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CONTENTS

Access No. 7 Fall 1995

The Transportation–Land Use Connection Still Matters
ROBERT CERVERO AND JOHN LANDIS
2

New Highways and Economic Growth: Rethinking the Link
MARLON G. BOARNET
11

Do New Highways Generate Traffic?
MARK HANSEN
16

Higher Speed Limits May Save Lives
CHARLES LAVE
23

Is Oxygen Enough?
ROBERT HARLEY
27

Papers In Print
32

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Introduction: Transportation's *Effects*

We all know that transportation facilities do far more than merely carry people and freight. We all agree that the returns from investments in transportation systems are paid in the coin of the systems' secondary effects, not in the coin of either transportation infrastructure or services themselves.

In grade school, we learned that the early railroads opened the West, promoting development of large urban centers in the former wilderness. Roads then interlaced the land between rail lines, facilitating growth in thousands of smaller cities and towns, and helping to transform agriculture from a handicraft enterprise into a highly productive industry. Later, motor vehicles and modern highways contributed to urban expansion, helping to turn cities into metropolises that spread into what we now call suburbs and exurbs.

The rapidly expanding land, air, and water transport systems of the past century not only helped urbanize the nation, they also facilitated explosive modernization of the national economy. By lowering time and money costs of transporting goods and passengers over long distances, the new transportation systems fed hungry factories, expanded retail markets, and gave people broader options in worksites, residential settings, and recreational activities.

Surely these outcomes are known to us all. So why are researchers of these matters so preoccupied with testing whether these really are the transportation systems' effects?

Why was Genevieve Giuliano's article in this magazine's last issue questioning the importance of land use effects of new transportation facilities? Why, in turn, were Robert Cervero and John Landis provoked to write a detailed rejoinder for this issue of ACCESS, contending that land use effects are real, measurable, and consequential? Why is Marlon Boarnet questioning the self-evident economic-developmental effects of highways? Why did Mark Hansen have to study whether the effects of new highway lanes are to generate new traffic, when everyone already knows they do? Why is Charles Lave seeking to demonstrate that the effects of the 65 mile per hour speed limit are to improve highway safety, when everyone knows that "speed kills." And why is Robert Harley subjecting oxygenated gasoline to additional systematic tests, checking whether its effect really is to reduce carbon monoxide?

Why do these transportation researchers doubt these known effects—these seeming truisms, these conventional wisdoms? Is it that they're cantankerous souls and congenitally obstreperous? Or is it that the conventional wisdom is often wrong and the truth often elusive?

We think the latter is so. Indeed, that's why the academic's role is to question, to challenge, to test, to dig out the empirically verifiable truth of the matter. Our colleagues in ACCESS are all professional doubters, searching to discover the true effects of transportation systems. You, the reader, may be equally querulous and unable to accept what they say. If so, we hope you'll respond to them, either directly or through us at the Center. There's nothing we like better than to fuel a lively exchange, especially if the debate yields tenable findings about the effects of transportation systems.

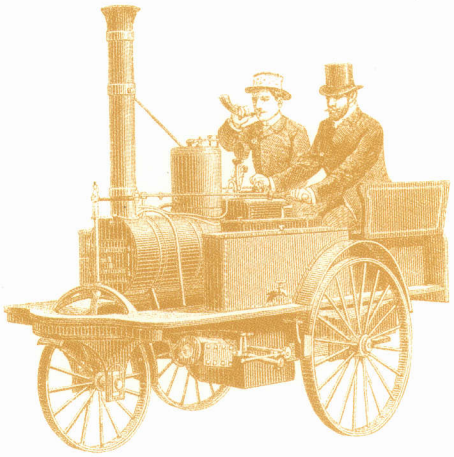
—Luci Yamamoto,
Editor

The Transportation-Land Use Connection Still Matters

BY ROBERT CERVERO AND JOHN LANDIS

Robert Cervero is professor of city and regional planning and John Landis is associate professor of city and regional planning, both at the University of California, Berkeley, CA 94720-1850.

In the Spring 1995 issue of ACCESS, Genevieve Giuliano contends there is a weakening connection between urban land uses and transportation. She therefore finds little justification for public initiatives such as programs to balance jobs and housing and investments in rail transit. She argues that because urban areas in the United States are already so accessible, settlement patterns so well-established, and maintenance of privacy so important, transportation plays an ever-decreasing role in the locational decisions of households and businesses. Her essay infers that the land use-transportation connection is now too weak to matter in terms of public policy.



Giuliano concludes that policies designed to reduce the negative externalities of automobile travel by altering land use patterns are doomed to fail. Similarly ineffective, she argues, are policies that seek to reshape America's urban landscape through transport investments, especially rail transit projects. Pricing and market-based strategies, she contends, are more appropriate mechanisms for dealing with today's transportation problems.

While we accept some of Giuliano's arguments, we disagree with her conclusions, especially the suggestion that we should abandon coordinated land use and transportation policymaking altogether. We believe the land use-transportation connection *still matters.* While the connection is undoubtedly much weaker today than it was a century ago, or even within the past three decades, the relationship remains important.

Investments in transportation systems still strongly affect land use patterns, urban densities, and housing prices. Although new transportation investments no longer shape urban form *by themselves,* they still play an important role in channeling growth and determining the spatial extent of metropolitan regions by acting *in combination* with policies such as supportive zoning and government-assisted land assembly.

Likewise, there remains strong evidence that characteristics of built environments—such as the size and diversity of neighborhoods and the siting of jobs and housing—significantly influence travel demand. Policies that expand travel choices can be important complements to policies that expand housing and job choices. And if the market-based transport pricing that Giuliano and most economists embrace were ever implemented, the consequence would be an even stronger land use-transportation connection.

Much recent research supports the land use-transportation connection, highlighting some of its subtle complexities. Further, these studies expose the vital role for public policy in shaping that connection. The context for our research is the San Francisco Bay Area, while Giuliano's work focused on Southern California. We offer these comments in hopes of stimulating further research and discussion on the transportation-land use relationship.

GIULIANO'S EVIDENCE

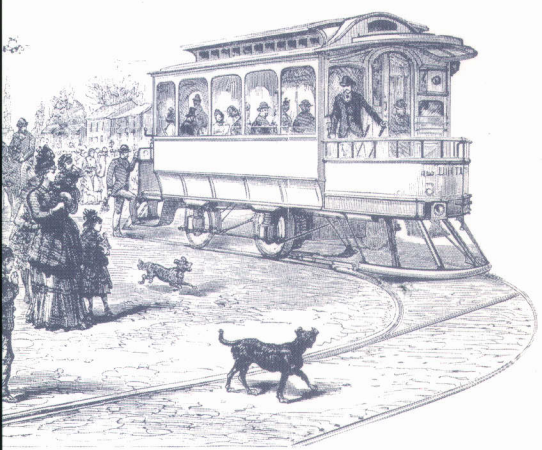
Giuliano makes a compelling case for a weakening linkage between land use and transportation. She first challenges the very foundation of urban land economics: the premise that cities are shaped by people economizing on commuting. She does so by reviewing the "excess commuting" literature, which shows that actual average commutes in U.S. cities are much longer than predicted by standard models. The studies Giuliano cites, however, are based on certain assumptions—such as one wage-earner and uniform transportation costs—that bear little resemblence to today's world. Giuliano contends ➢

the main reason for much longer average commutes is choice (for example, people may want privacy and better schools), not force (for example, workers may get displaced from their work location by expensive housing or jobs-housing mismatch).

We do not find it surprising that Southern Californians stress tranquility more than transportation when discussing qualities of a desirable neighborhood. However, we wouldn't base inferences about the major determinants of residential location on the results of a stated-preference survey conducted for the *Los Angeles Times.* In a distorted marketplace like Southern California, commuters don't pay for externalities like air pollution or congestion through higher motoring fees. It's therefore no surprise that many prefer the exurbs, voting with their feet and commuting with their wheels. Might not programs promoting more affordable housing near job centers, along with fuel prices of $3 per gallon (the cost in Europe) and minimum $3 per day employee parking fees, result in many more folks living closer to their workplaces? In such an environment, the "actual" and "predicted" commutes cited by Giuliano would undoubtedly be much closer, and the spatial proximity of jobs and housing far stronger determinants of commuting behavior.

Giuliano's view of the minuscule role of transit investments on urban form hinges largely on the outputs of regional forecasting models for one unbuilt project, the western light rail extension in Portland (part of the LUTRAQ study), and one project still in its infancy, Los Angeles's Metrorail system. We put less faith in conclusions gleaned from large-scale models on how rail affects land use patterns than does Giuliano. This field is littered with examples of inaccurate projections due to reasons that are all too well-known. Our findings are drawn from empirical evidence on how rail affects land use and housing from twenty years of experience with BART and about a decade's experience with other California rail systems.

Contrary to Giuliano's contentions, the LUTRAQ projections show that transit-oriented development (TOD) reduces the share of auto travel for all trips more than transportation demand management (TDM) strategies. (Giuliano's comment regarding Table 4 in her essay pertains only to home-based work trips.) TOD should be examined relative to all trips, not just commutes, since initiatives like siting stores in compact neighborhoods will exert more influence on shopping trips than work trips. We believe the projected decline in auto use that occurs most significantly in the LUTRAQ II scenario, which combines land use and TDM initiatives, is an important finding. It suggests that synergistic relationships exist and underscores the need to package land use initiatives with other programs like restricted parking.



Recently, Cambridge Systematics studied how land use patterns and TDM have combined to affect commuting to large employers in Southern California after the enaction of Regulation XV, which mandated trip reductions. In their 1994 report, *The Effects of Land Use and Travel Demand Management Strategies on Commuting Behavior,* they concluded that TDM and land use initiatives complement each other. Workplaces with on-site convenience stores and ambitious TDM programs like ridesharing, realized significantly greater reductions in drive-alone auto commuting than did single-use office projects.

We offer these remarks not to take a position for or against investments in light rail in Portland or heavy rail in Los Angeles. These projects cannot be judged solely on economic criteria because much of their motivation is political. The prospect of transferring billions of federal tax dollars to Southern California's struggling economy no doubt convinced many local politicians to move ahead with Metrorail.

Should we turn our back on Metrorail and continue to acquiesce to auto-oriented development just because these multi-billion-dollar investment decisions were not economically prudent? Or should we accept the fact that many large-scale public works projects in the United States, whether they create rural dams or expensive metros, are partly driven by pork-barrel politics, and try to capitalize on these investments by promoting transit-oriented development? We vote for the latter, if for no other reason than to exploit these sunk investments and give more people more choices on where to live and how to travel.

"In a distorted marketplace like Southern California, commuters don't pay for externalities like air pollution or congestion through higher motoring fees. It's therefore no surprise that many prefer the exurbs, voting with their feet and commuting with their wheels."

JOBS-HOUSING BALANCE MATTERS

For every study showing that jobs-housing balance doesn't matter, there are at least as many showing it does. For example, some researchers have long argued that in an unfettered marketplace, businesses and households co-locate to reduce commuting. Thus, they contend, planning initiatives like policies promoting jobs-housing balance are unnecessary and even counterproductive. Peter Gordon and Harry Richardson first made this argument based on a study that found average commuting times fell for eighteen of twenty large U.S. cities between 1980 to 1985. But these data, from the American Housing Survey, predated much of the suburban employment boom of the mid-to-late 1980s.

More recent data paint a much different portrait of trends: In the wake of rapid job decentralization, Americans are living and working farther apart today than ever before. The National Personal Transportation Survey showed the average commute length in the United States increased from 9.2 miles in 1983 to 10.6 miles in 1990. The number of women entering the labor force in the 1980s rose rapidly and, on average, they commuted shorter distances than men. This means that work trips by men lengthened even more. Moreover, census data reveal that mean journey-to-work times increased from 1980 to 1990 in thirty-five of the thirty-nine U.S. metropolitan areas with populations over one million. Three of the four metropolitan areas experiencing the greatest increases in commute durations were in California: metropolitan San Diego (19.5 to 22.2 minutes: +13.7 percent), Los Angeles-Long Beach (23.6 to 26.4 minutes: +11.9 percent), and Sacramento (19.5 to 21.8 minutes: +11.8 percent).

Recent research makes an even stronger case for public policies that encourage balanced growth in jobs and housing. In a study of 1989 travel in the greater Seattle-Tacoma region, Lawrence Frank and Gary Pivo found that commute distances and times tended to be shorter for those living in balanced areas. The average distance of work trips ending in balanced census tracts (with jobs-to-household ratios of 0.8 to 1.2) was twenty-nine percent shorter (6.9 versus 9.6 miles) than the distance of trips ending in unbalanced tracts. A recent study by Reid Ewing, titled "Before We Write Off Jobs-Housing Balance...," used 1990 census data to compute the proportion of work trips that stay within city boundaries for 500 cities and towns in Florida. Ewing found that the share of "internal," or within-community, commuting significantly increased with greater balance in the number of local jobs and working residents. ➢

Our recent work largely substantiates the findings from Seattle and Florida. The 1990 census data for the twenty-three largest cities in the San Francisco Bay Area reveal that cities with high shares of residents working in the community averaged shorter commutes, and more often commuted by non-auto modes. Cities with high housing prices (relative to earnings) also tended to have a proportionally large share of their workers residing elsewhere.

The city of Pleasanton, thirty-five miles east of San Francisco, experienced the fastest employment growth in the region (365 percent increase) during the 1980s, changing from a predominantly bedroom community in 1980 (jobs-to-employed residents ratio of .42) to a job-rich city in 1990 (ratio of 1.13). Paralleling this trend, commute distances have rapidly increased among Pleasanton's workforce. The average person working in Pleasanton commuted 18.8 miles in 1993, considerably above the Bay Area's average of 14.4 miles. Based on a gravity model designed to predict factors influencing the residential location of Pleasanton's workforce, we found that workers generally avoided living in cities with high housing prices, controlling for housing supply and distance from Pleasanton. That is, the jobs-housing mismatch mattered.

