A COMPARISON OF HIGHWAY AND TRAVEL DEMAND MANAGEMENT ALTERNATIVES USING AN INTEGRATED LAND USE AND TRANSPORTATION MODEL IN THE SACRAMENTO REGION

by

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ABSTRACT

In this study, we apply an integrated land use and transportation model, the Sacramento MEPLAN model, to evaluate transit investment alternatives combined with supportive land use policies and pricing polices in the Sacramento region. Highway investment alternatives are simulated as well for purposes of comparison. The application of the Sacramento MEPLAN model is relatively advanced because the model represents a number of induced travel effects, including land use, destination, mode choice, and route choices. A number of conclusions are made for the case study. First, transportation investment in both highway and light rail may allow for greater decentralization of regional development. Second, new highway capacity projects, even if they include HOV lanes, may increase VMT and emissions. Third, transit investment with supportive land use policies or pricing policies may be very effective in reducing VMT and emissions. Fourth, transit investment with supportive land use or pricing policies may provide congestion reduction that is as great, if not greater, than highway investment policies. Fifth, transit investment combined with land use policies may provide greater benefits (i.e., change in travel time and cost) than highway investment.

INTRODUCTION

To address roadway congestion problems, communities both in California and throughout the nation are proposing major and costly beltway highway projects. Just a few of these projects include Route 710 in California ($310 million per mile), the Grand Parkway in Houston, Texas, and the Legacy Highway in the Salt Lake region of Utah. These projects may also worsen community air quality problems.

The common methods used to evaluate the effectiveness of these highway projects are commonly limited because they do not represent induced travel effects, that is, how an increase in roadway supply will lower auto travel time costs and increase travel demand. Induced travel effects that can be represented in advanced methods include changes in land use patterns, the number of trips made, destination of trips, choice of travel time, choice of travel mode, and choice of travel route. As a result of their failure to represent induced travel effects, agencies' tools will tend to overestimate congestion reduction and underestimate emissions and air quality problems resulting from new highway projects.

Moreover, the environmental impact statements used to evaluate the environmental impacts and the effectiveness of proposed new highway projects commonly may not adequately identify and evaluate alternatives to highway projects. The literature suggests that alternatives such as transit investments combined with supportive land use policies and/or pricing policies may be just as, or more, effective in reducing congestion and may have the added benefit of improving air quality and protecting environmentally sensitive areas (see literature review below).

In this study, we apply an integrated land use and transportation model, the Sacramento MEPLAN model, to evaluate transit investment alternatives combined with supportive land use policies and pricing polices in the Sacramento region. Highway investment alternatives are simulated as well for purposes of comparison. The application of the Sacramento MEPLAN model is relatively advanced because the model represents a number of induced travel effects including land use, destination, mode choice, and route choices. As mentioned previously, most analytical tools used to evaluate transportation policies do not represents induced travel effects. State-of-the-practice tools may represent destination, mode choice, and route choice induced travel effects, but land use effects, which may be significant, are very rarely examined.

LITERATURE REVIEW

Modeling studies that have employed advanced analytical tools to simulate transit investment accompanied by land use intensification policies and/or auto pricing policies indicate that such policies may be more effective than highway investment in reducing congestion. Two recent case studies in the U.S. apply state-of-the-practice regional travel demand models, which represent the destination, mode, and route choice induced travel effects, to simulate such policies. The study in the Sacramento, California, region indicates that vehicle hours of delay could be reduced by 13.3% for the transit alternative with land use measures and auto pricing policies, compared to 5.2% for the highway alternative (Johnston and Rodier, 1999). A simulation study in the Portland, Oregon, region indicates that vehicle hours of delay could be reduced by 65.9% in the transit investment alternative with land use measures only, compared to 43% for the highway alternatives (CSI, 1996).

These case studies also indicate that highway alternatives will increase VMT and vehicle emissions and that the transit alternative will decrease VMT and emissions, relative to a no-build alternative. For example, the Sacramento simulation study found that the transit alternatives reduced VMT and emissions from approximately 0.2% to 8.8% and that the highway alternative increased VMT and emission from approximately 1.3% to 3%. The Portland study found that the transit alternatives would decrease VMT by 0.4% to 6.4% and NOx by 2.6% to 8.4% and that the highway alternative would increase VMT by 1.6% and NOx by 6.7%.

The results of these studies are limited to their regions, but they are suggestive of results that might be obtained by other regions that employ advanced analytical tools and seriously evaluate transit alternatives and compare them to proposed highway alternatives in environmental impact statements.

METHODS

The Sacramento MEPLAN model

The MEPLAN modeling framework is described in Hunt and Echenique (1993). The basis of the framework is the interaction between two parallel markets, the land market and the transportation market. This interaction is illustrated in Figure 1. Behavior in these two markets is in response to price signals that arise from market mechanisms. In the land markets, price and generalized cost (disutility) affect production, consumption, and location decisions by economic activities. In the transportation markets, money and time costs of travel affect both mode and route selection decisions.

INSERT FIGURE 1 ABOUT HERE

The cornerstone of the land market model is a spatially-disaggregated social accounting matrix (SAM) (Pyatt and Thorbecke, 1976) or input-output table (Leontieff, 1941) that is expanded to include variable technical coefficients and uses different categories of space (e.g., different types of building and/or land). Logit models of location choice are used to allocate volumes of activities in the different sectors of the SAM to geographic zones. The attractiveness or utility of zones is based on the cost of inputs (which include transportation costs) to the producing activity, location-specific disutilities, and the costs of transporting the resulting production to consumption activities. The resulting patterns of economic interactions among activities in different zones are used to generate origin-destination matrices of different types of trips. These matrices are loaded to a multi-modal network representation that includes nested logit forms for the mode choice models and stochastic user equilibrium for the traffic assignment model (with capacity restraint). The resulting network times and costs affect transportation costs, which then affect the attractiveness of zones and the location of activities, and thus the feedback from transportation to land use is accomplished.

