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Author

Johnston, Robert A.

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Indicators for Sustainable Transportation Planning

Robert A. Johnston

There is an ongoing debate worldwide about the indicators that policy makers should use to evaluate progress toward sustainable transportation systems. In general, studies of indicators lack an overall normative framework that allows decision makers or the public to make sense of the many overlapping and partial measures. A statewide urban growth model for California was run iteratively with the California statewide travel model to evaluate major transportation scenarios, such as freeway widening and high-speed rail. In addition, transportation and land use policies intended to provide more affordable housing accessible to jobs, widespread habitat protection, and strong reductions in greenhouse gas emissions were evaluated. This model provides many performance measures for travel, economic welfare and equity, rents paid, energy use, greenhouse gas emissions, vehicular air pollution, and habitat loss. A framework for interpreting these data on the basis of recent advances in the theories of well-being for individuals and nations is proposed. This theoretical framework for evaluating the model outputs used in planning also applies to the analysis of the empirical indicators used to track actual outcomes.

Research teams from the University of California, Davis (Davis, California), and the University of Calgary (Calgary, Alberta, Canada) have been developing an integrated urban model of California. The work began in 2006 and will continue through 2009. The Production, Exchange, and Consumption (PECAS) model will go through three stages of development: a setup model was developed in the first 18 months and will be taken to likely agency users for comments. A demonstration model with better data and a reasonable calibration will then be developed and submitted for further agency comments in 2009. If the model set is validated, a working model will be developed. The PECAS land use model will be run in iterative form with the California Department of Transportation (Caltrans) statewide travel model. The primary purposes for developing this integrated model set for Caltrans headquarters and district staff are to capture more of the feedbacks within the economy driven by changes in transportation systems, such as induced travel and the consequent land development, and to represent the economic effects of policies.

PECAS is the first spatial economic urban model to use zones and a network-based travel model to give a theoretically valid measure of regional and statewide utilities for locators. For a discussion of how PECAS differs from its progenitor model, MEPLAN, see the

work of Abraham and Hunt (1, 2). PECAS combines concepts from traditional Walrasian (general equilibrium) economics with random utility theory. Random utility theory permits the representation of heterogeneous goods and actors with heterogeneous tastes in which the prices of goods vary by zone. The implementation of discrete choice theory by the use of logit equations also permits partial utility to be represented, which is useful for analysis of the benefits of alternative goods and locations. This model structure gives utility measures for households and firms, both as producers and as consumers. A statistical discussion of the consistency of the model set with random utility theory is given by Abraham and Hunt (3).

The California travel model will produce typical measures of transportation system performance, such as vehicle miles of travel (VMT), person-hours of delay, mode shares, and roadway level of service (LOS). The California on-road vehicle emissions model will give levels of pollutant emissions, as well as energy use and greenhouse gas emissions. The PECAS model will give a broad array of outputs representing economic utility for firms by sector, households by income, housing rents, housing affordability for households by income class, and economic development (state product, wages, exports). It will also produce measures concerning changes in natural resources, such as the amount of land converted from croplands and grazing lands or from various habitat types to urban and suburban development. Related environmental impact measures will include energy use in buildings and the resultant greenhouse gas emissions. Basic measures of non-point-source water pollution (urban runoff) at various watershed levels will also be produced.

The comprehensive set of indicators in the model set raises interesting issues of how such a large set of outputs should be managed so that they are useful for public policy analysis. Single-purpose state and federal agencies will probably concern themselves mainly with measures that relate to the issues within their jurisdictions. Therefore, the state housing agency will be interested in housing affordability, whereas Caltrans headquarters and districts will chiefly be concerned with delay, congestion, and pollutant emissions. The state energy agency must report on the cost-effectiveness of transportation scenarios and energy use, and so it will be interested in economic costs, utility measures, energy use, and greenhouse gas emissions. State and federal natural resources agencies will likely be focused on air pollutant emissions, habitat conversion, the erosion potential of developed lands, and water quality. The outputs will be useful for the monitoring of greenhouse gas emissions, which, according to the California Climate Warming Act adopted in 2006, requires greenhouse gas emissions to be reduced by about 30% by 2020. A related executive order by the governor requires a reduction of 80% by 2050, in accordance with the recommendations of recent international studies. Many state agencies are now implementing this statute, which will reach into every aspect of California's economy.

Department of Environmental Science and Policy, Information Center for the Environment, University of California, 1 Shields Avenue, Davis, CA 95616. rajohnston@ucdavis.edu.

