

# Land Use–Transportation Scenarios and Future Vehicle Travel and Land Consumption

## A Meta-Analysis

Keith Bartholomew and Reid Ewing

**Problem:** Since the late 1980s, U.S. metropolitan regions have increasingly engaged in a style of land use–transportation scenario planning that merges techniques borrowed from military and business strategic planning with long-range transportation systems planning and project-level alternatives analysis. Aside from occasional anecdotal descriptions, the effectiveness of such approaches in generating compact growth plans has not been evaluated comprehensively.

**Purpose:** We analyzed a wide range of scenario planning studies to determine how far compact growth scenarios are predicted to reduce vehicular travel below existing trends.

**Methods:** Using hierarchical modeling, we developed a regional vehicle-miles-traveled (VMT) model based on 85 scenarios in 23 planning studies from 18 metropolitan areas.

**Results and conclusions:** Using coefficients from this model, we conservatively estimate that compact growth scenarios reduce VMT in 2050 by 17% below scenarios assuming a continuation of existing trends.

**Takeaway for practice:** Existing transportation models remain largely insensitive to changes in land use and transportation policy. This must change for scenario planning to achieve its full potential. In the future, scenario planning should incorporate the best current knowledge about how global economic and environmental trends will affect regions.

**Keywords:** scenario planning, land use, transportation, meta-analysis, hierarchical model

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Regional planning in the United States is back. A common subject among practitioners and policymakers in the 1970s (Bartholomew, 2007b), regional planning suffered a major contraction during the new federalism of the Reagan era (McDowell, 1984). However, by the time President George H. W. Bush was talking about “the vision thing” (Apple, 1988), U.S. metropolitan regions had started seeking visions of their own. Over the course of the next decade and a half, planners and citizens increasingly articulated priorities and values to help shape the futures of their metropolitan regions. One technique these visioning exercises commonly employ is land use–transportation scenario planning.

This article traces the rise of metropolitan scenario planning in the 1990s and early 2000s, and conducts a meta-analysis of scenarios extracted from these studies. Metropolitan scenario analysis is largely motivated by a desire to reduce vehicular travel below what would occur under a continuation of current trends. We ask whether the alternative scenarios developed, tested, and adopted by these processes meet these expectations. We find that they do. Coefficients drawn from the meta-analysis suggests that a typical compact land use–transportation scenario could, by 2050, produce 17% fewer vehicle miles traveled (VMT) than trend conditions at the same population and employment

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levels. This probably is a conservative estimate due to substantial shortcomings of current transportation models, which constrain scenario planning as a tool for assessing potential futures and developing effective policy responses.

## Asking “What If?”

Humans have always pondered the future and wondered how they might be able to anticipate change, particularly in areas over which they have little control. Scenario planning was developed to address those kinds of uncertainties (Schwartz, 1991).

A scenario is “an internally consistent view of what the future might turn out to be—not a forecast, but one possible future outcome” (Porter, 1985, p. 446). Fundamentally, scenarios are stories about the future, with beginnings, middles, and endings (Ogilvy, 2002), and the word *scenario* derives its meaning for planning from its use in Hollywood screenwriting (Godet, 2001). Scenarios need not, and indeed cannot, predict unerringly. Rather, each should present a vision of the future that is plausible in light of known information (Ringland, 2002).

Scenario planning defines a range of possible future conditions. The scenarios should reflect the forces that are most important and most uncertain, locally and at a macro scale (Schwartz, 1991), and conceiving, crafting, and evaluating them should identify one or more appropriate courses of action (Georgantzis & Acar, 1995). Hence, through this process, the wide-open question of what the future might bring can be narrowed down to a more manageable set of possibilities.

The military roots of scenario planning are evident in writings that date back as far as Sun Tsu’s fourth century treatise, *The Art of War* (Giles, 1910). More recently, the RAND Corporation used scenario planning in the 1950s to assess a range of potential nuclear conflict situations (Ringland, 1998). Corporate strategic planners then began making use of the technique to analyze economic conditions, most famously in the Royal Dutch/Shell study that effectively anticipated the 1973 Organization of the Petroleum Exporting Countries (OPEC) oil embargo (Schwartz, 1991).

## Scenario Planning by Metropolitan Planning Organizations

The land use–transportation scenario planning practice that emerged in the 1990s essentially grafted the military and business approaches onto to the more customary planning structures of the continuing, cooperative, and comprehensive (3C) process required by the Federal Aid Highway Act of 1962 and the environmental impact reporting requirements of the National Environmental Policy

Act (NEPA; Bartholomew, 2007a). The resulting hybrid infuses the more traditional alternatives analysis with a new set of variables drawn from land use and transportation demand management.

The motivation behind the merger was a growing dissatisfaction with the traditional practice of using a single allocation of household and employment growth for transportation modeling and forecasting (Bartholomew, 2005b), since this approach ignored well-established relationships between transportation investments and land use patterns. To incorporate those relationships, several leading transportation studies in the late 1980s and early 1990s began using land use as an input variable (1000 Friends of Oregon, 1997; DeCorla-Sousa, 1992; Montgomery County, Maryland, 1989). Although earlier academic studies pioneered the use of this approach (e.g., Edwards & Schofer, 1976; Weiner, 1999), the later projects formalized the method and brought it into public planning and decision making. Assisted by substantially expanded computing capacity and methods, the practice expanded substantially over the following two decades, becoming common enough to be considered state-of-the-practice (Ewing, 2007). Many agencies and firms were involved in this growth; however, the work of Peter Calthorpe and John Fregonese was particularly instrumental in popularizing the technique (e.g., Calthorpe & Fulton, 2001; Coalition for Utah’s Future, n.d.; Envision Central Texas, 2003; Southern California Association of Governments, 2003).

The typical land use–transportation scenario planning process compares one or more alternative future planning scenarios to a trend scenario. In the trend scenario, urban development and transportation investment patterns of the recent past are assumed to continue to the planning horizon 20 to 50 years in the future and the impacts of this on the region and its transportation system are assessed. This is followed by the formulation of one or more alternative futures that differ from the trend with respect to land use and transportation. Compared to the trend scenario, the alternative future planning scenarios usually have higher gross densities, mix land uses to a greater extent, and/or channel more development into urban centers. They may incorporate a variety of transportation infrastructure investments and pricing policies. One alternative may invest more in transit lines, another more in high occupancy vehicle lanes. These alternative scenarios are then assessed for their impacts using the same travel forecasting models and set of outcome measures that were used to analyze the trend scenario. The outcomes forecasted almost always include VMT. The scenarios are then compared, and a plan scenario is usually adopted that will generate less VMT and other social costs than will a continuation of existing trends.

A leading example of land use–transportation scenario planning comes from the Sacramento, California, region. Concerned about dispersed future growth patterns, housing, transportation, and air quality, the Sacramento Area Council of Governments (SACOG) launched the Sacramento Region Blueprint transportation and land use study to craft a future growth strategy for the region (SACOG, 2007). Scenarios were constructed using a bottom-up process, starting at the neighborhood level. At a series of 25 neighborhood workshops, residents were shown future “business as usual” development scenarios for their neighborhoods. Then they were asked to develop a series of alternative scenarios, which were fed into a version of the PLACE<sup>3</sup>S GIS modeling program (see California Energy Commission, Oregon Department of Energy, & Washington State Energy Office, 1996), which provided real-time assessments of each scenario’s land use and transportation impacts.