Critics have sometimes mistated the jobs-housing balance argument. Imbalances are rooted in fiscal zoning (shunning housing in favor of office, shops, and other high tax-yielding uses) and NIMBYism (the "not in my backyard" attitude that assumes more housing equates to more traffic and crowded schools). Policies supporting jobs-housing balance attempt to break down these barriers to residential mobility, not to mandate where people live and where businesses locate. In the Bay Area, while all bedroom communities in 1980 became more balanced by 1990 (supporting the co-location hypothesis), nearly all job-rich cities in 1980 became even more job-rich, or imbalanced, by 1990 (supporting the fiscal zoning and NIMBYism hypotheses).

In the late 1980s, developers of the Hacienda Business Park in Pleasanton were prohibited from building over 2,000 housing units, including moderately dense apartments, on their 860-acre property (worksite of over 11,000 employees) because of a NIMBY backlash by long-time residents. In Baltimore County, Maryland, developers have recently filed a lawsuit against a zoning change preventing them from building some 1,500 townhouses and garden apartments near the Hunt Valley employment center (where there are currently three jobs for every housing unit within a five-mile radius).

Perhaps the term "jobs-housing imbalance," by itself, is a misnomer. Problems occur when job-rich communities keep out housing for parochial reasons, to the detriment of the region at large. When developers are prevented from building housing near work centers for the local workforce, as in Pleasanton and Hunt Valley, we believe there are grounds for policy intervention of some kind—to correct the planning, not market, failure.

RAIL TRANSIT AND HOUSING PRICES

Giuliano contends transportation investments cannot effectively shape urban form because America's cities are already built-up, the building stock is durable, and transportation has a diminished influence on locational decisions. If so, land markets should reveal this weak connection. That is, if the higher levels of accessibility provided by transportation investments don't matter much, rents and land values for nearby properties should remain unaffected. Most empirical work on this topic focuses on the prop-

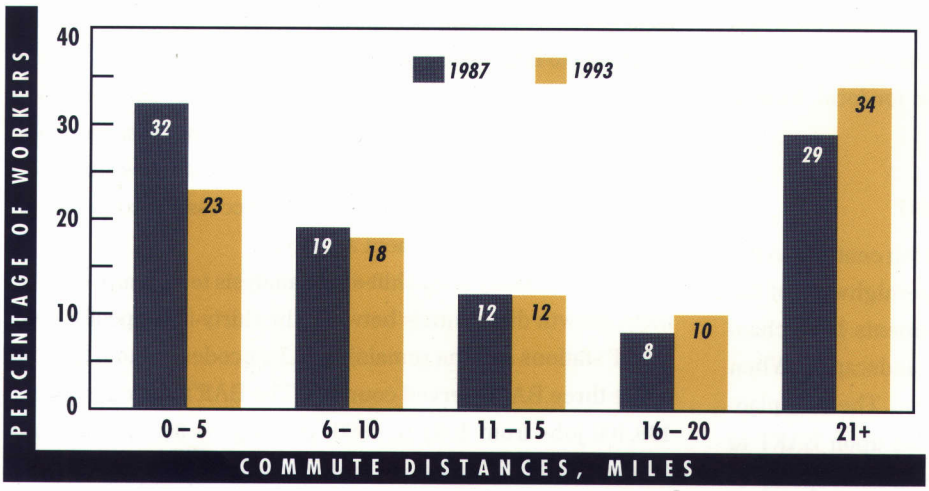


FIGURE 1

Commute Distances by Workers in Pleasanton, 1987-1993

The expansion of Pleasanton's commute-shed is revealed by the increase in average worker commute distances for the 1987-1993 period. The share of workers commuting under 5 miles fell by 9 percent over this six year period, matched by a 7 percent increase in those commuting over 16 miles.

Source: Annual Employee Surveys, City of Pleasanton

erty value effects of highway construction. Recent studies in Washington state and Phoenix report net positive property value effects associated with locating near new highways, but also show that for the closest homes, acccessibility premiums are offset by noise-related price reductions.

Studies of how proximity to urban transit affects property values have produced wildly divergent estimates. A study of repeated home sales found that the announcement of the Miami metrorail system only weakly affected prices. At the other extreme, another recent study estimated that single-family homes located within 500 meters of stations on Portland's light rail line sold at a premium of $4,300 (over ten percent) when compared with otherwise similar homes beyond that distance. To our knowledge, no single study has examined the combined price effects of highways and transit.

To help fill this gap, we analyzed the effects of nearby transit lines and highway interchanges on the 1990 sales prices of 4,180 homes in Alameda, Contra Costa, Sacramento, San Diego, San Mateo, and Santa Clara counties. In Alameda and Contra Costa counties, we examined the potential price effects of BART; in San Mateo, we looked at the effects of the CalTrain commuter rail line; and in San Diego, Sacramento, and San Jose, we considered the price effects of proximity to light-rail stations. We statistically controlled for home size and age, lot size, neighborhood income levels, homeownership rates, and racial composition.

The strongest capitalization effects were found for proximity to BART and San Diego's light rail system. In the case of freeway accessibility (measured as street distance to the nearest interchange), the opposite effect was observed. In Alameda county, for every meter a home was closer to a freeway, its sales price declined $2.80.

Thus our research shows that proximity to rail transit is indeed capitalized into home prices, but not universally. The most important factor is the quality and scope of service. Regional systems like BART, which provide reliable and frequent service over a large market area, generate the largest price premium. San Diego's trolley also falls in this category. Systems with more limited services and market areas, such as the CalTrain commuter line and newer light rail lines in Sacramento and San Jose, are less likely to generate appreciable capitalization benefits. Overall, the premiums associated with building higher density housing near transit stops are not likely to be large ➢

enough to overcome local opposition to such development. While transit matters to housing prices in many locations, it may not matter enough. This suggests a potential role for local, transit-supportive land use policies.

BART'S EFFECTS ON BAY AREA DEVELOPMENT

From the horse-drawn streetcars of the 19th century, to the electric trolleys of the early 1900s, to the superhighways of the post-World War II era, transportation investments have channeled growth and shaped America's urban landscapes. When first conceived, BART was to follow this tradition. The 1956 planning document, *Regional Rapid Transit,* called upon BART to transform the Bay Area into a "subcentered metropolis"—"something between the tightly nucleated clusters that form the typical metropolitan areas of the East Coast and the vast low-density sprawl of the West Coast's Los Angeles." As part of the twenty-year update to the original BART Impact Study, we recently evaluated BART's longer term influence on urban form and land use patterns. For the most part, BART has fulfilled its promise. BART has without question helped create and strengthen the Bay Area's multi-centered form.

One analysis compared the effects of proximity to BART stations and freeway interchanges on all land use changes (measured at a hectare grid-cell level) that occurred in Alameda and Contra Costa counties between 1985 and 1990, a period of accelerated land development in both counties. Using statistical models that controlled for topographical constraints, zoning policies, adjacent land uses, and development opportunities, we found that proximity to BART had a particularly strong influence on the likelihood of sites being redeveloped. All else being equal, residential sites near BART stations in both counties were far more likely to be converted to commercial or industrial uses than were more distant residential sites. Highway access, by contrast, had little effect on redevelopment activity.

Another study used shift-share analysis to measure employment growth differentials between the thirty-five zipcodes with BART stations and the remaining 117 zipcodes without stations in the three BART-served counties. The BART zipcodes gained 139,400 jobs from 1981 to 1990, growing by 30.3 percent and accounting for 57.1 percent of the employment growth in the three counties. Most of the BART-oriented job growth occurred in downtown San Francisco, suggesting that BART helped slow the exodus of jobs from the region's employment hub despite national trends toward office decentralization.

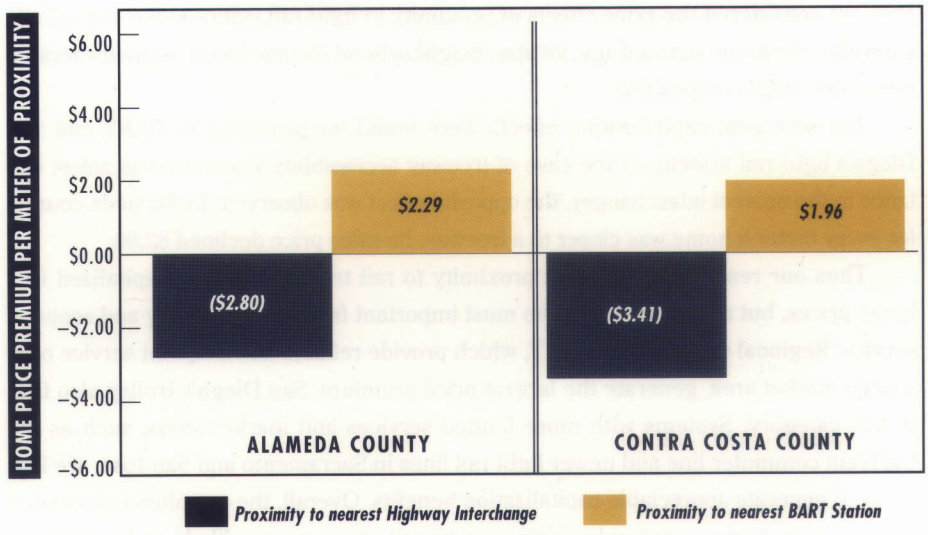
Outside downtown San Francisco, job growth and land use changes around BART stations have been uneven. Where little new growth has occurred, the chief reasons have been either downzoning and NIMBY resistance (for example, at the Rockridge and North Berkeley stations) or weak local real estate markets (for example, at the Richmond and Fruitvale stations). Where these barriers do not exist, a sizable amount of new development has generally occurred when local governments encourage it, through initiatives that assist with land assembly and finance supportive infrastructure like streets and sidewalks.

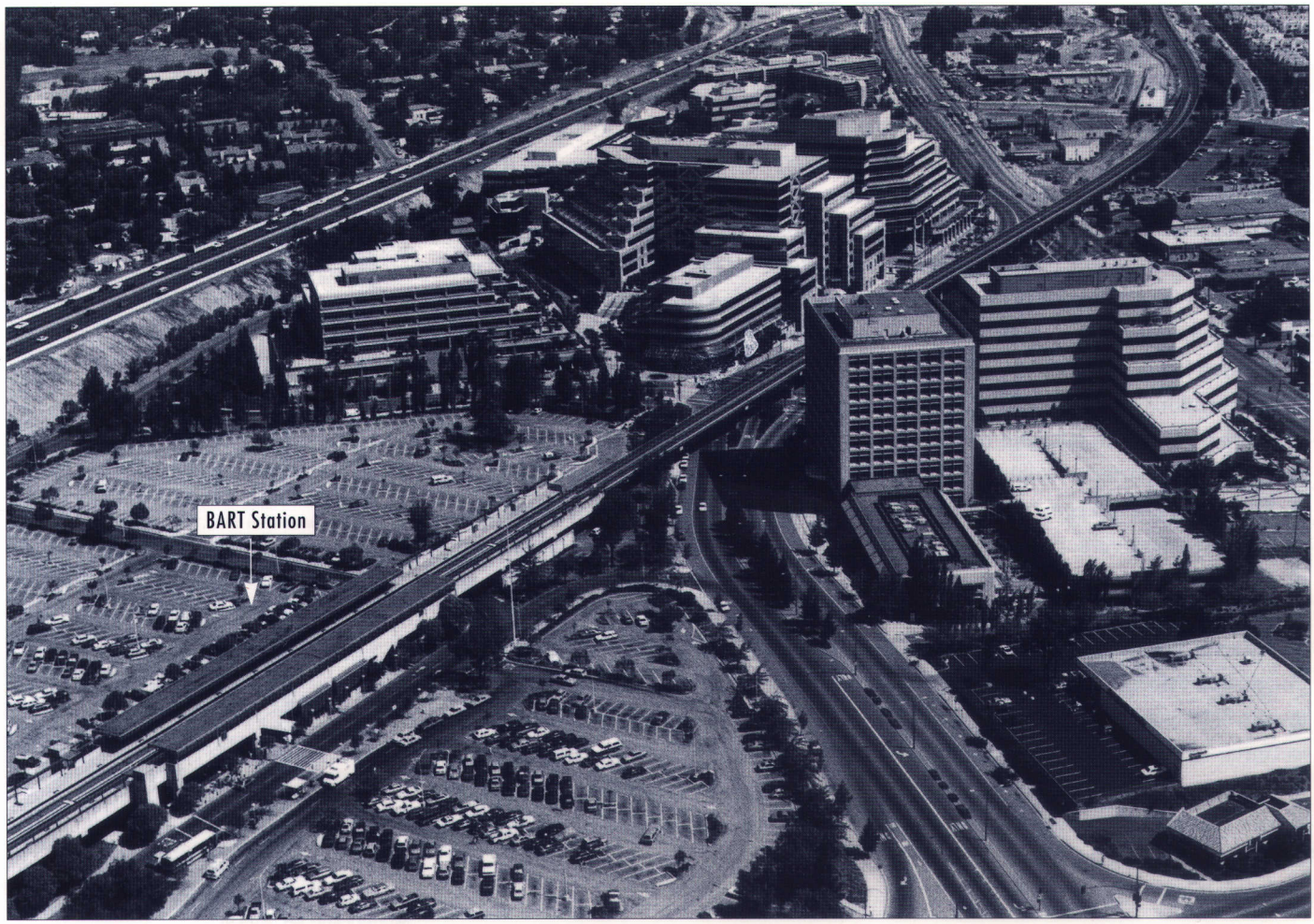
FIGURE 2

Home Price Premium Associated with Proximity to BART Station and Highway Interchange

The premium associated with proximity to BART stations was $2.29 per meter for Alameda County homes and $1.96 per meter for Contra Costa homes.

Source: Landis, et.al., from ABAG data





Although most BART stations have not yet attracted development, the station at Walnut Creek has been a magnet for new office buildings.

Over 4 million square feet of modern office space has been built within a quarter-mile ring of the Walnut Creek station since BART's 1973 opening. Farther down the Concord line, at the Pleasant Hill station, over 1,800 apartments and condominium units were built within a quarter mile from 1988 to 1993. Many tenants consciously elected to move into this housing to economize on commuting. Surveys show one-half of employed tenants living in these units work in downtown San Francisco or Oakland, compared to a city-wide average of just 10 percent. Further, surveys show that 47 percent of employed tenants of these project commute via BART, compared to 16 percent of all Pleasant Hill employed residents.