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It is hoped that Caltrans headquarters, the governor, the legislature, the state Department of Finance, and the state Department of Economic Development will be interested in the broader projections of overall economic growth and of economic welfare (utility) for counties and the state. In the United States, the use of economic welfare measures by metropolitan planning organizations (MPOs) and state departments of transportation (DOTs) is not common. Such measures are in fairly widespread use by nations in the European Community. It has been demonstrated that a traveler welfare measure (compensating variation) is used when a travel model (4, 5) and an urban model (6) are used. The problem with this measure, which is similar to consumer surplus, is that it does not capture changes in locator surplus for households and firms. This omission could result in misleading conclusions. For example, if a radial freeway was widened, a traveler could pay increased travel costs to travel farther out to a larger parcel and home. She or he would experience a higher utility as a locator but pay higher costs as a traveler, so the traveler welfare measure would be negative. The PECAS model gives both producer and consumer surplus measures for locators (households and firms), which is inclusive of changes in travel and goods movement costs, and so this measure captures almost half of the urban economy. PECAS can capture virtually all of the effects of changes in transportation systems but cannot capture social effects, such as the loss of community.

WHY A COMPREHENSIVE METHOD OF MODELING IMPACTS IS NEEDED

Most transportation planning and project evaluation exercises use lists of indicators, as required by state and federal laws. These systems are generally incoherent; that is, the lists of indicators are incomplete and overlapping. It is not enough to have lists of indicators, whether they are empirical (historical) or modeled. Public groups and decision makers tend to emphasize the measures related to those issues that they favor. This leads to a lack of rigor in discussions of the impacts of policies. Some normative framework that allows the aggregation of indicators or at least the placement of certain ones at a higher level in the analysis is needed.

A recent example of the list approach to sustainable transportation indicators is the draft paper of the TRB Sustainable Transportation Indicators Subcommittee (7). In that paper, 21 indicators were chosen to represent economic, environmental, and social issues. These indicators do not cover all impact types, they overlap, and they mix outcomes (impacts on the world) with transportation performance measures. This problem of a lack of a theoretical framework may be illustrated by the treatment of VMT, in which it is said that whether more VMT is good or bad is uncertain. VMT is not an impact on society but is just an attribute of the users of the transportation system, who are not explicitly seeking more or less VMT per se. This specific difficulty points to the larger problem of the lack of an overall theory of well-being. Another difficulty is the adoption of a priori criteria in the paper, which asserts that transportation should be safe, fair, and efficient. These criteria overlap and are incomplete. There is no objective way of deciding among alternative policies when the indicators are incomplete and overlapping. The present paper is part of a large literature on indicators obtained by the use of similar methods. Indeed, most agencies use such evaluation lists. For a recent discussion of sustainable transportation indicators and of several schemes for the organization of indicators, see the dissertation of Ralph Hall (8).

From past work on environmental impact assessments and multi-objective planning (9, 10), it is believed that, in general for policy evaluation, outputs should be kept in their natural units and should be presented in tables under the general headings economic, environmental, and social outputs. Economic outputs include monetized effects, environmental outputs describe changes to natural systems, and social outputs mainly include equity measures. These impacts can then be summarized in graphical and narrative fashion to enable the evaluation of trade-offs across the three mutually exclusive categories. This overall set of accounts conforms with generally accepted theories of democratic decision making, in which all indicators are kept in the open and trade-offs are highlighted and not minimized. This three-part system also gives equity a top-level listing, which is in accordance with the placement of equity by methods now used to evaluate sustainable development worldwide. Weighting, summing, or other transformations of the indicators are strongly resisted, as, in practice, such actions often hide value judgments.

The decision maker, then, is faced with making trade-offs among the types of impacts. In the past, elected officials have often tended to approve grab bags of policies to please most interest groups and to spread benefits around geographically. For example, MPOs in the United States have only slowly moved toward putting higher percentages of capital funds into transit, even though it has generally been accepted for some time that fuel prices will rise rapidly in the first decades of the 21st century. MPO boards have continued to fund roadway expansions in part because these expenditures can be spread around all of the counties in a region, whereas transit improvements tend to occur in the urban counties in the center of a region. Also, even if decision makers care about economic growth or economic welfare in their region or state, they have not had the tools with which to project these measures. In practice, they have assumed that increasing road capacity will reduce costs for firms and increase economic growth. It is hoped that the PECAS model set will assist decision makers in evaluating broader arrays of scenarios for the state and its regions on the basis of a more formal analysis and the use of a set of fairly complete and nonoverlapping indicators. It is also critical that a coherent model or a related set of models be used to project the indicator outputs. Only in this way can one be assured of conceptual consistency and accuracy. A model can fix the relationships among the indicators so that they are determined by use of the same theory.

