inherent connection with hours of service laws and implied industry values toward sleep and safety. Miles in the last 24 hours may provide a good illustration of an individual's driving pattern. For example, 2 drivers with the same annual mileage, say 110,000 miles, may have very different driving patterns, with 1 driving a regular schedule and never exceeding hours of service regulations and the other regularly exceeding limits on driving time either due to company pressures or his or her own preferences.

Annual income and annual miles are dropped in favor of a continuous, computed variable of the ratio of annual income to annual miles. The computed form is favorable because it avoids a correlation problem between income and mileage and allows for comparison across different methods of compensation. The calculated mileage rate also accounts for pay for nondriving time. A dummy variable for method of payment is included, taking a value of one if the driver is paid by the hour and zero otherwise. We would expect those paid by the hour to be more likely to be regional or local drivers or to be those drivers working in the "better" trucking jobs with better working conditions. Therefore, the coefficient on this variable is expected to be negative in each of the models.

Additionally, controls are included for type of commodity hauled. This provides a more detailed distinction between for-hire and private carriage drivers. The omitted group is general freight, typically characterized as "for-hire."[5]

Finally, regional dummies are included in the model for accidents. Drivers report that driving conditions are more hazardous in some parts of the country, so the region where the driver typically works may play a role in the probability of having been involved in an accident, making region an important control variable. The omitted group is Upper-Midwest, and we would expect the coefficients on the dummies for Northeast and Mid-Atlantic (the East coast states) to be positive in this model.

Results

Accident Probit

Table 5 summarizes the results of the probit estimation. The statistically significant variables in the accident model are pay rate and method of payment, marital status, firm size, region, and source of training. The coefficient on the mileage rate variable is –0.176, indicating that a $0.10 increase in the rate paid per mile would decrease the probability of being involved in an accident by 1.76%. Likewise, the coefficient on the dummy variable for hourly pay is negative and significant, –0.102, indicating that those drivers paid by the hour are 10.2% less likely to have been involved in an accident than those paid by the mile or by a percentage of revenue.

Also negative and statistically significant is the coefficient for the separated, widowed, or divorced group. This group is 8.9% less likely to be involved in an accident than their single counterparts, all else being equal. Those drivers who received training through a trucking company program are 14% more likely to have been involved in an accident that those who learned on-the-job.

The coefficients on firm size are negative for the larger firms but only statistically significant for firms with 1,000 to 4,999 employees. Drivers at

[5] Coefficients are not presented for these control variables; however, they are available from the authors on request.

TABLE 5 Results of Probit Estimation

Variable name	Accident model	Moving violation model	Logbook violation model
Pay characteristics			
Mileage rate	–0.176* (1.80)	–0.115 (1.06)	–0.353** (2.87)
Paid hourly	–0.102** (2.41)	–0.042 (0.55)	–0.168* (1.64)
Education			
Less than high school	0.0008 (0.02)	0.074 (1.11)	–0.014 (0.16)
Vocational/ associate's degree	–0.064 (1.07)	–0.029 (0.31)	–0.063 (0.52)
College	0.059 (1.22)	–0.027 (0.42)	0.273** (3.46)
Demographics			
African American	–0.064 (1.32)	0.046 (0.54)	–0.269** (2.66)
Hispanic and Native American	–0.063 (0.88)	0.077 (0.56)	–0.086 (0.51)
Veteran	0.007 (0.18)	–0.015 (0.28)	0.069 (0.98)
Union	0.079 (1.18)	–0.195** (2.45)	–0.041 (0.37)
Female	–0.043 (0.38)	–0.085 (0.49)	–0.374* (1.75)
Married	–0.087 (1.42)	–0.068 (0.79)	0.220** (1.96)
Separated, divorced, widowed	–0.089* (1.76)	0.057 (0.61)	0.179 (1.52)
Employee type			
Owner–operator	–0.041 (1.04)	0.102* (1.70)	0.102 (1.35)
Van type			
Drybox	–0.043 (1.14)	0.052 (0.93)	–0.179** (2.52)
Occupational experience	–0.004 (0.79)	0.002 (0.18)	0.015 (1.29)
Occupational experience—squared	0.00007 (0.59)	–0.00008 (0.39)	–0.0007** (2.48)
Firm size (in employees)			
25	0.028 (0.57)	–0.087 (1.34)	–0.013 (0.14)
100	–0.004 (0.07)	–0.123 (1.67)	0.110 (1.05)
250	–0.007 (0.11)	–0.050 (0.59)	0.059 (0.54)
500	–0.038 (0.66)	–0.254** (3.53)	0.271** (2.57)
1,000	–0.110** (2.47)	–0.127* (1.63)	–0.196* (1.68)
5,000	–0.083 (1.10)	–0.141 (1.00)	–0.204 (1.12)
Last 24 hours			
Miles	0.00003 (0.56)	0.0002* (1.82)	0.0001 (1.00)
Sleep	–0.005 (0.78)	0.007 (0.89)	–0.038** (3.16)
Source of driver training			
Private trucking school	–0.050 (1.07)	–0.151** (2.15)	0.064 (0.64)
Public or technical school	–0.089 (1.61)	0.183* (1.65)	–0.211 (1.58)
Trucking company	0.144* (1.67)	0.035 (0.34)	–0.008 (0.07)
Military	–0.032 (0.49)	0.069 (0.61)	0.107 (0.79)
Other, family member	–0.130 (0.28)	–0.065 (0.98)	–0.100 (1.11)
Diagnostics on model			
Likelihood ratio (p–value)	77.07 (0.014)	85.38 (0.0003)	126.4 (0.000)
Pseudo R^2	0.22	0.17	0.25

*significant at 10% level   ** significant at 5% level

this size firm are 11% less likely to be involved in an accident than those drivers employed at the smallest firms, those with less than 25 employees.

Finally, two regions had statistically significant coefficients in the accidents model. Those drivers who typically work in the Northeast are nearly 56% more likely to be involved in an accident than those working in the Upper Midwest. Those working in the Mid-Atlantic states are 21% more likely than their Midwest counterparts to be involved in an accident. These findings support the assumptions made a priori.