While BART probably didn't have much influence on the number of the jobs that ended up along the Walnut Creek-to-Concord axis, it unquestionably had a strong influence on the built form that emerged—concentrated, mixed-use development that is conducive to transit riding. The presence of BART itself has not necessarily been sufficient to bring about land use changes, but under the right circumstances, it can be an important contributor.

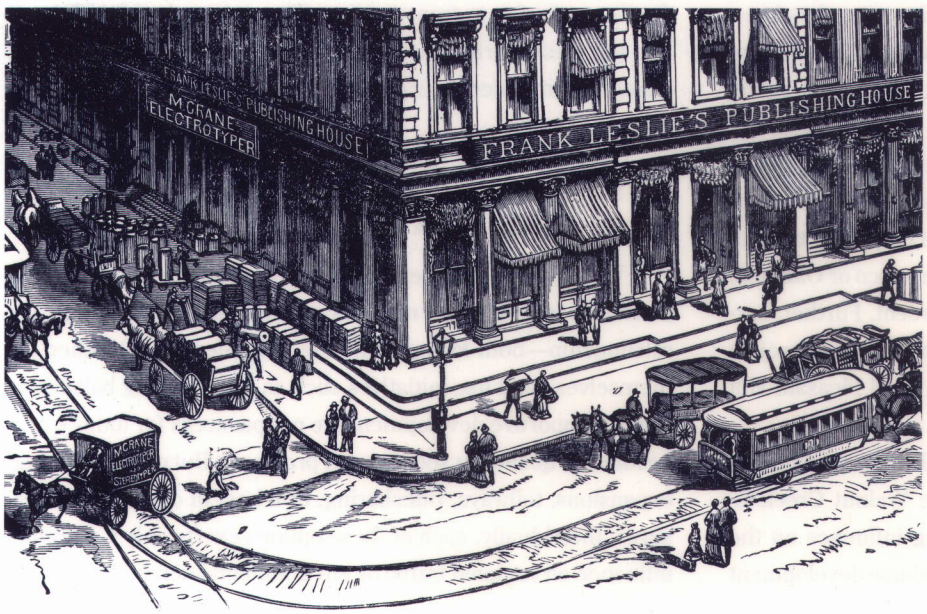
STRENGTHENING THE LAND USE-TRANSPORTATION CONNECTION

We conclude that the land use-transportation connection still matters because there remains considerable elasticity in the relationship—both factors continue to influence each other. By themselves, land use initiatives such as jobs-housing balance or transit-supportive development are not panaceas for today's congestion, air quality, or social equity problems. But neither are road expansions, tollways, ridesharing, or a host of other TDM measures. Individually, each of these options exerts only a marginal influence on regional traffic or environmental conditions. ➢

Part of the reason almost any policy strategy, including land use initiatives, has only a modest effect on regional travel and the environment is that the price signals passed on to motorists and parkers are far, far stronger, and thus swamp the influences of other measures. We must keep in mind that evaluations of how land use environments affect travel demand are being made in a distorted marketplace of cheap automobile travel, where motorists don't pay for externalities. It is no surprise that transportation-land use outcomes have been suboptimal in a world of suboptimal pricing. This, we argue, is not an indictment of the land use-transportation connection, but rather an indictment of current policies for pricing and managing our transportation and land resources.

We generally concur with Giuliano's observations that proper pricing—such as congestion fees and mandatory parking fees—would likely eliminate the need for public interventions like jobs-housing balance and transit-oriented development. People would move closer to jobs and transit stops to economize on travel. Yet, true market pricing of transportation might be even more unattainable than strengthening transportation-land use linkages in a pluralistic, democratic society like ours. So far, the only places with even a cursory form of road pricing are ruled by heavy-handed centralized planning doctrine (Singapore) are sparsely populated, culturally homogenous countries (Norway).

Martin Wachs, Chairman of the Transportation Research Board Committee on Congestion Pricing, concluded in the Spring 1994 issue of ACCESS that except for "professors of transportation economics and planning—who hardly constitute a potent political force—I can think of few interest groups that would willingly and vigorously fight for the concept..." In the absence of true market-based pricing of transportation, public initiatives that help strengthen the land use-transportation connection are, we believe, among the next best things. ◆



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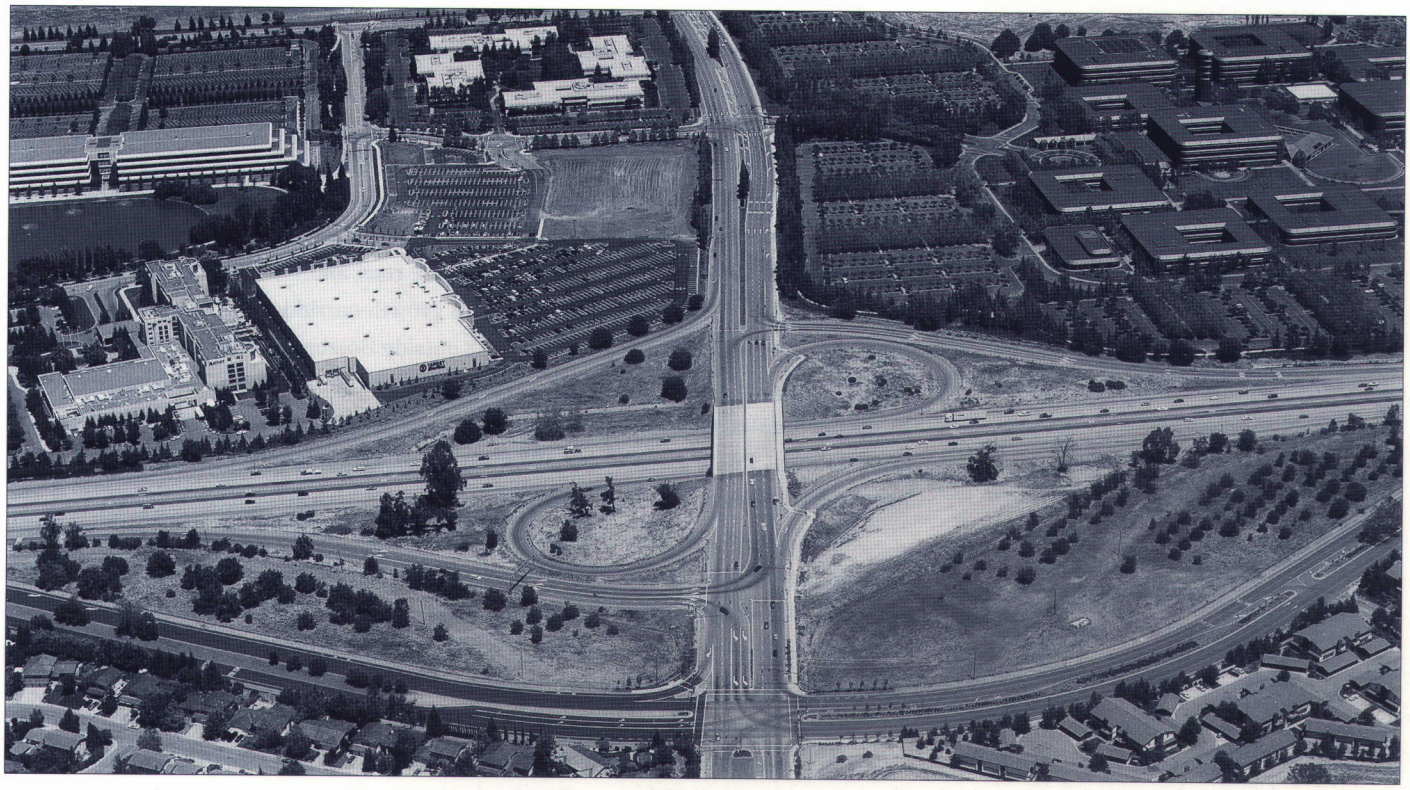
New Highways & Economic Growth: Rethinking the Link

BY MARLON G. BOARNET



A few decades ago, hardly anyone doubted that highways and other public infrastructure induce significant economic growth. Today the link between highways and growth appears tenuous. Some recent studies suggest that increasing the overall stock of highways in the country will cause little, if any, economic improvement. ➢

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The Interstate System, like the railroads before it, ties virtually every place in the country together. Incremental additions to that network will add comparatively small overall economic benefits.

There is no question that highways constitute an essential component of any modern economy. Surely, the National System of Interstate and Defense Highways contributed to post-war economic growth in the United States. But additional highways are not necessarily the path to greater riches in the twenty-first century, as they were in the twentieth.

The difference between the effects of current and past highway construction illustrates the difference between marginal and total economic effects. Most of the Interstate System was completed by the early 1970s. By now it provides a high degree of connectivity across the nation. Like the railroads before it, it ties virtually every place in the country to everywhere else, linking producers to raw materials, customers, and trading partners wherever they may be. Incremental additions to that network will add comparatively small overall economic benefits.

Although nationwide effects of new highway construction are now smaller than they were, effects on the economies of local areas are still important. Here, we focus on such localized effects.

Growth Corridors and Redistributed Growth

Consider what happened when a new highway was extended into the typical suburban fringe area twenty or thirty years ago. Land developers were attracted to the newly accessible sites adjacent to and near the road and built houses, shops, offices, and factories there. The highway became a growth corridor. In some places, such as Route 1 in central New Jersey or Route 128 outside Boston, the corridors even bear the highways' names. But suppose those highways had not been built. The houses and factories that located nearby surely were not created by the road; many would have sprung up elsewhere. Route 1 and Route 128 grew by attracting families and firms that would have settled along some other corridor.

Although researchers have long suspected that such redistribution occurs, it has been difficult to examine this effect in a systematic way. Empirical data have been scarce because highway-project evaluations typically don't look for economic losses outside the immediate project area. Recently, however, we conducted a study that illuminates some important aspects of this phenomenon.

Using a production-function study of California counties from 1969 through 1988, we found that increases in county economic output were higher in counties that also increased their spending for highways. But there was also evidence that county outputs were *lower* in counties that *bordered on* those that increased their highway spending. That is, increased highway spending in one county correlates not only with higher economic output in that county, but also with lower economic output in neighboring counties.

These findings corroborate results of studies done by David J. Forkenbrock and Norman S.J. Foster at the University of Iowa and by Yorgos J. Stephanedes and David Eagle at the University of Minnesota. Forkenbrock and Foster suggested that economic effects of highways are largely a redistribution of economic activity from one location to another. Stephanedes and Eagle found that highway spending in Minnesota increased employment in urban centers there, but the new jobs came largely at the expense of losses in neighboring counties.

The phenomenon is analogous to the action of an air mattress. If you push the mattress in one place, it bulges in another because the volume of air remains constant. With highways, if the volume of economic activity remains constant, there may be large economic gains near the project and losses elsewhere.

Of course, the volume of economic activity was not constant in the early days of Interstate Highway construction. By reducing the costs of shipping and personal travel, the Interstates contributed significantly to post-war economic expansion. But by focusing on the larger macro-economic outcomes, we may have overlooked the ways new highways have contributed to the relocation of local economic activities.

If highways were funded primarily with local money, this locational effect would pose no serious policy issue. However, most highway projects receive large state and federal subsidies. Thus taxpayers in one locality may be paying for highway projects that will ultimately undermine economic growth in their own community.

Further, if localities can receive economic benefits from projects that cause corresponding losses in neighboring locations, they may push for highway projects whose overall benefits are less than those projected. That is, by assessing only one locality's economic change, the economic benefits of modern highways may be overestimated. Thus state and federal governments may be funding more highways than a more geographically extensive benefit-cost analysis would justify. Local economic benefits may be offset by economic losses in other localities within the same funding jurisdiction.

The solution calls for either cautious analysis of highway-generated economic benefits or a restructuring of the current funding system—or both. Consider a case for reforming highway funding. ➢

Legacy of a new highway?

The Relationship Between Economic Benefits and Highway Funding

Whether a highway project should be funded by federal, state, or local governments depends on where the benefits fall. Large federal subsidies were the correct choice for funding the Interstate Highway System, because it produced far-reaching economic gains by connecting distant locations across the whole country. The system supported economic growth throughout the United States.

Note that there were also winners and losers in the initial round of Interstate Highway building. In many urban areas, the new highways contributed to growth at the periphery that probably came at the expense of more central locations. Yet one could argue that the national benefits, economic benefits included, were large and diffuse enough to offset concerns about the redistributive effects of the initial system. (Of course, some argue the converse—that the redistribution from central cities to suburbs offset national economic gains—but that's a discussion for another day.)

The ramifications of new highways have changed since the 1950s and 1960s. Now that the Interstate System is almost complete, the task has shifted from constructing that arterial network to maintaining the network and building intricate capillary systems at the peripheries. Accordingly, the newer highways play smaller roles in the national economy. Local economic gains and losses are becoming more important, suggesting that it's now time to change current funding arrangements for new highways.

The Intermodal Surface Transportation and Efficiency Act of 1991 (ISTEA) initiated some changes, but mainly in small and noncommittal ways. ISTEA does include several provisions making it easier for urban areas to construct tollroads and other public-private highway facilities. This reflects a small but important shift toward more cost-recovery in highway finance.

Tollroads encourage cost-recovery in two ways. First, individual highway users are required to pay for installing infrastructure, strengthening the user-fee principle implicit in charges such as the gasoline tax. Second, localities are required to pay larger shares of the costs of tollroads and other public-private highway projects than they pay for conventional roads. The uneven distribution of economic benefits from highways elevates the principal of local finance to the policy agenda. If localities gain an economic benefit from highways, they should be willing to pay for those benefits with local funds. Further, if benefits are gained at the expense of other areas, it is unfair to force the losers to pay for their economic harm. But how far should a system of local finance go?

Federal Role in Highway Funding

Should highway finance return to a system of primarily local funding, an arrangement not seen in the United States since the dawn of the automobile era? No, such drastic change is not warranted. The Interstate Highway System facilitates both passenger and freight movement, thereby boosting our nation's economic vitality. Part of the travel benefit accrues to the whole nation, and national funding is certainly appropriate for that. But it is less appropriate to use federal (and possibly even state) subsidies for economic benefits that are merely redistributed from one local area to another local area.