A previous modeling exercise that used comprehensive models similar to what is being attempted in California is the PROPOLIS program in the European Community (11). This research program implemented three urban models in seven urban regions in Europe and developed a complex set of indicators, a database, and viewing software to portray these outputs. The measures were depicted in maps, bar graphs, tables, and other graphics without much aggregation. Overall, this effort greatly advanced urban and transportation modeling. However, no regional economic growth or productivity measures were developed and no locator utility measures were used. Also, no overall theory of goodness was used, and so one is faced with long lists of indicators for each policy measure.

A recent study in the United Kingdom (12) used land use and travel models and pioneered the comprehensive evaluation of the macro- and microeconomic effects of transportation schemes, including changes in regional production, locator welfare, agglomeration economies, and productivity changes because of the movement of jobs. Transportation agencies in the United Kingdom are now required to model these indirect economic effects when they evaluate plans and large projects. The pioneering evaluation described above was an initial methodological

study of a small urban region, and some data were approximated and some calculations were simplified. The authors found that the agglomeration effects were larger than the direct welfare effects for some of the policies studied. They studied road improvements, transit improvements, and road tolls. The authors did not examine environmental impacts or equity effects. The PECAS model captures agglomeration economies and other productivity changes, and so the work accomplished by the development of the PECAS model should be comparable to that accomplished through the groundbreaking study of the macro- and microeconomic effects of transportation schemes but will use more inclusive indicators.

Recently, two useful theories of well-being that help with the conceptualization of changes in personal welfare and national (state) welfare have been put forward by economists. The next section reviews the research on personal well-being.

THEORY OF PERSONAL WELL-BEING

Easterlin has shown that there is zero marginal utility of income above the middle-income levels for each household size in both inter-country comparisons and interpersonal comparisons in the United States (13). Utility was measured by well-being stated in surveys. The range of incomes in the cross-country survey of 14 nations was 700%, and the range in the U.S. data was about 300% (\$10,000 to \$30,000 in 1994 dollars, 29 years of annual data). These studies used time series data from age cohorts to eliminate cohort bias. His findings contrast with those from previous bivariate cross-sectional studies, which found increasing utility but a diminishing marginal utility of income. Easterlin's findings do not apply within the lower-income range in the United States and in other countries, where utility is expected to rise with income.

In an earlier paper, Easterlin reached the same conclusion regarding income using U.S. data (14). As income rises within age cohorts, expectations also rise and the marginal utility of added income is zero. However, he found that changes in life events can have lasting effects on stated well-being. Married people are happier than unmarried, separated, and divorced people and people in good health are happier than people with poor health; and these changes in well-being do not diminish over time. Also, people with higher levels of education are consistently happier. Easterlin concludes that "happiness would be increased by greater attention to family life and health rather than economic gain" (14, p. 21).

This pathbreaking work by Easterlin provides a useful concept that can be used to examine economic growth in the California PECAS model. The health and education sectors are represented in the model set, and changes in their products can be used as indicators of the effects of various levels of spending on transportation improvements on health and education levels in California.

More specifically for the PECAS model set, however, Easterlin's work provides a valuable framework in which the equity effects of transportation investments and land use policies may be considered. For example, past work has shown that heavy investments in transit can benefit lower-income households, as determined by use of a traveler surplus measure (6). Easterlin's work provides evidence that such redistributive transportation policies would increase total (stated) societal well-being, if the extra tax burden fell on high-income households. This idea actually comes from the beginnings of economics in the 19th century, in which many utilitarians believed in redistributive policies. Another intent is to test land use policies intended to

increase the amount of affordable housing and to spread it into formerly exclusionary suburbs. It has also been shown that peak-period tolls increase total regional traveler welfare but hurt lower-income households. However, by also increasing transit coverage and service, it was found that the economic welfare of all household income classes could be increased (6). Therefore, the intent is to use the PECAS model to investigate peak-period tolls, transit investment, and inclusionary zoning in various combinations to see the economic welfare effects on households and firms by use of the locator surplus measure. The other economic impacts will also be evaluated in these equity scenarios to see the trade-offs.

THEORY OF NATIONAL WELL-BEING

Societies are becoming increasingly concerned with sustainable development, especially as certain natural resources become degraded or depleted. "Weak sustainability" is defined as not reducing the total assets of a nation that are bequeathed to future generations. This definition allows substitution among categories of assets, so, for example, natural assets that are lost can be replaced by human assets or manufactured assets that are added. This is a risky and morally fraught strategy. "Strong sustainability" is defined as a situation in which all three classes of assets must be maintained or increased intergenerationally. Whichever definition one chooses for policy-making purposes, a nation's (or, in the case of the PECAS model, a state's) assets must still be able to be measured comprehensively.