Based on the neighborhood scenarios, four countywide scenarios (a trend scenario plus three alternatives that assumed different growth rates, land use mixes, housing types, densities, and infill/redevelopment proportions) were crafted for each of the region’s six counties. These scenarios were analyzed for their land use and transportation impacts, and the results were presented at countywide workshops. Feedback from the countywide workshops provided the basis for creating four regional scenarios. These scenarios then were discussed and revised at regional workshops, leading to SACOG’s adoption of a Preferred Blueprint Scenario, which has a substantially smaller urban footprint and 26% fewer VMT than the trend scenario at the planning horizon (see Figure 1 and Table 1). The preferred blueprint scenario is now being implemented through amendments to local government land use plans and the region’s new long-range transportation plan (SACOG, 2008).

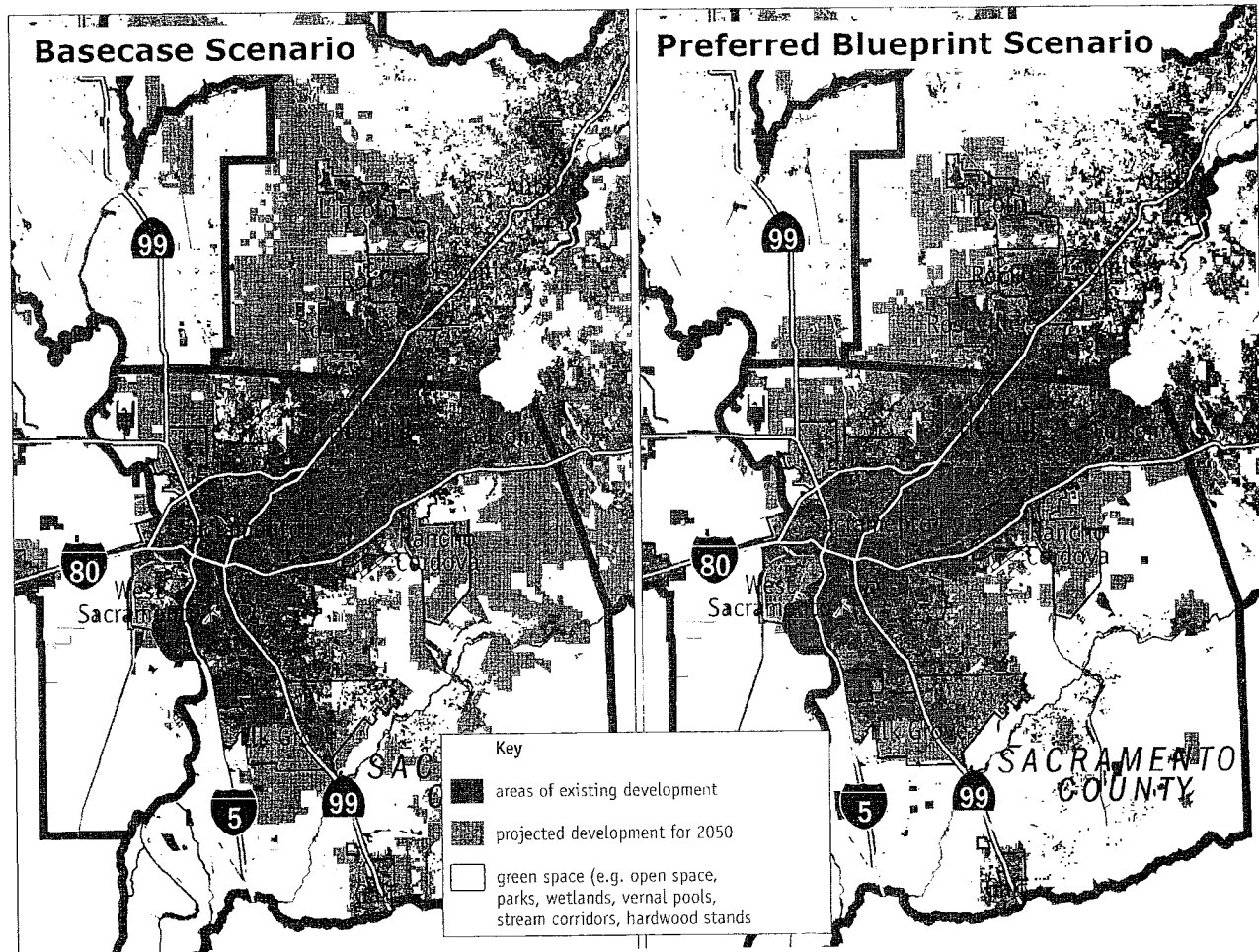


Figure 1. Urban footprints of base case and preferred scenarios from the *Sacramento Area Council of Governments, Sacramento Region Blueprint Transportation–Land Use Study* (SACOG, 2004b).

Table 1. Selected data for scenarios from the Sacramento Region Blueprint Transportation–Land Use Study.

Scenarios	% Single family housing	% Housing growth through infill	% Trips by auto	% Trips by transit	% Trips by walk/bike	Daily VMT per household
A: Business as usual (trend)	75.0	27.0	93.7	0.8	5.5	47.2
B: Higher housing densities than A, with growth focused at the urban fringe	67.0	39.0	83.2	4.0	12.7	37.6
C: Higher housing densities than A, with growth focused on central infill sites	65.0	38.3	81.8	4.8	13.4	36.7
D: Higher housing and employment densities, with growth focused on central infill sites	64.0	44.0	79.9	4.8	15.3	35.7
Preferred scenario	65.0	41.0	83.9	3.3	12.9	34.9

Source: SACOG (2004a, 2007).

### Research Method: Meta-Analysis

In a 2004 survey, Bartholomew identified 80 scenario planning projects completed between 1989 and 2003 that had used land use as a variable in some fashion (Bartholomew, 2005b). He sent an open-ended survey to the planning

directors of the 658 member organizations in the National Association of Regional Councils (NARC) and additional surveys to members of the Association of Metropolitan Planning Organizations that were not also NARC members. One-hundred fifty-two recipients responded, 45% of whom indicated that they had direct information on one



Figure 2. Locations of the scenario planning projects studied.

or more scenario planning projects, or knew of someone who might. Bartholomew then sent follow-up surveys to these 69 persons or organizations identified by respondents to the first survey, and supplemented responses from the two surveys with emails, telephone calls, and internet searches, resulting in an initial data pool of 153 projects.