Local finance is fitting where benefits are localized; state or federal finance is justified for connections to the national network. The appropriate split among local, state, and federal funding depends on the geographic extent of a project's effects. Available evi-

dence suggests that national economic gains from highways are less significant today than are local redistributional effects. If true, the principle of local finance for local benefits will likely lead to higher levels of local highway funding.

ISTEA's public-private tollroad provisions give local governments a new revenue tool to pay for local highway benefits. Note, however, that ISTEA allows federal subsidies as high as eighty percent of the cost for such public-private tollroads. This proportion likely reflects the thinking of a past era when national economic benefits were larger, and may be too high for many local projects today.

Conclusion

Analysis of the link between highway funding and economic growth illustrates the hazards of focusing on the wrong question. For years, analysts debated whether infrastructure investment boosts economic productivity. But the more relevant question asks: How will new highway projects redistribute growth within and across regions?

Federal and state governments should continue funding highways to the extent they will facilitate personal travel and freight shipments throughout national and statewide networks. However, decisions to build highways that will generate primarily local economic development—and the responsibility for funding those economic benefits—are best left to local authorities. ◆

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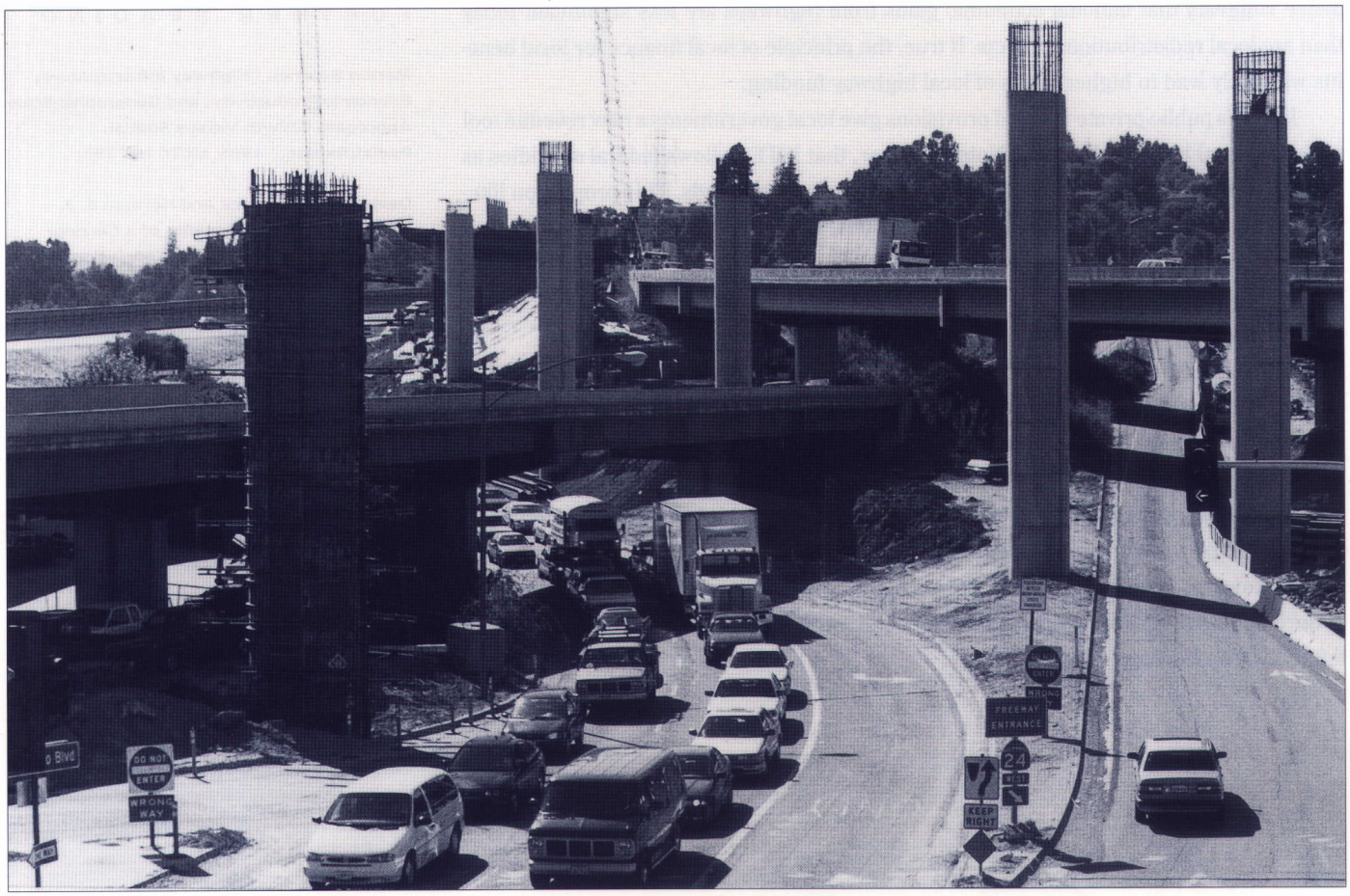

DO NEW HIGHWAYS GENERATE TRAFFIC?

BY MARK HANSEN

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Some people seem to think there's a universal Law of Traffic Congestion ruling that traffic expands to fill the space available to it. Thus, they believe it's impossible to relieve highway congestion by building more roads.

Conventional wisdom aside, however, we simply don't know whether new highway capacity affects travel behavior and, hence, traffic volumes. Advocates and opponents of new highway construction have debated this point for many construction projects in recent years—without the hard proof necessary to enlighten their debates.

Established planning procedures assume that most extra traffic on an enlarged road is reassigned from other parts of the network. Revisionists claim there are also sizable numbers of new trips and net increases in vehicle miles of travel (VMT). Thus advocates envision a fixed number of vehicles operating in improved traffic conditions, while opponents foresee more vehicles in conditions not much better, or perhaps even worse, than before.

Everyone recognizes that road construction, particularly in urban areas, is very costly. Even if traffic inducement is omitted from the project analysis, there are difficult trade-offs between the

benefits of reduced congestion and the costs, including severe an uncompensated social and environmental effects in addition to the monetary outlays. If induced traffic sharply reduces the benefits of reduced congestion, the trade-off tilts against urban road projects.

It's clear that traffic has grown steadily in recent years and that urban lane-miles have been carrying a lot of new traffic. Indeed, the ratio of VMT to lane-miles on California and other state highways is larger than ever, and increasing continually. But it remains unclear whether increased road supply has caused that increased travel. To gauge this effect, we must compare the outcomes of different road-supply scenarios. For example, we might compare scenarios with and without a particular project, or, at a more macroscopic scale, scenarios in which higher or lower numbers of lane-miles are constructed.

PREVIOUS RESEARCH

Direct comparison of those kinds are impossible because we can't perform controlled experiments. However, many efforts over the years have tried to measure or forecast the traffic-inducing effect of expanded road capacity. Starting in the 1940s, studies have attempted to measure induced traffic from individual projects. The approach was: (1) to gather time series of traffic counts on a corridor where a new road was being built, including observations both before and after project completion; (2) to estimate how traffic levels would have evolved in the absence of the project (the so-called "counterfactual scenario"); and (3) to estimate induced traffic by comparing the two scenarios.

Various methods have been used to estimate what traffic volumes would have occurred in the counterfactual scenario. In one early study, corridor traffic in the pre-project period closely tracked statewide gasoline sales; post-project gasoline sales were used to project traffic under the no-build scenario. More commonly, studies of individual projects have used "control corridors"—corridors elsewhere in the same region whose traffic is unlikely to be affected by the project. Post-project traffic growth on the new road and on the control corridors are compared to estimate traffic inducement.

Figure 1 summarizes the results of several project-level studies of traffic inducement. Reported levels range from 0 to 30 percent increase one year after expansion and from 20 to 80 percent four years after. It seems that substantial volumes of additional traffic develop in most corridors after capacity is increased. There's also a tendency for traffic to increase over time, a least during the first years following project completion. On the other hand, the level of estimated inducement is highly variable. Because the unit of analysis is a single corridor, it is impossible to determine whether induced traffic represents a net increase in regional VMT or whether it is merely redistributed from other parts of the region.

The relationship between road supply and traffic has also been studied through comparisons of different metropolitan areas. To see the basic logic of these cross-sectional studies, consider two regions, A and B. They are identical in all respects except their road supply and their VMT. If region A has x percent more lane-miles than region B, and if VMT in A is y percent greater than in region B, then it seems reasonable to attribute the VMT difference to the lane-mile difference. If we do so, we can go on ➢

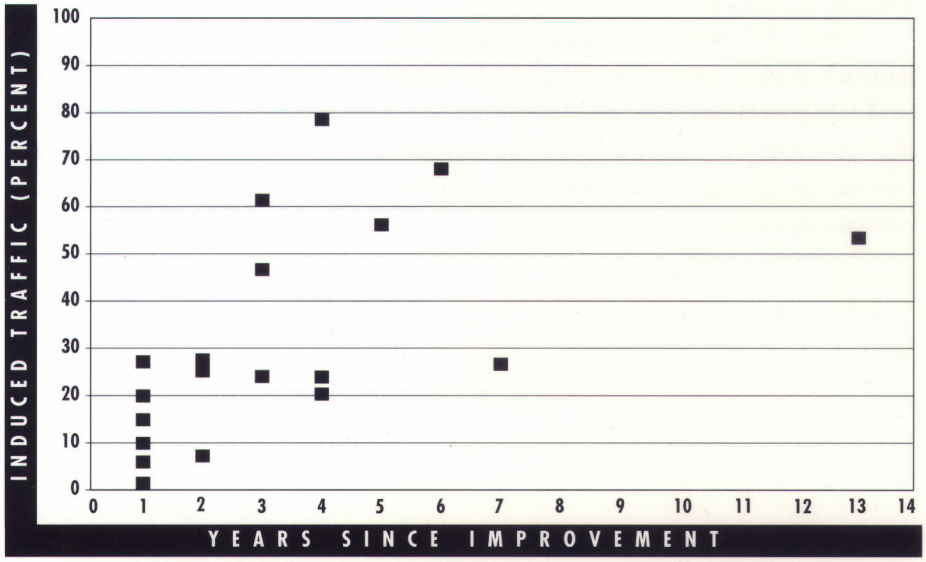


FIGURE 1

Estimates of Induced Traffic associated with Road Improvements

Each mark represents a different study.

Cross-sectional studies cannot deal with the direction of causality. Do roads generate traffic, or does traffic generate roads?

to measure the sensitivity of VMT to lane miles as y/x. The percentage change in one variable that results in a one-percent change in another variable is known as the "elasticity." Thus, y/x is the elasticity of VMT with respect to lane-miles.

Of course, the real world doesn't contain identical regions, so most cross-sectional studies attempt to control for variables, other than lane-miles, that affect traffic. It is difficult to identify these variables. One obstacle is the scarcity of data. The larger the number of variables, the more observations are required before it is possible to isolate the effect of one factor from that of another. Moreover, certain variables that influence VMT may themselves be affected by road supply. For example, some have argued that more road supply discourages transit use, leading to reduced quality of transit service, which in turn further stimulates VMT. If this were true, and if we control for transit service quality, then we would underestimate the effect of road supply on VMT. Similar issues emerge with regard to variables pertaining to urban form and density: To what extent are these variables determined by road supply? To what extent are they independent?

Cross-sectional studies also cannot deal with the direction of causality. Do roads generate traffic, or does traffic generate roads? Common sense suggests that causality runs both ways. If so, analyses that treat road supply as the cause and VMT as the result can yield misleading results. This problem is known as "simultaneity bias."

In light of these problems it's not surprising that cross-sectional studies have yielded widely varying estimates of the elasticity of VMT with respect to road-supply. The values range from as low as 0.13 to as high as 0.70. As a general rule, the studies yielding lower estimates have controlled for more variables. However, for reasons just explained, this does not necessarily mean that their results are more valid.

Regional transportation models are also routinely used to assess the effect of road supply on traffic. However, the vast majority of these studies focus on site-specific situations instead of searching for generalizable relationships. Therefore, they are of limited use. Furthermore, most transportation models are not used in ways that fully reveal whether or how adding capacity can increase traffic. For example, most modeling studies assume that the number of trips to and from places like households and offices are independent of transportation supply. A sizable number also assume that origin-destination trip matrices, and even the modal distribution of trips, are independent of road capacity.

Finally, and perhaps most important, it's far from clear that conventional transportation models, even when enhanced to capture numerous potential links between road supply and traffic, have much predictive power, even if they faithfully replicate baseline conditions. This is because these models make predictions that depend on numerous calibration parameters ("fudge factors") and are valid only if these parameters remain constant over time.

A Panel Study

A group of us at the University of California, Berkeley, have recently been studying the relations between road supply and traffic in urban areas. Our approach differs from those of previous efforts because it relies on time series data for a set of metropolitan areas. This is known as a "panel" data set. Specifically, we used annual data from thirty urban counties in the state of California from 1973 to 1990. The thirty counties constitute fourteen metropolitan areas, ranging in population from 150 thousand to 14 million. We analyzed the data at both the county and the metropolitan levels.

Our analysis focuses on state highway VMT (roughly half of total VMT in the state) and on the relationship of VMT to the supply of state highways, as measured in lane-miles. Because California has a systematic program for counting traffic on state highways, more and better data are available for state-highway VMT than for total VMT, which are based on gasoline sales and available at the county level for only a few recent years. However, we've also analyzed the limited data for total VMT to determine whether induced VMT on the state highway system represents a net increase in traffic or only redistributed travel from other roads.

Panel-data permit a more rigorous analysis than is possible with cross-sectional data for a single year. Cross-sectional studies must explicitly include all regional variables that independently influence traffic, but we can absorb many of these variables into a single region-specific correction factor. Similarly, time-specific variables that affect traffic in all regions, such as the OPEC oil embargo, are captured using a time-specific factor. Statisticians refer to these factors as "fixed effects."