Resource economists and others have developed a useful concept for the more accurate accounting of national well-being. Dasgupta maintains that the measurement of increases in national well-being with an increase in the gross national product (GNP) is incorrect because it omits changes in the value of assets, which affect GNP (15). Also, assets (wealth) are a more important indicator of the future well-being of a nation. He then says that assets are composed of manufactured capital (roads, buildings, etc.), human capital, and natural capital (oil, natural gas, minerals, fisheries, forests, soil, water, air, ecosystems). He argues that free markets can damage common resources (natural capital) because of a lack of ownership and a lack of exclusion from use. Natural capital has only recently been accounted for, and specifically, the World Bank has been asked to include it in its reports. Dasgupta then discusses a paper by Hamilton and Clemens (16) on what he calls "genuine investment" (changes in assets), including changes in natural capital. Only commercial forests, oil and minerals, and greenhouse gas emissions were included in the analysis. Water resources, fisheries, air and water pollution, soil, and biodiversity, most of which are in negative growth in most nations, were excluded. He then cites their data on the rates of growth of GNP per capita and of the genuine wealth per capita for several poor countries and shows that some countries, such as India, have positive growth in GNP per person but negative rates of growth of wealth per capita when only this limited set of measures for natural capital is included. Some nations are becoming poorer not only on a per capita basis but also overall. The changes in genuine wealth would likely be more strongly negative if all components of natural capital were included.

Valuing resource depletion and degradation in national economic accounts has been a topic of discussion for decades. This policy push has led to several formulations of "green accounts" and to other methods of valuation, such as determination of the "value of nature's services." Hamilton and Clemens build on this work and

conceptualize genuine wealth and genuine savings (16). They discuss how this field of research led the World Bank to publish *Expanding the Measure of Wealth* in 1997 (17). They also present a formal model of genuine wealth and then construct using the available data a preliminary set of measures for all nations. The data on changes in natural assets were limited to oil and minerals, the depletion of forests below replacement levels, and the social costs of greenhouse gas emissions. Water resources, fisheries, and soil were not included because of data limitations. With data for selected countries and groups of countries, they showed that this new measure gives different results (negative rates of growth of genuine wealth in nations with positive rates of growth of per capita GNP), and so genuine wealth should be considered in discussions of sustainable development policies.

They then adjusted their figures to include, in addition, changes in human capital, measured as expenditures on education. Many nations still had negative savings rates for total capital, and for most nations, the results were the same. The worst-off countries were those with rapid mineral or oil depletion. They concluded that nations and global banks should use this new comprehensive set of measures of wealth and that data on all natural resource types, including water resources, fisheries, air and water pollution, soils, and biodiversity, should also be gathered. Their policy conclusions were that most countries need stronger pollution controls and better resource management policies (resource tenure, royalties) and that resource depletion and pollution should be correctly priced. All of these findings apply to California, as its resources are declining (18, 19).

Most high-income countries had higher genuine savings rates than the United States in the 1970s, in the 1980s, and from 1990 to 1993 (16, Table 3). These data include educational expenditures. Some northern European countries have recently passed the United States in terms of the rate of growth of economic productivity. Many of the European Community nations have stronger air and water pollution controls than the United States does. Most of the core (original) European Community nations have national health services and stronger welfare support systems than the United States does. Lindert found that higher social spending, as a percentage of the gross domestic product, is not associated with lower rates of economic growth (20). This was found to be partially due to high levels of human capital (education, health, and child care). The high rates of growth of these nations are also partly due to their higher taxes on fuel and personal automobiles, which reduce negative externalities.

With reference to the work of Hamilton and Clemens (16) and the findings of Easterlin (13, 14), these data would seem to indicate that people in the European Community countries should be happier and that those nations are on a more sustainable path.

The genuine wealth concept is applied to the interpretation of the PECAS model outputs, as it will have many measures of natural and manufactured assets and some measures of human assets.

APPLICATION OF FRAMEWORKS TO UNDERSTANDING MODEL OUTPUTS

The two related theories of personal well-being and national well-being provide a conceptual framework for analysis of the indicators that come out of the California models. The earlier assertion that the indicators should be kept in three categories, the economic, environmental, and social categories, is supported by these theories of well-

being. However, an attempt will be made to collapse the environmental measures into the economic category by monetizing the value of these assets. This is controversial, so the separate measures of the environmental changes available will be retained. Social measures are chiefly concerned with economic equity, and social measures will be kept as a first-level category. These related theories reveal how much more useful the discussion of equity could be if it could be conceptualized in terms of personal well-being. For example, the trade-off between growth in aggregate wages (or utility) and wage (or utility) gains for lower-income households should be examined. All of these indicators will be for differences across two scenarios, typically, the policy scenario minus the trend scenario, both for future years. This is because the welfare measures are available only for differences.