It was expected that sleep in the last 24 hours and trailer configuration would significantly affect the probability of reporting an accident. It is likely that these variables and others were not significant because drivers were asked to report only if they had an accident within the last year. Also, "close calls," or nonreported accidents, are excluded. These important safety measures are, unfortunately, impossible to incorporate.

Moving Violation Probit

Union membership, firm size, owner-operator status, mileage in the last 24 hours, and training at a private trucking school or a public/technical school significantly affect the probability of a driver reporting a moving violation. Union employees are nearly 20% less likely to have received a moving violations than nonunion drivers. This is not surprising since union drivers typically experience better working conditions and are paid for all of their time, which makes driving at excessive speeds less necessary.

Owner-operators are 10% more likely to receive a moving violation than employee drivers. Also playing a positive and statistically significant role is miles in the last 24 hours, with a coefficient of 0.00017. This implies that driving an additional 100 miles in a 24-hour period increases the probability of receiving a moving violation by 2%.

Again, the coefficients on the larger firm sizes are negative and statistically significant. Drivers at firms with 500 to 999 employees are 25% less likely to receive a moving violation, and those at firms with 1,000 to 4,999 employees are 13% less likely to receive a moving violation than those drivers at firms with less than 25 employees. Those drivers who learned to drive a truck from a private trucking school are 15% less likely to receive a moving violation, and those who learned at a public or technical school are 18% more likely to receive a moving violation than those drivers who learned on-the-job.

Logbook Violation Probit

Greater amounts of sleep in the last 24 hours, hauling a drybox, higher mileage rates, pay by the hour, and being Black or female decrease the probability of reporting a logbook violation. Drivers who graduated from college or have some college are more likely than high school graduates to violate their logbook, and married drivers are more likely to violate their logbooks than their single counterparts.

Mileage rates and method of pay play a statistically significant role in driver safety when it comes to hours of service violations. Those drivers paid by the hour are nearly 17% less likely to violate their logbooks. The coefficient on mileage rate is –0.35, indicating that a $0.10 increase in the mileage rate decreases the probability of violating the logbook by 3.5%. Blacks are 27% less likely to report working more than they logged in the last 30 days than Whites, all else being equal. Females are also less likely to report violating their logbooks: 37% less likely than male drivers.

Firm size again plays a statistically significant role, though this is not as straightforward as the previous two models. Those drivers at firms with 500 to 999 employees are 27% more likely to violate their logbooks than drivers at the smallest firms. However, drivers at firms sized 1,000 to 4,999 are nearly 20% less likely to violate their logbooks. It should be noted that the coefficients on the largest firms (5,000 or more) are negative, and those at medium sized firms are positive, though not significant. Thus, it appears that drivers at the largest of the large firms are less likely to violate hours of service regulations (or less likely to admit doing so).

Drivers pulling a drybox rather than any other trailer configuration are 18% less likely to violate their logbooks. This is most likely because of the time constraint associated with perishables and other schedule-sensitive trailer configurations. Drivers who sleep more are less likely to violate their logbooks. For every increased hour of sleep, a driver is almost 4% less likely to report a logbook violation.

College graduates and drivers who have attended but not graduated from college follow the pattern first seen in the descriptive statistics. They are 27% more likely to violate their logbooks than those with a high school degree. A possible explanation is that as the education level increases, drivers become more sophisticated in manipulating their logbooks and feel more confident in their ability to successfully violate the law.

Those who are married are 22% more likely to violate their logbooks than single drivers. This may be due to those drivers being in more of a hurry to complete a dispatch and return home or due to pressures to drive more in order to increase annual earnings.

SUMMARY AND CONCLUSION

Using data on truck drivers from the 1997 University of Michigan Trucking Industry Program Survey of Drivers, we estimated the relationship between three safety measures and driver characteristics. As expected, sleep and miles driven significantly affect driver safety via moving and logbook violations. Driving 100 more miles in the last 24 hours increases the probability of receiving a moving violation by 2%, and sleeping an additional hour in a 24 hour period decreases the probability of violating the logbook by nearly 4%.

Most notably, occupational, not demographic, variables appear to be more significant determinants of safety in the trucking industry. Mileage rate and method of payment significantly affect the probability of being involved in an accident or violating a logbook. Those paid at higher effective mileage rates were less likely to be involved in an accident or violate the logbook, as were those who were paid by the hour rather than by some other pay scheme.

Also statistically significant is firm size. Those at very large firms (1,000 to 4,999 employees) were 11% less likely to be involved in an accident, 13% less likely to receive a moving violations, and 20% less likely to violate their logbooks than those at very small firms (less than 25 employees). This may indicate that the large trucking firms, long asserting their commitment to safety, are succeeding.

Although truck driving has the potential to be a dangerous job, we can see that safety could potentially be improved by changing key determinants, such as hours of sleep, miles driven, and method and rate of pay. This study is benefitted by a unique data set and should be replicated when the second wave of data (collected in 1998) is available to further determine policy prescriptions.

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The Highway and Railroad Operating Environments for Hazardous Shipments in the United States—Safer in the '90s?

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ABSTRACT

This paper seeks to illuminate the status of transportation safety and risk for large-quantity shipments of spent commercial reactor fuel and mixed and hazardous wastes by examining road and rail accident and vehicular travel data from the mid-1990s. Of special interest are the effect of speed limit changes on controlled–access expressways (chiefly the Interstate Highway System) and the possible effect of season-to-season climatic variation on road transport. We found that improvements in railroad technology and infrastructure have created a safer overall operating environment for railroad freight shipments. We also found recent evidence of an increase in accident rates of heavy combination trucks in states that have raised highway speed limits. Finally, cold weather increases road transport risk, while conditions associated with higher ambient temperatures do not. This last finding is in contrast to rail transport, for which the literature associates both hot and cold temperature extremes with higher accident rates.

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INTRODUCTION

Although the original waste acceptance timetable of the Nuclear Waste Policy Act of 1982 (42 U.S.C. 10101) was delayed, the U.S. Department of Energy within the next few years will begin to accept consignments of shipping casks containing spent reactor fuel (SRF) from licensed commercial nuclear power generating plants for transport and disposal. In all likelihood, these shipments will be conveyed by road or rail directly from each power plant site or from one or more shipment consolidation depots to the Yucca Mountain Nuclear Waste Repository in Nevada. Shipments of high-level nuclear and mixed waste are already being accepted at the Waste Isolation Pilot Project (WIPP) repository near Carlsbad, New Mexico, and these shipments will intensify in the future. Thus, within three to five years more hazardous nuclear and mixed wastes will be moving over the United States' railroads and highways than at any time in the recent past.

