TRANSPORTATION RESEARCH
CIRCULAR

Number 481 February 1998

Highway Capacity Expansion and Induced Travel

Evidence and Implications

TRANSPORTATION RESEARCH BOARD / NATIONAL RESEARCH COUNCIL

TRANSPORTATION RESEARCH
CIRCULAR

Number 481, February 1998
ISSN 0097-8515

HIGHWAY CAPACITY EXPANSION AND INDUCED TRAVEL: EVIDENCE AND IMPLICATIONS

COMMITTEE ON TRANSPORTATION PLANNING APPLICATIONS

Richard S. Marshment, Chair

Barbara J. Arens
Rick Donnelly
Julie K.P. Dunbar
Jerry M. Faris
Ron Fisher
David T. Hartgen
Jane Howard
George T. Lathrop
Adiele G. Nwankwo
Karl H. Quackenbush
George L. Reed
Karen Jones Savage
Eddie Shafie
Gordon A. Shunk
Montie G. Wade
William A. Woodford
Samuel L. Zimmerman

James A.Scott, TRB Staff Representative

Subscriber category
I planning, administration, and environment

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

FOREWORD

At the Transportation Research Board's 76th Annual Meeting, the Committee on Transportation Planning Applications sponsored a session on "Highway Capacity Expansion and Induced Travel: Evidence and Implications". The session contained four papers, comments by two discussants, and questions and comments from the audience. The circular contains the four papers and a summary of the discussion following the presentations.

The committee would like to express its appreciation to Harry Cohen, Cambridge Systematics Inc., for the preparation and editing of this research circular.

CONTENTS

INTRODUCTION

The question of highway capacity expansion and induced travel is one of the most troubling facing transportation planning today. Frequently, planners must present their demand forecasts to audiences who believe that highways create their own demand and that congestion relief from highway improvements is at best temporary in nature.

The travel demand models used by most State Departments of Transportation (DOTs) and metropolitan planning organizations (MPOs) account for the diversion of traffic from parallel facilities to an improved highway, for shifts of travelers from other modes, and (depending on how the models are applied) the role of improved highways in causing people to shift the destinations of their trips. However, these models usually do not account for any effects of highway improvements on the total number of trips made and shifts in the locations of households, businesses, and other activities that might have VMT implications. Hence, there remain questions about whether our models fully account for the effects of new highway capacity on the amount of highway use.

Shortcomings in travel forecasting models can have important regulatory implications. The 1990 Clean Air Act Amendments hold MPOs and DOTs directly accountable for demonstrating that transportation activities will not cause any new air quality violations, increase the severity of existing violations, or delay attainment of standards. Questions about whether our models adequately account for induced traffic cut directly at the credibility of these demonstrations.

TRB recently published Special Report 245, *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use*. The TRB study found that "existing travel demand forecasting models do not adequately reflect the effects of reductions in travel time or increased travel time reliability that result from an expansion of highway capacity. Of particular concern is the inability of current models to represent the effects of increased highway capacity on automobile ownership, the number of trips made, the time of day of travel, interdependencies among trips (i.e., trip chaining), and nonmotorized travel."

Given the high degree of uncertainty associated with our ability to predict induced traffic (as well as other major uncertainties in the forecasting process), can we really make the determinations called for by Clean Air Act Amendments with any degree of confidence? Or, is it the case (as stated by the TRB study) that the current regulations "demand a level of analytic precision beyond the current state of the art in modeling."

Difficulties in analyzing induced traffic also diminish our ability to assess the effectiveness of disincentives to highway use such as higher tolls and parking charges. These actions discourage some auto trips, which in turn improves speeds for other drivers. The speed improvement can then result in induced traffic, which would offset part of the initial decrease in auto trips. This problem could be especially serious if all vehicles are not subject to the higher tolls and parking charges. For example, increased parking charges in the Central Business District (CBD) could decrease the number of auto trips to the CBD but increase the number of auto trips through the CBD to other destinations.

TRB SESSION

At its 76th Annual Meeting in January 1997, the Transportation Research Board (TRB) presented a session on Highway Capacity Expansion and Induced Travel: Evidence and Implications. The session, which was sponsored by TRB's Committee on Transportation Planning Applications, included the presentation of four papers, comments by two discussants, and questions and comments from the audience. This report contains the four papers and a summary of the discussion following their presentation.

The papers take a broad view of induced traffic. Heanue defines induced traffic as any increase in daily travel (measured as passenger or vehicle miles of travel) resulting from a change in the transportation system.

Hansen measures induced traffic as the net change in VMT in a corridor or systemwide. Dunphy looks at the relationship between VMT per household and congestion to assess induced traffic.

The papers also note the importance of geographic scope and time period in attempting to measure induced traffic by comparing traffic volumes before and after highway improvements. Dowling found that the two most common responses to changes in congestion are change route (find a faster route if the current one becomes congested) and change schedule (find another time of day when congestion is less). Heanue discusses the possibility of confusing the diversion of traffic from other roads with induced traffic if the measurement of induced traffic is limited just to before and after counts on the improved facility. Regarding time of day, Heanue notes the results of a before and after study for the opening of the Zeeburger Tunnel in the Netherlands. After the opening of the tunnel, *peak period* traffic across the North Sea Canal increased by 16 percent, while total *daily* traffic increased by five percent.

The papers also distinguish induced traffic from growth in traffic that would have occurred with or without highway capacity expansion. The failure to make this distinction is the source of the commonly held point of view that highway capacity improvements are futile because congestion relief from them is at best temporary in nature.

Session participants identified several high priority areas for future research on induced traffic:

- The development of simplified procedures to account for induced traffic in benefit-cost analyses of highway improvements;
- More basic research on travel behavior oriented toward understanding the role of changes in travel times and costs on the amount of travel by households and businesses;
- Retrospective studies, which compare observed volumes in highway corridors with forecasts; and
- Before and after studies of major improvements in highway capacity.

Review of the four papers and the discussion following their presentation suggests that the range of disagreement between highway proponents and opponents on the subject of induced travel has narrowed considerably. In the past, many highway proponents contended that the potential for induced traffic due to highway improvements was very small and could be neglected in conducting analyses of highway user benefits and air quality impact due to highway improvements. However, the definition of "induced" travel was limited to increased total trip-making because other travel effects (e.g., path, mode choice) were accounted for separately in the model stream. Meanwhile, highway opponents contended that it was futile to attempt to improve highways, since induced traffic would reduce speeds back to the levels that would have occurred without the improvement, so that there would be no time savings as a result of the improvement. Today there is more acceptance among highway proponents of the idea that new highway capacity induces a variety of land use and travel changes, all of which should be accounted for in objective analyses of new highway investments. Similarly, there is more acceptance among highway opponents of the idea that induced traffic from highway improvements is a result of time savings, so if there are no time savings as a result of the improvement, there won't be any induced traffic and that most growth in traffic derives from socio-economic rather than system changes.

THE TRAFFIC INDUCEMENT EFFECT: ITS MEANING AND MEASUREMENT

Mark Hansen
University of California, Berkeley

INTRODUCTION

The "traffic inducement effect" of road improvements in urban areas is the subject of continuing controversy. Whether, to what extent, and under what conditions adding road capacity engenders traffic growth are, on the surface, empirical questions. However, these questions, like those of whether the death penalty deters crime, or whether welfare programs encourage teen pregnancy, have strong ideological overtones. These derive in part from the salience of the question to fundamental, highly contentious, issues in highway policy. The ideological dimension is enhanced because definitive answers to these questions have proved illusive, a consequence of our inability to conduct the relevant controlled experiments.

This paper seeks to contribute to the ongoing debate about the relationship between road supply and traffic in several ways. First, we reflect upon the policy context of the debate. Second, we seek to make the questions in dispute more precise by defining metrics that capture the impact of road supply on road traffic. Third, we report on research that has attempted to measure these impacts. Fourth, and finally, we offer recommendations for improving our ability to monitor and document on an ongoing basis how road improvements, and perhaps other transportation investments as well, influence traffic and travel in urban regions.

POLICY CONTEXT

In the 19th Century, as roads, canals, and railroads were built across the United States, analysts of the day distinguished between projects that were "developmental" and those and were "exploitive."[1] Developmental projects were expected to generate and serve new markets by enabling settlement of previously inaccessible hinterlands. Exploitive ones, in contrast, targeted existing markets, offering improved service compared with pre-existing alternatives. In a country where settlement of new territory was an urgent priority, projects in the former category were, as the above terms suggest, considered to have the higher purpose.

By their nature, developmental projects induced demand, whereas exploitive ones were more likely to divert pre-existing traffic. So in the 19th Century, traffic inducement was a considered a desirable impact of transportation improvements. In certain contexts, the same holds true today. For example, urban and intercity rail proponents stress (perhaps exaggerate) the ability of such systems to alter settlement and traffic patterns in ways that will stimulate traffic on the systems they advocate.

When it comes to roads, however, the tables are turned: advocates of road improvements view them a accommodations to largely exogenous demand, while opponents argue that such accommodation will inevitably spur more traffic in an endless spiral of road building and road filling.

Why this difference? In part, it has an economic interpretation, illustrated in Figure 1. Figure 1a depicts the impact of a road improvement, represented as a downward shift of the supply (average user cost versus traffic) curve for a road (or road network) from **s** to **s'**. If the demand curve (traffic level versus average user cost) is, like **d**, vertical--implying no induced traffic--the increase in consumer surplus resulting from the improvement is the rectangle **ABCD**. Conversely, if the demand curve is sloping like **d'**, so that some traffic is induced, the benefit is the smaller area **ABC'D'**. The difference derives from the fact that the supply curves are upward sloping i.e. that roads are subject to congestion effects.

In Figure 1b, the effect of an improvement to a transportation system not subject to congestion is shown. It can be seen that in this case, a sloping demand curve implies a greater benefit than a vertical one. The effect is even stronger when supply curves are downward sloping, due to economies or scale. Elastic demand also results in greater benefit if improvement and improvement of a congested system leads to an uncongested system at the new equilibrium (imagine that s' in Figure 1a remains flat beyond traffic level where it intersects with d'.)

Thus, a conventional welfare analysis offers on explanation for why induced traffic is seen in a negative light for road projects and a positive light for many others. In fact, however, such an analysis is ambiguous even in the case of a congestable road facility. But the negative view of induced traffic is also related to how we view the adjustments represented by movements along the demand curve from a normative standpoint. In the case of roads,

Figure 1a. Welfare Analysis of Transporation Improvement with Congestion

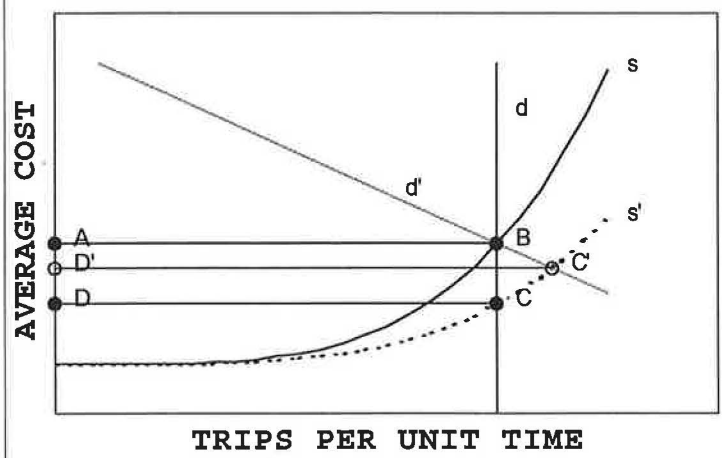
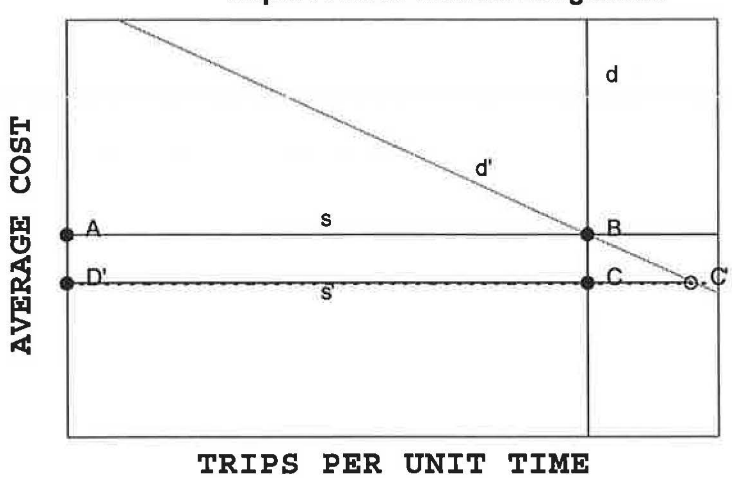


Figure 1b. Welfare Analysis of Transportation Improvement without Congestion



increased demand is associated with urban sprawl, increased fuel consumption, more emissions, and other ills associated with motorization. On the other hand, adjustments associated with increased rail use, such as more focussed development patterns or curtailed automobile use, are seen more favorably. Road advocates might, as they could in the welfare analysis, challenge these viewpoints, for example by pointing to increased road traffic as an indication of an invigorated economy, or of more households realizing the dream of owning a single family home in the suburbs. They have for the most part avoided this line, however, instead maintaining that the benefits or road improvements derive almost entirely from reduced congestion to an essentially fixed quantity of traffic.

MEASUREMENT ISSUES

The debate over the impact of road investments on traffic levels is sometimes caricatured as one over whether roads do or don't generate traffic. But this is not really the issue.

It is widely accepted that, holding traffic levels fixed, additional road capacity reduces traffic delays and travel times. It is also widely accepted that these impacts, by making vehicle travel more convenient, will tilt decisions about whether, where, and how to travel toward choices that involve increased vehicle usage. Neither of these generalizations is iron-clad. There are the familiar "paradoxes" in which a road improvement can lead to a redistribution of trips that result in increased travel times. There are also scenarios where a road improvement makes near-in places more accessible, altering activity and traffic patterns in a manner that reduces overall travel. (The results of Putman [2], suggest that this could occur if the Golden Gate Bridge were double-decked so that the San Francisco commuter shed shifted toward Marin and away from the East Bay.) Such counterexamples are, however, widely viewed as rare exceptions to the general rules. To the extent that the latter hold, it is a matter of logic that roads induce traffic to some degree.

The debate, therefore, is not over whether the effect exists, but its magnitude. This raises the question of metrics. Imagine that we have two identical regions with identical transportation systems and that, at some time t=0, we make a set of road capacity enhancements in one of the regions but not in the other, and that this is the only way in which we treat the regions differently. Over time one could monitor traffic levels in the two regions which, although equal at t=0, would presumably diverge thereafter as a result of the change to the road supply. Suppose we could characterize the magnitude of the road capacity change, as ΔS (or $\Delta\log(S)$), and the magnitude of the interregional traffic level difference a time t as $\Delta Q(t)$ (or $\Delta\log(Q(t))$). In this idealized situation, the traffic inducement effect of the capacity increase might be measured either as a simple ratio, $\Delta Q(t)/\Delta S$, or as an elasticity, $\Delta\log(Q(t))/\Delta\log(S)$. We prefer the latter, which we term the capacity elasticity of traffic, for two reasons. The elasticity indicates directly how a capacity increase affects the ratio of traffic to capacity, a widely accepted measure of level of service. Second, for a given elasticity and given capacity increase, the quantity of traffic induced varies directly with the ratio of traffic to capacity. This is plausible, since the higher ratio implies a higher level of congestion in the baseline situation.

The procedure in the above hypothetical experiment is not yet precisely defined, since we did not specify how S and Q are to be measured. Different procedures give different elasticities, each with its own significance. For example, if the capacity change involves the widening of a specific segment of road, than S could be the lane-width of that segment and Q the traffic on that segment. Alternatively, S and Q could be measured over larger subsets of the regional road networks, up to and including the networks in their entirety. When such aggregation is performed, it makes sense to measure S in terms of lane-miles and Q in terms of vehicle-miles.

With the measurement procedure specified, a given experiment like the one defined above would yield a specific set of measurement results--calculated capacity elasticities of traffic for different points in time after the road supply change in one of the regions. However, if the same experiment were performed using a different pair of regions, or using the same pair but a different road supply change, it is likely that different elasticity values would be obtained. These elasticities are not physical constants, but variables that depend in a complex way on characteristics of the region, its baseline transportation network, and the road supply change. But despite variation, the elasticities will have a central tendency, which could, in principle, be estimated by repeating the experiment using different regions and supply changes considered representative of the "populations" of interest.

TWO RECENT STUDIES

This section summarizes two recent studies whose objective was to estimate capacity elasticities of traffic. In one study [3], the elasticity was estimated at the road segment level. In this case, the question is: how does traffic on an individual road segment respond to an increase in capacity of that segment? In the second study [4], the elasticity is measured at the metropolitan area level. Here we are interested in how an increase in area-wide highway capacity affects area-wide highway traffic. Both studies focus on California metropolitan areas, and employ data for the last 2-3 decades.

The thought experiments described in the last section are useful for explaining what we are attempting to measure, but cannot actually be undertaken. Instead, we must devise quasi-experiments using real-world data. In both of segment-level and area-level studies, our quasi-experiments have used panel data. In the segment-level study, the panel consists of highway segments, while in the area-level study, it is metropolitan areas. In both studies, we follow the panel over time, using statistical methods to attempt to relate changes in traffic levels to changes in capacity levels.

Segment-Level Study

The panel consists of 18 highway segments, all of freeway or expressway grade, whose capacity was increased sometime in the late 1960s or 1970s. The segments are located in metropolitan areas–nine in the Los Angeles area, six in the Bay Area, two in Sacramento, and one in San Diego. The capacity expansions involved adding lanes--either one in each direction (11 cases), two in each direction (six cases), or a combination of one and two lane expansions (one case).

For each segment, annual average traffic count data, published by Caltrans, were obtained for selected years prior to and after completion of the capacity expansion. The years selected are those 1,4,7,10,... years before the capacity expansion and 1,4,7,10,... years after. The expansions themselves occur over a 1 to 4 year period over which no observations are included. Only years between 1960 and 1990 are included, so a given segment will have more observations prior to (after) the capacity expansion the later (earlier) the expansion took place. The maximum number of years after the expansion for which observations were available was 19, but only three segments have count data available for this time slice.

The data were used to estimate a model of the form:

$$\log(Q_{it}) = \alpha_i + \beta\cdot\log(C_{it}) + \gamma\cdot\log(SQ_t) + \lambda\cdot\frac{NC_{it}}{t^{\sigma}} + \epsilon_{it}$$

where:

- Q_{it} is the traffic volume of segment I in year t (t is measured from before the beginning or after the completion of the capacity expansion);
- C_{it} is the capacity (number of lanes) of segment I at time t;
- SQ_t is vehicle-miles traveled on the California state highway system in year t;
- NC_{it} is the ratio of capacity added to total capacity for $t > 0$, and zero for $t < 0$;
- $\alpha_i, \beta, \gamma, \lambda, \sigma$ are coefficients to be estimated;
- ϵ_{it} is a stochastic error term, drawn from a normal distribution with mean zero.