These ideas can also be applied to the evaluation of aggregate statewide economic performance. For example, the outputs should be categorized to include (a) changes in the value of manufactured assets (new transportation systems and buildings, net of the depreciation of the existing ones), (b) changes in the value of human assets (represented by education and health care products), and (c) changes in the value of environmental assets. The percentage of married households, education levels, and health status will not be able to be projected because they are not explicit in the model. The suite of models will give a set of measures for the value of manufactured goods, health and educational products, and environmental changes that is quite inclusive. An attempt will be made to analyze these outputs in the genuine wealth framework. An attempt will also be made to include in the evaluation models and accounts all environmental services that are affected by transportation and land use policies. Monetization of the value of environmental services is quite difficult (21), so this may not be able to be done adequately.

Proposed High-Level Model Outputs: Equity and Genuine Wealth

The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), passed by the U.S. Congress in 2005, now requires the consideration of many more factors than the numbers that were required to be considered in earlier surface transportation acts. It would seem to be useful to develop indicators for these factors. Regional and state plans must attempt to increase economic development, as well as mobility. Economic development, however, is not well defined in U.S. practice. It is usually taken to mean changes in one or more of the following: employment, personal income, property values, business sales, value added, or business profits (22). Another report states that economic development consists of improving one or more of the following: income, job choices, activity choices, economic stability, and amenities (23). The FHWA website focuses on increasing employment and wages (e.g., www.fhwa.dot.gov/planning/econdev/). In most countries the total product (GNP) is the usual measure, and for states the gross state product is the usual measure. Because the PECAS model has an input-output model in its core model set, it will give a measure of the total state product for all market goods and services. This can be viewed as the annual addition to the value of manufactured and human assets. Annual changes in the value of natural assets will be added. The depreciation of existing human and manufactured assets must be included by using basic accounting rules.

This approach, then, gives the genuine wealth measure. The second high-level measure will be equity, measured as the change in household utility, by income class.

Other, More Specific Indicators

Under SAFETEA-LU, regional and state transportation plans must strive to reduce greenhouse gas emissions, as well as air pollution. Greenhouse gases are fairly easy to project on the basis of vehicle fuel use and the floor space in buildings, which will be projected by the vintage of the building, the structure type, and the economic activity occupying the building.

States and regions are now also required by SAFETEA-LU to consider resource conservation issues in planning and are also encouraged to develop cumulative impact mitigation programs. Therefore, a comprehensive model such as PECAS, which will include geographic information system (GIS) data for important habitat lands and waters, will be useful for such proactive resource protection and mitigation planning and banking. MPOs and state DOTs are encouraged to perform evaluations of cumulative environmental impacts at the planning stage, but if they choose, they can defer this analysis to the project stage. Therefore, with these new requirements in mind, the range of outputs that will be available can be examined.

The statewide travel model will produce typical travel measures, such as VMT, vehicle hours of delay, mode shares, and lane miles of LOSs E and F. Accident costs (deaths and injuries), which are significant and which vary with VMT, speed, and facility type, will also be included. The consequent emissions of pollutants and the levels of production of greenhouse gases will be included. The life cycle whole-system energy use and consequent greenhouse gas emissions will also be calculated. Goods movements will be added to the travel model in a later phase and will increase the economic scope and accuracy of the model in projecting goods movement costs. The model currently represents heavy trucks with a fixed trip table. In the future, this model will be replaced in the PECAS model with one that projects goods movements in tour, on the basis of the dollar flows among sectors, by zone.

PECAS will be used to track total floor space by building vintage and type and by economic activity type, and so energy use in buildings and the consequent amounts of greenhouse gases produced by the relevant utilities will be able to be projected. Population exposure to noise can also be projected by using the GIS. Land development will be shown by the types of lands converted, such as urban, suburban, prime agriculture, nonprime agriculture, grazing, important habitat types, floodplain, high fire hazard, and other categories, and will be determined from agency interviews. Land use maps will be in 50-m grid cells, which will allow a fairly detailed evaluation of land consumption. An attempt will be made to determine some water quality measures, such as non-point-source runoff from roads (factored from average daily traffic). An indicator of non-point-source water pollution (urban runoff) will be constructed at the small watershed scale and will be based on the percentage of impervious surface from development (major roads and land uses). These output indicators will be provisional to get comments and suggestions from the various state departments.

Locator producer surplus will be able to be obtained by household income class and by type of firm. The PECAS model can also provide monthly housing costs by household income class and also housing affordability (housing costs and household income). The number of

households in the noise bands and also in the particulate fallout bands near highways will be able to be calculated by income.

The emphasis in the presentations and reports will be on the two high-level indicators of equity and genuine wealth. All of the various indicators that aggregate to genuine wealth, however, will be kept in subaccounts for viewing.