In addition to controlling for a host of region-specific and time-specific variables, by using fixed effects we reduce the potential problem of simultaneity bias. To see how this is so, compare Los Angeles and San Francisco. Los Angeles has more lane-miles, and VMT is greater there. It's likely that over the long run, each of these differences affects the other. Thus a cross-sectional comparison between them is subject to simultaneity bias.

However, in a panel study, the results depend on the correlation between year-to-year variations in traffic and in year-to-year variation in lane-miles. Because road projects require many years to plan and implement, it is virtually impossible for road supply to respond to VMT on a year-to-year basis. So, if lane-miles and VMT grow faster in Los Angeles over a short span of years, this growth is probably not the result of road supply responding to traffic. Therefore, by employing panel analysis, we could treat road supply as a strictly causal variable.

Finally, because our data set covers a considerable number of years, it is possible to explore the dynamics of traffic response to road supply. Both common sense and our research findings suggest that the positive influence of added lane-miles on VMT occurs gradually. Travelers, households, business firms, and others gradually adjust their behavior in response to the added capacity. Some adjustments, such as route shifting, can occur soon after lanes are added; others, such as changes in activity locations, may take several years. To analyze the dynamics of the adjustment process, we relate regional VMT in a given year to regional lane-mileage in several previous years. Models with this feature are known as "distributed lag" models. ➢

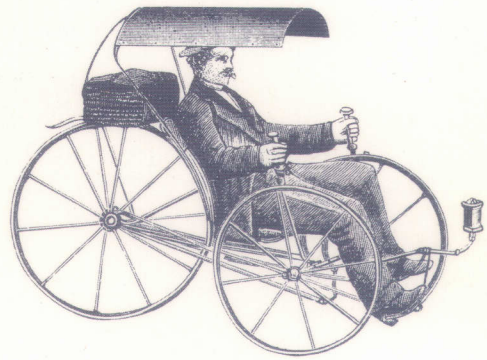
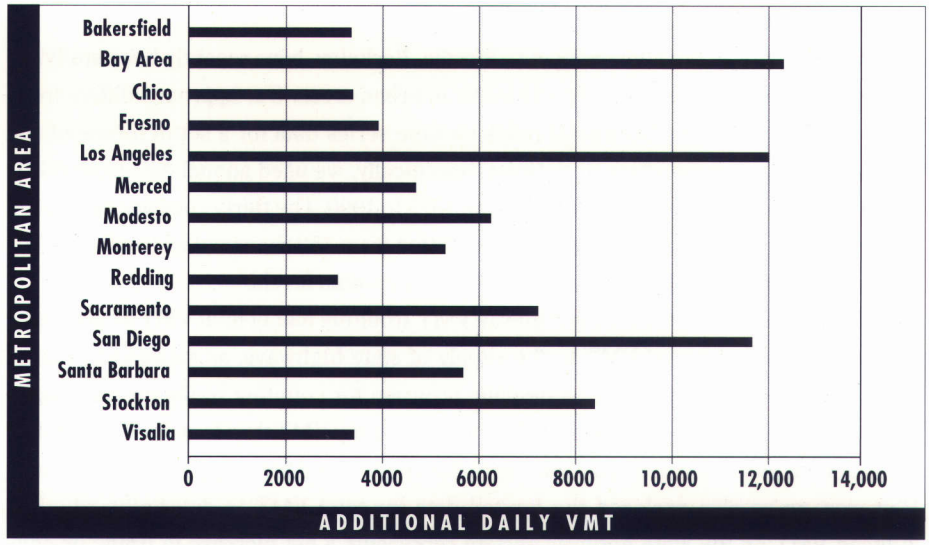


FIGURE 2

Estimated Additional VMT Generated Per Day from One Additional Lane-Mile, California Metropolitan Areas



Lane-Miles Induce New Traffic

Our study, based on such a distributed lag model, found that adding lane-miles does induce substantial new traffic. At the county level we find that a 1.0 percent increase in lane-miles soon induces an immediate 0.2 percent increase in traffic, building to a 0.6 percent increase within two years after the lane-miles are added. At the metropolitan level, the immediate effect is also about 0.2 percent, building to a 0.9 percent increase four years after. Therefore, it appears that adding road capacity does little to decrease congestion because of the substantial induced traffic.

Why is the lane-mile elasticity of VMT higher at the metropolitan level? One explanation is that adding lane-miles in one county induces traffic in neighboring counties since many trips cross county lines. Therefore, future studies of this kind should cover wide geographic areas.

We used our lane-mile elasticity measures to project additional daily VMT expected to result from a marginal lane-mile for the fourteen metropolitan areas in our study (see Figure 2). In the Bay Area, Los Angeles, and San Diego we expect an additional lane-mile to raise VMT by about 12 thousand per day. Among the other regions, the increases range from 3 to 8 thousand. Assuming a capacity of 2000 vehicles per lane per hour, the induced traffic would be equivalent to filling the added lane for six hours per day.

We also estimated the contributions to VMT growth from various sources during three periods: 1977-80, 1980-85, and 1985-90. For each period we calculated the average increase in VMT for fourteen metropolitan areas. We attributed VMT growth to population, per capita income, highway-lane miles, and "other" factors, including declining real prices of gasoline, increasing female employment, declining transit subsidies, and other trends affecting VMT in all regions.

Figure 3 shows the results of this analysis. The most consistent source of VMT growth has been population growth. Most recently, however, "other" factors became increasingly important. Lane-mile growth has become progressively less important, reflecting the continuing decline in numbers of lane-miles added to the system in recent years. Per capita income has played a modest role, reflecting both the recent stagnation in real family incomes and the modest effects that rising incomes among wealthy households have had on car ownership and, hence, on VMT.

Bear in mind that our findings pertain to VMT on state highways only. An obvious question is whether the state highway traffic induced by added lane-miles comes from non-state roads. Our ability to answer this question is hampered by the limited reliability of data on total VMT. Our analysis suggests that state highway lane-miles do not significantly affect VMT on off-state highways. However, because county and local roads are almost always used for to getting on and off state highways, increased state highway traffic can also add to non-state facilities. On balance, it appears that these two effects roughly cancel out. ➢

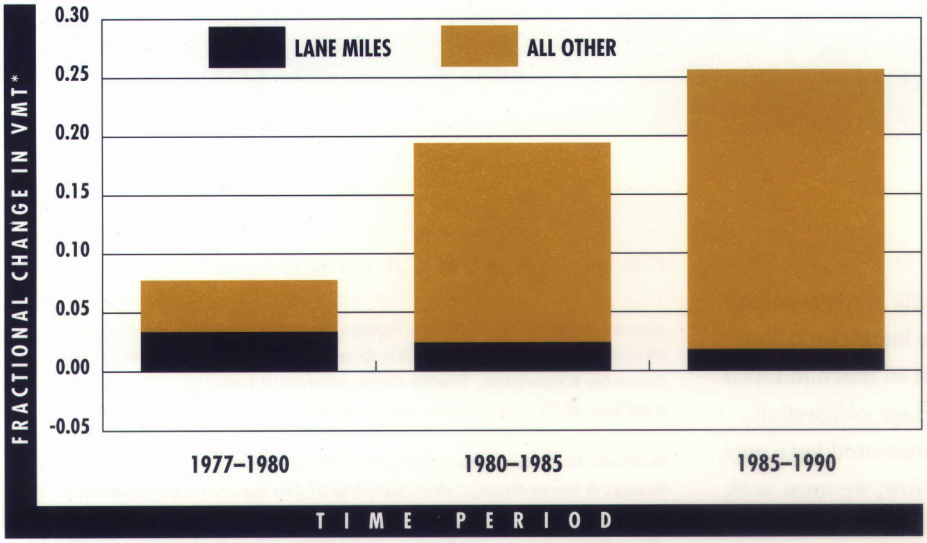


FIGURE 3

Sources of VMT Growth, California Metropolitan Areas, 1977-1990

* *Calculated based on change in natural log of VMT for average urban region in California*

Source: Author's calculations

Conclusion

New roads generate substantial new traffic in metropolitan regions. A 1.0 percent increase in lane miles induces a 0.9 percent increase in VMT within five years. With so much induced traffic, adding road capacity does little to reduce congestion.

However, the aggregate relationships presented here may not hold for an individual highway project. Now, we must seek convergence between macro-studies such as ours and more detailed and elaborate planning models that can predict the effects of specific road improvements. Without further and complementary macro- and micro-analyses, our ability to assess urban transportation improvements will remain limited. But at least in metropolitan areas, it seems that the Law of Traffic Congestion has been upheld. ◆

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Higher Speed Limits May Save Lives

BY CHARLES LAVE

Congress may soon pass a law that allows states to set their own speed limits. What might happen if states choose to raise these limits? We don't need to guess. We can examine what happened when states were allowed to raise certain speed limits in 1987. The result: Higher speed limits caused an overall *gain* in safety.

BACKGROUND: A NEW PERSPECTIVE

The common wisdom on traffic safety is not necessarily correct. Consider the often-repeated maxim, "speed kills." Empirical analysis shows that highway fatality rates are not related to average speed levels. The major factor is not average speed, but rather the *variation* in speed among cars. Differential speeds cause more turbulence in the traffic stream—passing and overtaking. Variance kills, not speed. What matters most in setting a speed limit is choosing a limit people will obey, to reduce the variation in speed among cars.

Analysis also shows that setting a certain speed limit in one location, such as the rural Interstate Highways, may affect policing resources and traffic in other locations. If more policing time is allocated to enforcing the speed limit, less time is available for other safety activities. Further, some drivers may shift from the now heavily policed Interstate Highways to side roads, so they can speed with less chance of being caught. When we evaluate the effect of changing local speed limits, we must cast a wide net because the reallocation of policing activities and traffic will have systemwide consequences, not just local ones. ➢

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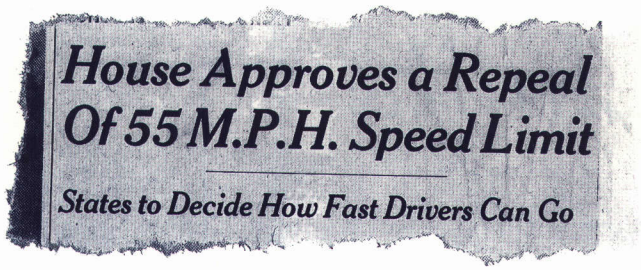


I studied data from a natural experiment to compare the analytic power of the resource allocation perspective against conventional analysis. The analysis found that an increase to 65 mph actually produced a decline in highway fatalities.

THE EXPERIMENT

In 1987, the federal government allowed states to raise speed limits on rural Interstate Highways; forty states did so. Safety analysts warned that the increase to 65 mph would cause an increase in fatalities. A few years after the higher limit was established, some analysts presented studies showing that fatalities did increase. However these studies look at only local effects: fatalities on a particular highway before and after the speed limit change. This approach ignores resource allocation.

The Allocation of Policing Resources The 55 mph national maximum speed limit resulted from a 1974 federal mandate that required states to: (1) reduce the speed limit to 55 mph; and (2) enforce this limit strictly and keep the proportion of speeders low—otherwise states would lose federal highway funds. In response, state highway patrols shifted resources from other safety activities, such as drunk driving checkpoints and truck equipment inspections, to enforcement of speed limits on Interstate Highways. These highways have the densest concentration of high speed traffic, so an hour of patrol-time there will control the greatest number of potential speeders. By 1983, twenty-nine percent of patrol staff hours were devoted to rural Interstate Highways, although these were already the safest highways in the state, producing only 9 percent of fatalities.

Highway patrol chiefs considered this a peculiar way to allocate manpower. Testifying before Congress in 1990, Elmer Tippet of the International Association of Chiefs of Police said: "[Federal financial sanctions] force the over-concentration of limited resources for the express purpose of attaining compliance rather than application of resources in a manner most effectively enhancing total highway safety..." Following the rise of the legal speed limit to 65 mph, highway patrols were allowed to shift their patrol resources.

The Allocation of Highway Resources Because of their physical design, the Interstates are our safest roads, and parallel side roads generally our most dangerous. Higher legal speeds on the Interstates would be expected to lure traffic away from the side roads, hence reducing fatalities on them. Is there evidence that traffic did shift to the Interstates following the 65 mph limit? We need to measure change relative to some expected baseline. Traffic on the rural Interstate Highways in the 65 mph states grew 1.73 times faster than did their overall VMT (vehicle miles traveled). Traffic on the non-Interstate Highways grew at only eighty-nine percent of the overall VMT growth. Further, VMT on rural Interstate Highways grew 1.62 times faster in the 65 mph states than it did in the 55 mph states. These findings support the reallocation theory.

MISALLOCATED RESOURCES MAKE A DIFFERENCE

Did the reallocation of traffic and highway patrol resources matter? Did it affect fatalities?

A Simple Test To answer this question, I aggregated the states into two groups—those that raised the speed limit to 65 mph, and those that did not—then computed their respective fatality rates.

TABLE 1

CHANGE IN STATEWIDE FATALITY RATES			
	1986 -1987	1987 -1988	1986 -1988
65 MPH STATES	-4.68%	-1.55%	-6.15%
55 MPH STATES	-.07%	-2.55%	-2.62%

The 65 mph states experienced greater decline in statewide fatality rates between 1986-1988.

Source: NHTSA, *The Effects of the 65 mph Speed Limit Through 1988: A Report to Congress*, 1989, pp. 33-44

The difference in fatality rates between the two groups of states indicates that the 65 mph experiment reduced the fatality rate by 3.62 percent.[1]

Table 1 shows the results. In states that raised speed limits, the overall fatality rate fell by 4.68 percent in 1987 (compared to the year before when the limit had been 55 mph), then fell an additional 1.55 percent in 1988. In the states that did not change their speed limits, fatality rates were essentially unchanged in 1987 compared to the year before, and then fell by 2.55 percent the next year.

State by State Analysis The results in Table 1 are clear, but do not control for the possibility that important differences may exist between the states that raised speed limits and those that did not. Thus we have to disaggregate the data and explicitly deal with the determinants of the fatality rate in individual states.