The framework is moved through time in steps from one time period to the next, making it “quasi-dynamic” (Meyer and Miller, 1984). In a given time period, the land market model is run first, followed by the transportation market model, and then an incremental model simulates changes in the next time period. The transportation costs arising in one period are fed into the land market model in the next time period, thereby introducing lags in the location response to transport conditions. See Hunt (1994) or Hunt and Echenique (1993) for descriptions of the mathematical forms used in MEPLAN.

The specific structure of the Sacramento MEPLAN model is shown in the diagram in Figure 2, and Table 1 defines the categories in the diagram. The large matrix in the middle of the diagram lists the factors in the land use submodel and describes the nature of the interaction between factors. A given row in this matrix describes the consumption needed to produce one unit of the factor, indicating which factors are consumed and whether the rate of consumption is fixed (*f*) or price elastic (*e*).

INSERT FIGURE 2 AND TABLE 1 ABOUT HERE

The Sacramento MEPLAN model uses eleven industry and service factors that are based on the SAM and aggregated to match employment and location data. Households are divided into three income categories (high, medium, and low) based on the SAM and residential location data. The consumption of households by businesses represents the purchase and supply of labor. The consumption of business activities by households represents the purchase of goods and services by consumers. Industry and households consume space at different rates and have different price elasticities, and thus there are seven land use factors in the model. Constraints are placed on the amount of manufacturing land to represent zoning regulations that restrict the location of heavy industry. Each of these land uses (except agricultural land use) locates on developed land represented by the factor URBAN LAND. Two factors are used to keep track of the amount of vacant land available for different purposes in future time periods (MANUF VAC LAND and TOTAL VAC LAND), and the development process converts these two factors to URBAN LAND. The MONEY factor is a calibration parameter that allows differential rents to be paid by different users of the same category of land.

The land use component of the Sacramento MEPLAN model was refined in this study to include a floorspace submodel allowing for integration with the UPLAN GIS-based urban model. The UPLAN model had different land use types than the original Sacramento MEPLAN model (described above). The land use categorizations were redesigned to match those of the UPLAN model. See Table 2 below.

INSERT TABLE 2 ABOUT HERE

In the MEPLAN implementation, each column and row of Table 2 is a MEPLAN factor. The development type factors (the columns in the table) are directly consumed by activities. The factors representing land use planning designations (the rows in the table) are consumed by the development type factors. The consumption rates represent the type of development in each zone and so are unique for each zone. These consumption rates are manipulated by custom software, written in the Java programming language using the MEPLAN file manipulation library from Abraham, 2000. This custom program is run between each time step and will model redevelopment and demolition as one process and new construction as another process.

The redevelopment and demolition model is a logit model of the choice between (1) redeveloping into a different development type, (2) demolishing into a "vacant" type, or (3) retaining the same type.

The new construction model, also a logit model, represents the choice of what to do with vacant land. Vacant land includes, in each time step, land previously categorized as "urban reserve" or "agricultural." The choice is between the different types of allowable development and the option to leave the land vacant for another time period.

In both of these submodels, the utility for each option is a function of

- the average price per unit for each space development type in the zone, representing the tendency of developers to be attracted to zones and development types where existing rents are high;
- the average price per unit for each space development type in the entire region, representing the condition that the total resources available for development are constrained and each zone has to compete with the region as a whole for development; and
- the average amount of space per employee or household compared to some reference average for the entire region, representing the tendency of developers to respond to vacancy rates.

The calibration used the data for the amount of land in each zone in each time period. The parameters of the development and redevelopment/demolition models used standard “rule-of-thumb” coefficients. We continue to work on obtaining better data on development and plan to conduct a peer review to improve the calibration of the floorspace submodel.

The single-row matrix (just above the large matrix in Figure 2) shows activity that is demanded exogenously, which includes exporting industry, retired households, and unemployed households. This corresponds to the “basic” economy in a Lowry model. The matrix directly above at the top of the diagram shows the structure of the incremental model that operates between time periods. The *r*’s for the industry and household factors indicate the economic growth in the region, and the *r*’s for the land use factors show how vacant land is converted to urban land.

The matrix on the left below the large matrix in Figure 2 indicates the structure of the interface between the land use and transportation submodels. Each row represents one of the matrices of transportation demand and indicates the producing factors (in the corresponding columns in the matrix above) whose matrices of trades are related to that flow.

The remaining three matrices at the bottom show the structure of the transportation model. Five modes are available, and each mode can consist of several different types of activity on different types of links. The matrix directly to the right shows that all modes are available to all flows (*m*). The matrix below this, on the right, indicates the travel states (*s*) that make up each mode. The matrix on the left shows which travel states are allowed on each transportation network link and whether capacity restraint is in effect (*a*) or not (*w*). The design of the mode choice and assignment models is based on the Sacramento Regional Travel Demand model (DKS Associates, 1994). A more detailed description of the Sacramento MEPLAN model design can be found in Abraham (2000).

Emissions Model

The California Department of Transportation's Direct Travel Impact Model 2 (DTIM2) emissions model and the California Air Resources Board's EMFAC7F emissions factors were used in the emission analysis. The outputs from the MEPLAN model used in the emissions analysis included the results of assignment for each trip purpose by each time period (AM peak, PM peak, and off-peak). The Sacramento Area Council of Governments (SACOG) provided regional cold-start and hot-start coefficients for each hour in a twenty-four hour summer period.

Equity and Total Benefit Measures

Transportation agencies in the U.S. typically use criteria such as lane-miles of congestion, hours of travel delay, VMT, and mode share to evaluate proposed transportation policies. Such criteria are limited because they fail to account for the balance of effects on travel time and cost from changes in transportation policies. Benefit measures that capture the change in travel time and cost for all modes that may result from a policy scenario can be used to measure gains or losses to specific groups (usually income groups) or the region as a whole.