Portrayal of Performance Measures

This is a vast undertaking because of the dozens of measures for each year for 50 years, 530 economic zones, 58 counties, and the state. A visualization specialist is working on methods of mapping these data spatially and over time in graphs and nesting the data sets in linked formats, but the issue of how the data should be portrayed so that the most important concepts, normatively, get the most attention remains. That is, a hierarchy of data sets is needed.

The most comprehensive and understandable method of portraying these many performance data is to show (a) genuine wealth (measured as the difference in the annual change in the total genuine wealth of the state between two scenarios, as noted above) and (b) equity (measured as changes in annual utility for households by income class and location).

The total state genuine wealth measure will result in one grand number that represents the monetary change for the evaluation year but that will actually be composed of many components. Many of the latter measures will be provisional and conceptual and will have estimated values. Natural capital will be able to be modeled in some ways, such as by the value of environmental services from floodplains, terrestrial habitats, wetlands, and surface water bodies. An attempt will be made to monetize such measures by using willingness-to-pay data, whenever they are available. Otherwise, stated willingness-to-pay values will be used. Several studies have attempted to place economic values on "nature's services" [see an overview by the Ecological Society of America (24) and the work of Costanza et al. (25)]. Pagiola et al. (21) have critiqued the work of Costanza et al. (25) and many other studies and have reviewed the pitfalls of valuing environmental services.

The equity effects measures will be difficult to portray. In the Oregon Bridges Study, for example, the changes in product for several broad groups of sectors were portrayed by county by using percent growth classes on a GIS map (26). That approach worked well, and so to start, the PECAS model will use such maps to determine changes in household utility for income groups.

Other, specialized measures will be provided for single-purpose state agencies. For example, the Department of Housing and Community Development will be interested in the percentage of income spent on housing for lower-income households by county. That department will also find other measures to be useful, such as the percentage of housing units under certain rent levels in each county. Caltrans, MPOs, and county-level poverty agencies will be interested in changes in travel costs for lower-income households, especially for work trips. County welfare agencies may also make use of measures of change in accessibility to employment for lower-income households.

Relevance to State and Regional Transportation Plans

The PECAS model set will be tested by using various policies relevant to the state transportation plan, that is, state and inter-

regional projects. Of current interest in California is the high-speed rail proposal, an expensive improvement with potentially large economic and land development effects. Also of concern are numerous freeway-widening projects, expansions of airports, and improvements on the land sides of seaports. As discussed above, this model set will enable Caltrans to evaluate the new factors in SAFETEA-LU, such as greenhouse gas emissions, economic development, and the cumulative impacts of the plans on natural resources and the environment.

Two California MPOs, the Sacramento MPO and the San Diego MPO, are also developing PECAS models. These model sets will similarly be useful to their regional transportation plans, as well as for the analysis of major investments, such as new rail lines, freeway widening, and multimodal corridor projects.

In addition to being used for plan evaluation, this model set could be used at the program level for analysis of interregional transportation improvement programs and regional transportation improvement programs (RTIPs) and the resultant state transportation improvement program for bundles of projects. In California, RTIPs are currently evaluated for their progress toward goals set in the various regional transportation plans. Therefore, there is no set of statewide goals against which the RTIPs are evaluated. The evaluation criteria are mostly transportation performance measures, and even these are overlapping. There are no general economic impact measures.

A more unusual planning process that could also use such a model set is the blueprint planning going on in more than a dozen California counties. This is a long-range broad scenario development and evaluation process intended to explore smart growth and related transportation improvements. This process has already occurred in the larger MPOs and is now being done in the non-MPO county transportation planning agencies. The counties are already using a simple GIS-based land use model, along with their travel models, in their blueprint planning processes. Caltrans has funded this work.

In 2006, a bill that requires a 30% reduction in greenhouse gases statewide by 2020 passed. The related executive order also sets a policy for an 80% reduction by 2050. These are strenuous objectives. As noted above, this model set can be used to project greenhouse gas emissions by vehicles and buildings. The policies regarding vehicle fuels and vehicle energy efficiency that have already been adopted will be supplemented by many future laws concerning land use and transit development. These complex policy sets will have myriad economic and social impacts that can be evaluated if the PECAS model set works as envisioned.

PROPOSED POLICY TESTS

After the development of as many measures as possible and then working out methods for aggregating and portraying the model outputs, various policy packages will then be experimented with in an attempt to find policy sets that maximize the aggregate genuine wealth of the state. Much of this effort, at least initially, will be a form of validating the models, in that the model outputs will be compared with what economic theory predicts in various sensitivity tests, one policy at a time.