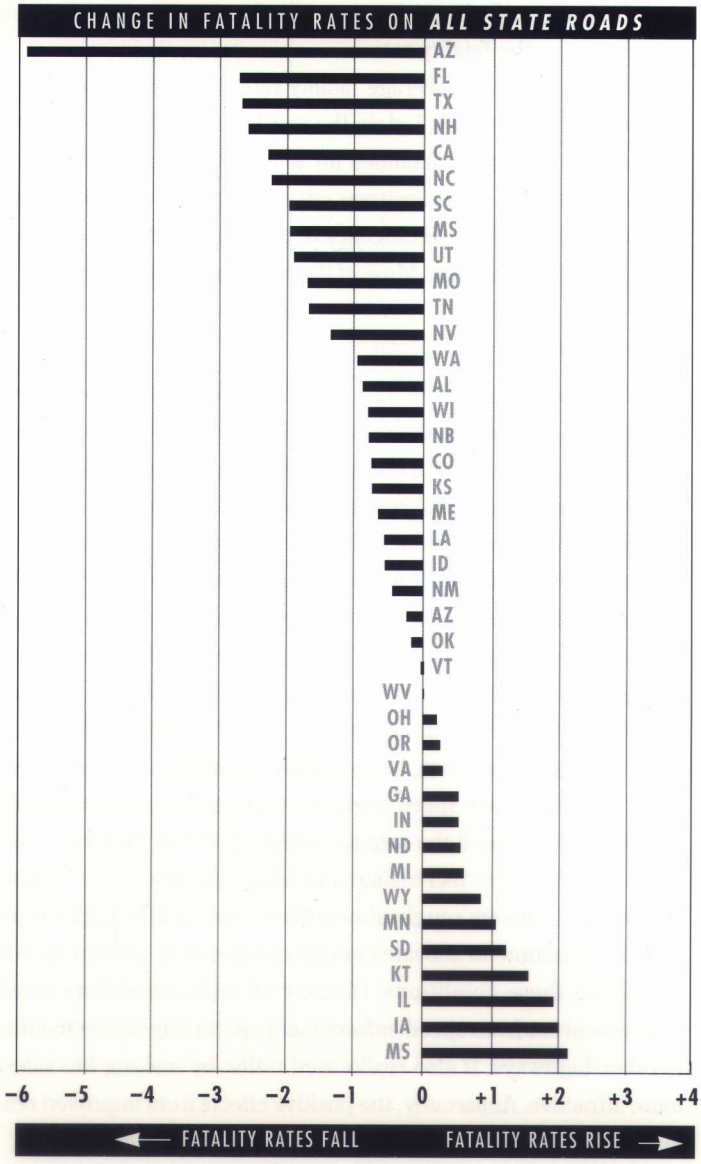
A 1990 state-by-state model by Garber and Graham was the most sophisticated existing analysis of the effects of the 65 mph limit. They estimated the number of fatalities per month on rural Interstate Highways, running separate analyses for each state that adopted the 65 mph limit. They accounted for the following factors:

- the 65 mph speed limit;
- the unemployment rate for each state (economic conditions strongly influence both the amount and type of driving);
- whether states have a mandatory-use seat belt law;
- trends in roads, cars, traffic, or population;
- monthly seasonal effects; and
- the number of weekend nights in each month (more drinking occurs on weekends, and drinking is highly associated with accidents).

If the higher speed limit were to reduce safety, accidents would rise when the speed limit is raised to 65 mph. Garber/Graham concluded, "The new 65 mph limit appears to be increasing rural Interstate fatalities in some states, reducing them in others, and having no detectable effect (given the experience to date) in the remainder. The number of states experiencing increased fatalities exceeds the number experiencing reduced fatalities..." Their analysis is thorough and ingenious, but they studied only the effects of the speed limit change on *local* roads. In contrast, the resource allocation perspective predicts there will also be systemwide effects. ➢

FIGURE 1

Statewide Effect of Rise to 65 mph



This figure shows whether the 65 mph speed limit lowered (–) or raised (+) the fatality rate, and the statistical significance of that estimated effect.

[1] The comparison could not correct for any large causal factor that differs systematically between the two groups of states. We were able to eliminate one possible factor: Seat belt usage is essentially identical in the two groups.

Thus I reestimated the Garber/Graham model to focus on the *statewide* fatality rate instead of considering only rural Interstate fatalities. In all other respects, the models are identical. Most of the results for the forty states confirm the Garber/Graham findings: for example, increased unemployment and seat belt laws both decrease the fatality rate.

But the statewide average fatality rate *declined by 3.43 percent* after the limit was raised to 65 mph. Figure 1 plots the results from the state analysis. Each bar in Figure 1 shows the change in fatalities for one state. If the bar points to the right, fatalities increased after the speed limit was raised; if it points to the left, they declined. The longer the bar, the greater the significance of the estimate. Figure 1 shows the statewide effects of the higher speed limit: Most of the bars point to the left.

SUMMARY AND CONCLUSIONS

Prior evaluation of the new 65 mph speed limits measured only the local effects of the change. I measured the systemwide effects, and found that statewide fatality rates fell by 3.4 to 5.1 percent in the group of states that adopted the 65 mph limit.

It appears that patrol resources and traffic had been misallocated prior to the 65 mph limit. What could have caused this? Consider the history of the 55 mph National Maximum Speed Limit. It was enacted to conserve gasoline after the 1973 OPEC oil embargo. Its conservation effect proved trivial, but there was a drop in highway fatalities in the following years. The causes of that fatality drop are difficult to identify: the deep post-OPEC economic recession produced a substantial decline in travel, hence a drop in fatalities. Patriotic compliance with the new speed limit produced a substantial decline in speed variance, hence a drop in collisions. There may also have been some effect from the lower speed itself, but subsequent empirical work has failed to find it.

Whatever caused the original safety effect had, however, lost its force by the mid-1980s. Drivers were increasingly avoiding the speed limit: Radar detectors became a new industry; drivers sought alternative routes; and the highway patrols found it increasingly burdensome to allocate enough manpower to control speeding.

Given these conditions, the new 65 mph speed limit freed highway patrols to shift resources from speed enforcement on the Interstates to other safety activities and to other highways. It also reallocated traffic by making the safer Interstate Highways more attractive. Apparently, the positive effects from improved resource allocation were more than enough to offset any negative effects of higher speed.

In our nation's past experience with speed limits, localities have demonstrated a better sense of their own safety needs than did our federal lawmakers. I expect a similar outcome if Congress eliminates the national speed limit, allowing states to determine their own. ◆

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IS OXYGEN ENOUGH?

BY ROBERT HARLEY

Recent amendments to the Clean Air Act require use of oxygenated gasoline during winter months in about forty urban areas across the United States. Generally, winter gasoline must contain 2.7 percent by weight of oxygen; California has been allowed to use a lower level, 2.0 percent. To determine the effectiveness of oxygenated gasoline in reducing carbon monoxide (CO) emissions, we designed a study to expand upon previous emission research by testing a large number of on-road vehicles. ➢

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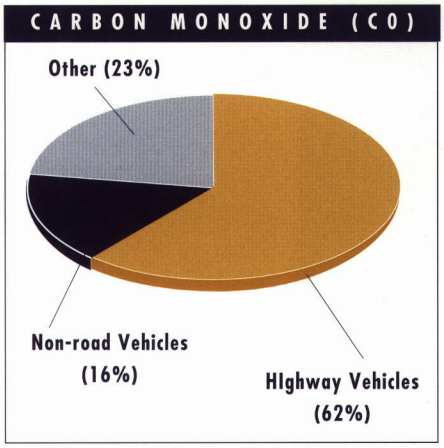
FIGURE 1

Sources of Carbon Monoxide Emissions



Source: 1993 U.S. National Emission Inventory

Testing Oygenated Gasoline in the Field

The federal government relies on a traditional testing method using a dynamometer to measure vehicle emissions. Testers keep vehicles stationary while running their engines and simulating standard stop-and-go city driving conditions. Since this procedure is time-consuming and expensive, the government could not feasibly test large numbers of vehicles. Therefore, the sample sizes studied may have been too small to represent the range of vehicles actually on the road.

To put oxygenated gasoline to a real-life test, two graduate students, Tom Kirchstetter and Brett Singer, and I measured vehicle emissions in the Caldecott Tunnel, located on Highway 24 between Oakland and Orinda, California. In cooperation with the Bay Area Air Quality Management District, we measured pollutant concentrations of exhaust samples drawn through slots in the ventilation system of the tunnel. By using the central bore of the three-bore tunnel, where no heavy-duty trucks are allowed, we could limit our study to light-duty vehicles. Over 4,000 vehicles pass through this section every hour during the afternoon rush-hour sampling period.

We took samples on ten days in August 1994 and ten days in October 1994. In California, gasoline must be oxygenated from October 1 to January 31. The California Air Resources Board collected and analyzed gasoline samples from Bay Area service stations during our two sampling periods at the Caldecott Tunnel. The measured oxygen content in gasoline increased from 0.3 percent by weight in August to 2.0 percent by weight in October. Measured ambient air temperatures at the Tunnel differed by only one or two degrees Celsius between August and October. Traffic leaving the Tunnel was monitored to determine traffic flow, proportion of cars and trucks, and average speed. As expected, the fraction of heavy-duty diesel trucks in the center bore of the Tunnel was small (less than 0.2 percent), so the measurements in the Tunnel reflect emissions from gasoline-powered cars and light trucks.

Our results showed a CO decrease of about 21 (±7) percent and a volatile organic compound (VOC) emissions decrease of about 18 (±10) percent following the introduction of oxygenated gasoline. However, no significant change was found for emissions of oxides of nitrogen (NOx).

Field measurements taken in the Caldecott Tunnel reflect emissions from vehicles operating in hot stabilized mode. An important issue that requires further study is the effect of oxygenated gasoline on cold start emissions. Vehicle exhaust emissions are especially high during the first few minutes of operation when the engine and emission control systems are still cold.

We had mixed results for certain individual hazardous organic species that are part of total VOC emissions. Following the introduction of oxygenated gasoline, measured emissions of benzene, a known human carcinogen, decreased by about 25 (±17) percent, while emissions of formaldehyde, a respiratory and ocular irritant, increased by about 13 (± 6) percent.

Carbon Monoxide's Decreasing Significance as a Major Air Pollutant

While motor vehicles continue to produce the greatest proportion of CO emissions nationwide (see Figure 1), along with significant amounts of VOC and NOx, ambient carbon monoxide concentrations are dropping rapidly (see Figure 2). These reductions, which are mainly due to stricter emission standards for new cars and trucks, are occurring despite increasing numbers of vehicles on the road. If we continue using oxygenated gasoline and retiring older vehicles, carbon monoxide will soon cease to be a major air pollution problem in outdoor air.

It is therefore surprising that carbon monoxide emissions still receive so much attention in transportation planning and motor vehicle emission-control efforts. California's air quality impact assessments hinge on dispersion modeling for carbon monoxide. Although these assessments should remain an important element of transportation systems design, the assessment should now focus on other emissions.

The Real Threats to Human Health

Ozone and airborne particulate matter pose a greater problem than CO. For example, in 1987, all regions in California exceeded air quality standards for those pollutants more often than for CO (see Table 1). ➢

TABLE 1

Percent of Days Over State Standard, 1987 Summer and Winter Seasons

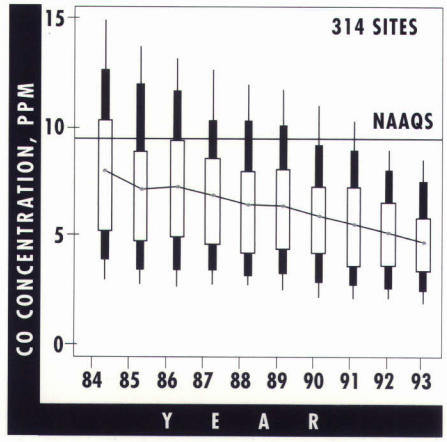
REGION	O_3 1 HOUR, SUMMER	CO 8 HOUR, WINTER	PM10* 24 HOUR
South Coast (LA)	90	42	78
SF Bay Area	22	1	37
Sacramento	35	4	23
San Diego	56	1	19
Fresno	59	3	59
Ventura	54	0	25
Kern	61	0	66

Source: California Air Resources Board (1988)

* *Particulate matter less than 10 microns in diameter*

FIGURE 2

Trends in Ambient Concentrations of Carbon Monoxide



This figure represents CO concentration measured at 314 sites from 1984 to 1993. Average CO concentrations decreased over the years, as shown by the downward trend line plotted in Figure 2. The bar-like graphics show the distribution of measurements that were used to compute the average for each year.

The widest, clear bars indicate the range from the 25th to 75th percentile in observed CO concentrations; the middle, colored bars indicate the range from the 10th to 90th percentile; the thin, outermost bars indicate the 5th to 95th percentile of measured CO.

The National Ambient Air Quality Standard (NAAQS) for CO, shown for comparison, is 9 ppm over an 8-hour averaging time.

Source: Environmental Protection Agency (1994)

Exit from Caldecott Tunnel test site.

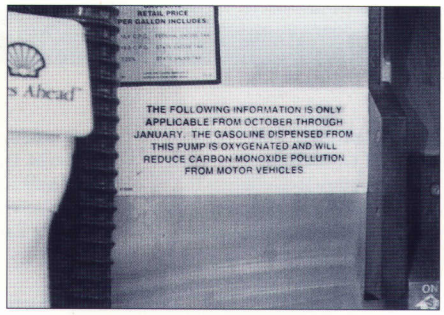
Ozone is not emitted directly, but formed in the lower atmosphere by reactions involving VOC and NOx emissions. As of 1989, ninety-six metropolitan areas nationwide did not meet the statutory ambient air quality standards for ozone. Oxygenated gasoline may help against ozone in some, but not all, areas. In locations such as Los Angeles and San Francisco, where VOC emissions are low, oxygenated gasoline may help reduce ozone formation. In locations such as Atlanta, where natural VOC emissions from vegetation are very high, ozone formation is controlled by NOx emissions, so oxygenated gasoline will not help against ozone.