Bartholomew (2005b) subjected this initial pool to a threshold analysis to determine whether the projects did in fact utilize land use–transportation scenario planning techniques. Projects were considered to have used these techniques if future land use inputs (i.e., the spatial allocation, density, heterogeneity, or design of growth) varied across scenarios. If they held such conditions static they were excluded from the data set. This left a total of 80 projects in the study. These projects are concentrated in large metropolitan areas along the east and west coasts (Figure 2). Most also occurred toward the end of the period studied (Figure 3), suggesting a trend toward greater use of scenario planning techniques over time.<sup>1</sup>

Most of the studies tested three or four scenarios (including a trend scenario) that varied in density, mix, and arrangement of future land uses. Half of the studies also tested alternative transportation infrastructure investments. Twelve incorporated a transportation pricing element. Three quarters of the studies evaluated scenarios for transportation impacts; over half for impacts on open space and resource lands; 33 for impacts on criteria air pollutants; 18 for impacts on fuel use; and 10 for greenhouse gas

emissions (Bartholomew, 2005b). Notwithstanding this variation in scenario elements and indices, a consistent set of objectives appeared to motivate the agencies doing the studies: sponsors of all but 6 of the 80 projects said they engaged in scenario planning primarily to reduce land consumption and slow the increase in automobile use (Bartholomew, 2005b). How well did they meet these objectives? We used meta-analysis to answer the question.

Meta-analysis is “the statistical analysis of a large collection of results from individual studies for the purpose of integrating the findings” (Glass, 1976, p. 3). By combining the outcomes from numerous studies, meta-analysis allows overall assessment of an approach or method and facilitates deeper investigation into the relationship between particular variables than could be afforded through a single study (Littell, Corcoran, & Pillai, 2008). The technique is thus appropriate for evaluating scenario planning practice in general, and the relationship between variables that represent land consumption and automobile use. Despite being relatively new (Smith & Glass, 1977), use of meta-analytic methods has increased rapidly since the mid 1990s (Littell et al., 2008) though few urban planning studies have made use of it (Ewing, 2007).

Lipsey and Wilson (2000) list five conditions for conducting meta-analysis properly: the subject studies must (1) be empirical (i.e., not theoretical papers, research reviews, etc.), (2) be conceptually comparable, (3) contain quantitative data that (4) can be encoded, and (5) be configured in

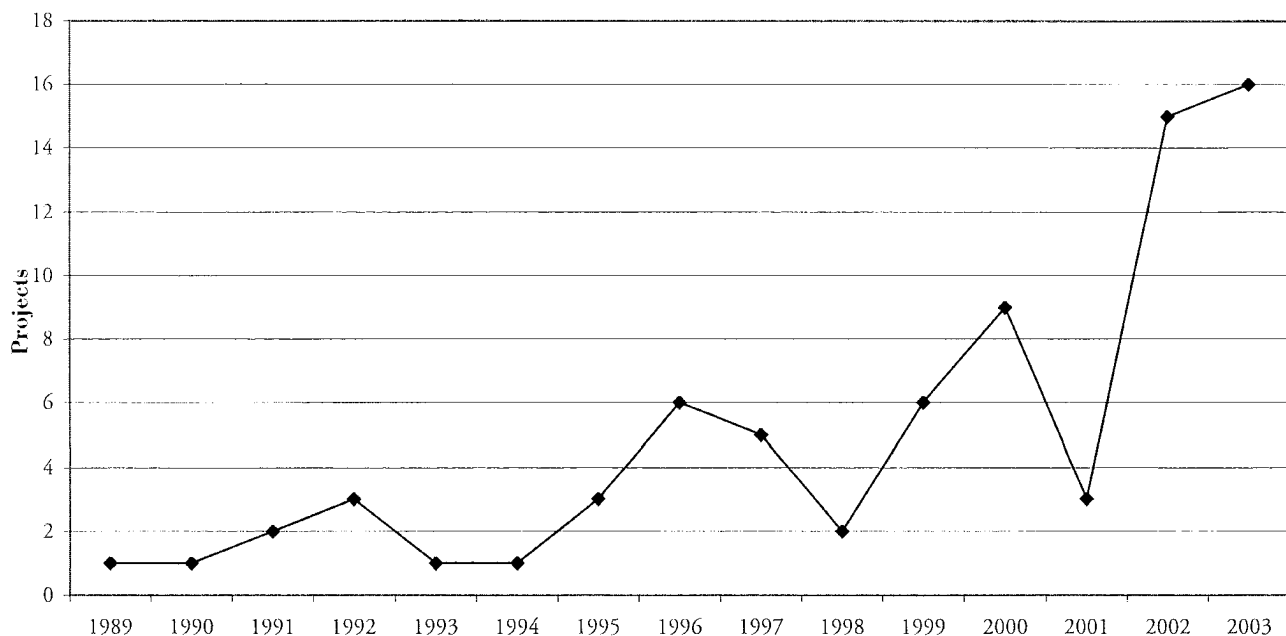


Figure 3. Number of scenario planning projects completed each year, 1989–2003.