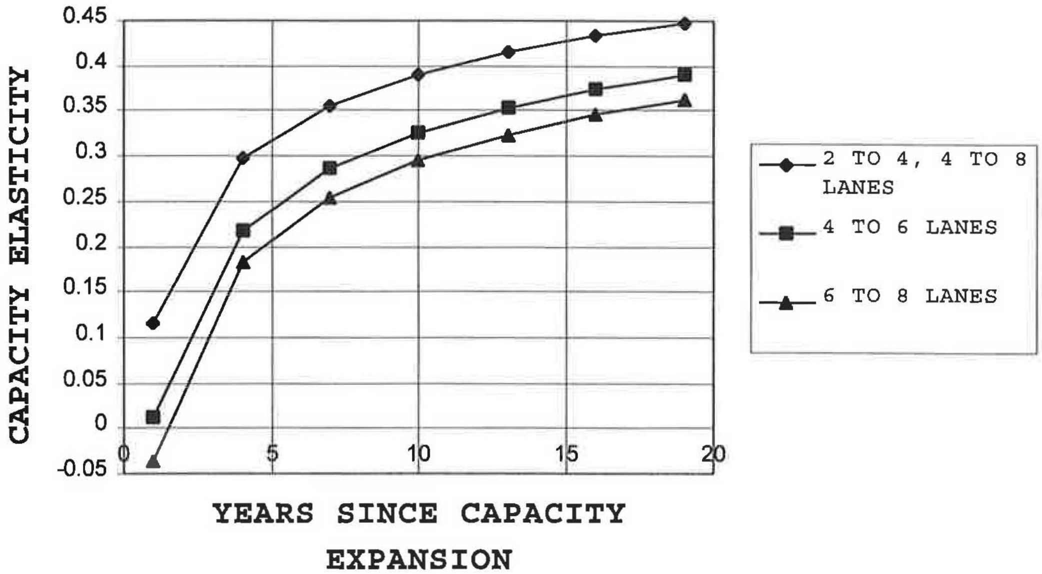
In this model, the hypothesis that traffic is unrelated to capacity implies that $\beta = 0$ and $\lambda = 0$. In that case, traffic on segment I in year t would be determined by the segment specific factor, α_i, and a time-specific factor related to the overall traffic level on California state highways, $\gamma\cdot\log(SQ_t)$. In other words, traffic on each segment would grow from a segment-specific baseline level, tracking growth of overall traffic on the state highway system. The hypothesis that traffic responds instantaneously to a change in capacity implies that $\beta > 0$ and $\lambda = 0$. In this case, an increase in capacity would immediately result in an upward shift of traffic, over and above any increase associated with statewide traffic growth. Finally, if $\lambda < 0$, the response of traffic to new capacity is gradual. One year after the expansion, $\log(Q_{it})$ is $\lambda\cdot NC_{it}$ less than it would be if the new capacity were not new. As the time since the capacity expansion increases, this difference decreases with $t^{-\sigma}$.

This model was estimated on the panel data set described above. The model is linear in all coefficients except σ. In the estimation, we assumed different values for this coefficient, and used least squares to estimate the remaining coefficients, ultimately choosing the model with the σ value that yielded the best fit. The estimation results appear in Table 1. The β estimate is positive and significant, while the λ estimate is negative and significant, across the range of σ values that give the best fits. This implies a positive, non-instantaneous response of traffic level to an increase in capacity.

The estimation results can be used to calculate segment-level capacity elasticities of traffic for different times after the expansion. The elasticity will of course depend on the amount of time since the capacity expansion and the ratio of expanded to original capacity. The elasticities for the model with $\sigma = 0.20$ are plotted against time since expansion, for different capacity increases, in Figure 2. The elasticities increase sharply during the first four years after the expansion, and more gradually thereafter. Four years after expansion, elasticities are in the 0.2-0.3 range. After 10 years, the elasticities are in the 0.3-0.4 range. Thereafter, increases are very slow, so that by 16 years after project completion the elasticities range from 0.35 to 0.43. Throughout, the highest elasticities are associated with larger fractional capacity expansions.

Throughout the period plotted, the elasticities are well below 1.0. This implies that the capacity expansion yields a sizable reduction in the ratio of traffic to capacity. In other words, although it appears that expanding the capacity of a highway segments results in an increase in segment traffic, there is still a substantial level-of-service gain.

Figure 2. Capacity Elasticity of Traffic, Road Segments



Area-Wide Study

In this study our panels consisted or urban areas, rather than highway segments. Our basic data consisted of state highway vehicle-miles traveled (VMT), state highway lane-miles, population, and per capita income for every urban county in the state of California, for the years 1973-1990. In one analysis, this panel was used directly. In a second analysis, the county-level data were aggregated to the metropolitan level--for example, observations from 10 counties considered by the federal government to belong to the San Francisco-Oakland-San Jose metropolitan area combined into one observation. As in the previous study, we sought to use this data to estimate a general relationship between road supply and traffic. Our basic model was:

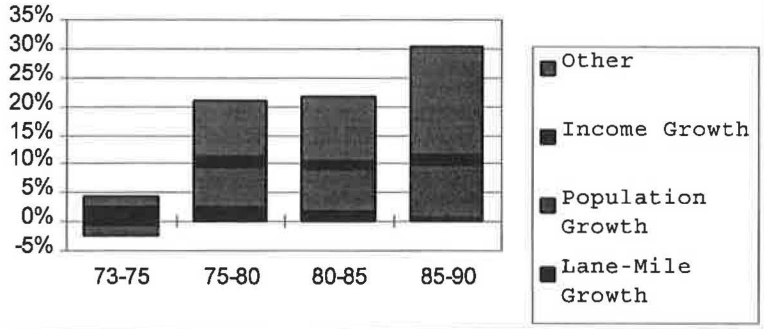
$$\log(VMT_{it}) = \alpha_i + \beta_t + \gamma \cdot POP_{it} + \psi \cdot PCI_{it} + \sum_{l=0}^{L} \omega^l LM_{it-l} + \epsilon_{it}$$

where:

- VMT_{it} is vehicle-miles traveled in area I and year t;
- POP_{it} population in area I and year t;
- PCI_{it} is income per capita in area I and year t;
- LM_{it-l} is state highway lane-miles in area I and year t-l;
- $\alpha_i, \beta_t, \gamma, \psi, \omega^l$ are coefficients to be estimated;
- ϵ_{it} is a random variable drawn from a normal distribution with mean zero.

This model contains fixed effects for both areas and years, the α_i and β_t respectively. In a world in which year to year changes in VMT were the same for each region, these fixed effects would explain all of its variation. If regions with higher population or income growth experience greater traffic growth, these effects will be captured by the γ and ψ coefficients. Finally, if after controlling for regional, time period, population, and income effects, covariation between road supply and VMT persists, this is captured by the ω^l coefficients. If the VMT response to a change in road supply were immediate, then only the ω^0 term would be positive. If coefficients on the lagged lane-miles variables are also positive, this implies that VMT response occurs over a period of time, with the complete adjustment occurring after L years.

Figure 3. Sources of California State Highway Urban VMT Growth, 1973-1990



To estimate these models, the value of L must first be determined. We did this by starting a L=0 and then incrementing L by 1 until we found the model that had the best statistical performance, labeling its associated L value as L^*. Next we determined the appropriate number of free parameters to allow for the ω^l. At one extreme, we could allow each of these coefficients to vary arbitrarily, while at the other we could force them all to have the same value. As before, we sought the choice be-tween these extremes that yielded a model with the best statistical performance. This turned out to be the model that forced all the ω^l coefficients to have the same value.

Table 2 contains the estimated coefficients for the preferred models at both the county and metropolitan levels. L^* is found to be two years for the county-level model and four years for the metropolitan level model. The estimated ω^l value, restricted to be the same for all l from 0 to L^*, is 0.21 for the county model and 0.19 for the metropolitan model. In both cases, these estimates are highly significant statistically. To calculate the long-run capacity elasticity of traffic—the effect we expect to see L^* years after a capacity expansion--we need only multiply ω^l by L^*+1. The resulting elasticity is 0.62 in the case of the county-level model and 0.94 for the metropolitan model.

Table 2 also shows that population has a strong effect on traffic, yielding population elasticities of 0.46 at the county level and 0.69 at the metropolitan level. Per capita income, in contrast, has a small effect, particularly at the county level. It is interesting to calculate how VMT change if population and road supply grow by the same amount, so that road supply per capita remains constant. At the county level, 1 percent increase in both population and road supply will result in a 0.62+0.46, or 0.96, increase in traffic–not statistically different from 1 percent. At the metropolitan level, the same scenario yields a traffic growth of 0.69+0.94, or 1.63 percent. Presumably, the traffic-generating impact of growth at the metropolitan level is stronger because it involves increased intercounty travel, an effect not readily captured in a county-level analysis.

The estimation results can be used to estimate the contributions of population, income, road supply, and "other factors" to the overall growth in VMT that has occurred over the past two decades in California's urban regions. The first three effects are estimated using the estimated elasticities and the average growth in population, income, and road supply for California metropolitan regions. The effect of "other factors" is captured by trends in the time period fixed effects (β_t). The results at the metropolitan level are shown in Figure 3, which reveals that population growth has been the most consistent contributor to VMT growth over the past two decades. Since 1980, "other factors", presumably a combination of demographic, life-style, and gasoline price effects, have also played a major role. In contrast, the contribution of increased highway supply to VMT growth has been modest, particularly during the 1980s when the supply grew very slowly.

The above results all pertain to state highway VMT, rather than total VMT. In California, about 50 percent of total VMT is on state highways. A natural question is therefore whether the additional state highway VMT that seems to result from added lane-miles is diverted from local roads and streets. Data to definitively answer this question are, unfortunately, lacking. Published estimates for total county VMT are available only for selected years. Furthermore, these estimates are based on gasoline sales data rather than direct traffic counts, and are therefore not very reliable. Nonetheless, we used the data available to look for a relationship between state highway lane-miles and off-state highway VMT. If the diversion hypothesis is correct, than we would expect a negative relationship

TABLE 1 ESTIMATION RESULTS, SEGMENT TRAFFIC MODEL

COEFFICIENT (VARIABLE)	COEFFICIENT ESTIMATE, BY ASSUMED σ VALUE		
	σ = 0.05	σ = 0.20 [1]	σ = 0.75
β (Road Capacity)	1.30 (3.70)[2]	0.86 (4.70)	0.46 (4.53)
γ (Fraction of new road capacity)	-1.59 (-3.07)	-1.03 (-3.68)	-0.44 (-3.04)
λ (State Highway VMT)	1.06 (19.23)	0.96 (15.29)	0.96 (14.54)
Adjusted R^2	.9568	.9580	.9568

Notes

1. Preferred model, based on adjusted R^2.
2. t statistics in parentheses.

between these variables. Using a model of the same form as the one described above, we find a strong, positive, but statistically marginal, relationship between state highway lane-miles and off-state highway VMT at the county level, and a very weak, negative, statistically insignificant relationship at the metropolitan level. These results certainly do not support the diversion hypothesis; nor can they, given the limitations in the data, definitively refute it.

Discussion

Taken at face value, these results show a significant positive impact of road supply on traffic. Moreover, they suggest the impact, as measured by the traffic capacity elasticity, becomes stronger as the level of aggregation increases. At the road segment level, the long-run capacity elasticity of traffic is in the 0.3-0.4 range. The comparable figures at the county and metropolitan level are 0.6 and 0.9 respectively. This pattern implies that much of the traffic induced by a particular capacity expansion project occurs *away* from the expanded segment. It is a classic example of a network effect arising from complementarity between links: in order to avail themselves of the improved level of service on the expanded link, drivers used other links to access it. While level of service on the expanded link improves markedly, induced traffic on other links leads to marginal increases in congestion elsewhere in the system. We cannot, on the basis of our findings, assess the net impact of expanded capacity on the level of service provided by the road network. It interesting to note, however, that at the metropolitan level the long-run capacity elasticity of traffic is fairly close to 1.0, the value at which induced traffic is enough to maintain a constant ratio of VMT to lane-miles.

Our findings are less consistent with regard to the dynamics of the response to new capacity. The area-level findings suggest a response time of less than five years, while at the segment level there is evidence of continued adjustment 5, 10, or more years after the capacity is added. On the other hand, the latter results indicate that the response after five years is dramatically slower than that in the earlier years. Perhaps the longer term response is merely an artifact of the model employed in the segment-level analysis, or perhaps it is real but lost in the statistical noise of the area-level data.

There are important grounds for skepticism however. Perhaps the most important to concerns the direction of causality. Our analysis assumes that road supply is the cause and traffic level the effect. But one might argue that in fact the causality runs in the opposite direction, or in both directions. Thus, where we claim that traffic grew as a result of adding road capacity, others might counter that road capacity was added in response to, or anticipation of, this traffic growth, which would have occurred anyway.

Our use of panel data sets reduces the potential distortion arising from this problem of mutual causality. To see this, consider the road segment analysis. Suppose instead of the procedure we followed, we simply compared traffic volumes on highway segments with different capacities. Then, it would clearly be inappropriate to attribute the difference in traffic level entirely to the difference in capacity--almost certainly, the wider road is wider in part because it has to carry more

TABLE 2 ESTIMATION RESULTS, AREA TRAFFIC MODELS BY GEOGRAPHIC UNIT OF ANALYSIS

COEFFICIENT (VARIABLE)	COUNTY PANEL MODEL, P-W[1] ESTIMATE	METROPOLITAN PANEL MODEL, P-W ESTIMATE
γ (Population)	0.46 (9.03)[2]	0.69 (3.92)
ψ (Per Capita Income)	0.05 (0.88)	0.21 (1.87)
ω^l (Lane-Miles)[3]	0.21 (5.33)	0.19 (4.20)
R^2	0.994	0.997
L^*	2	4
Long-Run Capacity Elasticity of Traffic[4]	0.62	0.94
Number of Observations	480	196

Notes

1. Prais-Winsten estimates. This is a least squares technique that corrects for serial correlation in the data, see [4].
2. t statistics in parentheses.
3. Coefficient applies to current lane-miles and lane-miles 1,2,...,L^* years before.
4. The percentage increase in VMT resulting from a 1 percent increase in lane-miles, after a sufficient period of time for the full effect to be realized. Equal to ω^l coefficient times L^*+1, with any differences in table due to rounding.

traffic. But this is not what we did. Rather, we followed traffic levels on a number of segments, and found that traffic growth on these segments accelerated, compared to traffic growth on the state highway system as a whole, *after* capacity was added. One could still argue that highway planners, in their infinite wisdom, foresaw when this accelerated growth would occur and added capacity in anticipation of it. There is no statistical analysis that can refute such a claim, but one must question whether the processes of planning and delivering highway capacity expansions, lengthy, political, and fiscally constrained as they are, can be so responsive. An analogous argument holds at the area level.

CONCLUSIONS AND RECOMMENDATIONS

We have presented evidence that adding road capacity generates traffic. The effect is "strong" in the sense that the proportionate increase in traffic is of the same magnitude, although smaller than, the proportionate increase in capacity. The effect is stronger at the aggregate network level than at the individual link level. Most of the response occurs within five years of the capacity expansion. Although the effects observed may derive from diversion of traffic from local roads, the limited evidence available does not support this interpretation.

The findings are subject to several caveats. First, they apply to urban highways for a single state, California, over a limited time period, the 1970s and 1980s. Second, they are based on pooled data, and therefore do not reliably characterize the impacts of any specific capacity enhancement project, or road improvement program in a particular urban area. Third, they are not based on controlled experiments, but rather evidence gathered from quasi-experiments. As noted above, statistical correlation of quasi-experimental data cannot prove causality in a particular direction. Such an interpretation must rest upon one's a priori understanding of the processes at work.

Most importantly of all, our findings do not demonstrate that adding road capacity is a bad idea. While opponents of road construction had traditionally emphasized the phenomenon of induced demand, and road advocates de-emphasized it, it is not obvious that induced demand detracts from the social value of road improvements.

Much is to be gained from additional retrospective studies of the impact of road capacity enhancements, and other transportation investments, on traffic, travel, system performance, and economic welfare in urban areas. These efforts should be accompanied by more concerted attempts to incorporate the findings of retrospective studies into the methods and models used in traditional, future-oriented, planning activities. Despite the substantial effort that has gone into developing and refining such techniques, surprisingly little is known about their reliability and accuracy in predicting the consequences of transportation improvements. We must strive for convergence between results of analyses like those presented here and the detailed, predictive models necessary for planning. When such convergence has been achieved, the induced traffic debate can be laid to rest, and we can turn our argumentative energies back to welfare and the death penalty.

REFERENCES

1. Carter Goodrich, Government Investment in American Railroads and Canals: 1818-1878, Academic Press, 1960.

2. Stephen Putman, Integrated Urban Models, Pergamon Press, 1983.

3. Mark Hansen et al., The Air Quality Impacts of Urban Highway Capacity Expansion: Traffic Generation and Land-Use Change, UC Berkeley Institute of Transportation Studies Research Report 93-5, Chapter 3.

4. Mark Hansen and Yuanlin Huang, Road Supply and Traffic in California Urban Areas, forthcoming in Transportation Research A.

WIDENING THE ROADS: DATA GAPS AND PHILOSOPHICAL PROBLEMS

Robert T. Dunphy
Urban Land Institute

One of the most fundamental tools for dealing with growing transportation demands is expanding the capacity of the transportation system, preferably by a little more than current needs, to allow for some future growth. New homes, new offices, and new stores require expanded transportation capacity. This can be accomplished by adding new routes, additional capacity to existing routes, or better operations to squeeze more output from the same facilities. The same principle applies to highways and transit, although in most cases the growth is in demand for highways. That is why criticism of highway expansion as facilitating sprawl and generating more demand is so troubling. If one cannot expand the supply, what other choices are there? Virtually none that are palatable in a democracy.

This disagreement moved from an academic argument to the court room, in San Francisco, when the Sierra Club and Citizens for a Better Environment sued the Metropolitan Transportation Commission (MTC), the regional transportation planning agency, for noncompliance with federal air quality standards. A major issue concerned whether large highway capacity additions would adversely affect air quality, as well as MTC's ability to model these impacts. Environmental groups argued that adding highway capacity in a congested system would increase vehicle use by making automobile travel easier and more convenient, thereby offsetting at least some of the initial reductions in emissions from smoothing traffic flows (i.e., travelers would cease to avoid the peak periods; would shift from transit or car pools to driving; would be less concerned about chaining trip destinations and limiting distances; and would reconsider making trips foregone because congestion is so onerous). Longer run implications claimed by opponents are that the improvements would lead to further development of auto oriented exurban suburbs rather than urban infill, and further encourage regional economic growth. Supporters of the MTC position argued that increased capacity would speed traffic flow, thereby promoting greater fuel efficiency and reduced emissions. While conceding the potential for longer run increases in trip making and distances, they maintained that the added capacity was a small addition compared to the scale of the current highway network, and that there was no empirical evidence that highway improvements were growth inducing at the regional level. [The court ruled in MTC's favor, allowing modifications in the computer models used for conformity and lifting a highway ban which also prevented reopening some roads damaged in the 1989 Loma Prieta earthquake].