Perhaps the most serious threat to current air quality comes from fine airborne particles (those with diameters less than 2 microns), which cause the brownish haze and visibility problems associated with smog. Major sources of fine particles include diesel engines and *in situ* atmospheric formation of particles from gaseous NOx and sulfur dioxide precursor emissions.

Current air quality standards address all particles with diameters less than 10 microns (PM10). Therefore, larger particles generated by mechanical processes such as wind erosion and tire abrasion are regulated together with fine particles generated by chemical and combustion pathways. This regulatory grouping of fine and coarse particles masks the importance of fine particles and encourages air control measures of dubious benefit, such as sweeping the entire state highway system.

Finally, by requiring costly oxygenated gasoline, we are placing a financial burden on all motorists when only ten percent of cars and trucks contribute fifty percent or more of all vehicle emissions. New cars, with effective emission control systems, no longer contribute significantly to pollution.

Our study shows that oxygenated gasoline effectively reduces CO emissions. Moreover, it emphasizes an important fact: CO is no longer a problem in outdoor air. Current research and legislation should focus on ozone and fine particles. The success of oxygenated gasoline must not foster complacency about overall motor vehicle emissions. Instead, it should be viewed as a first step toward creating a non-polluting fuel for the next century. ◆



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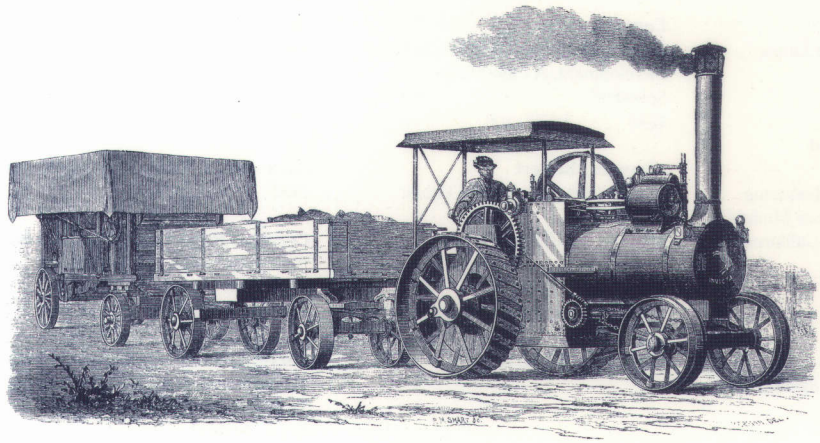

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* **Henderson, Dennis K., Brett E. Koenig and Patricia L. Mokhtarian**
"Using Travel Diary Data to Estimate the Emissions Impacts of Transportation Strategies: The Puget Sound Telecommuting Demonstration Project"
1995 UCTC 265

* **Hsu, Shi-Ling and Daniel Sperling**
"Uncertain Air Quality Impacts of Automobile Retirement Programs"
1994 UCTC 260

Hwang, Keith and Genevieve Giuliano
"The Determinants of Ridesharing: Literature Review"
1990 UCTC 38

Jacobs, Allan B., Yodan Y. Rofé and Elizabeth S. Macdonald
"Boulevards: A Study of Safety, Behavior, and Usefulness"
1994 UCTC 248

Jayakrishnan, R., Michael G. McNally and Michael I. Cohen
"Simulation of Advanced Traveller Information Systems (ATIS) Strategies to Reduce Non-Recurring Congestion from Special Events"
1993 UCTC 173

Jayakrishnan, R., Wei T. Tsai, Joseph N. Prashker, and Subodh Rajadhyaksha
"A Faster Path-Based Algorithm for Traffic Assignment"
1994 UCTC 191

* **Johnston, Robert A.**
"The Evaluation of Multimodal Transportation Systems for Economic Efficiency and Other Impacts"
1994 UCTC 272

Johnston, Robert A.
"The Evaluation of Transportation and Land Use Plans Using Linked Economic and GIS Models"
1995 UCTC 268

Johnston, Robert A. and Caroline J. Rodier
"Critique of Metropolitan Planning Organizations' Capabilities for Modeling Transportation Control Measures in California"
1994 UCTC 271

* **Johnston, Robert A. and Raju Ceerla**
"Effects of Land Use Intensification and Auto Pricing Policies on Regional Travel, Emissions, and Fuel Use"
1995 UCTC 269

* **Johnston, Robert A., Jay R. Lund and Paul P. Craig**
"Capacity-Allocation Methods for Reducing Urban Traffic Congestion"
1995 UCTC 270

Jovanis, Paul P., Tetsuya Kaneko and Tzuoo-Din Lin
"Exploratory Analysis of Motor Carrier Accident Risk and Daily Driving Patterns"
1991 UCTC 73

Kaneko, Tetsuya and Paul P. Jovanis
"Multiday Driving Patterns and Motor Carrier Accident Risk: A Disaggregate Analysis"
1991 UCTC 59

Keeler, Theodore E.
"Highway Safety, Economic Behavior, and Driving Environment"
1993 UCTC 65

Kim, Seyoung
"After the Resolution: Excess Commuting for Two-Worker Households in the Los Angeles Metropolitan Area"
1993 UCTC 144

Kim, Seyoung
"Gender Differences in Commuting: An Empirical Study of the Greater Los Angeles Metropolitan Area"
1994 UCTC 190

* **Kirchstetter, Thomas W., Brett C. Singer and Robert A. Harley**
"Impacts of Oxygenated Gasoline Use on California Light-Duty Vehicle Emissions"
1995 UCTC 280

Kitamura, Ryuichi
"Panel Analysis in Transportation Planning: An Overview"
1990 UCTC 68

Kitamura, Ryuichi and David S. Bunch
"Heterogeneity and State Dependence in Household Car Ownership: A Panel Analysis Using Ordered-Response Probit Models with Error Components"
1990 UCTC 52

Kitamura, Ryuichi, Jack M. Nilles, Patrick Conroy, and David M. Fleming
"Telecommuting as a Transportation Planning Measure: Initial Results of California Pilot Project"
1991 UCTC 58

Kitamura, Ryuichi, Patricia L. Mokhtarian, Ram M. Pendyala, and Konstadinos G. Goulias
"An Evaluation of Telecommuting as a Trip Reduction Measure"
1991 UCTC 5

Klein, Daniel B.
"The Voluntary Provision of Public Goods? The Turnpike Companies of Early America"
1990 UCTC 18

Klein, Daniel B. and Chi Yin
"The Private Provision of Frontier Infrastructure: Toll Roads in California, 1850-1902"
1994 UCTC 238

Klein, Daniel B. and Gordon J. Fielding
"Private Toll Roads: Learning from the 19th Century"
1992 UCTC 118

Klein, Daniel B. and John Majewski
"Economy, Community and Law: The Turnpike Movement in New York, 1797-1845"
1991 UCTC 76

Klein, Daniel B. and John Majewski
"Plank Road Fever in Antebellum America: New York State Origins"
1994 UCTC 243

Klein, Daniel B. and John Majewski
"Promoters and Investors in Antebellum America: The Spread of Plank Road Fever"
1991 UCTC 75

Kroll, Cynthia A., John D. Landis, Qing Shen, and Sean Stryker
"Economic Impacts of the Loma Prieta Earthquake: A Focus on Small Business," Studies on the Loma Prieta Earthquake, No. 3
1991 UCTC 154

Kurani, Kenneth S., Thomas Turrentine and Daniel Sperling
"Demand for Electric Vehicles in Hybrid Households: An Exploratory Analysis"
1994 UCTC 232

Kwan, Mei-Po and Reginald G. Golledge
"Contributions of GIS to ATIS"
1994 UCTC 215

Kwan, Mei-Po and Reginald Golledge
"Integration of GIS with Activity-based Model in ATIS"
1995 UCTC 254

Landis, John D.
"The California Urban Futures Model: A New Generation of Metropolitan Simulation Models"
1994 UCTC 244

Landis, John D. and Ming Zhao
"Pilot Study of Solano and Sonoma Land Use and Development Policy Alternatives"
1994 UCTC 245

Landis, John D., Subhrajit Guhathakurta and Ming Zhang
"Capitalization of Transportation Investments into Single Family Home Prices: A Comparative Analysis of California Transit Systems and Highways"
1994 UCTC 246

* **Landis, John D., Subhrajit Guhathakurta, William Huang, and Ming Zhang**
"Rail Transit Investments, Real Estate Values, and Land Use Change: A Comparative Analysis of Five California Rail Transit Systems"
1995 UCTC 285

Lasley, David J., Russell D. Hamer, Robert Dister, and Theodore E. Cohn
"Postural Stability and Stereo-Ambiguity in Man-Designed Visual Environments"
1991 UCTC 157

Lave, Charles
"Measuring the Decline in Transit Productivity in the U.S."
1991 UCTC 159

Lave, Charles
"State and National VMT Estimates: It Ain't Necessarily So"
1994 UCTC 231

Lave, Charles
"The Demand Curve Under Road-Pricing and the Problem of Political Feasibility"
1992 UCTC 136

Lave, Charles
"Things Won't Get a Lot Worse: The Future of U.S. Traffic Congestion"
1990 UCTC 33

Lave, Charles and Patrick Elias
"Did the 65 Mph Speed Limit Save Lives?" (revised)
1993 UCTC 69

Leavitt, Dan, Sean Ennis and Pat McGovern
"The Cost Escalation of Rail Projects: Using Previous Experience to Re-Evaluate the CalSpeed Estimates," CalSpeed Series
1993 UCTC 156

Leavitt, Daniel, Erin Vaca and Peter Hall
"Revenue and Ridership Potential for a High-Speed Rail Service in the San Francisco / Sacramento - Los Angeles Corridor" Calspeed Series
1994 UCTC 185

Leavitt, Daniel, Peter Cheng, Erin Vaca, and Peter Hall
"Potential for Improved Intercity Passenger Rail Service in California: Study of Corridors," Calspeed Series
1994 UCTC 222

Lem, Lewison Lee, Jian-Ling Li and Martin Wachs
"Comprehensive Transit Performance Indicators"
1994 UCTC 225

Lipman, Timothy E., Kenneth S. Kurani and Daniel Sperling (editors)
"Proceedings of the Neighborhood Electric Vehicle Workshop: A Policy, Technology, and Research Conference"
1994 UCTC 258

Loukaitou-Sideris, Anastasia
"Retrofit of Urban Corridors: Land Use Policies and Design Guidelines for Transit-Friendly Environments"
1993 UCTC 180

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"Form Follows Transit? The Blue Line Corridor's Development Potentials"
1994 UCTC 259

Majewksi, John, Christopher T. Baer and Daniel B. Klein
"Market and Community in Antebellum America: The Plank Roads of New York"
1991 UCTC 47

* **Majewski, John, Christopher Baer and Daniel B. Klein**
"Responding to Relative Decline: The Plank Road Boom of Antebellum New York"
1993 UCTC 267

* **Mannering, Jill S. and Patricia L. Mokhtarian**
"Modeling the Choice of Telecommuting Frequency in California: An Exploratory Analysis
1995 UCTC 282

McNally, Michael G.
"Regional Impacts of Neotraditional Neighborhood Development"
1993 UCTC 172

McNally, Michael G. and Sherry Ryan
"A Comparative Assessment of Travel Characteristics for Neotraditional Developments"
1992 UCTC 142

McNally, Michael G. and Sherry Ryan
"Accessibility of Neotraditional Neighborhoods: A Review of Design Concepts, Policies, and Recent Literature"
1992 UCTC 141

Meurs, Henk, Leo van Wissen and Jacqueline Visser
"Measurement Biases in Panel Data"
1989 UCTC 9

Miller, Vincent P. and John M. Quigley
"Segregation by Racial and Demographic Group: Evidence from the San Francisco Bay Area"
1989 UCTC 14

Mokhtarian, Patricia L.
"A Typology of Relationships Between Telecommunications and Transportation"
1990 UCTC 82

Mokhtarian, Patricia L.
"An Empirical Analysis of the Transportation Impacts of Telecommuting"
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"Defining Telecommuting"
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1995 UCTC 264

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"Modeling the Choice of Telecommuting 2: A Case of the Preferred Impossible Alternative"
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Mokhtarian, Patricia L. and Ilan Salomon
"Modeling the Choice of Telecommuting: Setting the Context"
1993 UCTC 147

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"Modeling the Desire to Telecommute: The Importance of Attitudinal Factors in Behavioral Models"
1994 UCTC 284

Monismith, C.L., J. Lysmer, J. Sousa, and J.K. Hedrick
"Truck Pavement Interactions: Requisite Research"
1988 UCTC 48

Munshi, Kaivan and Edward C. Sullivan
"A Freight Network Model for Mode and Route Choice"
1989 UCTC 25

Novaco, Raymond W.
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1989 UCTC 16

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"Automobile Driving and Aggressive Behavior"
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Novaco, Raymond W. and Cheryl Collier
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Novaco, Raymond W., Daniel Stokols and Louis Milanesi
"Objective and Subjective Dimensions of Travel Impedance as Determinants of Commuting Stress"
1990 UCTC 30

Novaco, Raymond W., Wendy Kliewer and Alexander Broquet
"Home Environment Consequences of Commute Travel Impedance"
1991 UCTC 77

O'Regan, Katherine M.
"Space and Poverty: The Effect of Concentrated Poverty"
1992 UCTC 150

O'Regan, Katherine M. and John M. Quigley
"Family Networks and Youth Access to Jobs"
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O'Regan, Katherine M. and John M. Quigley
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"Teenage Employment and the Spatial Isolation of Minority and Poverty Households"
1995 UCTC 290

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"Work and Car Ownership Among Welfare Recipients"
1995 UCTC 19

Parker, John K.
"Meeting Land Transportation Needs of the Ports of Long Beach and Los Angeles"
1990 UCTC 35

* *not previously listed*

Parker, John K.
"The Consolidated Transportation Corridor: Surface Access to the Ports of Long Beach and Los Angeles" Final Report
1990 UCTC 137