Kenneth Small and Harvey Rosen (1981) show how a consumer welfare measure known as compensating variation (CV) can be obtained from discrete choice models:

$$CV = 1/\lambda \left\{ \left[\ln \sum_{m \in M} e^{V_m(p^f)} \right] - \left[\ln \sum_{m \in M} e^{V_m(p^0)} \right] \right\} \qquad (1)$$

where λ is the individual's marginal utility of income, V_m is the individual's indirect utility of all m choices, p^0 indicates the initial point (i.e., before the policy change), and p^f indicates the final point (i.e., after the policy change). The change in indirect utility is converted to dollars by the factor, $1/\lambda$, or the inverse of the individual's marginal utility of income. Small and Rosen show how marginal utility of income can be obtained from the coefficient of the cost variable in discrete choice models.

The compensating variation formula (1) above was adapted to suit the specifications of the Sacramento MEPLAN model. In the work trip purpose, households are segmented into income categories, and person trips are generated for those categories. To obtain compensating variation for each income category h, the following formula was applied for all modes m and for all trips Q between all origins i and all destinations j:

$$CV_h = 1/\lambda_h \left\{ \sum_{i \in I} \sum_{j \in J} \left[\left(\ln \sum_{m \in M} e^{V_{ijmh}(p^f)} * Q_{ijh} \right) - \left(\ln \sum_{m \in M} e^{V_{ijmh}(p^0)} * Q_{ijh} \right) \right] \right\} \qquad (2)$$

Total compensating variation was obtained by summing the compensating variation obtained from each income group. This benefit measure captures changes in travel time and perceived travel costs by mode, but not changes in other externalities and capital and operation and maintenance costs. Values of the marginal utility of income were obtained from model parameters estimated from local data. In the scenarios that include pricing policies, increases in monetary costs from the base case are returned to the traveler. The figures are in 1990 dollars.

SCENARIOS

We examine ten transportation scenarios in the year 2020. Transportation network improvements in the alternative scenarios are made in the year 2005 for the scenarios, and thus land uses are affected in the years 2010, 2015, and 2020.

Base Case. The base case scenario represents a financially conservative expansion of the Sacramento region's transportation system and serves as a point of comparison for the other scenarios examined in this study. This scenario includes a relatively modest number of road-widening projects and new major roads, one freeway HOV lane segment, and a limited extension of light rail.

High Occupancy Vehicle Lanes (HOV). The HOV lane scenario represents an extensive expansion of the Sacramento region's HOV lane system. See Figure 3. HOV lanes are increased from 26 lane miles in the base case scenario to 179 lane miles. Mixed-flow freeway lanes are increased by 6% compared to the base case scenarios.

Beltway. This scenario adds two regional beltways to the HOV lane scenario described above. See Figure 3. This scenario includes 591 new lane-miles of highway, six new interchanges for beltways, 65 lane-miles of new arterial roads to serve the beltways, and 153 lane miles of new HOV lanes.

INSERT FIGURE 3 ABOUT HERE

Light Rail Transit (LRT). In this scenario, approximately 75 new track miles of light rail are added to the existing 18 miles of light rail. See Figure 4. This light rail network is combined with advanced transit information systems (ATIS) and local paratransit service. The value of wait time is reduced by a factor of three to represent ATIS, and the access time to transit in areas around transit stations is reduced by three minutes to represent paratransit service.

INSERT FIGURE 4 ABOUT HERE

Pricing. The pricing policies includes a $0.05 increase in the per mile cost of operating a private vehicle (which simulates a VMT or fuel tax) and a regionwide parking charge that represents an average surcharge of $2 for work trips and $1 for other trips. A $0.05 VMT tax for the Sacramento region is obtained from the low end of the average national estimates of the external costs of auto use (Delucchi, 1997). The pricing policies are implemented in the year 1995.

Pricing and LRT. This scenario combines the pricing scenario with the LRT scenario.

Urban reserve, infill subsidy, and LRT. This scenario reflects an effort to protect important native habitats in the region and promote more intense growth in the areas around transit stations. Development on vacant residential low density land was restricted in order to protect important habitats. Table 3 documents these restrictions. A land subsidy of 20% of expenditures in the year 2000 on land rent was imposed in the zones around transit stations. This scenario also includes the transit service in the LRT scenarios. The urban reserve and infill subsidy policies take effect in the year 2000.

INSERT TABLE 3 ABOUT HERE

Pricing, urban reserve, infill subsidy, and LRT . This scenario combines the pricing scenario and the urban reserve, infill subsidy, and LRT scenario.

Urban Growth Boundary (UGB) and LRT. Figure 5 illustrates the zones in this scenario that are designated as no-growth and slow-growth areas of the region. This scenario also includes the transit service in the LRT scenario. These designations are based on environmental considerations and are also intended to support the use of the light rail. In the no-growth zones, development of all vacant land is disallowed. In the slow growth scenarios, development is allowed on only half of the available vacant land. The UGB takes effect in the year 2000.

INSERT FIGURE 5 ABOUT HERE

Pricing, Urban Growth Boundary, and LRT. This scenario combines the urban growth boundary and the pricing scenarios.

RESULTS

Land Use

In the base case scenario, land development from 1990 to 2020 occurs north, east, and south of the City of Sacramento. There is limited land development in the west (Yolo County) because of exclusive agricultural zoning in the county. Over time for the 2020 time horizon, households and employment tend to locate primarily in existing, built-up areas northeast, east, and immediately south of the central business district (CBD). In general, household and employment location tends to follow land development; however, density increases in some zones. From 1990 to 2020, land development in the base case scenario increased by 959,230 acres. The land use results for the other scenarios are discussed in comparison to the future base case scenario.