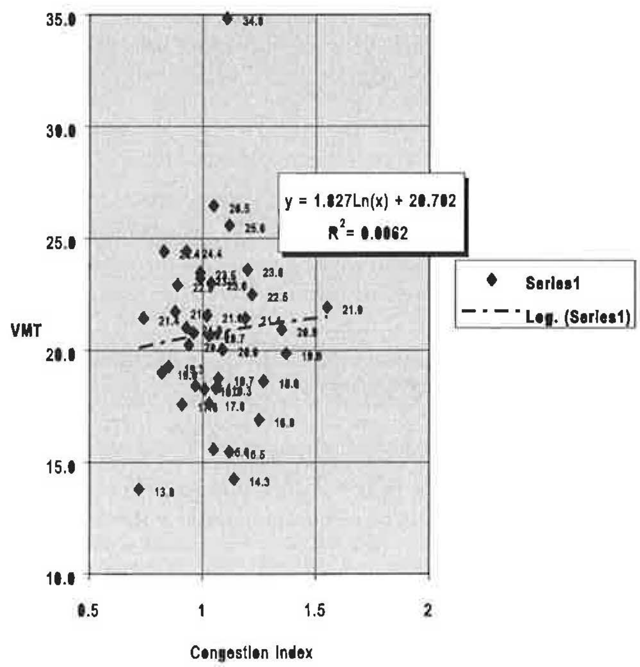
This paper offers some ideas on the topic based on the National Research Council report *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use*, analysis of 1990 regional data, and thoughts about pacing improvements in the highway system to underlying growth in population, the economy, and travel.

TRB SPECIAL REPORT 245 - EXPANDING METROPOLITAN HIGHWAYS

The report of this study committee of the National Research Council does a credible job of narrowing the focus from broad philosophical (and basically unanswerable) questions. The results, as often happens with scientific studies, are not as conclusive as many wish, with many criticisms of current data and models. The committee acknowledged that the effects depend greatly on the specifics of the situation, and reported that "*On the basis of current knowledge, it cannot be said that highway projects are always effective for reducing emissions and energy use. Neither can it be said that they necessarily increase emissions and energy use in all cases*" (Transportation Research Board, Committee for a Study of the Impacts of Highway Capacity Expansion on Air Quality and Energy Consumption, Expanding Metropolitan Highways: Implications for Air Quality and Energy Use, TRB Special Report 245, National Research Council, 1995). The point is also made that limiting highway capacity is at best an indirect approach for achieving emissions reductions, and is likely to have small effects. (See Figure 1 which shows the relationship between regional VMT/capita and regional highway congestion.)

The land use and urban form chapter offers some interesting perspectives on the strong forces leading to metropolitan decentralization, even before the automobile. Several references are made to the difference between growth which is redistributed by highway improvements (from an inner suburb to a more distant location next to

Figure 1Congestion Index vs VMT



a freeway, for example) vs. stimulative growth. Several researchers have argued that public infrastructure investments, including highways, can stimulate private productivity and output. There is still disagreement among some of the experts, however. The committee decided that the highway impacts of interest for this report cannot be assumed to stimulate growth, although they do when other conditions, such as the presence of agglomeration economies or improved access to labor or materials, hold. A key point seems to be that since most areas already have pretty good highway access, relative impacts of improvements show diminishing importance. An interesting conflict between researchers and practitioners was pointed out in a study which showed that residential development was accelerated in corridors with capacity additions in California . The consensus of planners and developers was that residential development was unrelated to capacity expansions. One view is that developers' plans were influenced by the plans for capacity additions. An alternative opinion was that road plans may have been influenced by public sector expectations concerning anticipated growth in the corridor. The difficulty of establishing cause and effect creates a serious methodological problem.

The availability of analytical methods to address these issues was a central concern, and the committee concluded that current methods do not give policy makers important information they need to reliably predict the effects of expanding highways. Beyond the difficulties of understanding the influences of improved travel on demand is the critical link to emissions, and thence to air quality. Not only is it necessary to understand the number of drivers on the road, for emissions impacts it is necessary to know what kinds of vehicles are on the road, and whether they are being driven by mutant teenagers or Sunday drivers.

The committee addressed the current regulatory focus on limiting highway construction projects, claiming relatively small effects on air quality by the year 2010, currently the deadline for EPA regulations. The committee reported that historically, measures to control travel demand have had limited effect. Moreover, going beyond the scientific aspects, the committee showed surprising political insights into some of the conflicts raised by air quality policies. Pointing out that the issue of limiting highways has the potential to pit economic concerns against environmental ones, and that the usual result of such conflicts has been that the environmental goals lose. Anticipating this problem, the committee looked for a more constructive approach, technological improvements or market mechanisms.

REGIONAL COMPARISONS

Without good information on the effects of a highway improvement on travel - a major flaw addressed below - one of the few avenues for analysis of the longer term impacts of congestion on driving is to analyze current conditions across regions with different degrees of mobility from free flowing conditions (if there are such a thing), through the spectrum to teeth grinding congestion. This is particularly useful to gain insights to longer term equilibrium issues. In addition, a regional rather than a corridor analysis recognizes that many travelers actually use portions of the highway network far away from their usual commute and shopping trips , at least occasionally. For purposes of this analysis, the Texas Transportation Institute Roadway Congestion index was used as a consistent measure of regional congestion for 1990 (Tim Lomax and David Schrank, Trends in Urban Congestion: 1982-1993, Texas Transportation Institute, College Station Texas, 1996). The relationship between this measure of congestion and Vehicle Miles Traveled (VMT) on an average day is shown in Figure 1, for urbanized areas over one million population. A simple linear regression shows no significant statistical relationship. Moreover, the slope is actually positive, indicating that areas with more congestion also have more driving. Obviously, more factors need to be taken into account - a good start for further research.

A review of the extremes, however, offers some interesting insights. Residents of the New York urbanized area, which experiences some of the highest congestion in the U.S., have the lowest levels of driving, about 14 miles daily. They also have the most extensive transit system, some of the highest densities, and the largest levels of households without cars. New York has both high congestion and high levels of transit . The TTI index, however, suggests that New York does not have the highest levels of congestion. That would be Los Angeles, which has been the congestion leader since this index was first calculated in 1991. While first in congestion, LA residents ranked only ninth in daily driving, an average of 22 miles daily- fifty percent higher than New York, but well behind the driving leaders. The other leaders in regional congestion were Washington, D.C., San Francisco, Chicago, and Miami. Among these, the lowest levels of VMT per capita were in Chicago, another high density urban area with an extensive transit system. Also below average in driving were Washington, D.C. and Miami. However, in San Francisco, where traffic congestion is so pervasive that it was the biggest concern of residents for years, VMT per capita ranked 15th out of the largest metropolitan areas - slightly above average. Despite San Francisco's reputation as one of the most livable, lovable , and transit oriented communities, and Los Angeles' renown as the center of the car culture, per capita driving levels are quite close- 21 vs. 22, respectively. Perhaps in this case, the high levels of congestion in both regions tend to reduce driving differences.

Shifting to high VMT regions, the clear leader was Atlanta, where residents drove an average of 35 miles daily. This is certainly not because the highways are free flowing. Atlanta ranked ninth in the regional congestion index. The second and third ranked regions for driving were Dallas and Houston, where congestion was above average - Houston ranked 13th and Dallas tied for 17th highest among 50 urbanized areas. Among the next five areas with the highest levels of driving- Seattle, Milwaukee, St. Louis, San Jose, and San Diego- the relationship with congestion levels is somewhat mixed. San Diego and Seattle ranked sixth and seventh in congestion levels in 1990, San Jose was 16th, and the others were somewhat lower, with an average of about 1.00 - considered by TTI to be the beginning level of undesirable congestion.

This unscientific review of regional data shows that regional congestion is not well linked with levels of driving, at least during the 1990 study period. New Yorkers drive less than residents of other large urban areas, although the New York region is not on the A list of most congested areas. High levels of driving do not necessarily correspond with low congestion. Of the top eight urbanized areas for driving , six had above average to high levels of congestion, and two - Atlanta and Seattle - were among the top ranks for per capita transit ridership. Even among the nine urbanized areas with the largest freeway capacity per capita, only four ranked in the top nine for VMT. Even when these areas are classified by congestion levels, there are still a range of experiences. Kansas City had the highest level of freeway lane miles per capita , combined with the lowest congestion levels, yet the VMT per capita ranked twelfth. Atlanta ranked second to Kansas City in freeway supply, and ninth in congestion, with the highest levels of VMT - fully one third higher than the runner-ups, Dallas and Houston. Other cases of regions with high levels of freeway systems and low congestion were Minneapolis and Cincinnati, which ranked fourth and seventh in congestion levels. Their driving levels were substantially reduced, however, at 14th and 16th - typical for large urbanized areas. Three regions with high levels of freeway and high levels of driving were Houston, Dallas/Fort Worth, St. Louis and San Diego. Their congestion levels cover a wide range, from San Diego which is high, to Houston and Dallas, about average, and St. Louis, which had fairly low congestion levels.

IMPACTS OF HIGHWAY CAPACITY EXPANSION IN HOUSTON

The comparison of different regions offers some interesting insights into some of the potential long range equilibrium effects of highway supply, congestion, and levels of driving. Much of the differences are likely to be caused by demographics, local patterns of land use and interaction, and interconnection, speed and congestion on the transportation system. A more pressing issue for individual regions is the extent to which transportation improvements increase travel - or perhaps whether failing to make improvements will actually cause people to reduce their travel. The most aggressive program of transportation improvements over the last decade probably took place in Houston, so an examination of travel impacts offers some insights into how much of these capacity improvements were "lost" through increased driving.

A review of the transportation improvements resulting from the 1982 Houston Regional Mobility Plan illustrates the massive scale of such improvements. New toll roads, arterial and intersection improvements, a completion of gaps . . . at a spending level of $1 billion annually. These improvements were not limited to serving solo drivers. A significant part of the program was for improving the regional bus system, and developing a unique system of transitways. This transitway system offered an exclusive lane for buses, vans and car pools. The total package represents one of the most significant investment packages in U.S. urban areas.

A major focus of the RMP was reducing congestion, and the results were positive. Freeway speeds during the evening peak period increased from 38 to 49 mph - a 28% increase. The number of miles of severely congested arterial streets was reduced from 74% in 1985 to 29 % in 1992. Especially important for downtown businesses was that the travel shed within 30 minutes of downtown - as measured in land area- tripled. Between 1979 and 1992, congestion, as measured by the TTI index, improved by more than 10%. Similarly, transit improvements were clearly evident, ranging from better on time performance to improved speeds in the HOV lanes. The results showed in bus ridership, which doubled over the decade. The number of transit commuters increased by 69%, quadruple the growth in overall commuting. The share of commuters driving to work alone actually declined, one of few urban areas to reduce the driving share.

Clearly, the vast improvements in mobility in Houston have had wide ranging impacts throughout the region. What impacts did this have on travel? That aspect of the question has not yet been studied in depth, to the authors' knowledge, and would certainly be an excellent research study. Over the decade between 1980 and 1990, regional VMT grew by 38%, about double the growth in regional population. This 2:1 ratio between travel and population growth is vastly smaller than the national averages - between 1983 and 1990, household VMT grew by 40% compared to a mere 4% gain in U.S. population (U.S. Department of Transportation, Federal Highway Administration, 1990 National Personal Transportation Survey: Summary of Travel Trends, page 6, Table 1). Regional comparisons offer some contrarian experiences as well. Between 1990 and 1994, federal data showed only a modest 1% growth in per capita VMT for the Houston urbanized area, where congestion has been declining, compared to a 14% increase in Dallas, where congestion was increasing. Portland, Oregon, where congestion has also been increasing as a result of public policies to reduce driving and increase alternate modes, also registered an 8% gain in VMT per capita (U.S. Department of Transportation, Federal Highway Administration, Highway Statistics, 1990 and 1994). While there may of course be data differences involved, the findings are certainly stimulating.

WHOSE VMT? A CONTEXT FOR CAPACITY EXPANSIONS

An important distinction needs to be made between the travel markets served by capacity additions. The three D's which accounted for roughly equal shares in the growth in driving at the national lever were demographics, dependence on the auto, and distances. Demographics includes not only overall population growth, but also the disproportionate increases in the prime driving cohorts , and increases in per capita trip making even after controlling for age and gender. Simplistically, this is the result of more people going more places. The second D, increased dependency on the private auto was due (nationally) about equally to declining use of transit and declining auto occupancy. The last D is the growth in trip distances, presumably as a result of the continuing spread of urban areas (Based on 1990 NPTS data and reported in: Robert T. Dunphy, *Transportation and Growth: Myth and Fact*, Urban Land Institute, 1996). Of these three factors, increased speeds which result from highway capacity additions could be presumed to affect both the dependency and distance factors. Higher highway speeds could make transit less attractive — presuming there were a transit alternative, and might encourage longer distance trips for commuting purposes. The impact on the demographic factor, especially the population growth through new development becomes highly theoretical, especially those living at the urbanizing fringe, where most new development takes place in metropolitan areas.

One of the problems with the question about the impact of highway expansion on increased driving is that it takes a simplistic view of the future, where a single facility is being considered and a fixed time horizon, without consideration of regional growth. Such single facility focus is anathema to comprehensive planning, where an entire system of facilities is usually considered to serve a pattern of future growth. If the plans were adhered to and publicized, future citizens could expect facilities to be approved during a certain time period. This would be followed by further development tied in to the new facilities, which would generate additional traffic, resulting in slower speeds, and eliminating the travel gains which might (or might not) cause additional driving. Depending on how closely the capacity additions match the trends in traffic growth, it is possible that residents may actually endure substantial periods of slower speeds and increased congestion.

Missing in the debate about capacity expansions and travel is consideration of the needs of new development. Most new development is located at the periphery of metropolitan areas, and good planning needs to carefully evaluate the areas suitable for new development, and prepare transportation plans in advance to serve those growth areas. Each new roof top requires a range of new public and private services, water, sewer, schools, shops and churches - as well as new roads. The proper issue is not whether to improve highways in such areas, but how much. A clearly enunciated policy on levels of service, or better yet transit and highway accessibility, allows for a rational approach to developing an adequate transportation network. It is in these newly developing areas where localities have the best opportunities to "fix" the transportation up front, before it is a problem. Regrettably, such areas are often allowed to undergo substantial growth before transportation needs are addressed, and some of the logical options are already precluded. Given the extraordinary difficulty of making highway improvements—or any infrastructure improvements—in established areas, we should certainly avoid repeating those mistakes in the newly urbanizing areas, where solving the problem should be much easier. Questioning the addition of new capacity seems like denial of the basics of growth. It would be inconceivable to plan for a growing population with no new schools, or no new water supplies. No one seriously questions the need for expanding landfills, sewers, or water supplies on the grounds that they will lead to more pollution. To limit highway additions is to anticipate that there is already excess capacity. Critics point out that solving the transportation problem by adding new highways is like letting one's belt out to accommodate a larger girth. On the other hand, limiting highways in a growing area may be like refusing to buy new shoes for the kids, because it will only allow their feet to grow.

A CRITICAL NEED FOR CURRENT INFORMATION

The oblique slant taken in much of this analysis points out the critical need for adequate information and studies to clarify some of these issues. Does improving the roads really make people drive enough more to wipe out all of the anticipated gains in congestion? Would a transit improvement have a similar impact, especially if it encouraged the opening up of a distant community where excessive driving were required, even beyond the amount of transit use. It is amazing that the transportation profession does not know the answer to these critical questions. Moreover, there seems to be no major initiative to redress this shameful gap. Perhaps when no one was building highways, this was an understandable transgression. However, there are now many cases of substantial highway improvements - in fact, creation of whole systems. As indicated above, Houston offers an example of improvements so substantial that congestion actually went down. The new freeway system in Phoenix offers another, as do the toll road systems being built in Orlando and Southern California. Research opportunities such as these are extremely rare, and may be a once in a lifetime chance for many in the profession. This session would have served well if we stop talking and start surveying.

EFFECTS OF INCREASED HIGHWAY CAPACITY: RESULTS OF A HOUSEHOLD TRAVEL BEHAVIOR SURVEY

Richard G. Dowling and Steven B. Colman
Dowling Associates

INTRODUCTION

Few current transportation issues engender more controversy than the effects of adding new highway capacity on traffic and travel demand. The purpose of adding new highway capacity is to reduce traffic congestion and improve automobile travel times, and in some cases, air quality. These changes in turn affect travel behavior by affecting peoples' choice of modes of travel, their choice of destination, and their choice of travel route.

Less well known is how travel time changes caused by capacity increases may affect total travel demand, especially trip generation (i.e., the number of vehicle trips made per person or per household). Estimating the magnitude of this effect on trip generation is particularly unclear. One of the primary purposes of this project was to examine the effects of new capacity on trip generation, since in most conventional North American travel forecasting models, trip generation is not sensitive to transportation supply variables (In some models, such as that used by the San Francisco Bay Area MTC, trip generation is indirectly linked to transportation supply. In MTC's case, it is through the auto ownership model, in which accessibility drives auto ownership rates, which in turn are the basis for trip generation).

The Importance of the Issue to Clean Air and Transportation

Federal, state and local governments spend billion dollars a year on new road improvements to reduce congestion, improve safety, and provide for economic development. Popular, and some professional, opinion has it that new capacity in urban areas is swamped by new demand, so that in the end motorists are no better off than before the improvement was made (Downs, 1962; Bass, 1992). Disagreements arise as to whether this effect exists, and if it does, what its magnitude is. The issue has moved to center stage because the *1990 Clean Air Act Amendments* prohibits recipients of federal transportation funds from constructing projects that worsen air quality in non-attainment areas.

Depending on the trip-inducing effect of the road improvement, it may improve air quality. New road capacity, to the extent that it reduces speed variations (stop-and-go driving) and allows vehicles to travel a steady 30-45 MPH, improves air quality. This claim has been challenged by others, who maintain that any air quality benefit of new road capacity in the short-term will be offset in the longer-term by increased travel demand that will nullify any improvement in the total emissions.

Of course, the trip induction effects of new highway capacity do not have to be zero for there to be a net air quality benefit, but they must be smaller than the increase in emissions per vehicle. An improvement that reduces vehicle emissions by five percent per trip, but increases trips by two percent, would still result in a three percent reduction in emissions.