Even low-severity accidents involving such wastes can have negative consequences with respect to both potential neutron exposure and to overall public perception of the shipment of nuclear materials. Given the surface transportation operating environment of the 1990s, we ask here if these and other hazardous shipments can be assured a lower risk of accident while in transit than when these shipments were originally scheduled to begin. Apparently, there has been no systematic attempt to address this question since 1994 when Argonne National Laboratory (ANL) published "Longitudinal Review of State-Level Accident Statistics for Carriers of Interstate Freight" (Saricks and Kvitek 1994). This study investigated highway, rail, and waterborne freight safety on a state-by-state basis, as revealed by mid-1980s transportation statistics.

FACTORS TO CONSIDER IN THE 1990s

The 1994 "Longitudinal Review of State Level Accident Statistics for Carriers of Interstate Freight" documented an analysis conducted earlier in the decade that had been performed for the U.S. Department of Energy (DOE), Office of Civilian Radioactive Waste Management (OCRWM) to improve the prospects for safe transport of hazardous shipments under the DOE's purview. These shipments would involve both commercial SRF and radioactive and mixed wastes from DOE facilities. A decade ago, when such shipments were originally slated to begin, there were important differences in the domestic surface transportation environment relative to today. Four key changes in the intervening years follow:

1. As recently as 1988, a few states still had incomplete links in their designated Interstate Highway System networks, which necessitated the relatively unsafe practice of combination trucks (that is, large, highway cargo vehicles in which one or more trailers are hauled behind a prime mover) having to depart controlled-access, multilane highways for two-lane roads. Moreover, standardized guidance for the routing of large, hazardous-material shipments over highways was lacking; such guidance was not issued by the U.S. Department of Transportation (DOT) for class 7 (radioactive) materials until 1992 (49 CFR 397.101). Today, both the completed interstate system and the appropriate routing guidance are in place.
2. An increase in speed limits by a factor of up to 36% relative to mid-1980 values was enacted during the past decade in most states for both controlled-access and at-grade (i.e., directly intersecting) highways (National Safety Council 1997). Between 1995 and 1996 alone, many states raised their maximum speed limit (nominally applicable only to automobiles and light trucks but generally adopted by all vehicle types) to 70 or 75 miles per hour on interstates and other controlled-access expressways in rural areas.
3. The U.S. rail freight system has experienced considerable restructuring, with consolidation both in the number of carrier corporations (leaving but five U.S.-controlled class 1 systems) and in the number of lines that carry the heaviest freight volumes. This change was accompanied by extensive elimination of "redundant" capacity (e.g., parallel rail routes formerly owned by pre-merger competitors), which in turn imposed unprecedented limits on rail shipment routing options.

4. The period also witnessed significant track and roadbed improvements on surviving rail routes, important advancements in locomotive technology (including the emergence of highly efficient and reliable AC traction motors), and a shift toward relatively cost-effective and time-sensitive intermodal haulage in which truck and rail (and occasionally waterborne freight) each carry a portion of an individual shipment.

In the absence of a more formal assessment, it is logical to assume that (1) and (4) have affected transportation safety positively, while (3) has been neutral to slightly negative, and (2) has been very likely negative in its effects. This reasoning neglects any potential synergism between (1) and (2) that might on balance result in a safer operating environment on controlled-access highways, even at significantly higher speeds. It may also be true that (3) and (4) are mutually exclusive in their effects, with one or the other having relatively little connection to safe operations.

Our objective is to highlight some recent statistical indicators about accidents, fatalities, and injuries sustained in the course of large-shipment commodity flow in heavy-duty vehicles (combination trucks and rail cars) during the middle years of the current decade and, if possible, to connect the trends or tendencies they may reveal to any of these four developments. Ideally, it might then be possible to test one or more useful hypotheses about the risks en route of hazardous materials transportation in the 1990s.

INVESTIGATIVE APPROACH

Although the occurrence of an accident involving a freight-hauling vehicle is not a priori a sign of unsafe conditions, the frequency or density of accidents on a given class of roadway in a defined geographical area may indicate, if other routing choices are available, that a particular road type and area combination should be avoided. Similarly, due to weather and topographic factors, the operating environment for freight railroads may not be uniformly safe across geographic regimes, even for a single carrier. The basic unit of movement for highway transport of spent fuel is the heavy tractor-trailer combination truck and the railcar. Estimating the total movement in kilometers of such units by geographic area provides a set of denominators for risk rates that, when coupled with the corresponding numerators of event counts, provides an indication of the relative safety of an operating regime. Systematic grouping and comparison of these rates (summing over numerators and denominators) can also be instructive with respect to other characteristics that cannot be defined on a strictly geographic basis. A common speed limit regime is one example. In this paper, we generate basic accident, fatality, and injury rates at the state-level of aggregation for the purpose of identifying the spread or range of values, and then we construct statistical groups in an effort to shed light on the possible effects of the factors discussed in the preceding paragraphs. We first discuss how the data for developing these rates were extracted.

DATA SOURCES FOR ESTIMATING STATE-LEVEL ACCIDENT, FATALITY, AND INJURY RATES

Combination Truck Accidents, Fatalities, and Injuries

Until March 4, 1993, Part 394 of Title 49 of the *Code of Federal Regulations* required motor carriers to submit accident reports to the Federal Highway Administration (FHWA) in the "50-T" reporting format. By Final Rule of February 2, 1993 (58 *Federal Register* 6726), this reporting requirement was removed; instead of submitting reports, carriers were required to maintain a register of occurrences meeting the definition of an accident (see below) for a period of one year after such an accident occurred. Carriers were to make the contents of these registers available to FHWA agents investigating specific accidents. They were also required to give ". . . all reasonable assistance in the investigation of any accident, including providing a full, true, and correct answer to any question or inquiry," to reveal whether hazardous materials other than spilled fuel from the fuel tanks were released, and to furnish copies of all state-required accident reports (49 CFR 390.15). The reason for this change in rule was the emergence of an automated state accident reporting system created out of law enforcement accident reports. Pursuant to provisions of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991

(Public Law 102.240), the new system was being established under the Motor Carrier Safety Assistance Program (MCSAP). Under Section 408 of Title IV of the Motor Carrier Act of 1991, a component of ISTEA, the Secretary of Transportation is authorized to make grants to states in order to help them achieve uniform implementation of the police accident reporting system for truck and bus accidents recommended by the National Governors' Association. Under this system, called SAFETYNET, accident data records generated by each state follow identical formatting and content instructions. The records are entered on approximately a weekly basis into a federally maintained database. This database is, in turn, compiled and managed by a DOT contractor as part of the Motor Carrier Management Information System (MCMIS).