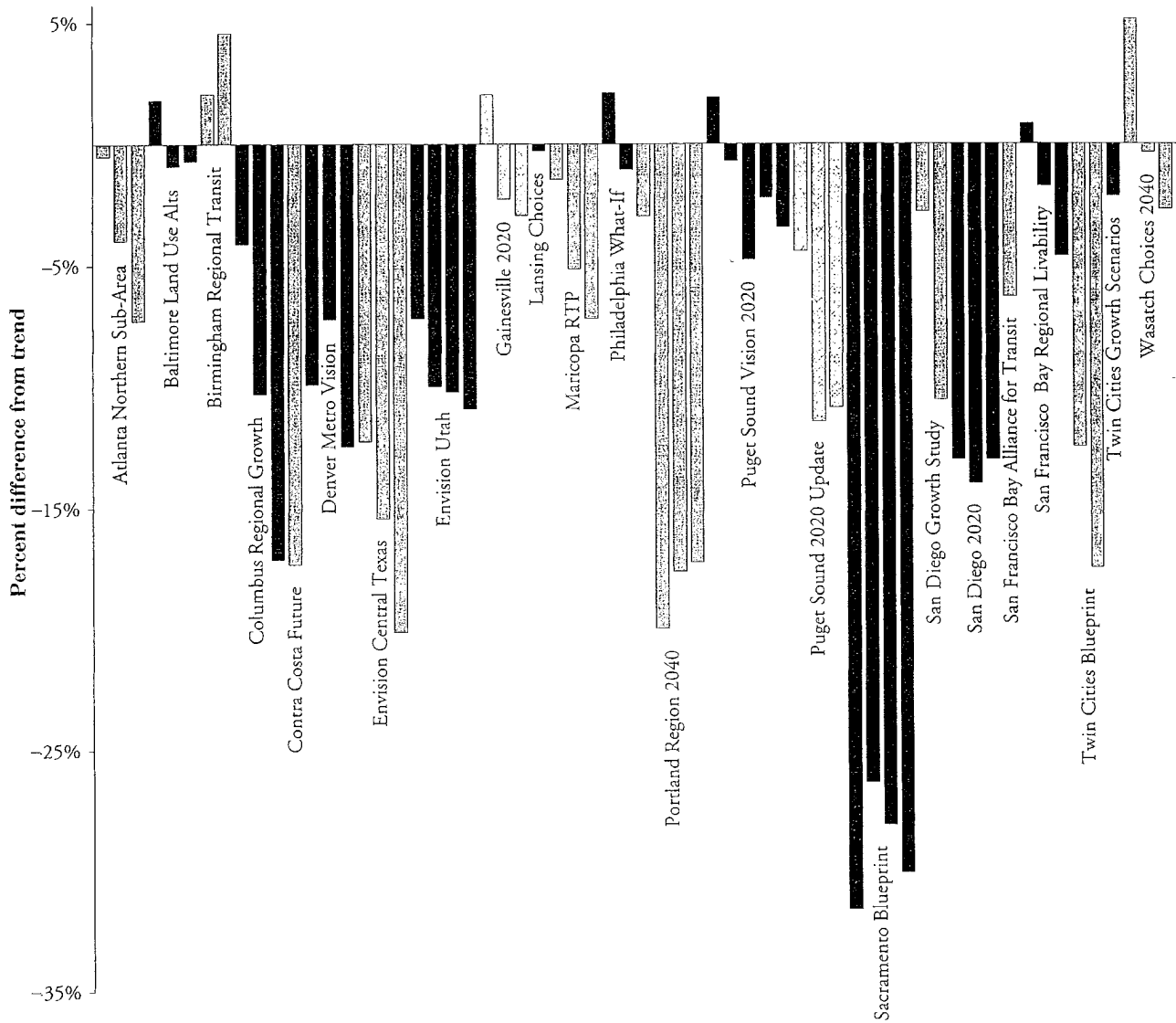


Figure 4. Percent difference in VMT from trend for 62 scenarios.

statistical forms. Although scenario planning study results are simulation outputs, not empirical observations, they are based on models that are empirically derived; the other four conditions are met, as outlined in the next section.

### Analysis

From the initial database of 80 studies, we identified a subset of 23 studies, selecting those that (a) are at a regional scale, (b) have consistent population and employment projections across scenarios, and (c) provide complete data

on regional density and VMT, the two variables most closely related to land consumption and automobile use. Together, these studies include a total of 85 scenarios: one trend scenario in each of the 23 studies, plus 62 alternative planning scenarios that can be compared to trend. The percentage of difference in regional VMT for each planning scenario relative to its respective trend scenario is shown in Figure 4. Each bar represents a different planning scenario; the value shown is the percentage difference between that scenario and the study's trend scenario. Across studies, regional VMT under the alternative scenarios averages only 7.9% less than under their regions' trend scenarios,

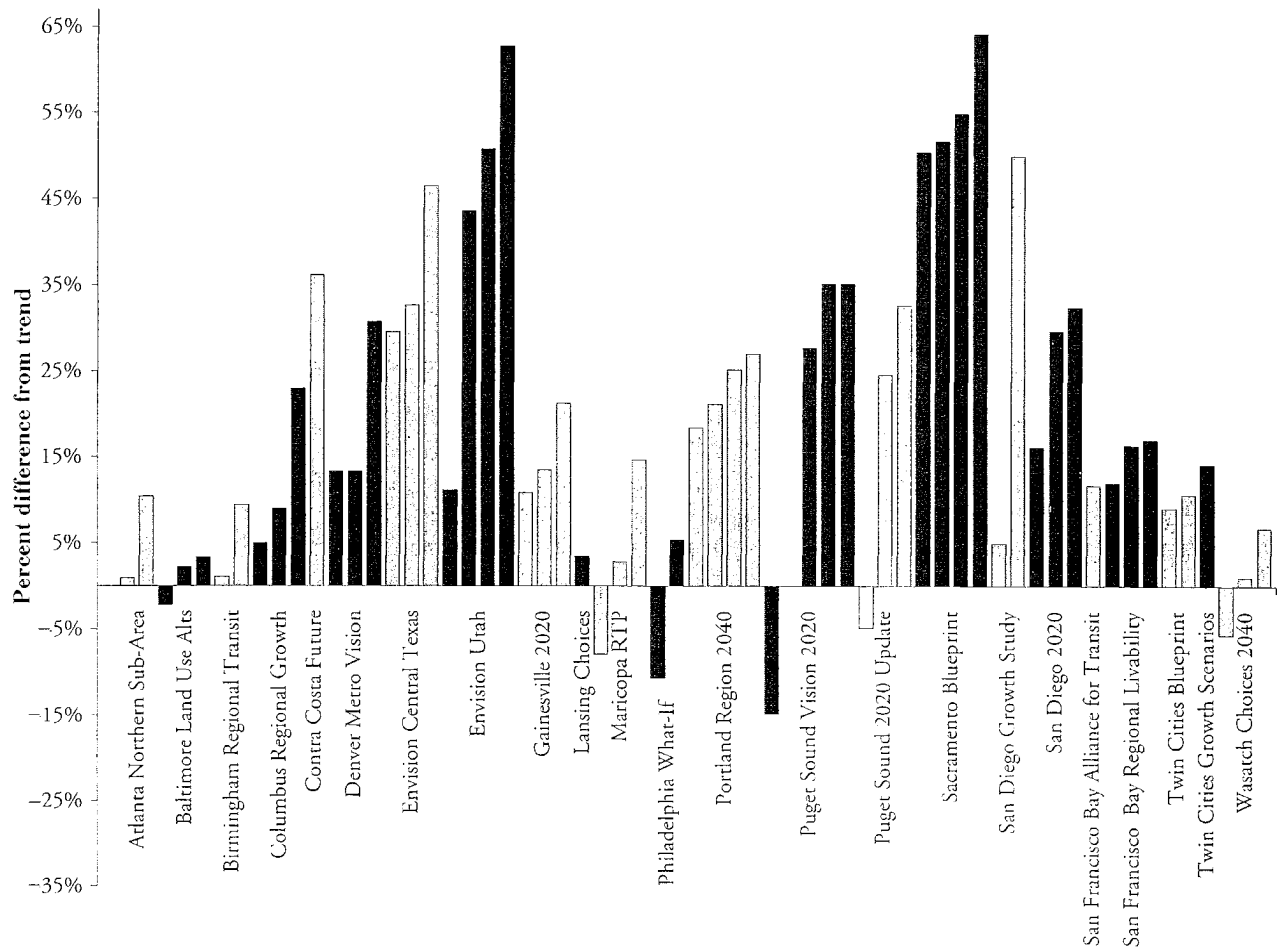


Figure 5. Percent difference in density from trend for 62 scenarios.

a modest result, though the alternatives range from 5.2% above the regional trend to 31.7% below it.

The following factors may be influencing this variation in VMT:

- if land use under the alternative scenario is denser, more mixed, and more concentrated in urban centers, the difference in VMT will be bigger;
- if, under the alternative scenario the planning time horizon is longer, the difference in VMT will be bigger;
- if, under the alternative scenario the rate of growth is higher, the difference in VMT will be bigger;
- if more transportation funds will be reallocated to transit under the alternative scenario, the difference in VMT will be bigger; and
- if the alternative scenario includes travel demand management strategies and thus increases the cost of automobile travel, the difference in VMT will be bigger.

We employed several techniques to analyze these factors, ranging from simple scatterplots to advanced multilevel modeling.