In the highway investment scenarios (HOV and beltway), industry locates further away from the households that it serves and employs. Employment location is more intense in the CBD in the existing, built-up areas northeast, east, and immediately south of the CBD. The distant eastern zones that include the cities of Auburn and Folsom lose commercial employment and become more like “bedroom communities” compared to the base case scenario. As a result of increased roadway capacity, retail activity can shift from local commercial to more remote zones where “big-box” retailing is likely to occur. Rancho Cordova becomes increasingly important as a commercial node east of the City of Sacramento and west of Folsom. These activity patterns produce an increase in land consumption, 624 acres for the HOV scenario and 547 acres for the beltway scenario. Table 4 presents the change in household and employment activities for the scenarios from the base case and Table 5 represents the change in total developed acres of land for the scenarios from the base case.

INSERT TABLE 4 ABOUT HERE

In the LRT scenario, households and employment location tends to follow the light rail lines. The improved mobility resulting from the transit investment allows a modest separation between household and employment location and an increase in land consumption (265 acres), compared to the base case scenario.

In the pricing-only scenario, regionwide parking pricing and a VMT tax produce increases in the location of household and employment activities in the CBD (2.5% and 1.3%, respectively) and in the inner suburbs (1.1%). There are also decreases the location of household and employment activities in the outer zones (1.6% for households and 2.8% for employment). Total land consumption is reduced by 617 acres.

The addition of pricing policies to the LRT network reverses the decentralization of activity location in the LRT only scenario. There are relatively large increases in activity location in the CBD for both households and employment (2.7% and 2.9%, respectively) and a reduction in the outer ring for both employment and households (1.4% and 2.4%, respectively). Land consumption is reduced by 519 acres compared to the base case.

In the urban reserve and infill scenarios, the 20% subsidy for infill development results in modest gains in employment activity location in the CBD (0.7%) and in the outer ring (0.9%). Household and employment activity is reduced in the remaining superzones. In general, there is a movement of employment activity to areas outside the region. Land consumption is significantly reduced by 10,892 acres. Thus, it appears that the reduction of land consumption results largely from loss of regional employment rather than increases in regional land use densities.

When pricing policies are added to the urban reserve and infill policies, household and employment activity is significantly intensified in the CBD (1.8% and 2.3%) and increased somewhat in the inner areas of the region (0.6% and 0.4%). Land consumption is modestly increased in this scenario by about 100 acres compared to the base and the urban reserve and infill scenarios. However, the reduction in land consumption in this scenario results less from losses in regional employment and more from increases in land use densities than in the urban reserve and infill scenario.

The UGB policy has a dramatic effect on activity location and development. For the outer rings, there is an almost 15% reduction in employment activities and almost a 7% increase in household activities compared to the base case scenario. There are relatively large increases in household and employment development along the light rail lines, particularly in the CBD (1.6% and 2.6%, respectively), Citrus Heights/Roseville (1.7% and 3.6%, respectively), and Rancho Cordova/Folsom areas (3.5% and 4.8%, respectively). An increase in the concentration of activities in the inner areas of the region and a reduction in the outer areas produce a reduction in land consumption of 19,023 acres compared to the base case scenario.

When the pricing policies are added to the UGB policy, changes in activity location and development are even more dramatic. There is a larger increase in household and employment activities in the CBD (3.7% and 4.6%, respectively), Rancho Cordova/Folsom (4.9% and 5.8%, respectively), and inner suburbs (2.3% for both). However, the reduction in land consumed in the outer ring is approximately the same as UGB and light rail scenario (6.9%). It appears the pricing policies may reduce congestion, compared to the UGB and light rail scenario and allow development to spread out more to the inner suburbs and the Ranch Cordova/Folsom areas. The reduction in total acres of land developed is dampened somewhat compared to the UGB only scenario (18,824 acres).

Travel

Mode Share

In both the HOV and Beltway scenarios, there is an increase in the HOV mode share compared to the base case scenario (5.5% and 5.9%, respectively). The mode share results are presented in Table 6. Faster travel times resulting from the HOV lanes in the HOV and Beltway scenarios make carpooling more attractive than most of the other available modes, and there is a reduction in the drive alone, transit, walk, and bike mode shares.

INSERT TABLE 6 ABOUT HERE

The light rail and advanced transit investments and a modest increase in the intensity of activities along light rail lines result in faster transit travel times and produce relatively large gains in the transit mode share (257.5%) and losses in the drive alone (4.5%), shared ride (4.9%), and walk and bike (7.1%) mode shares.

The regionwide parking charge, a $0.05 VMT tax, and an increase in activities in the CBD and inner areas of the region result in a 35% reduction in the drive alone mode share. There are large increases in the modes for which these charges do not apply (i.e., transit, walk, and bike modes) or are lower (i.e., shared ride). When the light rail network is added to the pricing policies, there is a larger increase in the transit mode share (429.3%), a reduction in the shared ride, walk, and bike mode shares, and little change in the drive alone mode.

In the urban reserve, infill, and LRT scenario, transit mode share is increased compared to the base case scenario and the LRT scenario (267%). Again, the drive alone, shared ride, walk, and bike mode shares are all reduced in this scenario compared to the base case. Faster travel times by transit and a modest increase in employment activity in the CBD attract travelers away from the auto and non-motorized modes to transit. When pricing policies are added to this scenario, again, we see large reductions in the drive alone mode share and large increases in the shared ride, transit, walk, and bike mode shares.

In the UGB and LRT scenario, there are relatively large increases in the transit mode share (269.7%), a modest increase in the walk and bike mode share (1.3%), and reductions in the drive alone and the shared ride mode shares (4.1% and 7.6%, respectively). It is difficult to represent the effect that UGBs, which would most likely be combined with urban design policies, could have on the walk and bike mode share. This is because the Sacramento MEPLAN model uses large zones and does not explicitly include variables that represent the "walkability and bikeability" of neighborhoods.