Motor carrier reporting rules in 49 CFR 390.5 define an accident as an occurrence involving a commercial motor vehicle operating on a public road that results in a fatality, that results in bodily injury to a person that requires medical treatment away from the accident scene, and/or when one or more involved motor vehicles incur disabling damage as a result of the accident such that the vehicle must be towed from the scene. Specifically excluded from this definition of "accident" are occurrences involving only boarding or alighting from a stationary vehicle, only the loading or unloading of cargo, and passenger cars or other multipurpose passenger vehicles owned by the carrier when transporting neither passengers for hire nor hazardous materials in placard quantities (i.e., above the weight or volume threshold for placard set by DOT).

Heavy combination truck accident counts have been extracted for this paper from the public use MCMIS accident files. The first year of database development, 1993, under the new system discussed above witnessed considerable inconsistency in data quality from state to state; many state-level records were found to be useless because of missing or incomplete data fields. Overall data quality improved steadily from 1994 through 1996, but some problems remain. Several states either do not furnish location-specific information, rendering assignment to a highway type impossible, or they provide this information in a coded manner, unintelligible to the general user. This problem was resolved for Texas, thanks to cooperation from state-level personnel there. However, Georgia, Louisiana, New York, Oregon, and South Carolina lack rates by road type. Also, a handful of other states, including Florida, Maine, Maryland, North Dakota, Ohio, and Tennessee, are missing data from portions of one or more of the years 1994 to 1996. This lack necessitated reliance on only the complete year(s) of data from these states for the purpose of developing state-level accident rate estimates.

Only MCMIS-reported accidents involving the categories (see table 1) of heavy combination trucks operated by interstate-registered carriers are included in our numerators. This is due to the near certainty that only such carriers will be authorized to transport spent reactor fuel (SRF) to a distant repository.

Three state-level denominators for highway combination-truck-kilometers were needed for each analysis year in order to complete the accident rates by using the above data. Estimates of combination truck travel on interstates, other principal highways (generally, other components of the National Highway System), and other roads (e.g., county highways, farm-to-market roads, local streets) for 1994, 1995, and 1996 were developed from the FHWA's annual publication *Highway Statistics* (USDOT FHWA 1995-97), tables VM-1 through VM-4 for 1995 and 1996 (see the web page of the Bureau of Transportation Statistics).

Table VM-2a of *Highway Statistics* provides updated, annual state-level vehicle-miles traveled (VMT) by functional system for the prior year. U.S. VMT totals by highway category (interstate/other, arterial/other) and vehicle type are found in table

TABLE 1 MCMIS Truck Categories Included in Rate Estimation

MCMIS vehicle configuration mode	Truck type
4	Truck/trailer
5	Bobtail (tractor only)
6	Tractor/semitrailer
7	Tractor/double
8	Tractor/triple

VM-1. The share of state-level VMT (distance traveled) accounted for by combination trucks (single and multiple trailer) was obtained from table VM-4, which consists of a series of tables that provide the distribution of annual VMT by vehicle and road classification. In general, the road classification categories found in table VM-4 correspond to those in table VM-2a, although some aggregation of the latter table's totals is required. Table VM-2a totals for rural minor arterial, major collector, minor collector, and local roads were combined into the category "rural other," and the truck share from "rural minor arterial" found in table VM-4 was applied. Similarly, the sum of urban "minor arterial," "collector," and "local" shares from table VM-2a was consolidated as table VM-4's "urban minor arterial;" this was used to estimate the "other urban" truck VMT, as in table VM-1. (Urban VMT totals could only be calibrated to "interstate" and "other," the aggregation level of table VM-1.) At the end of this process, there were three sets of state-level VMT totals, corresponding to the respective combination-truck fraction of national VMT for each highway type in table VM-1.

This distribution of truck VMT by state was compared with state data on highway diesel ("special fuels") sales (see table MF-21 of USDOT FHWA 1995–97) and results of an analysis of 1993 truck flows in the Commodity Transportation Study performed by Oak Ridge National Laboratory (Chin et al. 1998). Adjustments were made on the basis of this cross check. In general, the state shares for diesel sales from table MF-21 and adjusted truck-miles traveled were comparable. Additionally, the mean and variance of the respective distributions of state-level combination truck VMT shares and special fuels sales shares were not significantly different statistically.

Miles for the denominator of each state's rate were converted to kilometers and reduced by 25% to parallel the exclusion of accidents of non-interstate (local and regional) carriers from the numerator. This adjustment is supported by data from the 1992 *Truck Inventory and Use Survey* (TIUS) (USDOC 1992). Tabulated information from TIUS indicates that of the 41.9 billion miles (67.4 billion kilometers) of nationwide combination truck movement in 1992 that could be directly assigned to interstate, intrastate, or locally registered carriers, 34.1 billion (54.9 billion kilometers or about 81%) were by carriers of interstate registry. This might argue that the 25% discount is too conservative and should be set closer to 20%. However, some 29.6 billion combination truck miles in the TIUS could not be so assigned due to missing data entries on the survey data form. We assumed a slightly greater propensity on the part of non-interstate carriers to leave the needed entries blank and thus allocated to these carriers a higher proportion of the unattributable kilometers (35%) than their share of the recorded attributable kilometers (19%). This produced the final 75/25 split assigned to each of the three study years.