Study Purpose and Research Approach

The purposes of this study were to answer two fundamental questions: do capacity increases increase trip-making? And if so, what is the magnitude of this increase, if it exists? The overall research objectives were accomplished through a variety of means; this paper reports primarily on the results of a household survey of traveler behavior conducted as part of the study. Past attempts to assess the travel impacts of new highway capacity have generally relied on before-and-after traffic volume comparisons. In some cases traffic counts have been supplemented with roadside interview or home interview surveys. A few investigators have attempted to fit regression models for predicting regional VKT (vehicle-kilometers of travel) increases that result from regional increases in highway capacity. However, this approach has generally not been fruitful, since there are many extraneous factors that can affect the results, including the availability of alternative modes and routes in each corridor; the condition of the local economy (growing or stagnant); zoning; and natural constraints to development. These factors not only affect the conclusions but also limit the validity of extending these results to other situations and locations.

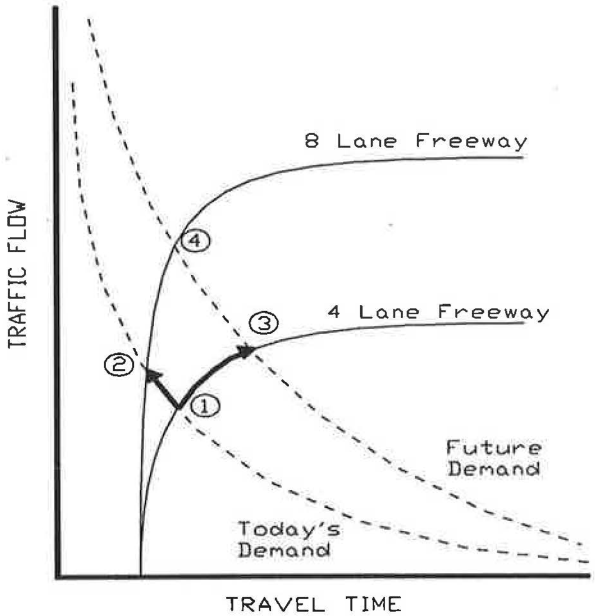


FIGURE 1 Demand vs. capacity change.

The original scope of work for this project had called for a relatively large number of case studies (30 or more) to be analyzed to identify the *ceteris paribus* effects of new highway capacity, including comparisons of projected traffic volumes with actual counts. It became apparent that this approach would not yield the desired results. Shortcomings of the case study approach are documented in the literature (ITE, 1980; Stopher, 1991). A brief summary of our own reasons for proposing an alternative approach follows:

Control of Exogenous Variables (e.g., economic conditions)

Transportation changes take place in a highly dynamic environment: variables such as household income, population, employment, fuel and parking prices, and other variables cannot be directly controlled for. A time series approach may not control for the distributional shifts in land use activities that transportation investments may induce if the area of analysis is limited. This creates a considerable problem in distinguishing between a shift *along* the demand curve (due to the reduced price of travel caused by added capacity), and a shift in *the demand curve itself* (see Figure 1). Demand curves may shift due to changes in income, tastes, demographic factors, and so forth. Point number 1 represents an initial condition with a four-lane freeway; point 2 is the result of a capacity increase (travel time reduction) and the associated movement along today's demand curve. Point 3 is purely the result of a demand curve shift, possibly due to such factors as increased population or income, but also possibly due to reduced transit service, higher fares, or changes in taste. Point 4 is the final equilibrium, a combined result of capacity and demand increase.

Completeness of Data Sets

The data requirements of a case study approach require that there be (as a minimum) traffic counts on the new facility and all paralleling routes on an annual basis, along with good records of land use changes in the corridor. Local agencies often lack consistent annual count programs with counters placed at the correct locations to assess changes in corridor demand due to capacity changes. Even if all of the count data were perfectly available, it may not have the appropriate temporal resolution needed to assess the impacts of new capacity. Ideally, counts would be available at 15-minute intervals, to assess the impacts of temporal shifting in travel, and especially the "peak within the peak." Information needs to be available on all paralleling transit services; even then, one would not know what the changes in destination choices were (were people driving further because of the new capacity in order to reach a "better" destination; or the shifts in land uses that took place over time.

Differences/Comparability of Data Collection Years

Traffic counts, income and other demographic information are typically not available on an annual basis. Most agencies make projections or estimates may be available at five-year intervals, and traffic counts are frequently only made at two or three year intervals (sometimes less often than that). This presents an awkward problem of interpolating between demographic data, traffic count, and traffic forecast years. Increased real income and family size (lifecycle issues) typically result in higher levels of auto ownership and a desire for more residential space. Detailed geographic information at the corridor level is usually available only from the US Census, which is conducted too infrequently (every ten years) to be useful.

Institutional Bias

Forecasts may contain an institutional bias, perhaps unconsciously, that tends to support the construction of a facility. An agency may make reasonable assumptions within a "gray area" of discretion that favors the action that the constructing agency wishes to take. This bias can vary with time, place, and the individuals involved, but can all lead to forecasting errors. An agency could use optimistic or pessimistic views of the economy, of population growth, and so forth.

All of these considerations pointed toward the need for an approach that:

- Considers trips in the context of the overall activity patterns of travelers;
- Considers a wider range of alternatives than would be possible to test with the case study approach; and
- Avoids the shortcomings of completeness of data sets, control of exogenous variables, and other limitations noted above.

RESULTS OF PREVIOUS RESEARCH

Increased highway capacity may affect travel in a number of ways. In urban areas, new capacity typically reduces congestion, resulting in shorter travel times during some or all of the day, and a less stressful driving experience (In many rural areas and small cities, where congestion is minimal, new capacity may or may not change travel times). The literature (Jorgensen, 1947; Pells, 1989; Loos, 1991; Dobbins, Hansen, 1993) documents a strong relationship between reduced travel times and these short term effects:

- The choice of the route taken. This effect has been found to be consistently important in the literature. A major assumption underlying the conventional four-step travel forecasting process is that people seek routes that minimize travel time and cost.
- The scheduling of the trip (time of day the trip starts/ends). This effect has also found to be consistently important in the literature; new highway capacity has often been found to cause shifts from off-peak or "shoulder" transitional times, to the "core" peak periods of travel. This affect was found in examining traffic count data before and after widening of California Highway 78 in San Diego, the M10 Orbital Motorway (Loos, 1992), and other locations.
- The choice of the travel mode used (e.g., carpool, transit, drive alone). This effect has been shown to be a much weaker impact than route and scheduling choice, but still important. The effect is probably more important in the longer term, as changes in auto ownership and land use take place. Studies of the substantial and sudden capacity *reductions* caused by the 1989 Loma Prieta earthquake indicate substantial shifts to transit modes (Homburger, 1990), with about a 10 to 15% reduction in the number of *total* daily trips (Markowitz, 1990). This reduction is modest compared to the very large increase in travel time occasioned by many transbay travelers during the approximately one-month period when the Bay Bridge was closed due to the Loma Prieta quake.
- The frequency the trip is made. The literature has been inconclusive on this topic, with some studies indicating significant impacts, and others indicating little or no measurable impact. Therefore, this impact was one of the primary concerns of this project.
- The linking of trips with several destinations together (sometimes known as "trip chaining" or "trip tours"). This appears to be an important impact, but has proven difficult to measure, and is generally outside the scope of this paper.
- A change in the choice of the destination of a trip; likewise, this impact has proven difficult to measure.

Rothblatt, Colman and Bossard (1994) have examined disaggregate household vehicle trip generation rates as a function of proximity to freeway ramps, using this distance as a proxy for accessibility to destinations in 24 urban California counties. About 6,200 randomly selected households were included in this study, allowing for important demographic variables to be normalized. They found no significant correlation between the two. However, this approach had limitations, in that distance to the freeway could only be measured as distance to the census tract centroid, since survey address records were destroyed (Caltrans, 1993). Furthermore, the results are complicated by the fact that the convergence of freeways near the cores of central cities mean that lower income residents often are the most proximate to one or more freeway interchanges.

Areawide models (derived by correlating VKT growth to highway growth) seem more desirable than facility-specific studies, since they eliminate the route choice effects by considering entire regions (Garrison and Worrall, 1966; Ruiter, 1980). They are also able to take into account long term land use effects by extending the analysis over several decades. However, they focus on VKT rather than PHT (person-hours traveled) and consequently confuse mode shift effects with true induced demand. These studies have been inconclusive about the elasticity of demand (trip generation) with respect to new lane-miles of capacity; although all the reported results have been inelastic, they range from a very inelastic 0.1 to a much more elastic 0.8 (Dobbins and Hansen, 1993).

But the areawide studies suffer from several critical deficiencies; first, they use a single relatively simple measure of capacity increases (such as lane-kilometers or lane-miles) that are insensitive to the potentially significant different demand effects that would occur if the same investment is made in the center of the region versus the fringes. There are definitional problems in computing the denominator of the elasticity equation; the percentage increase in capacity must be estimated, meaning that a "base" capacity must be measured. Should the base capacity be measured at the corridor, county, PMSA, or CMSA level? Economic theory, as well as experience with transportation/land use forecasting models, indicate that transportation supply cannot be treated as a homogeneous product (Association of Bay Area Governments, 1991).

Common sense suggests that new highway capacity has different impacts in an area that is already "built out" as opposed to one where much undeveloped land exists simultaneously with strong pressures for development. The costs of parcel assembly, structure demolition, and so forth, are simply too high. As Meyer and Gomez-Ibanez (1981) point out, in most cases the structure built on a parcel of land in the United States is the only one that has ever occupied that piece of property. Of course, common sense is not always right, but this view is also bolstered by economic theory.

Second, most areawide studies assume a constant elasticity of demand, probably due to the lack of enough data points to estimate anything else. Intuition suggests that the elasticity is not necessarily constant, but instead depends on the amount of current congestion and capacity of the system, the timeframe involved (short- vs. long-term), the trip purposes of road users, and possibly other factors. This issue requires further research.

Because of the problems associated with the case study before-and-after approaches (facility-specific or areawide), it was decided to use a survey of household travel behavior to isolate the various effects of new highway capacity, and identify those not currently treated by conventional travel forecasting models. The travel survey and its results are described below.

RESULTS OF THE TRAVEL BEHAVIOR SURVEY

A travel behavior survey was developed and administered to fill in the missing information from the case studies on the relative importance of the different effects of new highway capacity on travel behavior. Each potential effect (mode, time, destination, trip generation) would be identified and quantified for the purpose of determining its relative importance in estimating the total demand effects of new highway capacity.

Selection of Survey Approach

There are two general approaches to conducting behavioral surveys: stated preference (SP) and revealed preference (RP). Ben-Akiva, Morikawa and Shiroshi (1989) provide a comparison of these two methods; briefly, a stated preference survey poses various situations to the interview subject and asks: how would you respond to the given situation given certain constraints? A revealed preference survey relies upon the interviewee revealing his actual response to alternatives existing in the field. RP surveys can test only for the conditions that exist in the field, while an SP survey can explore behavioral changes due to a much wider range of options.

RP surveys have traditionally been used to calibrate travel forecasting models. RP surveys provide information on the actual, discrete choices made by individuals in the face of two or more options. A before-and-after study comparing travel diary information before and after the opening of a new freeway would be an example of the RP approach: the change in the number of trips per person would indicate the impact of opening the new freeway.

RP surveys have several limitations when applied to the problem of estimating the behavioral effects of new highway facilities. The critical shortcomings are the difficulty in avoiding bias in the selection of the survey sample and accounting for persons moving into and out of the presumed "impact" area of the new facility, and controlling for changes in background variables, such as economic and demographic changes.

The major drawback in applying an SP survey to the research problem was that traditional SP surveys require that the respondent be offered a choice between trip or transportation system attributes that force a realistic trade-off by the user. In the classic SP survey, the respondent is offered a higher fare/shorter travel time option, and a lower fare/longer travel time option. With increased highway capacity/reduced congestion, such a tradeoff was not possible, since presumably everyone would prefer a shorter travel time. In order to make meaningful tradeoffs between alternatives, the respondent was asked to describe *all* of his previous day's activities, and then contemplate how he would alter them if more (or less) time were available yesterday to perform those activities. Perhaps more precisely, it is how people would used "released" or "freed up" time, if congestion-relief projects made such time available.

The survey also embodied concepts from the developing field of activity analysis (Kitamura, 1991). The basic concept of the activity-based travel model is that everyone has exactly 24 hours in a day, 168 hours in a week, to allocate among various activities-- including travel. For the person who works eight hours a day, and sleeps eight hours a day, this leaves only eight hours for commuting, handling errands, household and family chores, recreation, and so forth. The allocation of time is not a simple process, since each person faces a set of constraints that must be met: be at work by 8 AM, pick up a child from Little League between 4:00 and 4:15 PM, and so on. Within the survey instrument developed here, people were asked about all of the previous day's activities, and then asked to respond to changes in travel and activity patterns given changes in travel time for trips made on the reference day.

Although the 24 hours available each day is fixed for every individual, the allocation of time to each activity is not. The time and money allocated to travel is further subdivided among mandatory activities like going to work, school, etc., and discretionary activities such as going to a movie. These various daily activities can be thought of as "goods" in the economic sense which people "purchase" by spending "time" and money on the activity. A 1987 survey (Wiley, 1991) found that the average California adult spends 1.8 hours a day traveling, more than 10% of his or her waking hours.

Each survey respondent was told:

We are trying to find out how traffic congestion affects what people do. I am going to describe what might happen if traffic congestion got better or worse, and ask you how you might change your activities or travel as a result. Please take some time to think carefully about what you might do.

The respondent was then read back all of the trips he or she made the previous day, and asked:

Consider what you told me about what you did yesterday. For each trip I am going to ask you what you would have done if it had taken less time to make the trip. Consider your first trip yesterday. You started at... [time] and went to ...[destination] by... [mode]. This trip took ... [duration previously stated by respondent]. Now suppose that this trip took [randomized duration] less time to make. Please select one or more of these statements that best describe what you would have done.

Respondents were not asked about trips that were less than 10 minutes in duration, since the minimum travel time savings "offered" was five minutes, and it was felt that for trips of less than 10 minutes, a 50% time savings would be unrealistic and unlikely to be achieved by any plausible capacity-increasing project. In fact, one of the survey problems was that the total travel time change was independent of the individual's reported trips. Also the total released time during the day was not keyed to a specific hour, which some respondents indicated would condition their response of how the time were used.

Survey Methodology

Adults over the age of 16 in the San Francisco and San Diego metropolitan areas were randomly selected; these two areas contain about 8.7 million people. Respondents were interviewed regarding their existing travel behavior, activity patterns, and hypothetical behavior under changes in travel time. 'Number plus one' dialing was used to reach unlisted numbers. The Los Angeles area was excluded because the Northridge Earthquake occurred shortly before the survey commenced and had dramatically impacted travel patterns there. The survey was administered using computer-assisted telephone interviewing (CATI), because of the complex branching required in the survey. Interviews were conducted on Tuesday through Friday evenings and Saturday mid-day, because survey questions were asked about the prior day's travel and weekday travel was the focus of the study. Randomization techniques were used to assure that the person who answered the phone was not necessarily the person interviewed.

After all trips were enumerated, the CATI program selects each trip made the previous day that was at least 10 minutes long. Trips shorter than 10 minutes were excluded on the assumption that capacity increases would probably have a marginal impact on them, and also because of the desire to offer travel time savings in increments of five minutes (a savings of five minutes on a trip that is seven minutes today would not seem plausible). For trips between 10 and 15 minutes, a five minute reduction in travel was offered. For trips longer than 15 minutes, a randomized travel time savings of between one and 50% was offered; the randomized savings was a minimum of five minutes if the survey number was odd, and 10 minutes if the survey number was even.

Survey respondents were given the options of: doing nothing differently; starting at the same time and arriving earlier; starting later and arriving at the same time; changing mode; changing trip destination; making an extra stop along the way; or "other". Only one additional "extra stop" was allowed for in the questionnaire, although in reality it is possible that some individuals might add two (or more) trips to their tour. The possibility of entirely new trips was allowed for at the end of this process by asking, *Would you have left home again before the end of your day if you had* [randomized time] *minutes extra time?* If the answer was yes, the respondent was asked where he/she would have gone, how much time they would have spent there, and for what purpose.

Survey Results

A total of 676 individuals over the age of 16 were interviewed in 676 households. They collectively made a total of 2,182 trips the previous day. The respondent demographics (age, income, educational achievement, auto ownership) were compared with the 1990 Census. The respondent pool was very close to the state average, except

TABLE 1 RESPONSES OF TRAVELERS TO TRAVEL TIME *SAVINGS* FOR EACH TRIP

	Travel Time Savings due to Congestion Relief (minutes)				
Response	5	10	15	20+	All
No Change	46.5%	49.6%	35.1%	38.1%	46.5%
Arrive Earlier	34.9%	33.9%	40.5%	31.0%	34.6%
Leave Later	12.9%	12.5%	16.2%	23.8%	13.5%
Change Mode	0.4%	0.4%	2.7%	2.4%	0.6%
Change Destination	0.9%				0.5%
Make Extra Stop	2.9%	2.8%	5.4%	4.8%	3.1%
Other	1.5%	0.8%			1.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

TABLE 2 RESPONSES OF TRAVELERS TO TRAVEL TIME *INCREASES* FOR EACH TRIP

	Travel Time Increase due to Congestion (minutes)				
Response	5	10	15	20+	All
No Change	53.5%	41.3%	38.6%	24.4%	45.7%
Arrive Later	22.1%	31.0%	38.6%	36.6%	27.8%
Leave Earlier	17.3%	17.6%	9.1%	24.4%	17.4%
Change Mode	1.2%	1.5%	4.5%	2.4%	1.6%
Change Destination	1.0%	0.4%	2.3%		0.7%
Make Extra Stop	0.2%	1.3%			0.7%
Other	4.6%	6.9%	6.8%	12.2%	6.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

that poor households (those earning under $15,000 per year) were somewhat underrepresented (About 90% of the respondents were willing to report their household income. Of those answering the question, 9.5% reported household incomes under $15,000 per year. The 1990 Census found the same group constituted 15.1% of the households in the San Francisco Bay Area (CMSA). Some of the difference can be accounted for by inflation between 1989 (the reference year for the census) and 1994, the year of our survey). Very low income groups tend to be underrepresented in most telephone surveys, but the importance of these households is mitigated by the fact that they produce a small percentage of VKT (The National Personal Transportation Survey (USDOT, 1993) found that households with incomes under $10,000 generate VKT/household that is only 40% of the average rate for all households (using auto-driver miles as the measure). The 1990 Census found that these households represent about 15.5% of all households in the US;

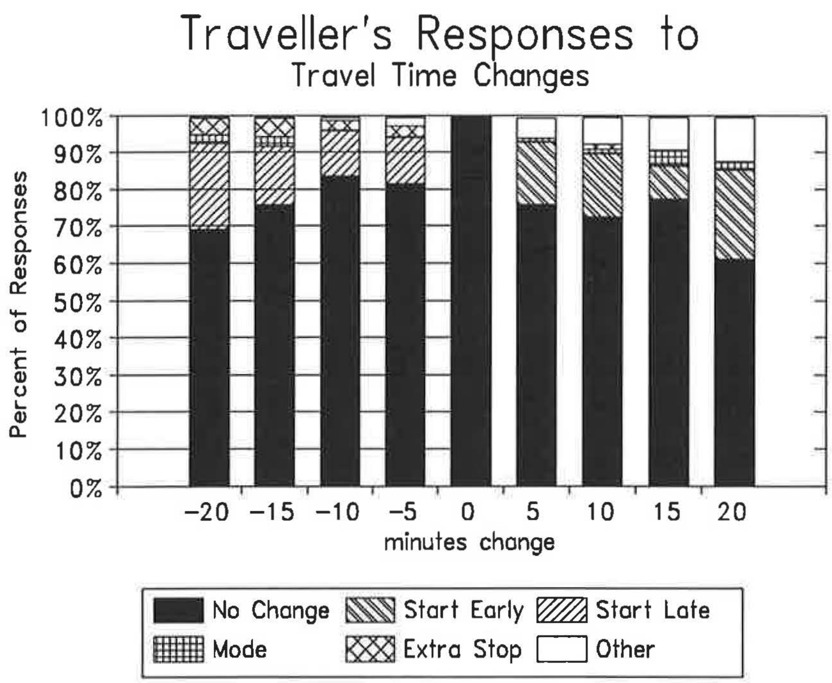


FIGURE 2 Response of travelers to hypothetical trip time changes.

therefore, it appears that they are responsible for somewhat over six percent of VKT).