When pricing policies are added to the UGB and LRT scenarios, the reduction in the drive alone mode share is significantly increased (41.5%) and transit mode share is much larger (600%), compared to both the base case and the UGB and LRT policies. The shared ride and walk, and bike mode shares are also increased in this scenario. The shared ride mode becomes more attractive in this scenario because auto pricing policies reduce congestion and the shared ride mode offers a break on auto pricing policies. The walk and bike share increases in this scenario because these modes are free and there is a greater concentration of activities in the CBD.

Vehicle Travel

In the HOV and beltway scenarios, the HOV lanes provide faster travel times by the carpool mode to produce larger shared-ride mode share and smaller drive-alone mode share, and thus there is a modest decrease in vehicle trips. Vehicle travel results are presented in Table 7. Despite these mode shifts, significantly reduced peak auto travel speeds (18.6% and 31.2%, respectively) and decentralization of employment and household activities produce longer trips and significantly increased VMT (5.2% and 9.2%, respectively).

INSERT TABLE 7 ABOUT HERE

In the light rail scenario, increased transit accessibility and a modest centralization of activities shift trips from the auto modes to transit and reduce vehicle trips (4.6%) and VMT (5.9%). The costs imposed on the auto modes in the pricing scenario increase the centralization of activities, produce large reductions in vehicle trips (19.9%) and VMT (21.8%), and significantly increase peak travel speeds (25.7%). When light rail is added to the pricing policies, the reduction in vehicle trips and VMT is increased (22.0% and 24.8%, respectively), and the increase in peak travel speed is greater (27.3%).

The pricing only and the pricing and light rail scenarios produce reductions in peak travel time that are greater than those in the HOV lane and the Beltway scenarios and increases in peak travel speed that are greater than in the HOV lane scenario and almost as great as in the beltway scenario.

The addition of the urban reserve and infill policies to the LRT policy produces somewhat larger reductions in vehicle trips (5.6%), VMT (6.5%), and peak mean travel time (5.6%). The addition of the pricing policy significantly improves these results, even compared to the pricing and LRT scenario.

In the UGB and LRT scenario, there is an increase in the reduction of vehicle trips (6.1%), VMT (10.3%), and travel time (16.5%) compared to the LRT only scenario. The reduction in peak travel time is greater than that obtained for the HOV lane and beltway scenarios. When pricing policies are added to the scenario, the reduction in vehicle trips and VMT is dramatically increased (28.4% and 57.0%, respectively). These reductions are larger than the results for the pricing and LRT scenario. There are also large reductions in peak travel time (27.2%) and large increases in peak travel speed (43.0%), which are both larger than the results for the HOV and beltway scenarios.

Emissions

The daily emissions results are presented in Table 8. The emissions results generally follow from the travel results. The HOV and Beltway scenarios increase vehicle emissions (e.g., 0.9% and 8.1% for NOx, respectively). The increase in emission for the beltway scenario is relatively large. All the other scenarios result in a reduction in emissions. The UGB, LRT, and pricing scenario produces the greatest reduction in emissions (e.g., 28.8% for NOx), followed by the urban reserve, infill, LRT, and pricing scenario (e.g., 25% for NOx), the pricing only scenario (e.g., 19.6% for NOx), followed by the pricing and LRT scenario (e.g., 19.3% for NOx), the UGB and LRT scenario (e.g., 8.6% for NOx), and finally the urban reserve, infill, and LRT scenario (e.g., 6.8% for NOx).

INSERT TABLE 8 ABOUT HERE.

Total Benefit and Equity Results

The UGB and LRT policy with and with pricing policies produces the greatest level of total regional benefits. Total benefit and equity results are presented in Table 9. The UGB policies and the pricing policies produce substantial reductions in peak travel times. Note, however, that the addition of pricing policies to the UGB and LRT scenario reduces benefits because travel benefits are lower than the cost of those policies.

INSERT TABLE 9 ABOUT HERE

The beltway scenario produces the next greatest total benefits, followed by the HOV scenario, the urban reserve, infill, and LRT scenario, and finally the LRT only scenario. It is important to note, however, that the highway networks in these scenarios represent a larger investment and serve a greater number of travelers than the LRT network. In addition, the capital and operation and maintenance costs are not included in the benefit analysis. However, past research by us in the region has indicated that inclusion of these costs will not change the rank ordering of scenarios. Further research is being conducted with highway and transit networks that represent similar levels of investment.

All the scenarios that include pricing policies (except the URB, LRT, and pricing scenario noted above) result in a loss of benefits. The greatest loss is obtained for the urban reserve, infill, LRT, and pricing scenario, followed by the pricing scenario, and, finally, by the pricing and LRT scenario. All of these scenarios produce significant reductions in peak period travel times; however, the costs of the pricing policies are not offset by a gain in traveler benefits (i.e., reduced congestion). Further research is being conducted to evaluate more optimal pricing levels for the pricing policies.

For most of the scenarios, the higher income groups benefit (or are hurt less) from the new transportation projects, pricing policies, and land use policies compared to the lower income groups. The higher income groups have a higher value of time than the lower income groups. As a result, the travel time saving to the higher income classes from the projects and policies in the scenarios are weighted more heavily. Alternative values of time and marginal utility of income assumptions can be used to address the income bias in the benefit analysis. It is also possible that the facility location benefits the higher income groups more than the lower income groups. The examination of equity measures (like the one in this study) can help highlight potential disparities in capital investment facility location. Note that the highest income group actually benefited from the pricing and LRT scenario even though the lower groups lost.

CONCLUSIONS

A number of conclusions can be made for this case study.

(1) Transportation investment in both highway and light rail may allow for greater decentalization of regional development. Land use and pricing policies may be used to "tame" the decentralizating effects of transportation investments. The HOV and beltway scenarios allowed for greater separation of household and employment development and increased regional land consumption. The LRT scenario also allowed for decentralization of activities along light rail lines and increased regional land consumption. When pricing and land use policies were added to the LRT network, this decentralizing trend was dramatically reversed.