Railroad Freight Accidents, Fatalities, and Injuries

Under 49 U.S.C. 20901, rail carriers must file a report with the Secretary of Transportation, not later than 30 days after the end of each month in which an accident or incident occurs, that states the nature, cause, and circumstances of the reported accident or incident. The format for such reports is provided by the Federal Railroad Administration (FRA) under 49 CFR 225.11. The criteria for a reportable accident or incident currently encoded in 49 CFR Part 225 follow:

- Impact occurs between railroad on-track equipment and 1) a motorized or non-motorized highway or farm vehicle, 2) a pedestrian, or 3) other highway user at a highway-rail crossing.
- Collision, derailment, fire, explosion, act of God, or other event involving the operation of standing or moving on-track equipment results in aggregate damage (to on-track equipment, signals, track and/or other track structures, and/or roadbed) of more than $6,300 (as of 1998).
- An event arising from railroad operation results in 1) the death of one or more persons, 2) injury to one or more persons, other than railroad employees, requiring medical treatment, 3) injury to one or more employees requiring medical treatment or resulting in restriction of work or motion for one or more days, one or more lost work days, transfer to another job, termination of employment, or loss of consciousness,

and/or 4) any occupational illness of a railroad employee diagnosed by a physician.

Certain types of railroad carriers are exempted from these requirements, specifically those owning or operating on-track equipment entirely within a facility not part of the general freight railroad system, rail urban mass transit operations not connected to the general railroad transportation system, and those owning or operating an exclusively passenger-hauling railroad entirely within an installation isolated from the general freight railroad system.

Carriers covered by these requirements must fulfill several bookkeeping tasks. FRA requires the submittal of a monthly status report, even if there were no reportable events during the period. Accidents and incidents must be reported on the FRA standardized form, but certain types of incidents require immediate telephone notification. Logs of both reportable injuries and on-track incidents must be maintained by each railroad on which they occur, and a listing of such events must be posted and made available to employees and to the FRA, along with required records and reports, on request. The data entries extracted from the FRA reporting forms are consolidated into an accident/incident database that separates reportable accidents from grade-crossing incidents. These are annually processed into event, fatality, and injury count tables as part of the *Accident/Incident Bulletin* (USDOT FRA 1994-96) published on the Internet by the Office of Safety. All reported trespasser and non-trespasser fatalities and injuries have been included in the data used for the analysis discussed here. According to the FRA *Accident/Incident Bulletin* for 1996, only approximately 3.3% (141) of the 4,257 highway-rail accidents reported in 1996 exceeded the damage cost threshold required for reportable train accidents. In most years, this proportion is well under five percent. Thus, the vast majority of accidents at grade crossings in the FRA database appear due to fatality or injury.

Rate denominators (car-kilometers) come directly from state-level data on carloads handled by year as reported by the Association of American Railroads (AAR). Statistics for 1995 and 1996 have been posted on the Internet for easier access (Association of American Railroads 1998). We estimated the average distance traveled in kilometers by railcar shipments in each state based on the distance from the rail "centroid"[1] of each state to the nearest border, except for corridor states clearly dominated by through (as opposed to originating and terminating) hauls. For states in this category, average haul length was increased by 25%. Examples include Kansas, Mississippi, Montana, New Mexico, and North Dakota. The product of the AAR number times the resulting distance was then multiplied by the ratio of total car-miles to loaded car-miles shown in the "Freight Car Miles" figure of AAR's annual publication *Railroad Facts* (Association of American Railroads 1997). In recent years, this ratio has fluctuated closely around 1.68. Finally, the state-level totals of car-kilometers thus derived are summed for comparison to the control total for railcar miles (kilometers) in *Railroad Facts.* The control total for each year is the metric-converted value for total U.S. freight car miles in the "Freight Car Miles" table (American Association of Railroads 1997, p. 34). Any discrepancy with respect to this control total is corrected by adjusting the average haul length for all states by a uniform percentage, which in no case resulted in a state-level increase or decrease of greater than 10 kilometers per average haul.

VARIATION IN RATES ACROSS THE STATES

From the description above, it should be manifest that an accident rate computed for any single state's combination truck or railcar flows is subject to error from many sources in both numerator and denominator. However, no one state is necessarily more prone to such error than another, unless its sample size in both numerator and denominator is relatively small. We have elected not to present the individual composite (1994 to 1996) state rates computed according to the procedure described but instead to give an indication of their distribution, if it may be assumed that errors are uniform from state to state. Computed rates for individual states are tabulated in Saricks and Tompkins

[1] A "centroid" is the midpoint between east and west or north and south state border crossings on the principal rail line, based on flow data.

TABLE 2 Distribution by Road Type of MCMIS Composite 1994–96 State-Level Accident, Fatality, and Injury Rates per Unit of Travel by Heavy Combination Trucks of Interstate Registry

	I	P	O	T
Accident rate (10^{-7} per truck-km.)				
Total rate	3.00	2.78	4.56	3.21
Mean rate	3.15	3.66	6.54	3.52
Standard deviation	1.87	2.41	8.02	2.06
5th percentile	0.87	0.75	0.23	0.94
Median	2.83	3.15	3.59	3.34
95th percentile	6.19	8.00	27.16	7.12
Fatality rate (10^{-8} per truck-km.)				
Total rate	0.96	1.78	1.71	1.42
Mean rate	0.88	2.32	1.96	1.49
Standard deviation	0.45	1.64	2.19	0.68
5th percentile	0.09	0.22	0.00	0.38
Median	0.92	2.06	1.13	1.30
95th percentile	1.49	5.30	6.32	2.57
Injury rate (10^{-7} per truck-km.)				
Total rate	2.25	2.17	3.33	2.39
Mean rate	2.27	2.73	4.69	2.56
Standard deviation	1.32	1.75	5.91	1.48
5th percentile	0.57	0.60	0.24	0.77
Median	1.93	2.51	2.52	2.20
95th percentile	4.56	5.95	19.31	5.35

I = Interstate Highway System
P = Primary (non-interstate) National Highway System
O = Other roads and highways
T = All highways and other roads

(1999). The respective "spreads" of highway, heavy combination truck accident, fatality, and injury rates of interstate-registered carriers by road type for the continental U.S. as a whole is shown in table 2, with the three sets of rates distributed over all road types charted in figure 1. These distributions are similar to those reported for earlier data series in Saricks and Kvitek (1994), shown in table 3, but with modest reductions for National Highway System road classifications below that of Interstate Highway.