Pendyala, Ram M., Konstadinos G. Goulias and Ryuichi Kitamura
"Impact of Telecommuting on Spatial and Temporal Patterns of Household Travel"
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Prosser, Neil A. and Stephen G. Ritchie
"Real-Time Knowledge-Based Integration of Freeway Surveillance Data"
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Ritchie, Stephen G.
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1990 UCTC 31

Ritchie, Stephen G. and Neil A. Prosser
"A Real-Time Expert System Approach to Freeway Incident Management"
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Rodier, Caroline J. and Robert A. Johnston
"Incentives for Local Governments to Implement Travel Demand Management Measures"
1995 UCTC 251

* **Rosenbloom, Sandra and Elizabeth Burns**
"Gender Differences in Commuter Travel in Tucson: Implications for Travel Demand Management Programs"
1993 UCTC 273

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"Why Working Women Drive Alone: Implications for Travel Reduction Programs"
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"An Emission Saved is an Emission Earned: An Empirical Study of Emission Banking for Light Duty Vehicle Manufacturers
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"Restricted Least Squares Subject to Monotonicity and Concavity Constraints"
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Sampath, Srikanth, Somitra Saxena and Patricia L. Mokhtarian
"The Effectiveness of Telecommuting as a Transportation Control Measure"
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Sands, Brian D.
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Schipper, Lee, Maria Josefina Figueroa, Lynn Price, and Molly Espey.
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Scott, Allen J. (editor)
"Electric Vehicle Manufacturing in Southern California: Current Developments, Future Prospects"
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* **Shaw, John**
"Transit-Based Housing and Residential Satisfaction: Review of the Literature and Methodological Approach"
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Shaw, Peter L.
"New Federal Transportation Financing and Legislative Directions: No New Taxes or $31 Billion a Year?"
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"Seaport-Surface Transportation Access and Air Quality"
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Shoup, Donald C.
"Cashing Out Employer-Paid Parking"
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"Cashing Out Employer-Paid Parking: A Precedent for Congestion Pricing?"
1993 UCTC 205

Shoup, Donald C.
"Cashing Out Employer-Paid Parking: An Opportunity to Reduce Minimum Parking Requirements"
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Shoup, Donald C. and Richard W. Willson
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Shoup, Donald C. and Richard W. Willson
"Employer-Paid Parking: The Problem and Proposed Solutions"
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Small, Kenneth A.
"Economics and Urban Transportation Policy in the United States"
1993 UCTC 219

Small, Kenneth A.
"Real Costs of Transportation and Influence of Pricing Policies"
1993 UCTC 187

Small, Kenneth A. and Camilla Kazimi
"On the Costs of Air Pollution from Motor Vehicles"
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Small, Kenneth A. and Shunfeng Song
"Population and Employment Densities: Structure and Change"
1993 UCTC 161

Small, Kenneth A. and Shunfeng Song
"Wasteful Commuting: A Resolution"
1992 UCTC 87

Song, Shunfeng
"Does Generalizing Density Functions Better Explain Urban Commuting? Some Evidence from the Los Angeles Region"
1994 UCTC 197

Song, Shunfeng
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1993 UCTC 196

Song, Shunfeng
"Monocentric and Polycentric Density Functions and Their Required Commutes"
1992 UCTC 198

Song, Shunfeng
"Spatial Structure and Urban Commuting"
1992 UCTC 117

Song, Shunfeng
"The Distribution of Population in a Contemporary Metropolitan Area: The Case of Orange County [A Replication]"
1991 UCTC 44

Southworth, Michael and Raymond Isaacs
"SmartMaps for Advanced Traveler Information Systems Based on User Characteristics" Final Report
1994 UCTC 236

* **Sperling, Daniel**
"Gearing Up for Electric Cars"
1994-95 UCTC 146

* **Sperling, Daniel**
"Prospects for Neighborhood Electric Vehicles"
1994 UCTC 261

Sperling, Daniel and Mark A. Delucchi
"Alternative Transportation Energy"
1993 UCTC 256

Sperling, Daniel and Mark A. Delucchi
"Is Methanol the Transportation Fuel of the Future?"
1989 UCTC 10

Sperling, Daniel and Mark A. Delucchi
"Transportation Energy Futures"
1989 UCTC 11

* **Sperling, Daniel, Winardi Setiawan and David Hungerford**
"The Target Market for Methanol Fuel"
1995 UCTC 168

Streeter, Walter C.
"The French Train à Grande Vitesse: Focusing on the TGV-Atlantique," CalSpeed Series
1992 UCTC 100

Swan, D.H., B.E.Dickinson and M.P. Arikara
"Proton Exchange Membrane Fuel Cell Characterization for Electric Vehicle Applications"
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Taniguchi, Mamoru
"High Speed Rail in Japan: A Review and Evaluation of Magnetic Levitation Trains," CalSpeed Series
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Taniguchi, Mamoru
"High Speed Rail in Japan: A Review and Evaluation of the Shinkansen Train," CalSpeed Series
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Taylor, Brian D.
"Unjust Equity: An Examination of California's Transportation Development Act"
1991 UCTC 64

Taylor, Brian D. and Paul M. Ong
"Racial and Ethnic Variations in Employment Access: An Examination of Residential Location and Commuting in Metropolitan Areas"
1993 UCTC 175

Tsuchida, Pamela and Linda Wilshusen
"Commute Behavior in Santa Cruz County," Studies on the Loma Prieta Earthquake, No. 4
1991 UCTC 155

Turrentine, Thomas and Daniel Sperling
"Theories of New Technology Purchase Decisions: The Case of Alternative Fuel Vehicles"
1992 UCTC 129

Turrentine, Thomas, Martin Lee-Gosselin, Kenneth Kurani, and Daniel Sperling
"A Study of Adaptive and Optimizing Behavior for Electric Vehicles Based on Interactive Simulation Games and Revealed Behavior of Electric Vehicle Owners"
1992 UCTC 130

Uhlaner, Carole J. and Seyoung Kim
"Designing and Implementing a Panel Study of Commuter Behavior: Lessons for Future Research"
1993 UCTC 145

Vaca, Erin
"Intercity Rail Ridership Forecasting and the Implementation of High-Speed Rail in California," Calspeed Series
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Vaca, Erin, Thomas Bordeaux, Daniel Leavitt, and Peter Hall
"Revenue and Ridership Potential for a High-Speed Rail Service in the San Francisco / Sacramento - Los Angeles Corridor: Technical Appendix" Calspeed Series
1994 UCTC 186

van Wissen, Leo J.
"A Model of Household Interactions in Activity Patterns"
1991 UCTC 15

van Wissen, Leo J. and Thomas F. Golob
"Simultaneous Equation Systems Involving Binary Choice Variables"
1990 UCTC 20

van Wissen, Leo J., Thomas F. Golob and Hank J. Meurs
"A Simultaneous Dynamic Travel and Activities Time Allocation Model"
1991 UCTC 21

Wachs, Martin
"Learning from Los Angeles: Transport, Urban Form, and Air Quality"
1993 UCTC 166

Wachs, Martin
"Policy Implications of Recent Behavioral Research in Transportation Demand Management"
1991 UCTC 165

Wachs, Martin
"Regulating Traffic by Controlling Land Use: The Southern California Experience"
1990 UCTC 12

Wachs, Martin
"Transportation Demand Management: Policy Implications of Recent Behavioral Research"
1990 UCTC 23

Wachs, Martin and Genevieve Giuliano
"Employee Transportation Coordinators: A New Profession in Southern California"
1992 UCTC 99

Wachs, Martin, Brian D. Taylor, Ned Levine, and Paul Ong
"The Changing Commute: A Case Study of the Jobs/Housing Relationship over Time"
1993 UCTC 167

Walls, W. David
"A Cointegration Rank Test of Market Linkages with an Application to the U.S. Natural Gas Industry"
1993 UCTC 201

Walls, W. David
"Competition and Prices in the Deregulated Gas Pipeline Network: A Multivariate Cointegration Analysis"
1993 UCTC 203

Walls, W. David
"Competition in a Network of Markets: The Natural Gas Industry"
1992 UCTC 122

Wang, Quanlu and Mark A. Delucchi
"Impacts of Electric Vehicles on Primary Energy Consumption and Petroleum Displacement"
1991 UCTC 6

Wang, Quanlu, Catherine Kling and Daniel Sperling
"Light-Duty Vehicle Exhaust Emission Control Cost Estimates Using a Part-Pricing Approach"
1993 UCTC 206

Wang, Quanlu, Catherine Kling and Daniel Sperling
"Marketable Credits for Light-Duty Vehicle Emission Control in California"
1992 UCTC 109

Wang, Quanlu, Daniel Sperling and Janis Olmstead
"Emission Control Cost-Effectiveness of Alternative-Fuel Vehicles"
1993 UCTC 227

Wang, Quanlu, Mark A. Delucchi and Daniel Sperling
"Emission Impacts of Electric Vehicles"
1990 UCTC 41

* **Washington, Simon and Randall Guensler**
"Modeling Air Quality for Conformity, Current Deficiencies, and New Directions"
1994 UCTC 98

Webber, Melvin M.
"The Joys of Automobility"
1991 UCTC 110

Willson, Richard W.
"Estimating the Travel and Parking Demand Effects of Employer-Paid Parking"
1992 UCTC 139

Willson, Richard W. and Donald Shoup
"Parking Subsidies and Travel Choices: Assessing the Evidence"
1990 UCTC 34

Willson, Richard W. and Elham Shirazi
"Transportation Demand Management: Policy Implications of Recent Behavioral Research" Symposium Summary
1991 UCTC 29

Yi, Kyongsu and J.K. Hedrick
"Active and Semi-active Heavy Truck Suspensions to Reduce Pavement Damage"
1989 UCTC 27

Yi, Kyongsu, Margaret Wargelin and J.K. Hedrick
"Dynamic Tire Force Control by Semi-Active Suspensions"
1992 UCTC 97

Yim, Youngbin
"Shopping Trips and Spatial Distribution of Food Stores"
1993 UCTC 125

Yim, Youngbin
"The Effects of Transportation Services on the Scale of Food Retailing"
1992 UCTC 112

Yim, Youngbin
"Travel Distance and Market Size in Food Retailing"
1992 UCTC 124

* *not previously listed*

Ph.D. DISSERTATIONS

* **Abdel-Aty, Mohamed Ahmed**
"Investigating the Factors Influencing Route Choice: New Approaches in Data Collection and Modeling"
1995 Diss 27

Adler, Jeffrey L.
"An Interactive Simulation Approach to Systematically Evaluate the Impacts of Real-Time Traffic Condition Information on Driver Behavioral Choice"
1993 Diss 18

* **Ben-Joseph, Eran**
"Subdivision Guidelines and Standards for Residential Streets and their Impact on Suburban Neighborhoods"
1995 Diss 29

Blankson, Charles
"A Study of the Los Angeles Coastal Transportation Corridor Specific Plan"
1989 Diss 10

Chatti, Karim
"Dynamic Analysis of Jointed Concrete Pavements Subjected to Moving Transient Loads" 1992
Diss 9

Chu, Xuehao
"Trip Scheduling and Economic Analysis of Transportation Policies"
1993 Diss 16

Dahlgren, Joy W.
"An Analysis of the Effectiveness of High Occupancy Vehicle Lanes"
1994 Diss 25

Delucchi, Mark A.
"Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity"
1991 Diss 6

Du, Yafeng
"Fleet Sizing and Empty Equipment Redistribution for Transportation Networks"
1993 Diss 11

Goulias, Konstadinos G.
"Long Term Forecasting with Dynamic Microsimulation" 1991
Diss 21

Guensler, Randall
"Vehicle Emission Rates and Average Vehicle Operating Speeds"
1994 Diss 19

Handy, Susan L.
"Regional versus Local Accessibility: Variations in Suburban Form and the Effects on Non-Work Travel"
1992 Diss 5

Kim, Seyoung
"Commuting Behavior of Two-Worker Households in the Los Angeles Metropolitan Area" 1993
Diss 22

Kurani, Kenneth Stuart
"Application of a Behavioral Market Segmentation Theory to New Transportation Fuels in New Zealand"
1992 Diss 15

Kwan, Mei-Po
"GISICAS: A GIS-Interfaced Computational-Process Model for Activity Scheduling in Advanced Traveler Information Systems"
1994 Diss 24

Levine, Jonathan Charles
"Employment Suburbanization and the Journey to Work"
1990 Diss 12

O'Regan, Katherine M.
"Social Networks and Low Wage Labor Markets"
1990 Diss 3

Pendyala, Ram Mohan
"Causal Modeling of Travel Behavior Using Simultaneous Equations Systems: A Critical Examination"
1993 Diss 14

Rubin, Jonathan D.
"Marketable Emission Permit Trading and Banking for Light-Duty Vehicle Manufacturers and Fuel Suppliers"
1993 Diss 13

* **Shaw, John**
"Transit, Density, and Residential Satisfaction"
1994 Diss 28

Smith, James E.
"A Comparative Study of Entrepreneurial Strategies among African-American and Latino Truckers in the Los Angeles and Long Beach Ports"
1993 Diss 23

Song, Shunfeng
"Spatial Structure and Urban Commuting"
1992 Diss 8

Souleyrette, Reginald R. II
"Transportation Services and Innovation in the Housing Industry: A Study of the Relations Between Transportation and Production"
1989 Diss 7

Taylor, Brian D.
"When Finance Leads Planning: The Influence of Public Finance on Transportation Planning and Policy in California"
1992 Diss 1

Turrentine, Thomas
"Lifestyle and Life Politics: Towards a Green Car Market"
1995 Diss 26

Walls, W. David
"Open Access Transportation, Network Competition, and Market Integration in the Natural Gas Pipeline Industry"
1992 Diss 17

Wang, Quanlu
"The Use of a Marketable Permit System for Light-Duty Vehicle Emission Control"
1992 Diss 2

Willson, Richard W.
"Employer Parking Subsidies, Mode Choice, and Public Policy"
1991 Diss 4

Yim, Youngbin
"The Relationship between Transportation Services and Urban Activities: The Food Retail Distribution Case"
1990 Diss 20

VIDEOS

Jacobs, Allan B., Yodan Y. Rofé and Elizabeth S. Macdonald
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