(2) New highway capacity projects, even if they include HOV lanes, may increase VMT and emissions. The HOV and beltway projects in the scenarios evaluated in this study increased development in the outer areas of the region and increased total land consumption regionwide by approximately 500 to 600 acres compared to the base case. These land use patterns contributed to relatively large increases in VMT (5% and 10%, respectively) and emissions (1% and 8%, respectively for NOx).

(3) Transit investment with supportive land use policies and/or pricing policies may be very effective in reducing VMT and emissions. For example, we found a 7% to 29% reduction in NOx emissions for the pricing, urban growth boundary, urban reserve, and infill policies in this study.

(4) Transit investment with supportive land use and/or pricing policies may provide congestion reduction that is as great, if not greater, than highway investment policies. The HOV lane and the beltway scenarios produced an 8% and 14% reduction in peak travel time and the transit with supportive land use and/or pricing policies produced a reduction in peak period travel time of 6% to 27%.

(5) The transit investment combined with land use policies may provide greater benefits (i.e., change in travel time and cost from the base case) than highway investment policies. For example, the UGB and LRT policy provided a change in total benefit that was more than double the beltway scenario during the AM peak hour.

(6) Equity measures are useful to identify possible disparities in the benefits that may result from the location of transportation investments and policies that may result in losses to certain groups. With this knowledge, it may be possible to redesign policies to redress losses to certain groups. For example in this study, the results suggested that auto pricing policies alone could result in losses to the lowest income class; however, these losses were offset when the policies were combined with transit investment.

In sum, if the scenarios in this report are evaluated against four criteria, (1) congestion reduction, (2) emissions reduction, (3) total regional benefits and benefits by income class, and (4) protection of environmentally sensitive lands, then the LRT with the UGB and/or the pricing scenarios are the clear winners. The conclusions of this report strongly suggest that a fair evaluation of proposed new highway projects should use state-of-the-practice methods that represent induced travel effects and should analyze alternatives that include transit investment accompanied by supportive land use and auto pricing policies.

ACKNOWLEDGEMENTS

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LIST OF TABLE AND FIGURES

Table 1. Description of categories in Figure 2.

Type of Category	Category Name	Category Description
Industry and Service	AGMIN	Agriculture and mining
	MANUF	Manufacturing
	OFSRV-RES	Services and office employment consumed by households
	OFSRV-IND	Services and office employment consumed by other industry
	RETAIL	Retail
	HEALTH	Health
	EDUCATION	Primary and secondary education
	GOVT	Government
	PRIV EDU	Private education
	TRANSPORT	Commercial transportation
	WHOLESALE	Wholesale
Households	HH LOW	Households with annual income less than $20,000
	HHMID	Households with annual income between $20,000 and $50,000
	HH HIGH	Households with annual income greater than $50,000
Land Use	AGMIN LU	Land used for agriculture
	MANUF LU	Land used for manufacturing
	OFSRV LU	Land used for services and office employment
	RETAIL LU	Land used for retail
	HEALTH LU	Land used for health
	EDUCATION LU	Land used for education
	GOVT LU	Land used for government
	RES LU	Land used by residences

Table 2. Zoning system for the enhanced Sacramento MEPLAN model. Shading indicates permitted uses. 'x' indicates uses that are theoretically permitted but do not occur in the base data.

Land zoning designation by planner	Space developed by developer						
	Vacant	Industrial	Commercial High Density	Commercial Low Density	Residential High Density	Residential Med Density	Residential Low Density
Industrial							x
Commercial High Density							x
Commercial Low Density							x
Residential High Density							
Residential Med Density							
Residential Low Density							
Urban Reserve							
Agricultural							

Table 3. Documentation of acres of residential low vacant land used in the urban reserve scenario.

RAD	DESCRIPTION	ACRES OF DEVELOPABLE RESIDENTIAL LOW VACANT LAND		
1	North Natomas	Total in 1990	Habitat Preservation	Total in scenario
2	Rio Linda	259	126	133
3	North Highlands	6228	4675	1553
4	Citrus Heights	397	264	132
5	Orangevale	4	0	4
6	Folsom	1903	828	1075
7	South Natomas	1	0	1
8	N Sacramento	0	0	0
9	Arden Arcada	198	178	20
10	Carmichael	0	0	0
11	Fair Oaks	0	0	0
12	Rancho Cordova	64	17	46
13	Downtown	0	0	0
14	Parkpocket	0	0	0
15	E Sacramento	69	27	42
16	S Sacramento	0	0	0
17	Vineyard	458	346	112
18	Franklin L	2396	2286	110
19	Elk Grove	425	371	54
20	Delta	4951	4581	370
21	Galt	86	79	7
22	Cosumnes	2425	2029	396
23	SE County	11602	10509	1093
24	Rancho Murieta	8246	7828	418
25	Antelope	0	0	0
30	South Sutter	755	561	194
50	W Sacramento	646	255	391
51	Woodland	0	0	0
52	Davis	46	40	7
53	Clarksburg	0	0	0
54	Esparto/Ca	0	0	0
55	Winters	14	12	2
56	NoName	0	0	0
70	Roseville	0	0	0
71	Rocklin	2002	1515	487
72	Lincoln	241	193	48
73	W Placer	2767	2587	180
74	Sheridan	289	210	79
75	N Auburn	1741	1552	190
76	Auburn	11953	10114	1839
77	Loomis	14019	11965	2054
78	Granite Bay	14805	12721	2084
79	Foresthill	7823	6163	1661
80	Colfax	10204	9370	834
81	Placer High	17338	15501	1838
85	El Dorado	10787	9728	1058
86	Cameron Park	25383	22180	3204
87	Pilot Hill	6808	6370	438
88	Coloma Lot	18018	17312	706
89	Diamond Springs	16546	14742	1804
90	W Placerville	28097	26976	1121
91	S Placerville	2710	2268	441
92	E Placerville	819	776	43
93	Pollock Pines	4753	4176	577
94	Grizzly Flats	9684	7460	2224
95	Georgetown	32638	31918	720
96	High Country	34187	31342	2845

Table 4. Percentage change (from 2020) in household and employment by superzone for the 2020 MEPLAN scenarios.