The "total rate" in table 2 reflects the sum of all applicable MCMIS incidents for all interstate-registered heavy combination trucks in the category, divided by corresponding national travel-kilometers, while the "mean rate" is the average over the rates for the 47 continental U.S. states with qualifying (reportable) accidents in the three-year period. The latter value is generally higher in each instance

TABLE 3 Total and Standard Deviation for OMC Composite 1986-88 State-Level Accident, Fatality, and Injury Rates per Unit of Travel by Road Type by Heavy Combination Trucks of Interstate Registry[1]

	I	P	O
Accident rate (10^{-7} per truck-km.)			
Total rate	2.44	3.94	3.48
Standard deviation	0.69	1.77	6.98
Fatality rate (10^{-8} per truck-km.)			
Total rate	2.03	5.82	4.62
Standard deviation	0.63	3.01	11.74
Injury rate (10^{-7} per truck-km.)			
Total rate	2.28	3.82	3.30
Standard deviation	0.69	1.79	7.10

[1] Reported in Saricks and Kvitek (1994)—percentile distributions not computed.
I = Interstate Highway System
P = Primary (non-interstate) National Highway System
O = Other roads and highways

because of the disproportionate weight assumed by states with less total truck activity. Overall, the data appear to show that, although the likelihood of injury in accidents involving heavy combination trucks is higher for most states than during the 1980s, the likelihood of being killed is almost uniformly lower. This may be due primarily to an increase in seat belt use and safer vehicle design, including the use of airbags and other active restraints, rather than to generally safer roadway conditions. However, the root cause remains unknown. If, due in part to the new restraint systems, those that would formerly have been fatalities are now injuries instead, then the observed increase in injury rate should be expected.

The corresponding spread of accident rates per railcar-kilometer is shown in table 4. Domestic rail freight accidents, fatalities, and injuries on class 1 and 2 railroads have apparently stabilized or declined slightly since the late 1980s (see table 5). Reductions in fatalities and injuries, likely due to an extent to increased grade-crossing safety, ongoing grade-crossing elimination programs, and AAR's "Operation Lifesaver" program, are especially noteworthy.

TABLE 4 Distribution of FRA State-Level Accident, Fatality, and Injury Rates per Railcar-km

	Accidents	Grade crossing incidents	Non-trespasser fatalities	Trespasser fatalities	All fatalities	Non-trespasser injuries	Trespasser injuries	All injuries
Mean rate	2.74E-07	2.16E-07	1.38E-08	6.44E-08	7.82E-08	1.04E-07	1.25E-08	1.17E-07
Std. dev.	7.61E-07	5.68E-07	1.16E-08	2.13E-07	2.15E-07	3.80E-07	1.64E-08	3.79E-07
5th pctile.	1.95E-08	1.39E-08	1.86E-09	1.64E-09	5.78E-09	5.87E-09	6.72E-10	9.62E-09
Median	6.10E-08	1.02E-07	1.31E-08	8.92E-09	2.27E-08	3.40E-08	1.15E-08	4.26E-08
95th pctile.	1.53E-06	3.87E-07	4.17E-08	2.11E-07	2.23E-07	1.86E-07	5.44E-08	2.07E-07

SPEED LIMIT EFFECTS

Between 1995 and 1996, the 25 states listed in table 6 raised the maximum daylight speed limit for cars and light trucks on interstate highways. Although nominally restricted to a speed limit lower than the posted maximum, heavy combination trucks are often seen moving on rural interstates at speeds comparable to the rate of primary vehicular flow (i.e., the overall maximum limit). Using the accident data compiled for this study, we analyzed the relationship between maximum speed and accident rate. For this investigation, we examined only data for interstate highways by state for 1995 and 1996. Of the 48 states included in the study, 5 had incomplete road class information, and 1, Rhode Island, had no qualifying accidents. Therefore, these six states were excluded from the speed limit analysis. The five states without road class information were Georgia, Louisiana, New York, Oregon, and South Carolina. Two of these states, Georgia and New York, raised the maximum speed limit: Georgia to 70 miles per hour and New York to 65 miles per hour. (Note that all accident rates are in units of 10^{-7} accidents/kilometer.) The remaining states were separated into two groups: states that raised the speed limit during the 1995 to 1996 period (group A) and those that did not (group B). The mean and variance for accident rates in 1995 and 1996 for all states combined and for groups A and B, respectively, are shown in table 7.

The mean accident rate for all states increased from 2.93 in 1995 to 3.45 in 1996. The mean accident rate for the group A states, those that raised the speed limit, increased from 2.70 to 3.69, while the mean accident rate for group B states remained approximately the same. The quality and inherent variability of the data across states indicates caution be used in imparting significance to any differences noted, but it is interesting nonetheless that the change in mean accident rates is in the expected direction.

TABLE 5 Composite 1985–88 FRA State-Level Accident, Fatality, and Injury Rates per Unit of Railcar Movement[1]

	Total[a]	Mainline only
Accident rate (10^{-8} per railcar-km.)		
Total rate	5.57	2.66
Standard deviation	21.48	11.12
Nontrespasser fatality rate (10^{-8} per railcar-km.)		
Total rate	2.35	—
Standard deviation	(not reported)	
Nontrespasser injury rate (10^{-7} per railcar-km.)		
Total rate	5.37	—
Standard deviation	(not reported)	

[1] Reported in Saricks and Kvitek (1994)—percentile distributions not computed; grade crossing incidents not included in accident counts.

[a] Includes switching yards and industrial lead tracks.