### Density

Compact regions tend to have lower automobile use per capita and greater use of alternative transportation modes than do sprawling areas (Ewing, Pendall, & Chen, 2003; Newman & Kenworthy, 1989). While a few of the planning scenarios analyzed here are more dispersed than the trend, the great majority are more compact (Figure 5). The mean increase in density is 18.7%. As with VMT, there is wide variation across scenarios, ranging from a 14.8% density reduction to an increase in density of 64.3%.

The density and VMT differences from trend for each scenario are plotted against one another in Figure 6. As anticipated, this simple scatterplot shows that higher

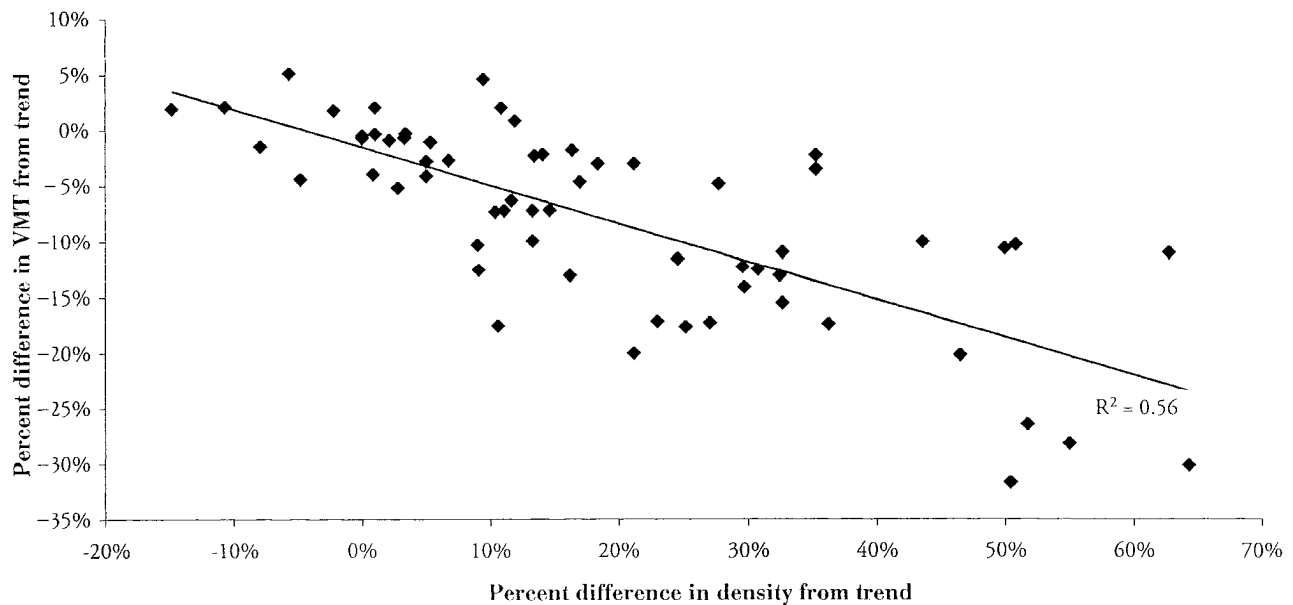


Figure 6. Percent difference in VMT from trend versus percent difference in density from trend for 62 scenarios.

densities are associated with larger differences of VMT from the trend. While much of the variation in VMT may be accounted for by higher densities, the scatter around the regression line in Figure 6 suggests that other factors are at work as well.

### Planning Horizon and Rate of Growth

Scenario planning studies also vary in the time horizons studied (from 20 to 50 years) and the rates of growth assumed (from 0.4% to 2.44% per year). We use the total *increment of growth* as the measure for this analysis, as it incorporates both planning horizon and growth rate. Figure 7 plots the percentage by which each planning scenario's VMT differs from trend against the percentage of metropolitan population growth during the planning period (from base year to target year). Again, the results indicate correlation. The greater the increment of population growth that can be redirected in a planning scenario, the greater the difference in VMT. The scatter around the trend line in Figure 7 is much more widely distributed than in the density scatterplot, indicating that many factors other than planning horizons and growth rates are also in play. The instances of multiple VMT values associated with the same value of population growth represent different scenarios from the same study, each containing different land use and transportation elements, but using the same

population assumptions. Because these scenarios all come from the same region, they are not truly independent of each other. Scenarios from a single region will share many economic, geographic, and other characteristics that are not shared between scenarios from different regions. Analysis across the multiple levels of variance requires the use of a hierarchical model, as discussed below.

### Other Factors

The literature suggests that the remaining factors listed above (mixed use, centeredness, transportation investments, and demand management) may be important in explaining variations in VMT (Ewing et al., 2003). Lacking numeric data on these variables, we relied on narrative descriptions in study documents to create dichotomous dummy variables. One dummy variable was used to distinguish between scenarios that mix and balance residential and commercial land uses to a high degree (assigned a value of 1) and scenarios that mix and balance land uses only to the same degree as in the trend scenario (assigned a value of 0). Similar dummy variables were created for centeredness, coordinated transportation investment, and demand management policies.

### Multilevel Meta-Analysis

Scenarios are nested within regions, with the typical study having two or three scenarios in addition to the trend.