After further model calibration and validation, policy packages will be tested to see how they affect the genuine wealth of the state. Then, it will be seen if aggregate genuine wealth can be kept high while not damaging lower-income households or certain types of firms,

statewide and by region. Because this work is funded by Caltrans, high-speed rail will be tested to determine its effects on aggregate wealth and equity. Modal capacity expansion alternatives for certain key interregional corridors, such as Altamont Pass, which leads from the South San Francisco Bay Area to the Central Valley, will also be tested.

The most interesting policy packages may well be ones that promise broad benefits, such as high-speed rail combined with intensive infill development around the rail stations, large-scale habitat protection, and inclusionary zoning (multifamily zoning near employment centers in all cities and counties). The results from these preliminary scenario tests will be taken to the state agencies in charge of transportation, housing, habitats, and other services to get the responses of managers. This exercise will then result in the making of improvements to the models, to the methods of portraying performance measures, and to the design of scenarios that more closely serve the interests of the agencies and the state.

As mentioned above, the major policy push in the state is now the climate warming statute. Therefore, various policies and policy sets intended to reduce VMT and greenhouse gas emissions will be tested. It is not enough to project their impacts on greenhouse gas emissions, though. The economic and other impacts of these transformative policies must also be determined. In this regard, the California experience may help show the way forward for the United States and other nations. Virtually all of the policies so far identified to be useful for reducing greenhouse gas emissions can be represented in the model set.

Figure 1 shows an example of how impacts might be represented by using county-level outputs from the current initial version of the PECAS model. It shows the effects that high-speed rail would have on county employment in the year 2000 compared with the effects without it.

Figure 2 shows what the environmental impact maps will look like. This was obtained by using a simpler model but shows the same 50-m grid cell outputs used in the PECAS model and shows the effects of development on oak woodland habitats in Sonoma County, California.

CONCLUSIONS

For decades, planners have sought out models that can represent the effects of transportation and land use policies on the economy and on the natural environment of regions and states. At last, planners now have these capabilities, and in addition, models can address economic equity issues. The California models will be a test of these ideals of comprehensive policy evaluation and so present the challenge of portraying the many outputs in a theoretically consistent fashion. Recent theories of personal and national well-being greatly facilitate understanding of the many indicators that will result from the policy tests. Two high-level indicators that best represent overall societal well-being, equity and genuine wealth, will be presented. Dozens of indicators of interest to certain agencies and for statutory reporting requirements will also be presented.

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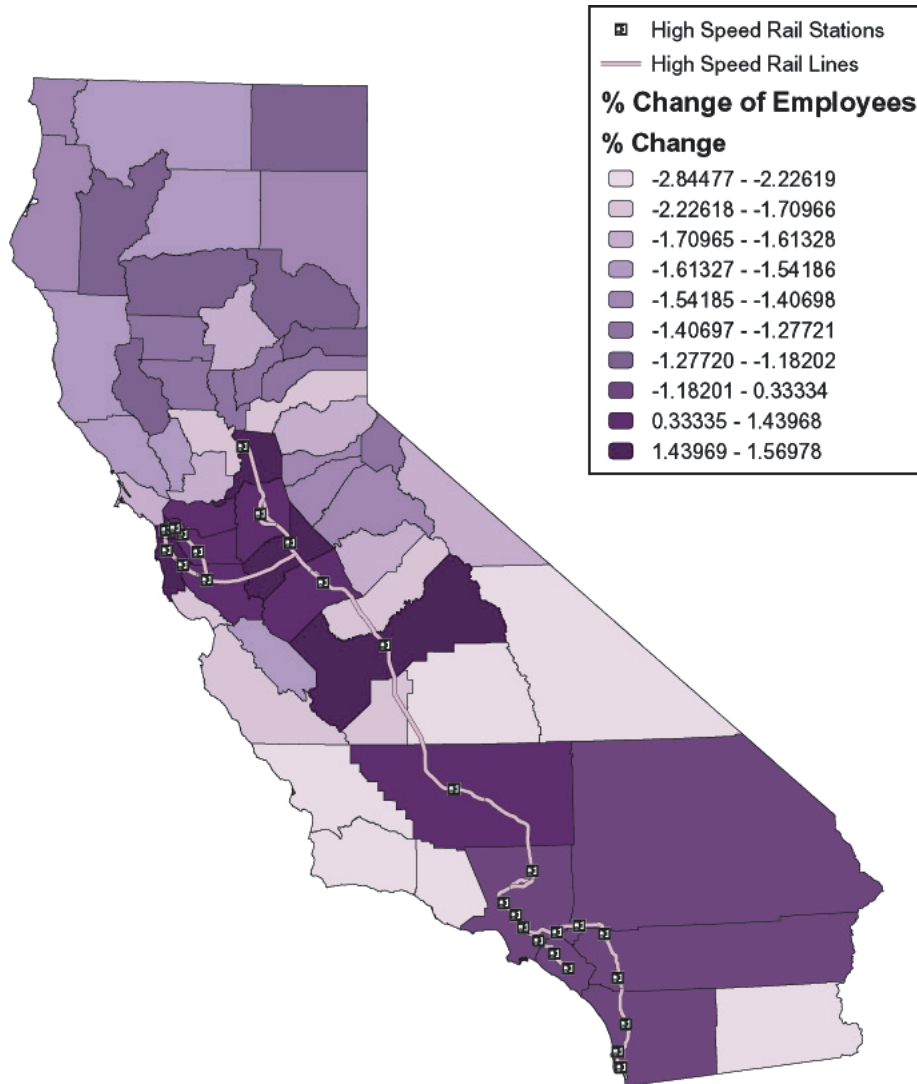