The key results of the survey (see Tables 1 and 2) were that:

- Over 35% of the trips made would be unaffected when the trip travel time increased or decreased by 15 minutes or less when all trip purposes are considered.
- Another 20% to 40% of trips made would change only to the extent that the respondent would arrive earlier or later at a destination and make no change to the departure time to compensate for the effect of the travel time change.
- About 10% to 15% of the trips would be rescheduled to compensate for or take advantage of the travel time change.
- A time savings of five minutes would generate extra stops for about three percent of the trips where this time savings was offered. This percentage increased to five percent when 15 minute time savings was offered. The average across all time savings offered was three percent.

The overall result is that 90% to 95% of the trips would be unchanged or would have schedule changes in response to travel time increases and reductions of 15 minutes or less. As expected, the greater the magnitude of the travel time change, the greater the traveler response. Interestingly, the results are not symmetric: respondents tended to react slightly more strongly to increases in travel time than to decreases (see Figure 2). When faced with a travel time increase, respondents would try to adapt by changing mode, destination, and route for a higher percentage of the trips than if they were offered an equal amount of time decrease. Given the nature of the two metropolitan areas in which the survey was conducted, it is likely that more respondents have had recent experience adjusting to travel time increases than decreases. And this type of asymmetric behavior is probably not surprising. For example, some gaming simulations have shown that even given the same actuarial odds (expected value), people are much more concerned with a possible loss of wealth than they are with a possible gain.

The respondents indicated that only approximately 1.6% of their trips would be susceptible to a modal change given increased travel time for a specific trip. Of these hypothetical "mode switchers," most (38% and 35%, respectively) said they would switch to driving alone or public transit. It was implicit in the survey that the travel time by alternative modes was not changed. Greater time increases and decreases had a greater effect on traveler responses than smaller amounts of time changes. However, given that only 13% of survey trips were greater than 30 minutes in length, it was not realistic to ask the majority of the respondents about time savings of greater than 15 minutes.

CONCLUSIONS AND RECOMMENDATIONS

Most previous investigations of the effects of new highway capacity have been facility-specific "before and after" studies. At first, this approach seems highly appealing and only logical, but on reflection, it becomes clear that it is nearly impossible to use this approach to isolate the effects of new highway capacity on induced trip making. There are too many extraneous factors that can affect the results, including the availability of alternative modes and routes in each corridor; the condition of the local economy (growing or stagnant); zoning; and natural constraints to development. These factors not only affect the conclusions but also limit the validity of extending these results to other situations and locations. These factors may have been responsible for the conflicting conclusions that researchers have frequently arrived at in the past.

The results of this survey must be qualified by its relatively small size (under 700 households) and limited geographic scope. However, some of the indications from this survey are that:

- Current travel forecasting practice probably results in an underprediction of three to five percent in the number of trips that may be induced by *major* new highway capacity projects. Where a project is expected to yield travel time savings of more than five minutes for a large number of trips, adjusting travel demand upward to reflect induced travel is probably warranted.
- A key impact of new highway capacity is temporal shifts in demand (trips formerly made in the off-peak moving to the peak periods). From the highway user's perspective, this is not necessarily bad, since it simply means that he or she can make a trip in response to personal needs rather than traffic conditions. On the other hand, it will affect the congestion, speeds, and emission estimates produced by travel models. There is a strong need to develop better models to predict peak spreading/time of day of travel.

Not surprisingly, there were some questions that could not be answered in this study. They include: expanding the survey in the future to cover more households in more areas of the state; developing alternative survey mechanisms that can assess the possible interactions between household members to changes in travel times; and assessing how difficult-to-quantify factors (such as stress) may influence travel behavior when congestion is reduced. It seems logical to presume that a 30 minute drive in stop-and-go traffic would be perceived differently from a 30 minute drive in free flowing traffic, but our survey instrument was not able to distinguish between the two. A small sample of commuters in Orange County, California (Novaco, 1991) found that most, but not all, drivers perceived commuting in congested traffic as more stressful than commuting in uncongested traffic. To the extent this is true, it suggests that the results of the travel survey conducted here could underestimate the true effects on tripmaking of reduced congestion.

In the longer term, new highway capacity may influence decisions about auto ownership, residential location, the location of where a person finds employment, and the choice of expansion areas for businesses and government. These effects are important, but are beyond the scope of this paper. Indeed, several of these effects cannot be addressed with a household travel behavior survey. However, some of these impacts are already accounted for in current transportation/land use forecasting practices in California's largest metropolitan areas, using models such as DRAM/EMPAL and POLIS.

Key Conclusions

Highway capacity changes influence travel behavior principally by affecting travel time and cost. The principal conclusions from the survey are as follows:

- The sample population had definite preferences as to how they would respond to changes in travel time. Their response preferences are in this order:

  1. Change route (find a faster route if the current one becomes congested);
  2. Change schedule (find another time of day when congestion is less);
  3. Consolidate trips (reduce number of daily trips by accomplishing more activities with a given trip);
  4. Change mode (switch to more convenient mode);
  5. Change destination (find another location with similar services).

- Whether a person prefers to change mode over destination (or *vice versa)* may depend upon the trip purpose, e.g., a destination change is probably preferred over a mode change for most shopping trips.
- The order of preference responses appears to be similar for travel time decreases as well as for travel time decreases, although the magnitude is different. Whether faced with an travel time increase or decrease, both changes would result in the respondent preferring a different route or rescheduling the trip, rather than changing the trip mode or destination.
- Survey respondents indicated a high degree of resistance to change in their travel behavior when offered travel time savings of between five and fifteen minutes per trip. A five minute travel time savings (on average) resulted in a three percent increase in daily trips made per person, and a 15 minute time savings resulted in a five percent increase in trips/person/day.

Since most trips in metropolitan areas are under 15 minutes duration (The *1991 Statewide Travel Survey* (Table 20a, Caltrans final report, December 1993) indicates that 64% of trips (all purpose/all mode) are 15 minutes or less, and that even of home-work trips, 42% are 15 minutes or less) and realistic time savings on such short trips would rarely exceed five minutes, it appears unlikely that new highway capacity would significantly reduce travel times for the majority of trips. Home-work (commute) trips may be an important exception, since these are typically between 20-30 minutes in duration. It has also been pointed out that the commute trip also drives many other decisions, such as vehicle-holdings and household location, and those considerations have a substantial influence on generation of short trips. Thus, there could be some important secondary impacts that are not accounted for here.

This survey asked respondents about travel time changes in five minute increments, a decision made early in the study process that people would not be sensitive to time increments less than this. The reactions of respondents (not captured in the survey form) seems to support this *a priori* decision, since many respondents dismissed five minute time savings as being too trivial to affect their behavior. This is also corroborated by the observation that, in reporting their own travel time, nearly all survey respondents (in this and other surveys) round the time to the nearest five minutes. A similar conclusion has been reached in another study (Hague Consulting Group, 1991) in which British travelers were found to ignore travel time changes less than two minutes.

Recommendations for Future Research and Survey Improvement

It is recommended that the following steps be taken to improve the understanding of the effects of increased highway capacity on travel behavior and to improve the ability to forecast these effects at the regional level. Repeating the behavioral survey in other metropolitan, and possibly rural, areas to determine if the survey results can be reliably extrapolated to all travelers would be desirable. A larger survey sample would also yield more information on the effect of new highway capacity on various trip types and purposes.

The wording of survey questions and presentation of alternatives is critical in most SP surveys, and is one of the known weaknesses of the method. Some respondents were confused as to whether a visit to a different location meant a different location for the same purpose, or a different location for a different or additional purpose. For some respondents who made fairly short trips, the total travel time savings presented was near or greater than the amount of time the respondent had reported in travel. Some respondents who realized this were confused.

This survey did not allow for the possibility that people could save their travel time savings over a week, and "spend" them then. This approach was thought to be appropriate since time, unlike money, is not as easily "banked" and then spent later. However, the authors recognize that the greater the flexibility in allocating time, the more likely the possibility that travel time savings should be investigated using a week as the reference time (rather than 24-hours). The non-employed or those working part-time would appear to have the greatest flexibility in this regard (the increasing use of four-day work weeks may also be important). This area deserves further investigation.

It would be useful to use other research approaches to corroborate the results of this survey. One is activity gaming and simulation, which allows researchers to better understand the intra-household allocation of travel and other activities. This study made only a rudimentary attempt to consider how one household member's travel time changes might affect the travel and activity patterns of other members of the household.

Another approach would be to collect detailed information on the before and after effects of those living in a corridor where travel times are improved. Recently developed automatic vehicle location technology, using cellular phone technology, would allow detailed multi-day travel diaries to be analyzed without the tedium and error associated with the traditional manually kept diaries.

Additional study would need to be done to examine whether travel time savings are treated equally by motorists, regardless of the initial congestion condition. Since some studies by psychologists indicate that commuting in stop-and-go traffic is a stressful experience, traffic relief schemes that reduce congestion could have an impact beyond just the travel time savings. However, since there is no easy way to measure stress and present it to survey respondents, this issue could not be addressed as part of the current research effort.

ACKNOWLEDGMENTS

Although the authors are responsible for all statements of fact and opinion in the paper, we would like to thank Fereidun Fezollahi, Anne Geraghty, and Doug Thompson of the California Air Resources Board for their guidance. Dr. Ryuichi Kitamura developed the concept of the stated preference and prior day's activity survey along with David Reinke. Dr. Peter R. Stopher made many helpful comments on the survey, as well as the overall study process. We thank them all for their thoughtful assistance.

SELECTED BIBLIOGRAPHY

In the interests of space, only key reports and studies have been noted here.

Addison, Tom (1990). "A Study of Freeway Capacity Increases in the San Francisco Bay Area and Greater Sacramento." EPA Region IX Air Programs Branch, September 28, 1990.

Allard, John (1988). "A Review of the Traffic Generation Effect of Road Improvements." London: University College.

Alonso, William (1964). *Location and Land Use - Toward A General Theory of Land Rent.* Harvard University Press.

Applied Management and Planning Group (1990). "Traffic Congestion and Capacity Increases," prepared for the Sierra Club Legal Defense Fund, Inc. and Citizens for a Better Environment.

Association of Bay Area Governments [ABAG] (1991). "Assessing the Future: A Sensitivity Analysis of Highway and Road Improvements on Growth in the San Francisco Bay Area," working paper 91-4. Oakland, CA.: ABAG.

ibid., (1984). "POLIS: The Land Use Information and Transportation System for the San Francisco Bay Area," Berkeley: Association of Bay Area Governments, reprinted June 1990.

Bass, Thomas (1992). "Road to Ruin" in *Discover* Magazine (May 1992), p. 56ff.

Ben-Akiva, Moshe, T. Morikawa and F. Shiroshi (1989). "Analysis of the Reliability of Stated Preference Data in Estimating Mode Choice Models." *Transport Policy, Management and Technology Towards 2001.* Ventura, CA: Western Periodicals.

Bonsall, P.W. and P.J. Mackie (1990). "Identification of User Response to New Road Capacity," Transportation and Road Research Laboratory.

Bonsall, P.W. (1990) "Measuring Impacts of New Highway Capacity - A Discussion of Potential Survey Methods," Working Paper 289, Institute for Transport Studies, The University of Leeds, March 1990.

Brand, Daniel (1991). "Use of Travel Forecasting Models to Evaluate the Travel and Environmental Effects of Added Transportation Capacity," Presented at Conference on the Travel and Environmental Effects of Added Transportation Capacity, December 6, 1991.

Burns, Lawrence D. (1979). *Transportation, Temporal, and Spatial Components of Accessibility.* Lexington, MA.: DC Heath & Company.

Caltrans [California Department of Transportation], Office of Traffic Improvement (1993). *1991 Statewide Travel Survey,* final report. Sacramento, California.

Dobbins, A., M. Hansen, D. Gillen, Y. Huang, and M. Puvathingal (1993). "Air Quality Impacts of Urban Highway Capacity Expansion: Traffic Generation and Land Use Impacts," draft report, April 1993. Report UCB-ITS-RR-93-5.

Dowling Associates (1994). "Effects of Increased Highway Capacity on Travel Behavior." Sacramento, CA: California Air Resources Board.

Downs, Anthony (1962). "The Law of Peak-Hour Expressway Congestion." *Traffic Quarterly.* Westport, CT: Eno Foundation, vol. XVI no. 3 (July 1962).

Garrison, W.L. and R.D. Worrall (1966). "Monitoring Urban Travel," final report of Project 2-8, *Estimation and Evaluation of Diverted and Generated (Induced) Traffic,* National Cooperative Highway Research Program.

Giuliano, Genevieve (1986). "Land Use Impacts of Transportation Investments: Highway and Transit," in *The Geography of Urban Transportation,* Susan Hanson, editor. New York: The Guilford Press.

ibid., (1989) "New Directions for Understanding Transportation and Land Use," *Environment and Planning A,* vol. 21, pp. 145-159.

Hague Consulting Group and Steer Davies Gleave (1991). "Stated Preference Techniques: A Guide to Practice," second edition. The Hague, Netherlands.

Homburger, Wolfgang S. (1990). "The Loma Prieta Earthquake: What Happened to the Trip Makers? A Preliminary Report." In *Compendium of Technical Papers,* Institute of Transportation Engineers (District 6) Annual Meeting, Boise, ID., pp. 1-6.

Institute of Transportation Engineers, Committee 6F-13 (1980). "Evaluation of the Accuracy of Past Urban Transportation Forecasts," in *ITE Journal,* February 1980, pp. 24-34. Washington, DC: Institute of Transportation Engineers.

Jorgensen, R.E. (1947). "Influence of Expressways in Diverting Traffic from Alternate Routes and Generating New Traffic," *Proceedings of the 27th Annual Highway Research Board.* Washington, DC: Highway Research Board.

Kitamura, Ryuichi (1991). "Effects of Added Capacity on Travel: A Review of Theoretical and Empirical Results," A Paper Presented at a National Conference on the Effects of Added Transportation Capacity, December 16-17, 1991, Bethesda, MD.

ibid. (1988), "An Evaluation of Activity-Based Travel Analysis." *Transportation,* vol. 15, pp. 9-34.

Loos, Andre L. *et. al.* (1991). "The M10 Amsterdam Orbital Motorway: Effects of Opening Upon Travel Behavior." PTRC Transport, Highways, and Planning Summer Annual Meeting. University of Sussex, September 9-13, 1991.

Markowitz, Joel (1990). "Effects of the October 1989 Earthquake on the Transportation System in the San Francisco Bay Area." Unpublished paper.

Meyer, John R. and Jose A. Gomez-Ibañez (1981). *Autos Transit and Cities.* A Twentieth Century Fund Report. Cambridge, MA: Harvard University Press.

Novaco, Raymond W., Daniel Stokols, and Louis Milanesi (1990). "Objective and Subjective Dimensions of Travel Impedance as Determinants of Commuting Stress." Berkeley: The University of California Transportation Center, reprint no. 30.

Payne-Maxie Consultants (1980). "The Land Use and Urban Development Impacts of Beltways." Washington, DC: Payne-Maxie Consultants.

Pells, S.R. (1989). "User Response to New Road Capacity: A Review of Published Evidence." University of Leeds Institute for Transport Studies Working Paper 283.

Pratt, Richard H. (1991). "Discussion on Effects on System Performance," Presented at a Conference on Effects of Added Transportation Capacity, Bethesda, MD.

Purvis, Charles L. (1994). "Changes in Regional Travel Characteristics and Travel Time Expenditures in the San Francisco Bay Area, 1960-1990." Presented at the 73rd Annual Meeting of the Transportation Research Board, Washington, DC, Paper #940509.

Robinson, John P. (1977). *How Americans Use Time.* New York, Praeger Publishers.

Rogers, Keith (1991). "Congested Assignment and Matrix Capping-- Constraining the Trip Matrix to Reflect Network Capacity," in *Traffic Engineering+Control,* July-August 1991, pp. 342-346.

Rothblatt, Donald R., Steven B. Colman, and Earl Bossard (1994). "Effects of Residential Density on Transit Usage and Residential Trip Generation," prepared for the Caltrans Research and Training Program by the Institute for Metropolitan Studies, San Jose State University.

Ruiter, Earl R., W.R. Loudon, et. al. (1980). NCHRP Project 8-19: "The Relationship of Changes in Urban Highway Supply to Vehicle Miles of Travel," *in* NCHRP Research Digest #127, December 1980. Washington, DC: National Cooperative Highway Research Program.

Small, Kenneth. A. (1982). "The Scheduling of Consumer Activities: Work Trips" in *The American Economic Review,* June 1982, p. 467 ff. New York: American Economic Association.

Stopher, Peter R. (1992), "The Impact of Capacity Increases on Congestion," paper prepared for presentation to the 7th REAAA conference. (Singapore: June 1992).

ibid. (1991), "Travel and Locational Impacts of Added Transportation Capacity: Experimental Designs," resource paper presented at the Conference on Travel Effects of Added Transportation Capacity, Bethesda, MD., December 16-17, 1991.