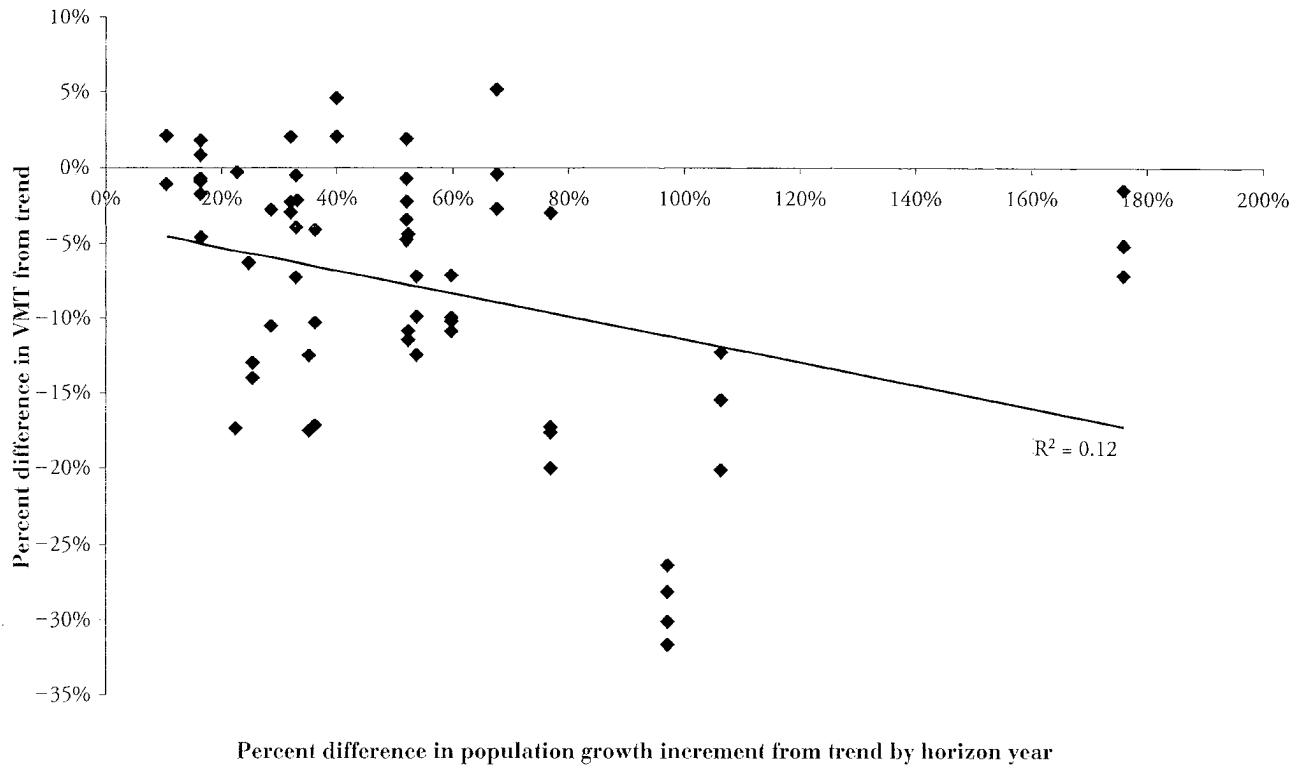


Figure 7. Percent difference in VMT from trend versus percent difference in population growth increment from trend by horizon year for 62 scenarios.

As outlined above, scenarios for the same region are not independent of each other, as they share the characteristics of their respective regions. Conventional ordinary least squares (OLS) regression analysis cannot account for this lack of independence. For such region-level characteristics, OLS underestimates standard errors of regression coefficients and produces inefficient regression coefficient estimates.

To overcome these limitations, a hierarchical or multi-level modeling technique is required. A hierarchical model accounts for the interdependence of scenarios in the same region and produces more accurate regression coefficient and standard error estimates (Raudenbush & Byrk, 2002). Within a hierarchical model, each level in the data structure is represented by its own submodel. Each submodel captures the structural relations occurring at that level and the residual variability at that level. To represent such complex data structures, this study relied on HLM 6 (Hierarchical Linear and Nonlinear Modeling) software.

The dependent variable is the percentage of difference in VMT between the planning scenario and the trend scenario. The following independent variables are specific

to scenarios. *Percentage of density difference* is a continuous variable measuring the percentage density difference between a planning scenario and its respective trend scenario. *Infill/compactness* is a dichotomous (dummy) variable indicating whether a scenario focused growth into central areas. *Mixed use* is a dichotomous variable indicating whether a scenario emphasized land use mixing.

The following independent variables are common to all scenarios in a region, but may differ across regions and studies. *Population growth increment* is a continuous variable measuring the percentage growth in population between base and forecast years. *Coordinated transportation investment* is a dichotomous variable indicating whether transportation system elements varied across scenarios. *Pricing policies* is a dichotomous variable indicating whether scenarios contained elements that would affect the cost of driving or using transit.

The best-fit model is presented in Table 2. The model was estimated with no constant term (as a regression through the origin); hence, if nothing changes from trend, there should be no change in regional VMT. The model indicates

three significant influences on VMT: infill/compact development, mixed land use, and the population growth increment. All three are associated with decreases in VMT relative to trend. The density variable has the expected sign but falls short of significance. Coordinated transportation investment also has the expected sign but is not significant.

We find the elasticity of VMT with respect to population growth to be  $-0.068$ , meaning that VMT per capita falls below trend by 0.068% for every 1% increase in population over the base year. This does not argue for population growth, but simply indicates that regions that are growing rapidly have more opportunity to evolve toward a compact urban form than do regions that are growing slowly.

We also find that infill and compact development and mixing of land uses are both inversely related to VMT at the 0.05 probability level. Their coefficients predict that our definition of infill and compact development pushes regional VMT 1.5% below trend, and our definition of mixed-use development pushes regional VMT 4.6% below trend, after controlling for other variables.

While the regional density variable is not statistically significant, our best guess at the elasticity of VMT with respect to regional density is  $-0.075$ , meaning that VMT would fall 0.075% below trend for every 1% increase in population density. This is a little higher than the elasticity estimates reported in some disaggregate travel studies (e.g., Ewing & Cervero, 2001). Likely, the density variable is soaking up some of the effect of other D variables (diversity, design, and distance to transit) that are not adequately represented in the simulations.

The coordinated transportation investment variable is also not statistically significant. Again, our best estimate of the impact of coordinated transportation investment, controlling for other variables, is that it reduces regional VMT 2.1% below the trend.

The modeled effect of imposing transportation pricing policies is positive, implying that transportation pricing would raise VMT above the trend without such policies. This counterintuitive result might be explained by confounding variables and the small sample of studies that actually test pricing policies. However, the literature does provide some support for this result. Increasing the price of driving (roads or parking) in only one part of a metropolitan region or along only a limited number of corridors could shift future economic and development activity away from the priced areas toward areas that are unpriced (Deakin, Harvey, Pozdena, & Yarema, 1996), and this could increase overall driving and VMT. On the other hand, using an areawide pricing approach would likely concentrate future growth as households and businesses sought to reduce or avoid the extra costs (Komanoff, 1997).

Table 2. Results from hierarchical model predicting percent difference in planning scenario VMT relative to trend for 62 scenarios.

	Coefficient	<i>t</i>	<i>p</i>
% density difference			
(above trend)	-0.074	-1.48	0.15
Infill/compact (yes = 1)	-1.50	-2.13	0.04
Mixed use (yes = 1)	-4.64	-2.15	0.04
Population growth increment			
(% over base)	-0.068	-2.02	0.06
Coordinated transportation investment (yes = 1)	-2.12	-1.01	0.33

There is some simulation-based evidence supporting these conclusions (Gupta, Kalmanje, & Kockelman, 2006).

We can estimate the effect of a shift to compact development on VMT relative to the trend by plugging realistic numbers into the best-fit model in Table 2. If such a shift increases average regional density by 50% in 2050,<sup>2</sup> emphasizes infill, mixes land uses to a high degree, and has coordinated transportation investments, the model predicts that VMT would be 17% lower than projected trend conditions over the 43 years to 2050 at an average metropolitan growth rate of 1.3% annually.<sup>3</sup>

Although 17% is, admittedly, not a very large number, it is very likely a conservative estimate for two reasons. First, limitations in the models and methods used to generate the data for the meta-analysis likely underestimated the degree to which the land use strategies in many of the scenarios would reduce travel. Second, all of the scenarios assumed the continuation of national and global economic and environmental trends, but it is very possible that these conditions will change in ways that would make continued reliance on personal vehicle travel less tenable, increasing the difference between the planning and trend scenarios. Both limitations are discussed below.