FIGURE 1 Example of representation of outputs: map of county economic change showing the percent change in employees.

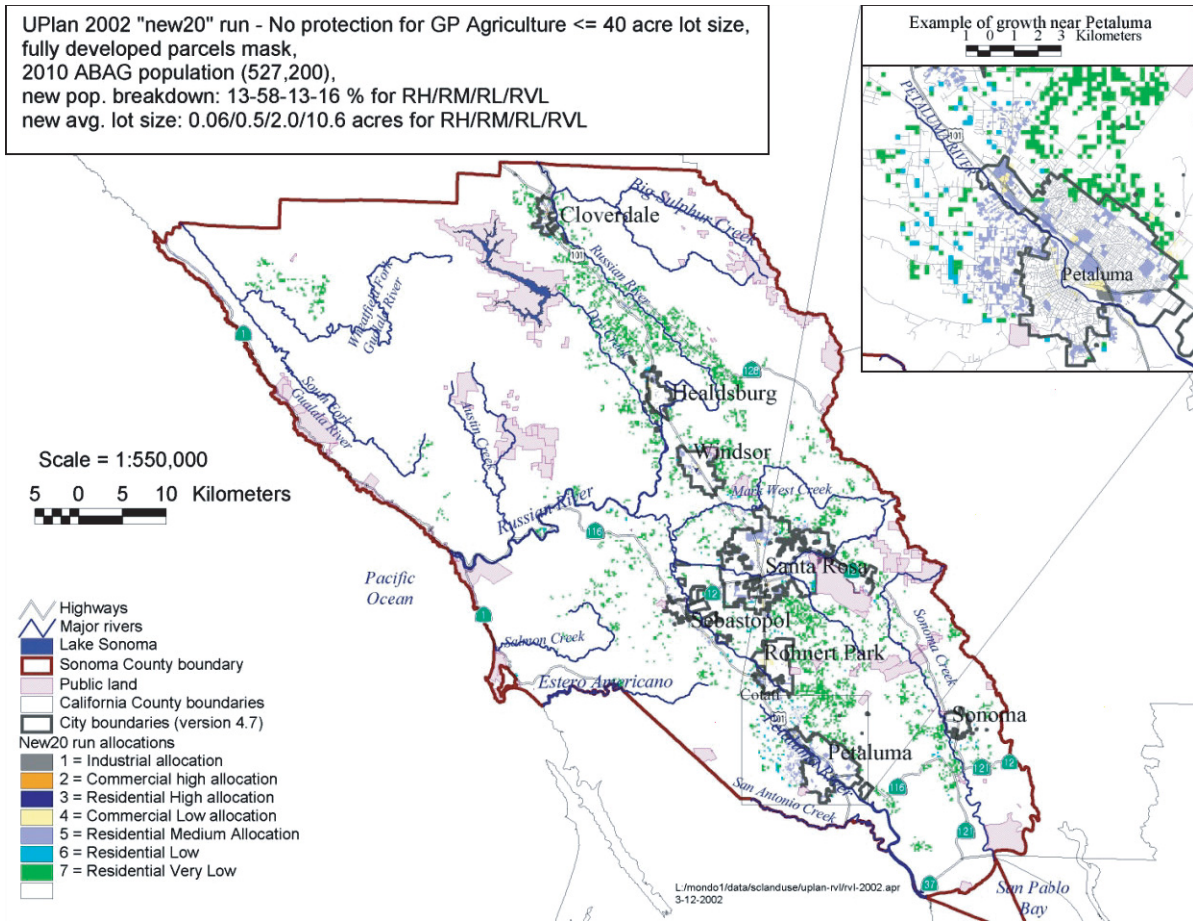


FIGURE 2 Habitat fragmentation in Sonoma County, California, in 2010 (GP = general plan; ABAG = Association of Bay Area Governments; RH = residential, high density; RM = residential, medium density; RL = residential, low density; RVL = residential, very low density).

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