Suhrbier, John H. (1991). "Environmental Effects of Added Transportation Capacity," Cambridge Systematics, Inc., December 1991.

United States Department of Transportation (1993). "1990 NPTS Databook - Nationwide Personal Transportation Survey - Volume I," Washington, DC.

Wiley, James A. (1991). *Activity Patterns of California Residents.* Sacramento, CA: California Air Resources Board Research Division, contract No. A6-177-33.

Winfrey, Robley and Carl Zellner (1971). "Summary and Evaluation of Economic Consequences of Highway Improvements." National Cooperative Highway Research Program Report 122. Washington, DC: Highway Research Board.

HIGHWAY CAPACITY AND INDUCED TRAVEL: ISSUES, EVIDENCE AND IMPLICATIONS

Kevin Heanue,
Federal Highway Administration

ACKNOWLEDGMENTS

Sam Zimmerman, Patrick Decorla-Souza, Brian Gardner, and James Hunt of FHWA's Metropolitan Planning Division contributed extensively to the development of this paper.

INTRODUCTION

Purpose

The popular (and frequently even the academic) press often alludes to the traffic-inducing qualities of new highway construction. A columnist writing in the Washington *Post* once remarked that "Building highways to reduce congestion is equivalent to buying a larger belt to cure obesity." A 12/21/96 letter to the editor of the same paper said ". . . anecdotal evidence suggests a strong correlation between amount of pavement and intensity of gridlock: i.e., more pavement equals more gridlock." An example of this view in the academic press is a recent paper by Professor Mark Hansen which appeared in the Fall issue of the University of California's journal Access (1). In the article, *Do New Highways Generate Traffic?*, Professor Hansen stated: "New roads generate substantial new traffic in metropolitan regions. A 1.0 percent increase in lane miles generates a 0.9 percent increase in VMT within five years. With so much induced traffic, adding road capacity does little to reduce congestion."

There are a number of related implications of the frequently heard assertion about the traffic inducing properties of highways. The first is that by itself, new highway capacity "induces" an amount of new travel sufficient to fill the new capacity and therefore, highway construction cannot effect congestion relief. And second, since new highways cannot "cure" congestion, they are not useful.

This paper is an attempt to objectively address the induced travel issue, by answering the following questions: First, if new highway capacity does indeed "induce" new travel, to what extent compared to other factors? Second, if new highway capacity (as one of many factors) induces new travel, how should induced traffic be accounted for in the objective evaluation of highway investments?

Definition of "Induced" Travel

In order to understand the relationship between "induced travel" and new highway capacity, one must first define the term "induced travel". At one time, highway planners defined induced travel as the increase in highway trip making resulting from a highway improvement. All other changes such as shifts in destination, mode, and route were accounted for separately. The popular press and academicians now define induced travel as encompassing any combination of increases in trips and trip lengths resulting from a system change. Therefore, for the purposes of this paper, *induced travel is any increase in daily travel (measured as passenger or vehicle miles of travel) resulting from a change in the transportation system.*

Accounting for Induced Travel: Network, Geographic and Temporal Context/Scope

The network and geographic context/scope accounting for urban travel changes is an issue that must be considered with respect to the travel inducing effect of highways. As an example of the importance of measurement scale, assume a simple "slip" ramp was added between the collector/distributor lanes and the main lanes of a major freeway to minimize merging safety problems at a close-by location.

In most cases such a modest system change would have little or no effect on the absolute number of highway trips made and/or the length of existing trips. However, if the travel measurement or counts were limited to the main lanes of the freeway, this modest change might be seen to generate significant "induced" travel. In reality, little or no *net* additional travel actually would have occurred, just a "route" shift from the outer to inner lanes. This same type of accounting error can occur when the scope of travel measurement is by functional class of facility (e.g. tracking freeway volumes but not travel on surface arterials), by jurisdictional class (e.g. counting travel on state, but not locally, maintained streets) or by sub-area (e.g., measuring travel in one corridor but not in a parallel corridor).

In general, the narrower the geographic or network scope of the measurement, the larger the apparent amount of "induced" vehicular travel one might find as the result of a capacity increase or other system supply change.

Redistribution of traffic in time is another major effect of expansion of highway capacity. Travel previously undertaken in the off-peak periods may shift to peak periods because of the added peak period capacity now available, without an increase in total daily traffic. A recent study of the Zeeburger Tunnel in the Netherlands estimated the short-term effects of removing a bottleneck (2) and illustrated temporal distribution as well as route shifts. The study was based on panel surveys in the affected area and traffic counts 6 months apart, the first 4 months before the opening of the new roadway, and the second 2 months after. Considerable changes occurred in departure times and route choice. Twenty-nine per cent of commuters and 15% of non-commuters in the corridor changed their route to take advantage of the new tunnel. At the same time, a 19% increase occurred in morning peak (7-9am) commuter trips, with 6% and 11% reductions in the off-peak shoulders (i.e. 0-7 am and 9 am-noon).

For all purposes, peak trips increased 16%, while there were 8% and 11% reductions in the off-peak shoulders. There also was a 4% reduction in transit use and an 11% reduction in auto passenger journeys. Despite these changes, there was only a 5% increase in auto driver trips and virtually the same number of total person trips.

Observations limited to post-construction *peak* vehicle trip traffic flows in this case might lead to the false conclusion that 16% of the traffic on the facility had been induced, even though total *daily auto driver* trips increased only 5%. Since the primary effects of the new Dutch tunnel were route and departure time changes, only a small amount of new daily traffic was actually *induced* by the tunnel.

TRAVEL BEHAVIOR AND HIGHWAY CAPACITY EXPANSION

Decisions Affecting Urban Travel

All travel is a derivative of an individual's need or desire to pursue an activity at a location other than the given trip origin, at the given time. Over fifty years of research suggests that there are a number of highly inter-related decisions which impact travel defined in this way. The individual traveler must decide:

- Whether to travel to satisfy the activity need (or desire) such as to work, shop, visit relatives, attend school, etc.; in travel model terms, this decision is referred to as a trip frequency choice or trip generation.
- When to travel, i.e., what time of day and/or day of the week.
- Where to go to satisfy the activity need/desire; in travel model terms, this is referred to as destination choice or trip distribution.
- How to travel, i.e., by what mode and path; in travel model terms, this is referred to as mode and path choice, or mode split and trip assignment.

We know that the above travel decisions are influenced by three sets of attributes:

- Characteristics of the trip maker (e.g., income, age, employment status, family status/stage of life, household size, auto-ownership, housing type and location, etc.)
- Nature of the activity in question (e.g., work, school, shopping, etc.). Will it be undertaken by an individual, or a group such as a couple or family? When will it be undertaken (e.g., during the day, at night, on the weekend)?
- The characteristics of the transportation system. What are the costs, total travel times and other attributes such as the reliability and walking/waiting/transferring time of the available travel options?

The Role of Urban Highway Capacity

Transportation system capacity itself, a priori, does not influence travel behavior. Travel times, costs and other measures of perceived travel difficulty do influence travel decisions. Rapid expansion of capacity in highly congested conditions will result in reductions in travel times and costs, and like any change in the difficulty or ease of travel (e.g., reduced tolls, reduced price of gasoline or transit fares, reduced transit waiting times), will result in immediate changes in one or more of the travel decisions noted above. Modest capacity additions in marginally congested situations will result in smaller changes in perceived travel times and cost and therefore less dramatic travel changes.

To the extent that travel changes are induced by time and/or cost changes, their character and magnitude will differ in the short term vs. the long term. For example, in the short term, people are more likely to change their time of departure and/or their travel route because of the availability of a new, faster and/or cheaper transportation facility than they are to change their trip origin (e.g., residence) or destination, (e.g., job).

Land use changes induced by a new transportation facility obviously take the most time to occur.

Travel decisions are made by the universe of travelers in response to the need/desire to perform activities in locations. Transportation system connectivity, usage, and performance can influence the location, nature and timing of activity growth, i.e., where and how people choose to live and where and how developers decide to build new residential communities, factories, offices, stores, recreational facilities, hospitals, schools, etc. In some cases, e.g., regions with tremendous system-wide congestion, where mobility and access are extremely low, the character and extent of the transportation system can also effect the total amount of activity rather than simply its distribution within the given region.

Interestingly enough, there is evidence that transportation is not currently playing as important a role in land use decisions as in prior years. For example, *Money* magazine recently polled its subscribers (admittedly of higher than average income, education, etc.) about their decision criteria for choosing the ideal place to live (3). "Short commutes," the highest ranked direct transportation criterion, ranked 22nd out of 41 community factors. The availability of good public transportation was ranked 34th. Crime, the environment and health services, in that order, were the highest ranked factors. This is consistent with other surveys of citizens and developers and may reflect the fact that the high level of access and mobility generally available in the U.S. lessens its impact on specific location decisions.

Problems with Performing Analyses of the Relationship of Highway Capacity to Travel Demand

Establishing the precise causal relationship between urban travel and highway capacity is a difficult task. The key to success in these studies is to avoid attributing travel growth "induced" by changes in other causal factors such as changes in the total number of trip makers and their characteristics (e.g., incomes, employment status) and other exogenous factors such as real gasoline price reductions to highway capacity expansion . Analyses of the effect of highway capacity changes on travel over time, as a minimum, require traveler, system and travel data collected continuously over a relatively long period for comparable populations split into two groups - those benefitting from highway supply additions, and a control group for which highway supply did not change.

In North America, finding a reasonable control group for which highway capacity did not change over a significant period is practically impossible (4). Some empirical studies relating to induced travel have been done using aggregate data, which is more easily obtained. However, disaggregate data on individuals and their travel decision history is necessary to do a truly behavior- based analysis.

CHANGES IN FACTORS CAUSING TRAVEL GROWTH

Major Causal Factors Driving VMT Growth

Three types of factors have driven the increase in total person travel and VMT in the U.S. and elsewhere over the post-war period:

- Socio-economic/demographic factors, such as growth in population and households, labor force participation and employment, income, auto-ownership, vehicles owned and licenced drivers.
- Land use factors, such as: increasing single family home ownership and declining development densities, separation of different types of land uses, and auto-oriented site planning and urban design.
- Stable or declining transportation costs, reflecting real declines in gasoline prices and increased fuel efficiency, shifts to higher speed modes and disproportional growth in less congested regions (e.g., in the South and West) and less-congested parts of regions (e.g, suburbs at the urban fringe).

What has been the relative contribution of the various factors to travel growth? Consideration of historical changes in these factors, and their impacts on travel behavior, helps place the highway-induced travel issue in perspective.

Changes in Socio-economic/Demographic Factors

Obviously, all things being equal, the more people, households, employees, jobs, autos and economic activity there is, the more travel there will be.

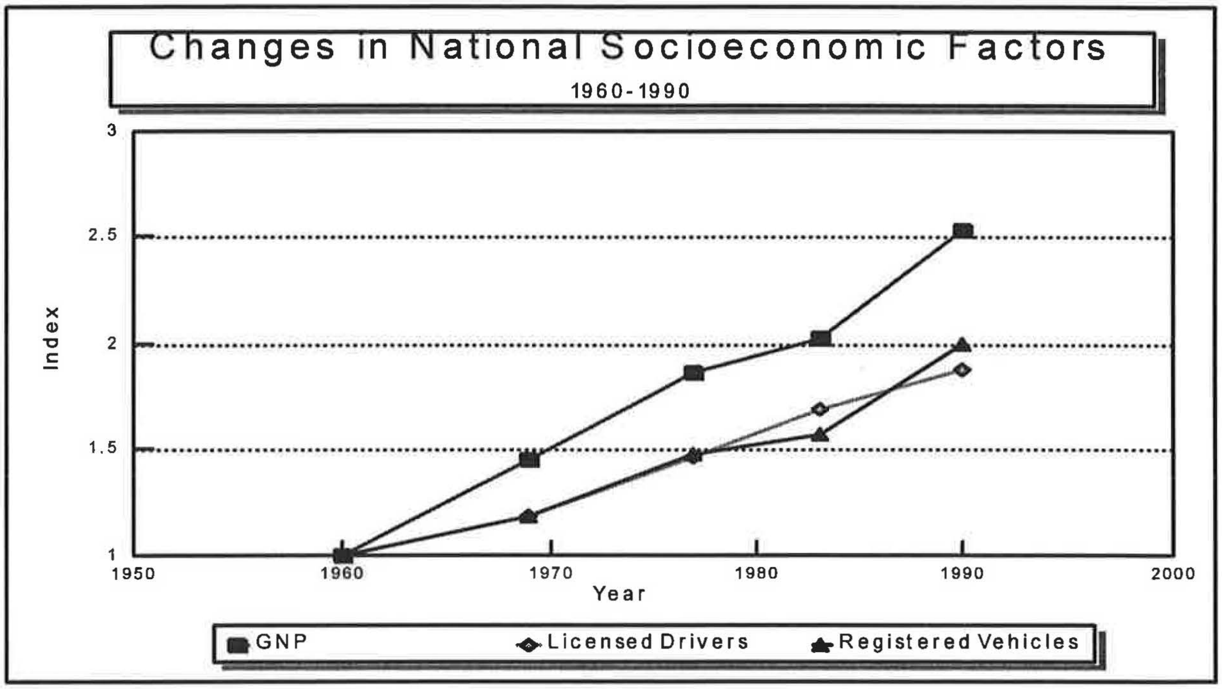


FIGURE 1

Population in major metro areas grew rapidly over the last 35 years. Aggregate growth amounted to about 15% in the Northeast, 20% in the Midwest, and 100% and 90% in the South and the West respectively (5). Nationally, suburban population grew from 35.2 million in 1950, to 117 million in 1990 (6). As the data show, one would expect travel to have more than doubled in major southern and western metro areas since trip-making is a near linear function of population, all else being equal.

Households are an even stronger determinant of travel than population because most travel (e.g., social-recreation travel, shopping) occurs as a collective activity by and for household members as a group. The 1969 NPTS showed that the average household contained 3.16 people (7). In 1990, the average was 2.56 people. This means that the same number of people constituted 23% more households in 1990 than in 1969. Therefore, all things being equal, there were up to 23% more trips for household serving purposes such as food shopping, laundry/dry cleaning pick-up, banking, etc. in 1990 than in 1969.

Employment grew at an even faster rate than population in largest metro areas. In part, this reflected the dramatic increase in the labor force participation of women, many of whom retain primary family care responsibilities. This combination of work and family-related activity generates unique travel needs that are difficult to serve.

Not only has the total growth in jobs been profound, but there has been a shift in jobs from central cities to the suburbs. *Commuting in America II*, (6) shows that in 1980, 38% of the total national employment, or 36.2 million jobs, were in central cities, 33% or 32.6 million jobs were in the suburbs and 29% were in non-metropolitan areas. In 1990, only ten years later, the number of jobs in the suburbs had risen to 48 million, or 37% of the total, while the number in central cities had risen to only 44 million, or 34% of the total. New jobs, irrespective of where they are, require additional commute travel, most of which takes place in the peak periods. In the suburbs, new commuters also usually mean additional auto trips. In 1990, 77.5% of all commuters destined to suburban jobs drove alone, compared to 68% for commuters going to jobs in central cities. New jobs also mean an increase in commercial travel related to new economic activity, and that travel can be expected to be highway oriented as well.

Other socio-economic factors with direct effects on travel also changed at rapid rates. As shown in Figure 1, over the period from 1960 to 1990, Gross National Product (GNP) grew nationally by 150%, the number of licensed drivers grew nationally by 87% (reflecting, in part, increasing driving parity between men and women) and registered vehicles grew by 100% (8). Each of these factors results in increases in highway travel.

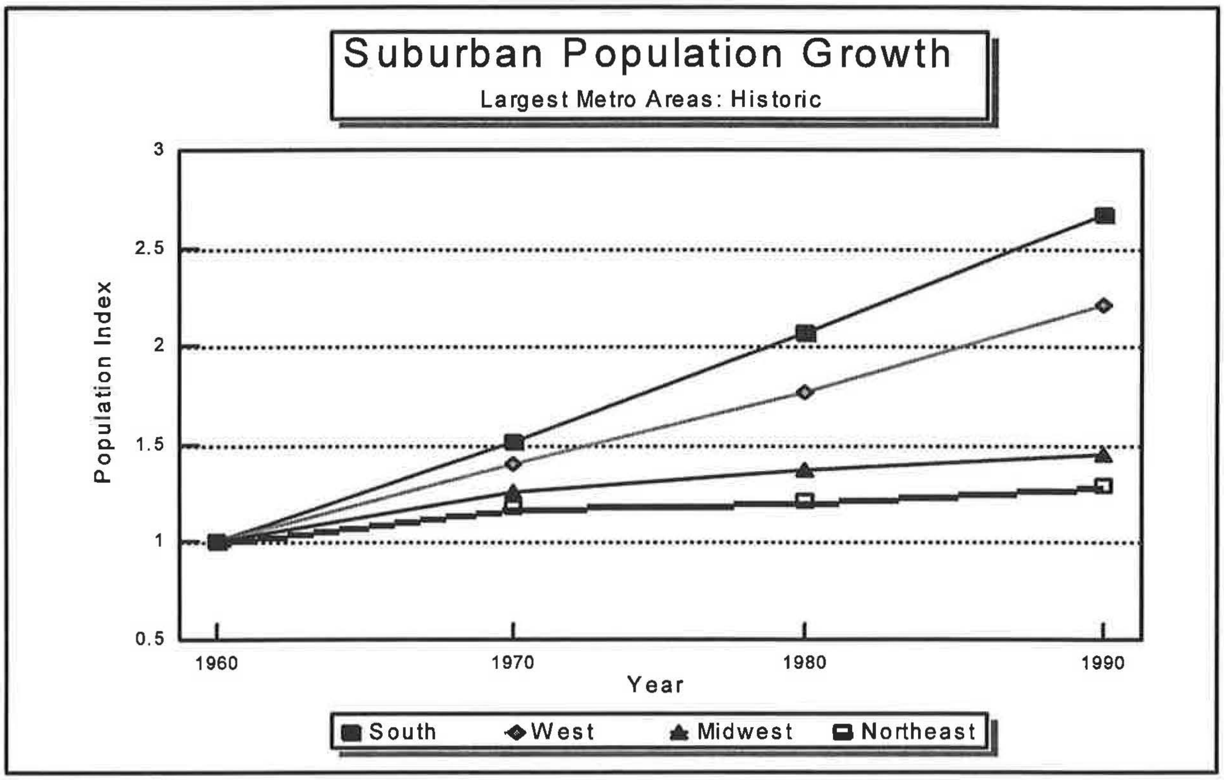


FIGURE 2

Figure 2 shows the growth in suburban populations in major metropolitan areas in each region of the country (5). In 1950, suburban population comprised 23% of the national population, while central cities had 33% and non-metropolitan areas had 44%. By 1990, suburban population grew to 47% of the total, while central cities declined to 29% and non-metropolitan areas to 24% (6). While much of the suburban growth was the result of absolute population shifts from central city and non-metropolitan areas, the disproportional growth in suburban population was also a direct result of new generations of natives and new immigrants choosing to live (and work) in the suburbs. For a variety of reasons, suburban dwellers tend to be auto-dependent. For example, in Montgomery County, Maryland, suburban residents generate on average twice as much VMT per person as residents of Washington D.C. (9).