## Analytical Limitations

### Models and Methods

With one exception, all of the models used in the scenario projects were some version of the standard four-step Urban Transportation Modeling System (UTMS). UTMS models, initially created to estimate demand for large-scale highway facilities (Pas, 1995), are generally insensitive to the impacts that land use variables can have

on travel mode and trip length. A recent survey of local and regional governments in California identified a number of features in current UTMS-based modeling structures and practices that limit their ability to evaluate smart-growth land use strategies. These features include the inability to model trip-chaining behavior; the total neglect of walk and bike trips; the use of fixed vehicle trip rates by land use type; the failure to consider the effect of building, street, and sidewalk layout; the use of large travel analysis zones that blur land use patterns; and the failure of transportation system performance to feed back to land use allocation decisions (DKS Associates & University of California [DKS], 2007). These shortcomings are echoed in other recent critiques of modeling systems and practices (Beimborn, Kennedy, & Schaefer, n.d.; Cervero, 2006; Committee for Determination of the State of the Practice in Metropolitan Area Travel Forecasting, Transportation Research Board [TRB], 2007; Johnston, 2004; Walters, Ewing, & Schroeer, 2000).

Most critics identify advanced modeling (such as tour-based modeling, activity-based modeling, and supply-side modeling), or microsimulation modeling as preferred remedies for these problems. While these techniques hold great promise, they have yet to be deployed widely; in a recent count, activity-based models were in use or under development by only 11 of the nation's 385 metropolitan planning organizations (MPOs; TRB, 2007, p. 101). Post-processing models using travel elasticities are a simpler, cheaper way to overcome the limitations of the four-step models. Although more commonly used to estimate mobile emissions of criteria air pollutants (Cervero, 2006), some MPOs are using post-processing to predict factors needed for land use–transportation scenario analysis, including land use density, diversity, design, destination, and distance to transit (DKS, 2007).<sup>4</sup> Yet, of the 23 projects in the meta-analysis only three reported using some type of post-processing technique to incorporate any of these factors. Interestingly, the three projects using post-processing techniques (Shaping Our Future, Sacramento Blueprint, and Portland Metro's Region 2040) are among those for which future VMT is furthest below trend (see Figure 4), suggesting that perhaps the use of those techniques is at least partially responsible.

This raises broader questions about the role that the different modeling structures and techniques played in the results of our hierarchical model (Table 2). Unfortunately, we were limited by what was reported in project documentation, and collected only categorical information on modeling for the meta-analysis. In addition to the three projects that used post-processing techniques, 12 made use of GIS to assist with scenario building, 3 used a land use

model to develop spatial allocations of population and employment (only 1 used the land use model interactively with the travel demand model), and 1 project used a sketch model<sup>5</sup> instead of a traditional UTMS model.

The literature is replete with analyses showing the role that differences in modeling techniques can play on forecasted outcomes within a single region (e.g., 1000 Friends of Oregon, 1991; Johnston, Rodier, Abraham, & Hunt, 2001; Rodier, Johnston, & Abraham, 2002; Webster, Bly, & Paulley, 1988). In our meta-analysis, each scenario project represents a potentially different modeling system applied to a different set of geographic, demographic, economic, and policy circumstances. Clearly, modeling structure and technique might be confounding variables not represented in the meta-analysis model.

### Broader Economic and Environmental Conditions

Business-style scenario planning focuses on influences that extend beyond the control of the agency doing the analysis (Smith, 2007) to articulate a range of risks and to develop a commensurate range of responses. When the technique was grafted onto 3C and NEPA-style processes, however, this dimension was suppressed in favor of transportation agencies' more traditional approach, which varies only the transportation investments and land use policies arguably under local and regional governmental control. There are, of course, many other factors that influence travel choices and patterns, including the potential effects of large-scale economic and environmental issues like peak oil and climate change.

**Peak Oil.** Large-scale discoveries of new oil reserves have declined steadily since the mid-1960s, while oil production and consumption have increased substantially (IHS Energy, 2006). Because of this mismatch, many observers anticipate a peak in oil production, followed by a long period of decline. Production peaking occurs because of the natural preference to mine the largest and most accessible, and hence least costly, sources first. As quantities from those sources diminish, production levels can be maintained only by mining smaller, less accessible sources, causing costs per unit of output to increase. Eventually, production levels become too costly to maintain and overall production declines. This phenomenon has already occurred at a national level in countries around the world, with peaks in the lower 48 United States, Alaska, and Mexico occurring in 1971, 1989, and 2004, respectively (Zittel & Schindler, 2007).

Researchers' estimates of when the global peak will occur vary widely, with some asserting that it has already occurred, and others projecting it early in the next century.

A 2000 scenario analysis by the U.S. Energy Information Administration shows a range between 2021 and 2112 (Wood & Long, 2000). A more recent analysis by the U.S. General Accounting Office (GAO, 2007) puts the date sometime before 2040, which is within the timeframe of many of the scenario projects studied for this article. The variation in the projections is driven by the range and number of factors incorporated into the analyses, including estimated oil reserves, economic growth, technological innovations, and demand reductions in response to price increases. Regardless of the peaking date, all the analyses anticipate that oil prices will increase significantly; the only real debate is how fast (Haubrich & Meyer, 2007).

A recent multivariate analysis of travel and economic data in 84 U.S. urban areas between 1985 and 2005 found an elasticity of VMT with respect to fuel price of  $-0.17$ , meaning that for every 1% increase in the price of fuel, VMT decreased by 0.17% (Ewing, Bartholomew, Winkelman, Walters, & Chen, 2008, p. 123). Given that land use change lags well behind changes in the price of vehicle fuels (GAO, 2007, pp. 11–12), it is likely that this elasticity understates the possible impact of future fuel prices on travel.

Portland, Oregon's LUTRAQ study provides an example of the how incorporating fuel price increases into a scenario analysis might influence project outcomes. The study assessed relative impacts from three scenarios: (1) a trend scenario that assumed the continuation of recent development practices and transportation investments, including a new highway, (2) the same scenario with an areawide parking pricing and transit-pass-subsidy policy,<sup>6</sup> and (3) a compact development scenario with two additional light rail lines instead of the proposed highway and the previously described areawide pricing and subsidy policy. The areawide pricing and subsidy component alone yields future VMT 2% below the trend. The scenario that combines pricing with compact land use and transit investment, however, nearly quadruples the VMT reductions (see Table 3). Although an increase in the price of parking will not impact travel patterns in precisely the same way as a fuel price increase, these results suggest that incorporating the fuel price effects associated with peak oil could significantly alter the output of scenario analyses.

**Climate Change.** In addition to oil supply, climate change also presents a set of conditions that could significantly influence scenario analysis outcomes. There is now scientific consensus that the rapid increase in atmospheric greenhouse gas concentrations over the past two centuries has already resulted in changes in the global climate and that further substantial change is likely over the next century (Intergovernmental Panel on Climate Change, 2007), and

Table 3. Percent reduction in VMT and emissions compared to trend: Two scenarios from the LUTRAQ study in Portland, OR.

	First scenario: Transportation pricing and subsidy	Second scenario: Compact development plus transportation pricing and subsidy
Daily VMT	-2.0%	-7.9%
NO <sub>x</sub> emissions (kg/day)	-2.9%	-8.7%
CO <sub>2</sub> emissions (kg/day)	-2.0%	-7.9%

Note:

The LUTRAQ study used 1990 as the baseline and 2010 as the planning horizon year.