HOUSEHOLDS	HOV	BELTWAY	LRT	PRICING	PRICING +LRT	URBAN RESERVE + INFILL +LRT	PRICING +URBAN RESERVE +INFILL +LRT	UGB +LRT	PRICING +UGB +LRT
Sacramento CBD (13)	-0.4%	-0.5%	-0.1%	2.5%	2.7%	-0.5%	1.8%	1.6%	2.3%
Citrus Hgts/Roseville (70,71,4)	-0.4%	-0.8%	0.3%	0.5%	0.9%	-0.3%	0.0%	1.7%	1.8%
Rancho Cordova/Folsom (6,12)	-1.8%	-1.6%	-0.2%	0.6%	0.8%	-0.8%	-0.5%	3.5%	6.2%
Inner Suburbs (1-3, 7-11, 14, 16, 25)	-0.2%	-0.4%	0.1%	1.1%	1.4%	-0.4%	0.6%	0.5%	1.7%
Outer Ring (Remainder)	1.2%	1.2%	0.0%	-1.6%	-1.4%	-3.1%	-4.4%	-6.7%	-7.8%
EMPLOYMENT									
Sacramento CBD (13)	2.7%	2.9%	1.3%	1.3%	2.9%	0.7%	2.3%	2.6%	3.6%
Citrus Hgts/Roseville (70,71,4)	-0.6%	0.4%	-0.3%	-0.3%	-1.5%	-1.0%	-2.3%	3.6%	3.3%
Rancho Cordova/Folsom (6,12)	8.8%	7.8%	-1.4%	5.7%	6.1%	-1.9%	5.6%	4.8%	4.3%
Inner Suburbs (1-3, 7-11, 14, 16, 25)	1.4%	1.5%	0.0%	1.1%	1.0%	-0.7%	0.4%	1.2%	1.2%
Outer Ring (Remainder)	-4.2%	-4.5%	1.9%	-2.8%	-2.4%	0.9%	-2.3%	-14.9%	-15.0%

Table 5. Percentage change (from 2020) in total developed acres by superzone for the 2020 MEPLAN scenarios.

	HOV	BELTWAY	LRT	PRICING	PRICING +LRT	URBAN RESERVE + INFILL +LRT	PRICING +URBAN RESERVE +INFILL +LRT	UGB +LRT	PRICING +UGB +LRT
Sacramento CBD (13)	0.4%	0.4%	0.2%	0.5%	0.8%	0.1%	0.5%	1.6%	2.3%
Citrus Hgts/Roseville (70,71,4)	0.0%	0.0%	0.0%	0.2%	0.2%	-0.5%	-0.4%	1.7%	1.8%
Rancho Cordova/Folsom (6,12)	0.6%	0.3%	0.0%	1.0%	1.1%	-0.4%	0.2%	3.5%	6.2%
Inner Suburbs (1-3, 7-11, 14, 16, 25)	0.0%	-0.1%	0.0%	0.3%	0.3%	-0.5%	-0.3%	0.5%	1.7%
Outer Ring (Remainder)	0.3%	0.3%	0.2%	-0.6%	-0.6%	-6.0%	-6.2%	-6.7%	-7.8%
Total percentage change	0.2%	0.2%	0.1%	-0.2%	-0.2%	-4.0%	-4.0%	-7.0%	-6.9%
Total change in acres	624	547	265	-617	-519	-10,892	-10,929	-19,023	-18,824

Table 6. Daily mode share projections for the MEPLAN scenarios.

SCENARIOS	DRIVE ALONE	SHARED RIDE	TRANSIT	WALK & BIKE
Base	45.0	43.8	1.9	9.3
HOV	43.2 (-4.0%)[1]	46.2 (5.5%)	1.8 (-6.4%)	8.8 (-5.1%)
Beltway	43.2 (-4.0%)	46.4 (5.9%)	1.8 (-4.8%)	8.6 (-7.3%)
LRT	43.0 (-4.5%)	41.7 (-4.9%)	6.7 (257.5%)	8.6 (-7.1%)
Pricing	29.2 (-35.1)	51.7 (18.1)	3.8 (100.5%)	15.3 (64.8%)
Pricing + LRT	29.0 (-35.7)	49.0 (11.9%)	10.0 (429.3%)	12.1 (30.1%)
Urban Reserve + Infill + LRT	43.0 (-4.6%)	41.5 (-5.3%)	6.9 (267.0%)	8.6 (-6.9%)
Urban Reserve + Infill + LRT + Pricing	26.3 (-41.5%)	47.6 (8.6%)	13.0 (588.8%)	13.2 (41.7%)
UGB + LRT	43.2 (-4.1%)	40.5 (-7.6%)	7.0 (269.7%)	9.4 (1.3%)
UGB + LRT + Pricing	26.3 (-41.5%)	46.7 (6.7%)	13.2 (600.0%)	13.8 (48.4%)

[1] Percentage change from the base scenario.

Table 7. Vehicle travel results for the MEPLAN scenarios.