TABLE 6 States that Raised the Maximum Controlled-Access Highway Speed Limit 1995–96

Alabama	Nevada
Arizona	New Mexico
California	New York
Colorado	North Carolina
Delaware	Oklahoma
Florida	Pennsylvania
Georgia	South Dakota
Idaho	Tennessee
Kansas	Texas
Mississippi	Utah
Missouri	Washington
Montana	Wyoming
Nebraska	

FIGURE 1 Two-Tail Distributions of Composite 1994–96 Mean State-Level Accident, Fatality, and Injury Rates for Interstate-Registered Combination Trucks Over All Highway Types

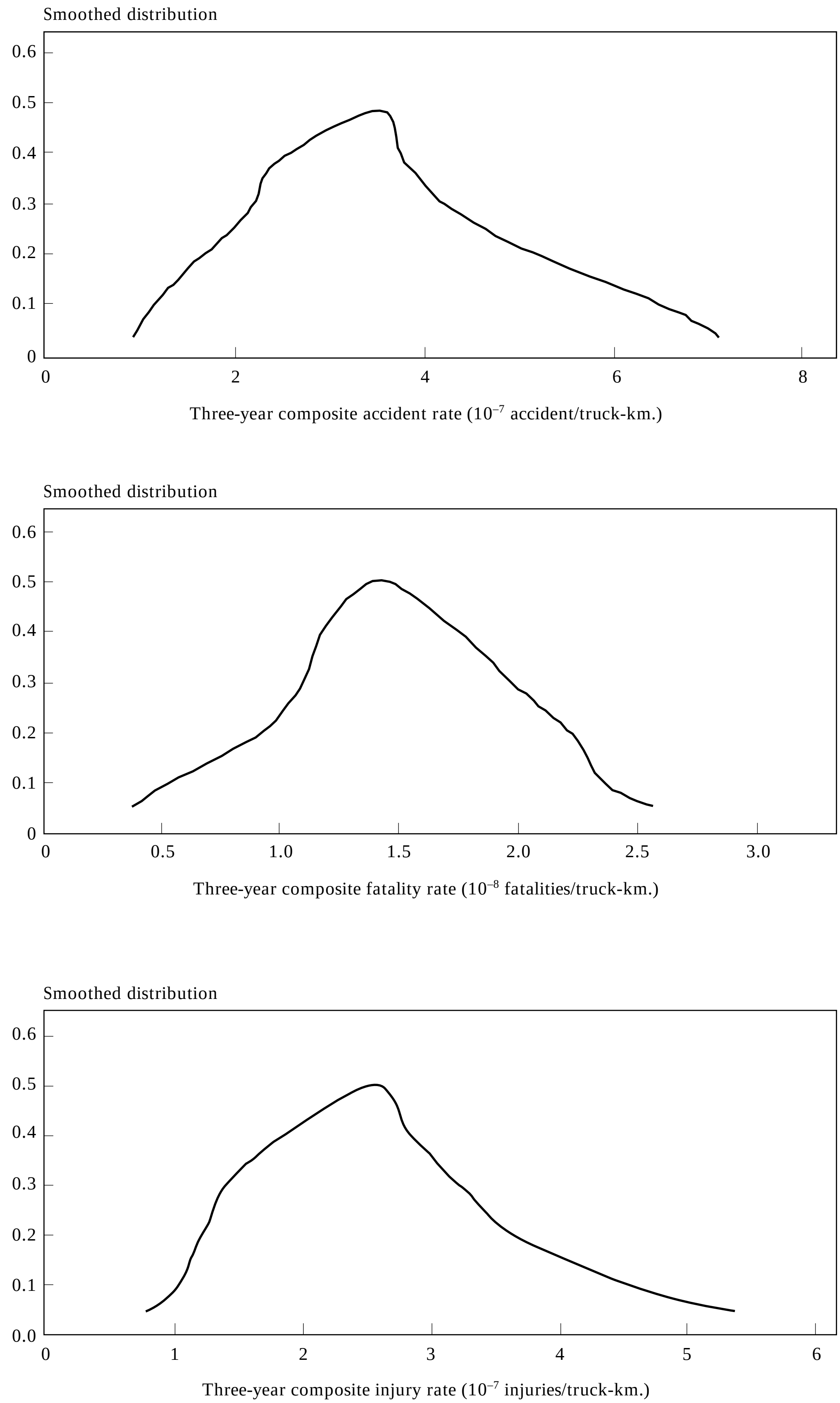


TABLE 7 Accident Rates 1995 and 1996—Descriptive Statistics

Accident rate	1995	1996
All states		
mean	2.93	3.45
variance	3.62	5.56
Group A		
mean	2.70	3.69
variance	3.05	3.93
Group B		
mean	3.22	3.15
variance	4.36	7.68

No further statistical analysis is presented here, but underlying relationships in these data should remain a topic for future investigation. Many factors affect the occurrence or avoidance of an accident, and speed is but one of them. The ability to adjust to a rapidly developing, dangerous situation on the roads can be impaired at higher speed driving, but under some circumstances speed differences within the traffic stream, rather than at its maximum speed, have greater importance. Without access to comprehensive reports on individual accidents and their causes, it is premature to judge whether an increase in speed limits per se is inherently less safe for heavy combination truck movements.

CORRIDOR ANALYSIS

In earlier analyses applying extensive statistical testing to all rail accident and incident records in the FRA database for 1984 through 1988, strong and consistent positive correlation was discovered between temperature extremes and accident frequencies (Lee and Saricks 1991; Saricks and Janssen 1991). Descriptive statistics using the MCMIS data are presented in an effort to gain some insight into whether a similar phenomenon occurred for truck accidents. States were partitioned into three primary east-west highway corridors representing different seasonal temperature regimes (shown in figure 2). These states and east-west interstate highways were included in each corridor:

Central: CO, IL, IA, KS, MO, NE, NV, UT, WY; I-44 (MO), I-70, I-76, I-80, I-88

North: II, MI, ME, MT, ND, OR, SD, WA, WI; I-82, I-84, I-86, I-90, I-94

South: AK, AZ, AR, CA, FL, GA, LA, MS, NM, NC, OK, SC, TN, TX, VA; I-8, I-10, I-20, I-30, I-40, I-44 (OK)

Along each corridor, three years of MCMIS truck accident counts were partitioned into three-month groupings approximately representing the four seasons. Accident involvement counts of interstate-registered heavy combination trucks for the years 1994, 1995, and 1996 were pooled and compared for the corridors. From monthly counts, it appeared that there is greater seasonal variation in the number of accidents for the north corridor (west of Chicago) and less pronounced variation in the south corridor (entire Sun Belt). Results for the central corridor are mixed and may involve differences between routes such as I-70 and I-80 that were not investigated. Table 8 shows the mean number of accidents and the variance along each of the defined corridors for the winter and summer seasons. The months January, February, and December are designated as winter, and the months June, July, and August are designated as summer. No formal tests are presented in this paper due to the quality and inherent variability of the data. The descriptive statistics, however, indicate that there may be a seasonal variation in truck accidents. In particular, based on the accident counts, it appears that truck transport risk, like rail transport, may exhibit sensitivity to conditions associated with winter driving, such as short days with their low-light conditions, snow, sleet, and ice. However, unlike rail transport, it may be relatively insensitive to conditions associated with extreme heat.