Source: Data from 1000 Friends of Oregon (1996).

will likely produce local and regional impacts as well. For example, a steady increase in average winter temperatures in the Salt Lake City region could have notable effects on winter snow pack, triggering a cascade of economic effects on Utah's tourist and ski manufacturing industries. It could also dampen the state's ability to attract highly skilled work forces in other industries. In addition, warming trends could alter precipitation levels and water availability, which could limit local capacity to support population and economic growth, further dampening growth in population, employment and household income, which in turn could substantially reduce overall travel.

Taken as a whole, prognostications about the influence of global oil supplies and climate change on future conditions vary widely with respect to the nature, magnitude, location, and timing of anticipated impacts. This variability, however, does not mean that such conditions should be excluded from scenario analysis. Quite the opposite; the scenario planning technique was created precisely to deal with unknown and potentially volatile futures shaped by external conditions. While it is not possible or appropriate to include all global influences in scenario analyses (Avin, 2007), those that have ready ties to local and regional conditions, such as oil and climate, should be incorporated.

## Conclusion

This analysis reviews the development of land use–transportation scenario planning in U.S. metropolitan areas

over the past two decades, showing a notable increase in the use of the technique over the study period. Meta-analysis of a sample of those projects shows that the scenarios being developed meet their studies' predominant objectives: reducing land consumption and vehicular travel. Although, as reported by Bartholomew (2005b), scenario projects undertaken before the year 2000 involved citizens less in the crafting and selection of scenarios, later projects demonstrated that scenario planning could provide the basis for vigorous citizen engagement on land use and development issues. It also appears that scenario analysis leads reasonably effectively toward policy adoption; three quarters of the projects (60 out of 80) resulted in the approval of a new or revised transportation, land use, or other policy plan (Bartholomew, 2007a).

While this review confirms the usefulness of scenario analysis, it also demonstrates significant limitations in the current practice. Chief among these limitations are the travel modeling tools and methods employed in many metropolitan areas. While long-term solutions will probably include broad restructuring of model systems, interim techniques such as post-processing can and should be employed to capture some of the effects of alternative development patterns. Current scenario planning practice is also limited by its failure to address changes in global economic and environmental conditions. The current practice of land use–transportation scenario planning recognizes that single-allocation land use forecasts were based on a fictional assumption that land use patterns were immutably isolated from transportation investments and other influences. The practice must now recognize that global economic and environmental conditions underlying planning analyses are similarly mutable.

Land use and transportation planning and analysis have changed markedly in the four and a half decades since the introduction of the 3C requirements (Weiner, 1999). Although these changes in the state of the practice are important, further improvement is needed. Taking the steps suggested here will make scenario planning a more effective tool for anticipating future conditions, allowing planners to lead their communities in positive directions.

## Notes

1. An annotated bibliography of the projects is available at <http://content.lib.utah.edu/u?ir-main,101>. Many of the project reports that were used as source data for this article are available at <http://www.lib.utah.edu/digital/collections/highways/>. At this site, click on "Digital Collections A-Z" and select "Land Use–Transportation Scenario Planning."

2. A regional density increase of 50% is within the range of the scenarios studied in this article (see Figure 5). Although it is near the top end of that range, the median scenario study horizon is 25 years. Therefore, a

50% increase in density over 43 years is reasonable. Moreover, the major demographic shifts anticipated through 2050 suggest that this assumption may be conservative (see Ewing, Bartholomew, Winkelman, Walters, & Chen, 2008; Nelson, 2006).

3. Computed using the coefficient values from Table 2 as:  $(-0.074 \times 50) - (1.50 \times 1) - (4.64 \times 1) - (0.068 \times 73) - (2.12 \times 1)$ . The 73 represents a growth increment of 73%, or 43 years at an average growth rate of just over 1.28% per year.

4. In Contra Costa County's Shaping Our Future project, the study team used a spreadsheet-based sketch model to adjust the MPO's standard travel demand model for travel behavior changes resulting from changes in local land use patterns. The adjustments were based on travel elasticities derived from Bay Area household surveys, census data, and neighborhood paired-comparison studies. For each subarea zone in the study area the study team established an index combining population and employment density per acre; the mix of population, retail and nonretail employment; and a measure of pedestrian friendliness for each scenario. They then calculated the percentage differences between the indices for the scenarios in each subzone and applied the corresponding elasticities to create adjusted trip tables for each scenario (Bartholomew, 2005a).

5. Sketch models are broad-based decision support tools that use elasticities derived from a wide range of data sources. For estimating travel demand impacts of alternative land use scenarios, sketch models, such as EPA's Smart Growth INDEX Model, "can demonstrate the direction and magnitude of change and calculate rough estimates of relative impacts" (U.S. Environmental Protection Agency, 2003, p. 4). However, because sketch models are usually not calibrated to data from the region where they are applied, they are not considered appropriate for demonstrating compliance with regulatory mandates, such as those associated with air quality conformity.

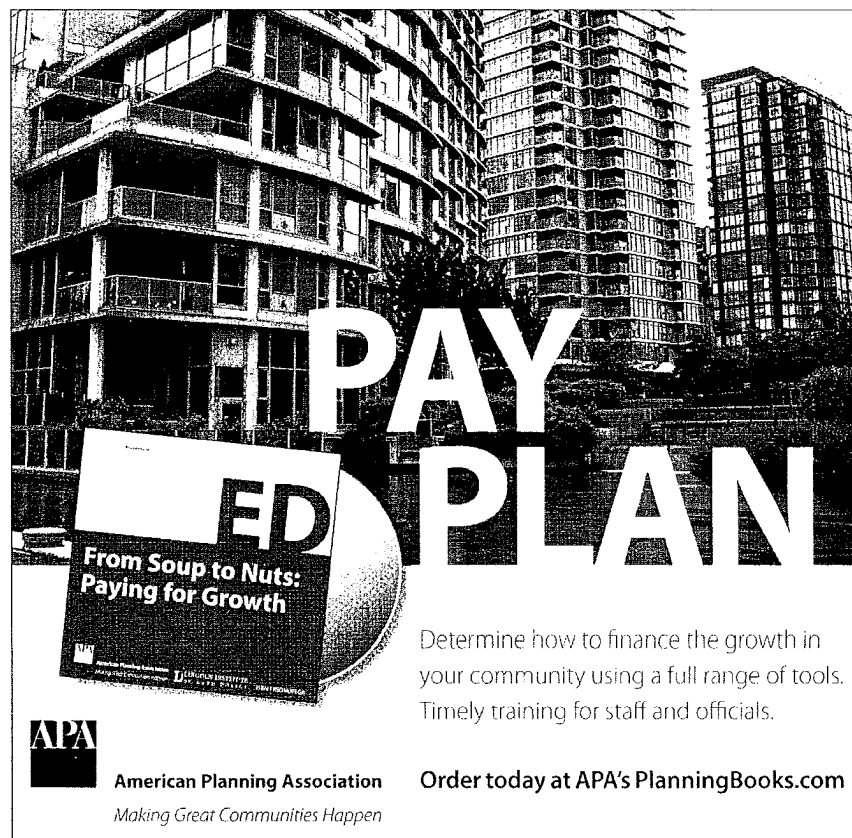
6. The pricing policy assumes that all those in the area who drive alone to work will be charged \$3.00 per day to park, and this revenue will be used to provide free transit passes to all commuters in the study area.

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