At the same time as suburbs were disproportionally growing, residential densities continued to decrease, in central cities as well as the suburbs. Over a ten year period alone, from 1970 to 1980, residential densities in the 25 largest metro areas dropped by 17% in central cities and 13% in the urban fringe. The drop in central city densities was the result of declining population and household size, while the drop in suburban densities was the simple result of smaller households living on larger lots. Over-all urban residential densities dropped by 17.4% (10) The implications for travel are that as densities decline, so do the opportunities for making non-motorized trips. All things being equal, as densities decline, the number of motorized trips and probably trip lengths increase.

Other land use attributes in addition to density are important determinants of total travel. Data from the "LUTRAQ" (Land Use, Transportation and Air Quality) study (11) in Portland, Oregon suggest that a household in a low density, auto-oriented suburb will make, on average, 7.7 vehicle trips per day, while the same household in a higher density, transit-oriented suburb will make 6.05 vehicle trips per day. This study focused on how land-use and other policies could be used to forestall the need for additional highway capacity. LUTRAQ probably

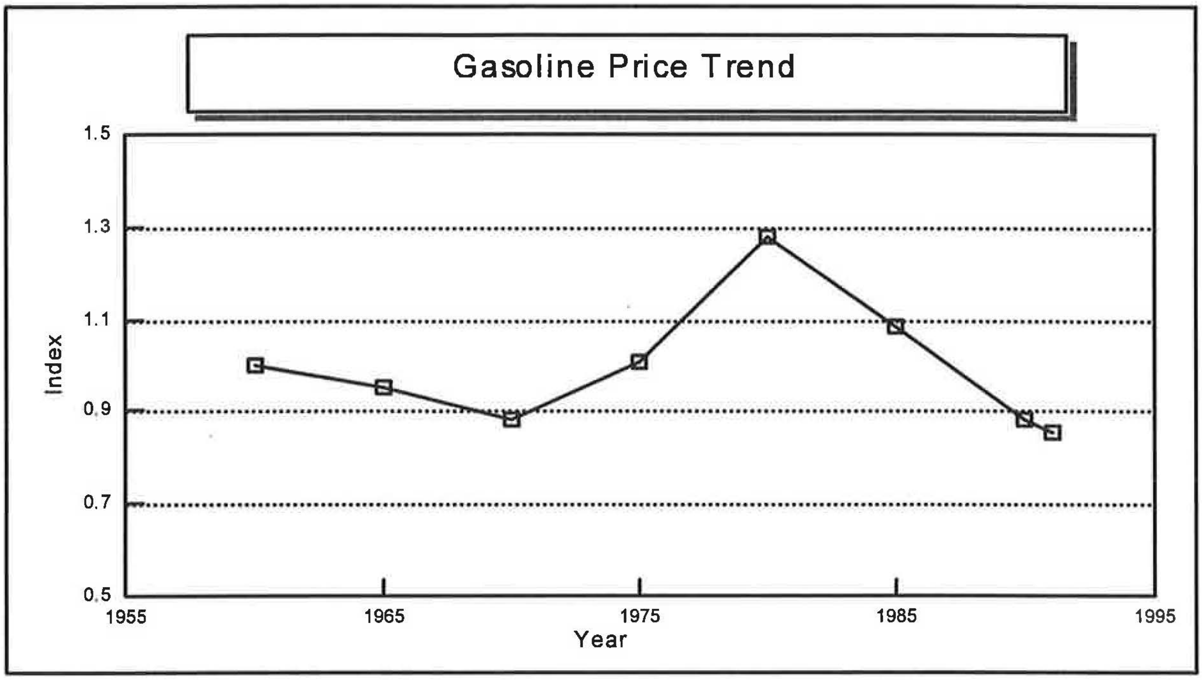


FIGURE 3

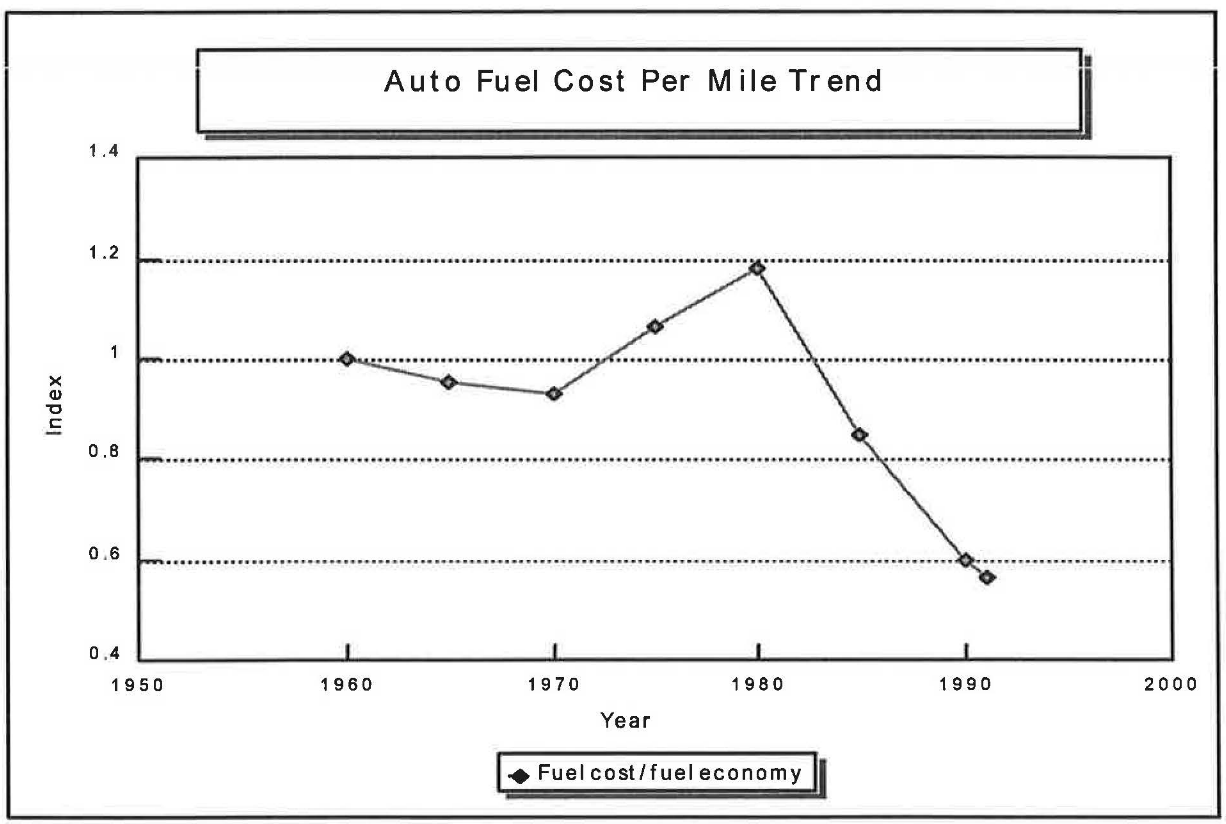


FIGURE 4

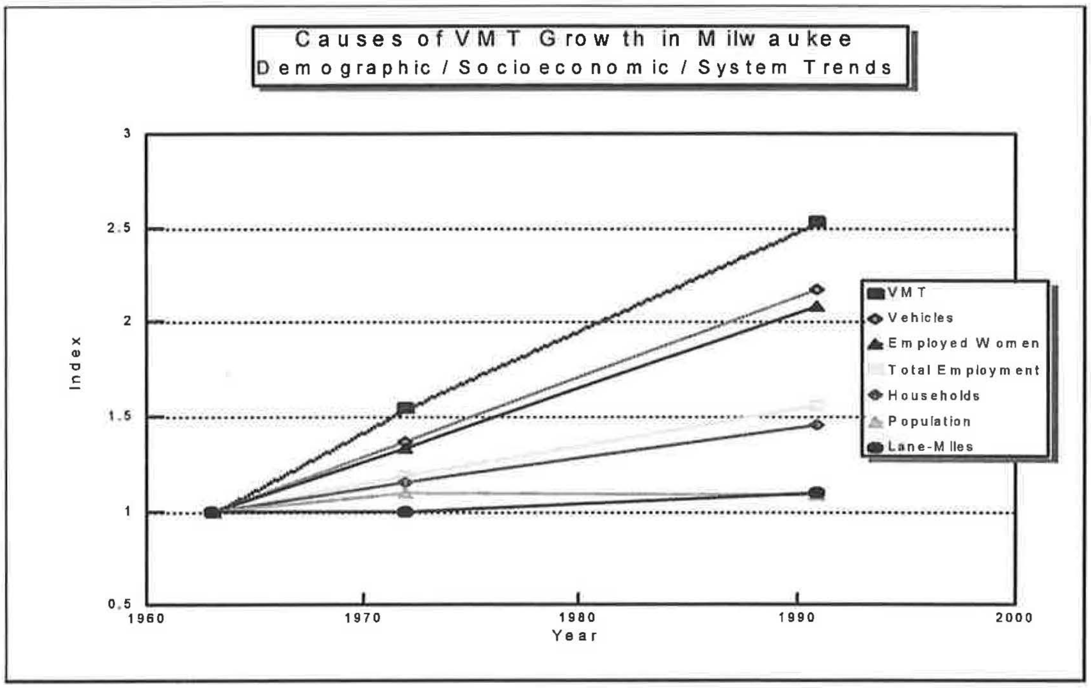


FIGURE 5

represents the best that can be done in rapidly growing U.S. suburbs to reduce vehicular travel demand through macro and micro-scale land-use policies such as an emphasis on mixed-use development, higher densities and transit-oriented site planning.

As Figure 3 shows, gasoline price, the monetary cost component of travel most evident to drivers, has actually dropped (in real terms) from the levels experienced during the oil shocks of the seventies (12). Compounding the drop in real gasoline prices has been the dramatic increases in auto fuel economy (13). Shown in Figure 4 is the combined effect of lower real gasoline prices and increasing fuel economy on the real cost of fuel per mile of vehicular travel.

Estimates of speed (travel time per mile of travel), based on National Personal Transportation Study (NPTS) data, suggest that, *weighted average* travel speeds actually increased by about 20% between 1969 and 1990 for commuters by all modes (7). This is due to a number of coinciding phenomena. First, the proportion of workers using faster modes (e.g., driving and commuter rail) has been increasing, while the proportion using slower modes, (e.g., buses and car pools) was declining. Second, though highway speeds everywhere have been declining for some time, an increasing proportion of highway travel is taking place in the suburbs, where trip densities are lower and relative speeds tend to be higher than in densely developed central cities. Current suburban speeds, though lower than previous suburban speeds, are still faster than previous speeds in central cities, so that speeds weighted by amount of travel have been either increasing or stable.

How Does Highway Capacity Stack Up Against the Other Causal Factors?

The previous discussion of the various factors influencing travel behavior has demonstrated how they affect travel and how they are changing. To answer the question of how relatively important they are compared to highway capacity, travel growth over time due to these primarily socio-economic factors was compared by FHWA staff to "induced" travel generated by new highway capacity. This was done for a "typical" U.S. city.

Data for the "typical" city actually comes from Milwaukee, Wisconsin (14). Milwaukee was selected by FHWA staff both because consistent data over time were available for it, and because it is relatively slow growing. If the effect of system supply and performance on highway travel is shown to be relatively small in Milwaukee compared to travel changes resulting from its relatively modest changes in important demographic factors, then they are likely to be even less significant as travel determinants in other, more rapidly growing regions. Figure 5 shows that from the period 1963 to 1991, Milwaukee has experienced relatively slow population growth compared to other U.S. metropolitan areas. While the total U.S. metropolitan population grew by 67% from 1960 to 1990, Milwaukee metropolitan area grew by only 9% during essentially the same period. Note in Figure 5, however, that in spite of the relatively small population growth, other socio-economic factors grew rapidly. Households and employment increased by about 50%, and registered vehicles and employed women more than doubled.

As Figure 5 shows, total VMT growth exceeded 150%. Total VMT changes are due to *all* causal factors, i.e., socio-economic, land use and transportation system, as discussed above.

In order to understand the relative importance of system supply/performance changes, total travel changes need to be partitioned into two parts, those "induced" by system supply/performance changes and those resulting from changes in other factors. We attempted to do this analytically, as described in the following paragraphs.

In order to do the partitioning analysis, it was necessary to use a travel elasticity (i.e., percentage change in travel demand proportional to a percent change in a system supply characteristic.) The literature was examined to investigate what the travel response to changes in highway capacity have actually been. Three sources of elasticities were utilized.

The first source was Hansen (1). He found that the *change in California State highway VMT per unit change in State highway lane miles was 0.9*, based on an evaluation of California county data over time. Although much of the change in State highway VMT in response to additional capacity may have come from diversions from non State highways and may not be truly "induced" per the definition given above, this elasticity was used in the analysis below to provide an upper bound estimate of induced travel based on Hansen's results.

The second source was the 1995 TRB publication "Expanding Metropolitan Highways; Implications for Air Quality and Energy Use," (15). In Appendix B, Cohen cites elasticities of highway percentage VMT change per unit percent travel time change, from a variety of sources ranging from a low of 0 to a high of -1.0. In particular, he notes the British "SACTRA" study finding of highway *VMT/travel time* (not capacity) elasticities ranging from -.5 in the short run, to -.1.0 in the long run.

Finally, a recent European study examined empirical evidence with regard to magnitude of induced traffic (16). The study was based on a comparison of forecast and observed traffic growth for a large number of road improvement projects. The study found that when traffic growth due to other factors is forecasted correctly for an average road improvement, the road will see 10% higher traffic than that which was forecasted in the short term, and 20% higher traffic in the long term. Goodwin suggested that these findings are consistent with VMT elasticities with respect to *travel time* of -0.5 in the short term and -1.0 in the long term.

In the analysis shown below, highway travel/travel time elasticities of both -.5 and -1.0 are used, along with Hansen's State highway lane mile elasticity of 0.9. In Figures 6-8, actual total VMT growth in the typical city is plotted over the period 1963 through 1991 (14). This total travel is partitioned into the VMT growth that could have been attributed to system supply/ performance changes, given the elasticities noted above, and that resulting from changes in the other factors.

What is clear from the figures is that regardless of the highway travel vs. highway supply / performance elasticity chosen (Cohen, Goodwin or Hansen), the vast majority of the VMT growth shown is directly related to factors other than changes in the highway system. Figure 9 shows that depending on the elasticity assumed, the percentage of the 1963 to 1991 VMT growth in Milwaukee that could be directly attributed to growth in the capacity of the highway system ranges from 6 to 22%. In other words, a conservative estimate is that over 78% of the VMT change in this slowly growing U.S. city was due to the non-system supply factors noted above.

Though the higher VMT/travel time elasticity used in Figure 8 (-1.0) undoubtedly reflects changes in land-use induced by additional highway capacity as well as travel behavior changes, there may be additional, even longer-term relationships between highway supply and land-use they do not reflect.

In the very long-term, highway capacity additions may lead to lower densities, more auto-oriented urban design and higher auto ownership and hence more total travel than would have been the case without the capacity. However, it can be shown that even with land-use policies in place which strongly discourage sprawl/ low densities/ high auto ownership and encourage transit use, auto travel growth will still remain heavily dependent on socio-economic and demographic change. Even in regions with these policies in place, if there is significant population growth, there will be significant new highway travel!

The LUTRAQ study mentioned above showed that the vehicle trips associated with each new household in a region could be reduced from 7.7 per day to 6.05 with pro-transit / pedestrian and auto-discouraging transportation and land use policies in place. This is a 22% drop, but the 78% remainder or 6.05 new vehicle trips per new