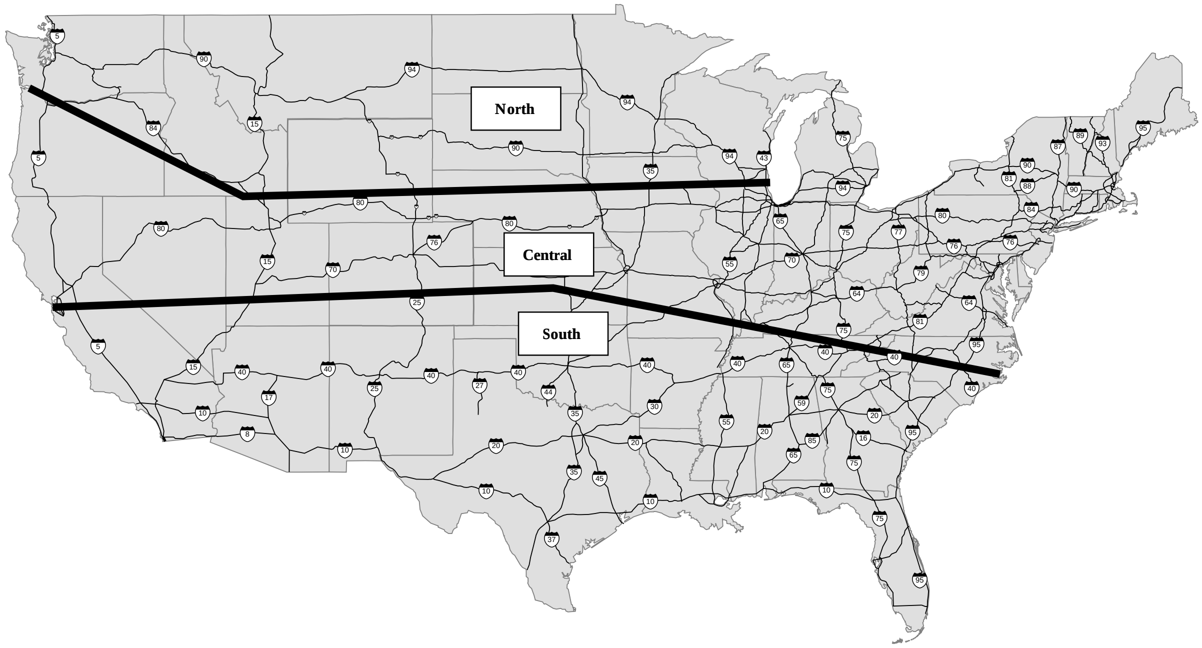
DISCUSSION AND CONCLUSIONS

Earlier, four relatively recent developments were identified as possible modifying influences on acci-

TABLE 8 Descriptive Statistics of Corridor Accident Involvement Counts: 1994–96 Composite

	Summer	Winter
South		
mean	1,644	1,625
variance	25,101	48,326
Central		
mean	1,220	1,508
variance	16,168	139,311
North		
mean	539	874
variance	9,168	45,650

FIGURE 2 Transcontinental Corridors Defined for Comparative Seasonal Analysis



dent involvement rates of surface freight transportation, relative to their mid-1980s counterparts. The first of these, completion of the Interstate Highway System, appears to have contributed to a mitigation of these rates. For example, West Virginia was one of the last states to see completion of its designated interstate highway network. There, the accident involvement rate for interstate-registered heavy combination trucks on the primary (non-interstate) highway system—some of which in the mid-1980s was carrying truck traffic diverted from interstate highways under construction—declined by at least 65%. The fatality rate dropped by over 60%, and the injury rate, by over 70%.

There is limited evidence that the second development, increased highway speed limits, especially on the interstate system, poses a valid concern, as documented in earlier sections of this report. Additional analysis is warranted when a longer time series of data that includes at least three years prior to and three after 1996 becomes available. Such an interval will be necessary to reveal whether higher 1996 rates for states that raised the speed limit represent an anomalous fluctuation in the time series or the beginning of a sustained reversal of long-term downward accident trends for heavy combination trucks.

The third development, the continued consolidation and rationalization of the railroad freight system, also appears positive in that such consolidation has, to date, resulted in a network capable of safer, more efficient operations. Changes in economic conditions have combined with elimination of "excess" track miles to bring about shifts in state shares of total freight flows; for example, major increases are evident on the consolidated trunk lines in several central, northern, and western states. A continuing shift of shorter hauls to trucks is reducing total railcar flow in New England and in some Mid-Atlantic States. This latter phenomenon causes incremental accidents to have an exaggerated effect on state-level rates in the affected areas. Although this analysis could not positively identify a consistent mid-1990s reduction in accident rates relative to mid-1980s conditions (in fact, the national rate is statistically unchanged), it did identify a downturn in most fatality and injury rates. Again, this may be the result of increased awareness of good safety practice both on the railways and among the general public at railroad crossings due to such outreach efforts as "Operation Lifesaver."

The final development cited in the first section of this report may no longer be relevant to an intensive shipping campaign for large consignments of radioactive and hazardous materials. Road and rail routing options are now generally constrained by published guidance (49 CFR 397.101). However, options remaining for routing via railroad can be worked out directly with carriers during contract negotiations and, in any case, based on recent data do not to possess (other factors being equal) a clearly "safer" routing choice in the current selection set. With respect to intermodalism and technological advance, current plans for the spent reactor fuel shipping campaign generally exclude all but necessary near-site transshipment, with casks moving by either railroad or highway exclusively from plant site to repository. If additional transshipment options were actively under consideration, the effect and relative safety of intermodal haulage would merit further discussion, but such analysis is now premature. Also, statistics presented in sources noted above appear to support the concept that that the adoption of higher operating speeds over improved track in advanced-technology locomotives does not compromise safe railroad operation.

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