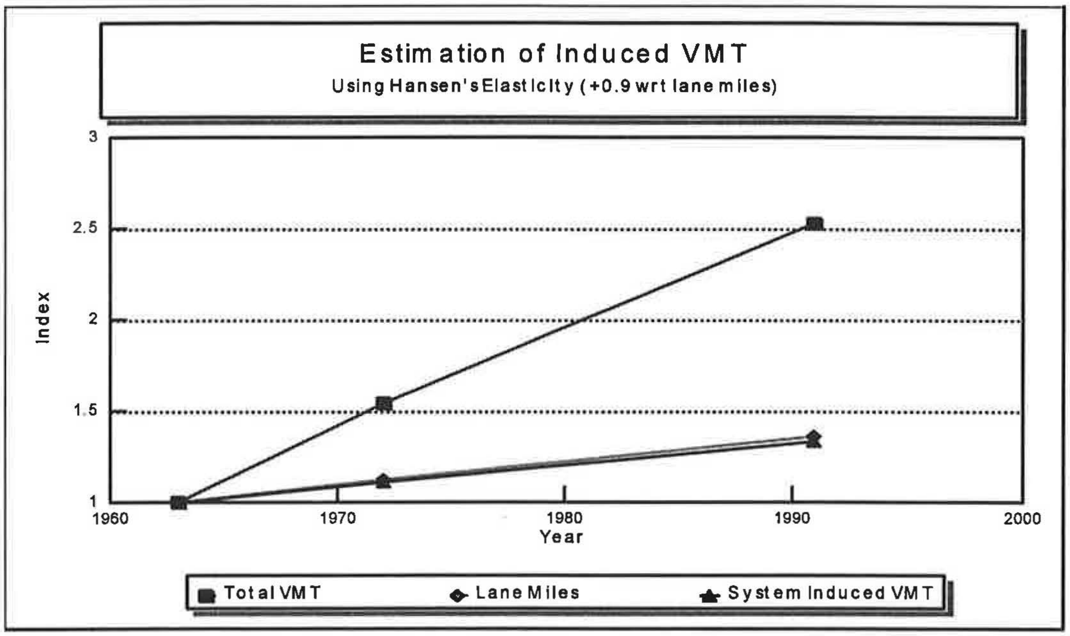


FIGURE 6

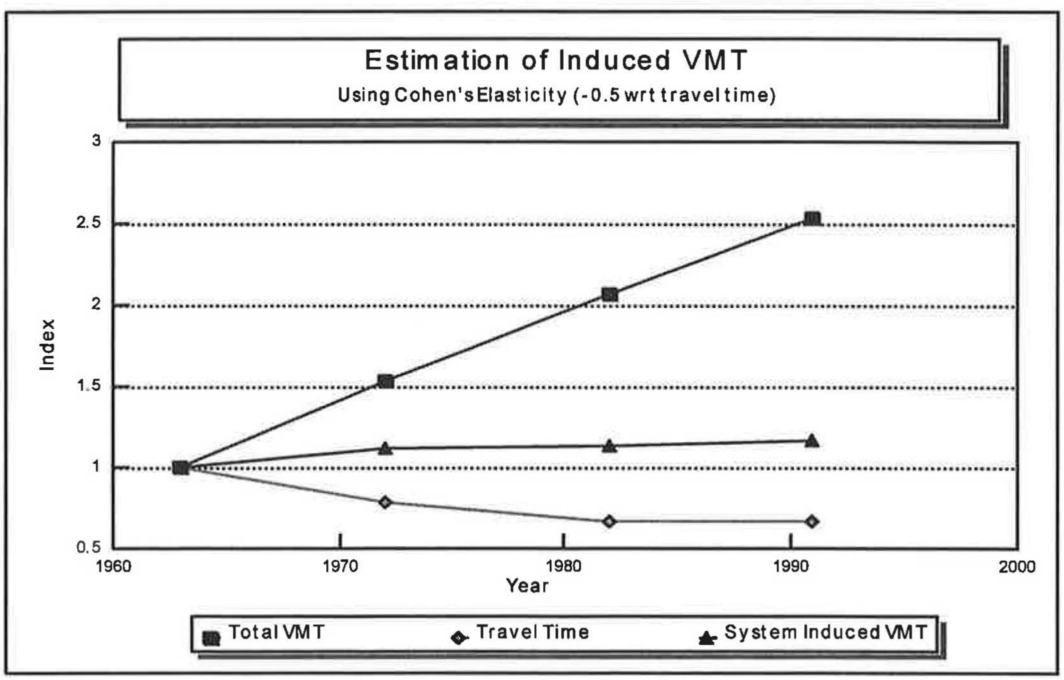


FIGURE 7

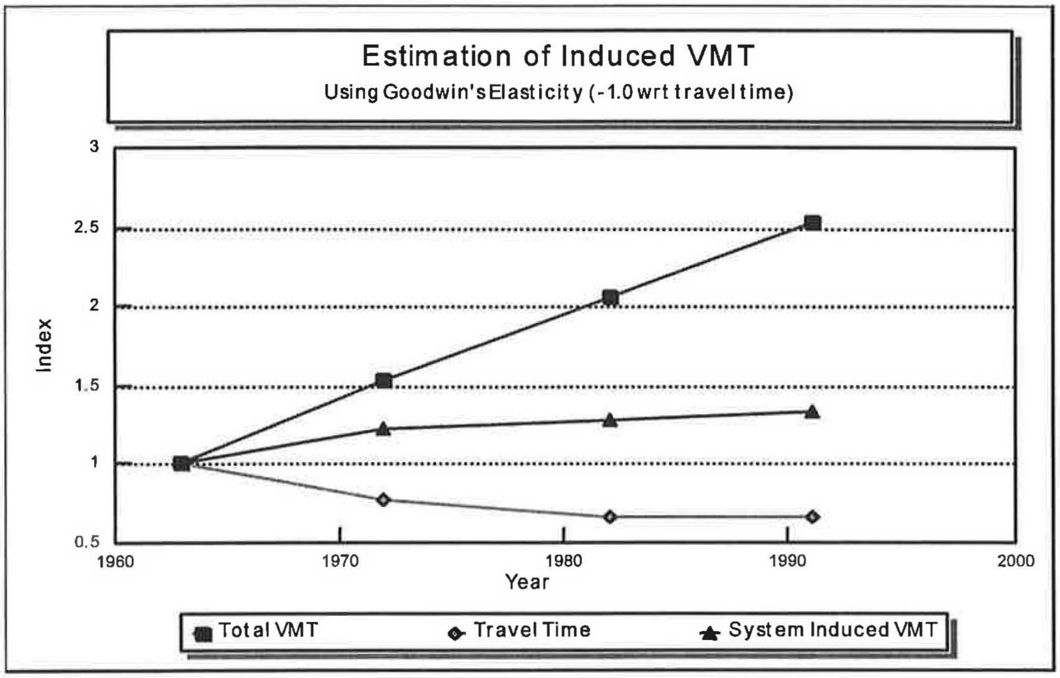


FIGURE 8

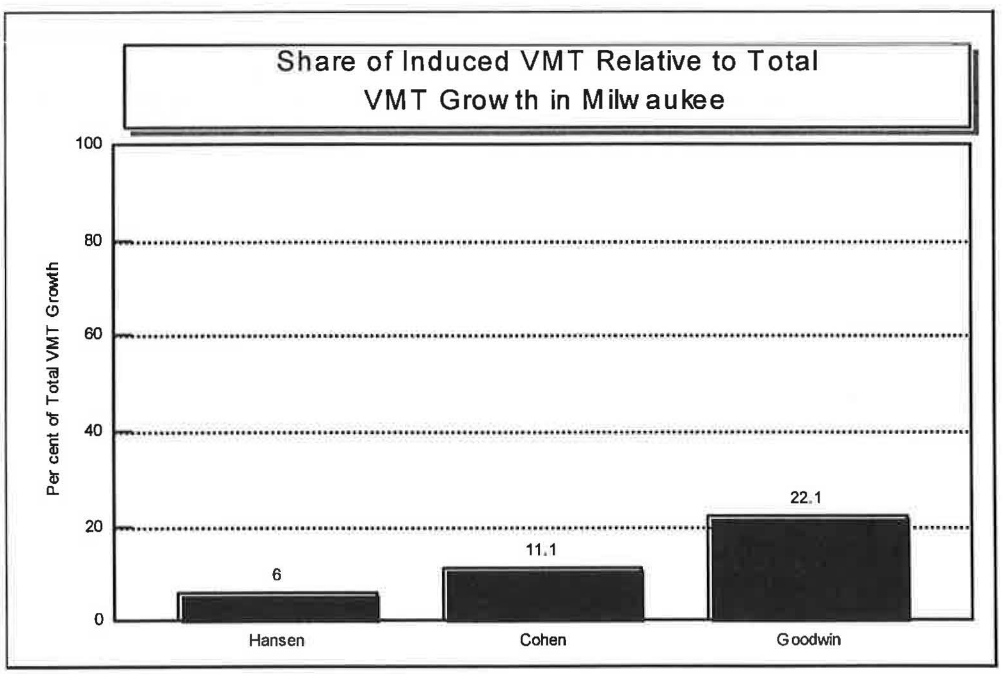


FIGURE 9

household will still need to be provided for. LUTRAQ land-use policies, with their strong emphasis on mixed use development and transit-oriented site design, would lessen suburban highway travel demand to the lowest level likely in the U.S. context short of constraints on lifestyles which are currently politically unacceptable.

The type of policy agenda LUTRAQ formulated and evaluated appears to have very positive transportation and other benefits. However, even with such strong efforts to reduce auto reliance and with extensive, costly complementary transit facilities and services, highway travel would still grow significantly due to population, household and employment growth and changes in the other socio-economic and demographic factors noted previously.

IMPLICATIONS FOR PLANNING AND EVALUATION

Implications for Evaluation of Highway Capacity Expansion Projects

Savings in the travel time component of total trip generalized cost is the primary, direct highway supply related cause of "induced" travel. In the long term, this direct effect can lead to changes in land-use and related auto ownership which also foster additional highway travel. However, there is strong empirical evidence which suggests that the magnitude of the travel changes resulting from changes in other, primarily socio-economic and demographic factors overwhelms those directly and indirectly driven by the expansion of highway capacity.

Given the complexity of highway supply/demand/socio-economic factor interactions, there are three issues of concern in evaluation of highway capacity projects:

- How might we evaluate the trade-offs between mobility benefits to highway users (both current and induced travelers) from highway expansion and costs to society in terms of public infrastructure and other environmental and social costs?
- Are the demand forecasting tools used by metropolitan planners adequate to the task of forecasting "induced" demand?
- How can we address induced travel concerns in the planning process?

These issues are addressed in the following sub-sections.

Evaluation

The discussion in Section 3 was an attempt to show how there are many factors which influence the growth of travel in general and highway travel in particular. Whether a particular highway investment is capable of reducing congestion over the short and long term, and whether the total benefits of the investment, congestion reduction and otherwise, exceed its total economic, environmental and social costs must be appraised on a case-by-case basis. This appraisal should not be limited to highway investments.

Clearly transit and any other type of investment which "removes" vehicle trips from the traffic stream and/or which may provide increased access to the urban fringe has travel inducing potential which must be considered in an evaluation framework for the particular facility. MPO's, state DOT's and transit operators will need to evaluate the trade-offs between the economic, social, and environmental benefits and costs of new transportation capacity, and this accounting should reflect induced travel.

MPOs will need good estimates of travel demand, travel time and travel cost effects, as well as positive and negative economic, environmental and social impacts so that a comprehensive, multi-modal evaluation can be accomplished.

Travel Demand Forecasting Tools

Travel demand forecasting models used by MPOs are already capable of estimating most of the demand impacts of highway capacity expansion:

- Changes in macro-scale land-use (and related trip making) can be estimated with a Lowry type land-use model or through Delphi techniques which reflect a consensus of best professional judgements.
- The propensity to shift destinations in response to travel time savings is addressed by trip distribution models.
- Mode and occupancy shifts, due to lower generalized costs for auto travel, are appropriately forecasted by mode choice models.
- Route diversions are forecasted with traffic assignment models.

The trip generation models used by most MPOs are not directly sensitive to capacity expansion. However, this does not necessarily pose a major problem. Recent research (17) has demonstrated that total person trip making is generally unaffected by the small savings in travel time typically achieved for most existing trips as a result of highway capacity expansion. Also, use of a trip generation model sensitive to land-use character and auto ownership, with a system-sensitive land-use forecasting approach and auto-ownership model can provide an indirect linkage between system supply and trip generation.

Unfortunately, a deficiency in most travel models is their inability to address shifts in travel by time of day as a result of peak period travel time changes. Only a few MPOs forecast travel by time period, and most models that forecast travel by time period use fixed peaking factors to obtain peak trips from daily trips. This is an important issue for estimation of travel speeds and evaluation of user travel time savings, because fixed peaking factors tend to overestimate peak travel (and therefore underestimate speeds) in the "no build" case, and underestimate peak travel (and therefore overestimate speeds) in the "build" case. This can lead to overestimation of travel time savings to both existing and induced travelers in the "build" case. This is an important issue in the evaluation of highway user benefits. However, estimates of total daily travel are generally not affected if the four-step models have been calibrated with appropriate peak and off-peak travel speeds by trip purpose.

Forecasting Land Use Impacts

Since transportation systems in major metropolitan areas in the U.S. are already highly developed, capacity expansion by itself is not likely to create net new economic growth and development (18). However, capacity expansion *can* cause shifts in patterns of development in ways that may ultimately change total travel. Recognizing this issue, some MPOs have developed integrated land use/transportation models. Others use Delphi techniques, ad-hoc processes or reasonableness checks of their land use inputs, and still others use sketch planning procedures to ensure a dynamic balance between forecasted land-use and proposed transportation supply changes.

CONCLUSIONS

The discussion of the various factors influencing travel growth historically suggests that the role of highway capacity expansion in increasing highway travel has been small relative to other factors. Highway capacity expansion interacts with far more important variables such as population, household and employment growth, personal income and auto ownership increases, regional economic growth and fuel price changes as determinants of total travel demand.

Adding highway capacity as a city grows (to cite Robert Dunphy of the Urban Land Institute) may thus be thought of as akin to buying new, larger shoes for a rapidly growing child. The child's feet may well grow faster without the constraining effects of undersized shoes, but its feet will grow regardless of whether new, larger shoes are purchased. Just as it would be irresponsible not to buy new, larger clothes for a growing child, it is irresponsible not to consider additional highway and other transportation capacity for a growing population, despite the fact that there is a relationship between new capacity and travel.

Planning processes must have the capability to objectively examine a thoughtful combination of strategies to assure that, while the population of a region grows, its access and mobility needs are sustained and its environmental quality is enhanced. It would be best to do this as part of comprehensive planning that includes coordinated land use and transportation planning, but no formal coordinated land-use planning mechanism exists at the regional level in the vast majority of U.S. cities. Most local jurisdictions jealously guard their land use planning and control prerogatives.

Regardless, metropolitan areas are encouraged to consider combinations of synergistic strategies, including:

- Balanced investment, covering both capacity expansion and better system operation and management (e.g., through Intelligent Transportation System (ITS) applications) for all modes.
- Alternative urban forms (at the macro level) and urban design (at the micro level)
- Appropriate pricing to maximize transportation system efficiency

The major determinants of travel demand are clearly socio-economic in nature. However, the inducement of travel due to any transportation system change, is an issue that needs to be and can be addressed by considering behavioral and land use change mechanisms.

Travel and land-use modeling techniques should be used in ways which account for the direct and indirect relationships between travel and system supply/performance. A need also exists for the development and application of improved modeling techniques which are sensitive to time-of-day, macro and micro land-use and other critical supply/demand interactions. This is the major thrust of the FHWA/FTA/OST/EPA Travel Model Improvement Program.

REFERENCES

1. Hansen, Mark. Do Highways Generate Traffic? *Access*, Fall 1995. University of California Transportation Center.

2. Kroes, Eric et al. The Opening of the Amsterdam Ring Road: A Case Study on Short-term Effects of Removing A Bottleneck. *Transportation*, Vol. 23 No. 1, Feb. 1996. Klewer Academic Publishers.

3. *Money Magazine*, July 1996.

4. Bonsall, Peter. Can Induced Traffic be Measured by Surveys? *Transportation*, vol. 23 No. 1, Feb. 1996. Klewer Academic Publishers.

5. Kasarda, John. Population and Employment Change in the United States: Past, Present and Future. *A Look Ahead: Year 2020*. Transportation Research Board. Special Report No. 220. TRB.1988

6. Pisarski, Alan E. *Commuting in America II. The Second National Report on Commuting Patterns and Trends.* Eno Transportation Foundation, Inc. 1996.

7. Hu, Patricia and Jennifer Young. *1990 Nationwide Personal Transportation Survey: Summary of Travel Trends*. U.S. DOT. March 1992.

8. U.S. DOT. *Our Nation's Highways: Selected Facts and Figures*. Publication No.
FHWA-PL-92-004.

9. Kumar, Ajay. *Changes in Travel Behavior and Patterns in Montgomery County: A Comparison from the 1968 and 1988 Travel Surveys*. The Maryland National Capital Park and Planning Commission. 1992.

10. Lowry, Ira. Planning for Urban Sprawl. *A Look Ahead: Year 2020*. TRB Special Report No. 220. TRB. 1988.

11. Cambridge Systematics, Inc. *The LUTRAQ Alternative /Analysis of Alternatives*. 1000 Friends of Oregon. October 1992.

12. Allen Jr., William G. *Forecasting the Cost of Diving*. ITE Journal, Feb. 1996. Institute of Transportation Engineers.

13. US. DOT. *National Transportation Statistics*. November, 1995.

14. Southeastern Wisconsin Regional Planning Commission. *A Regional Transportation System Plan for Southeastern Wisconsin: 2010*. SEWRPC. Waukesha, WI. December, 1994

15. Committee for Study of Impacts of Highway Capacity Improvements on Air Quality and Energy Consumption. *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use*. TRB Special Report 245. TRB. 1995.

16. Goodwin, Phil B. Empirical Evidence on Induced Traffic: A Review and Synthesis. *Transportation*. Vol. 23, No. 1. Feb. 1996. Klewer Academic Publishers.

17. Dowling, Richard G. and Steven B. Colman. *Effects of Increased Highway Capacity: Results of Household Travel Behavior Survey*. TRB No. 1493. TRB. 1995.

18. Forkenbrock, David J. et al. *Road Investment to Foster Local Economic Development*. Ames, Iowa Midwest Transportation Center. 1990.

SUMMARY OF DISCUSSION

This section summarizes the comments of the two discussants, as well as questions and comments from the audience.

Eric Beshers commented on the implications of induced traffic. While induced traffic may affect estimates of the benefits and disbenefits of highways, the fact that a proposed highway project may result in significant induced traffic does not necessarily imply that the project should not be built. Induced traffic occurs because highway improvements reduce congestion, and that those making induced trips do so because they receive benefits from the improvement. In some cases, taking induced traffic into account will result in higher estimates of user benefits.

Hank Dittmar noted important considerations affecting the amount of induced travel from transportation system improvements, and its consequences. He distinguished projects that serve new areas (and would be expected to have significant development impacts) from those that serve already built-up areas. He noted that both highway and transit projects can result in induced travel, and that the consequences of this travel can be good or bad, depending on the situation. He noted further that, while highways are not the primary determinants of VMT growth, they will become a more important source as other influences (such as growth in the number of automobiles per licensed driver) diminish over time.

Dittmar discussed the range of possible responses by travelers to highway capacity increases. Some, such as route diversion, are well-handled by existing models. Other important responses are not well-handled. These include changes in trip frequency, time of day, and development.

Dittmar noted the need for consistency in treating the benefits of highway projects. Projects undertaken to stimulate economic development will (if successful in achieving that objective) result in increased highway use.

Dittmar identified a number of priority areas for research: careful collection of travel data before and after highway improvements, retrospective studies of highway projects in which actual changes in traffic are compared with forecasts of these changes made prior to implementation, research on peak-spreading, procedures to take induced traffic into account in benefit-cost analyses, and continued funding and dissemination of results from the Travel Model Improvement Program (TMIP).

In the question and answer session, Michael Replogle of the Environmental Defense Fund asked Kevin Heanue about FHWA's position on modeling time-of-day shifts and the appropriateness of assuming fixed temporal distributions. Kevin Heanue noted that time of day shifts are difficult to estimate, and when better models are available FHWA will promote their use.

David Rogers of the North Jersey Transportation Authority asked Mark Hansen about difficulties in accounting for land use and other characteristics of a region that affect potential induced traffic. Hansen said that his model accounted for these effects, but only in a rough way. The model included a factor for each region which represents its propensity to experience induced traffic.

Janet Gregor of the Carroll County Planning Department asked about the definition of induced traffic and how it relates to traffic caused by increased development resulting from a new highway. Eric Beshers responded that the effects of new highways on development (and associated traffic increases) should be included in the definition of induced traffic.

Alan Greenberg from the League of American Bicyclists asked whether Mark Hansen's results implied that 90 percent of added highway capacity would be taken up by induced traffic. Hansen said that was not the meaning of the 0.9 elasticity produced by his model. He noted that much of the increase in VMT associated with added capacity occurs on uncongested highways, and that his analysis shows that highway improvements do provide significant congestion relief.

Doug Thompson of the California Air Resources Board asked what specific changes should be made to travel forecasting models in the short term. He noted that many current state air quality plans don't take this effect into account. Rick Dowling stated that his research suggested the need for explicitly accounting for travel time in trip generation. Kevin Heanue indicated that state of the art modeling systems do a good job in accounting for induced traffic, but there is a large gap between the state of the art and the state of the practice.