	DAILY TRIPS (MILLIONS)	DAILY VMT (MILLIONS)	PEAK MEAN TRAVEL TIME (MINUTES)	PEAK TRAVEL SPEED (MPH)
Base	5.41	44.69	28	21
HOV	5.36 (-1.0%)[1]	47.0 (5.2%)	26 (-7.7%)	25 (18.6%)
Beltway	5.36 (-0.9%)	48.98 (9.6%)	24 (-14.0%)	28 (31.2%)
LRT	5.16 (-4.6%)	42.05 (-5.9%)	27 (-3.5%)	22 (4.2%)
Pricing	4.33 (-19.9%)	35.00 (-21.8%)	23 (-17.5%)	26 (25.7%)
Pricing + LRT	4.22 (-22.0%)	33.58 (-24.8%)	23 (-18.3%)	27 (27.3%)
Urban Reserve+Infill+LRT	5.11 (-5.6%)	41.79 (-6.5%)	27 (-5.6%)	22 (6.2%)
Urban Reserve+Infill+LRT+Pricing	3.91 (-27.7%)	20.08 (-55.1%)	23 (-17.6%)	28 (31.3%)
UGB+LRT	5.08 (-6.1%)	40.07 (-10.3%)	24 (-16.5%)	25 (16.6%)
UGB+LRT+Pricing	3.87 (-28.4%)	19.24 (-57.0%)	21 (-27.2%)	30 (43.0%)

[1] Percentage change from the base scenario.

Table 8. Daily emissions results for the MEPLAN scenarios.

	TOG (TON)	CO (TON)	NOX (TON)	PM (TON)
Base	14.2	124.4	55.1	84.6
HOV	14.5 (2.1%)[1]	126.1 (1.4%)	55.6 (0.9%)	84.8 (0.3%)
Beltway	15.0 (5.9%)	134.7 (8.3%)	59.6 (8.2%)	86.7 (2.5%)
LRT	12.5 (-11.8%)	113.7 (-8.6%)	51.7 (-6.1%)	74.1 (-12.4%)
Pricing	10.3 (-27.0%)	95.9 (-22.9%)	44.3 (-19.6%)	60.4 (-28.5%)
Pricing+LRT	10.6 (-25.4%)	96.7 (-22.2%)	44.4 (-19.3%)	61.0 (-27.9%)
Urban Reserve+Infill+LRT	12.4 (-12.6%)	112.7 (-9.4%)	51.3 (-6.8%)	73.3 (-13.3%)
Urban Reserve+Infill+LRT+pricing	9.5 (-32.9%)	88.7 (-28.7%)	41.3 (-25.0%)	56.6 (-33.1%)
UGB+LRT	9.5 (-32.6%)	108.0 (-13.2%)	50.3 (-8.6%)	68.9 (-18.6%)
UGB+LRT+pricing	8.8 (-38.1%)	83.3 (-33.1%)	39.2 (-28.8%)	51.6 (-39.0%)

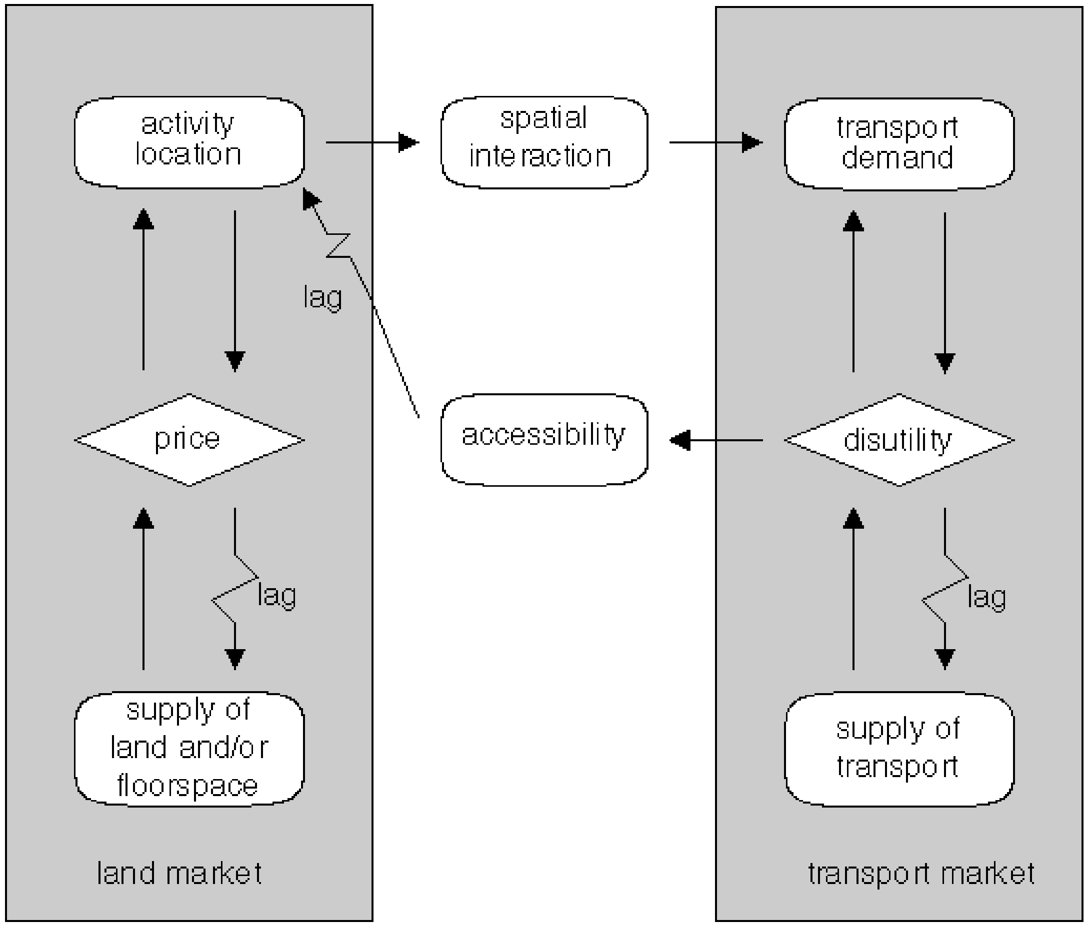
[1] Percentage change from the base scenario.

Table 9. Results of the benefit measure for the MEPLAN scenarios.

	Low Income		Middle Income		High Income		Total	
	Total	By Trip	Total	By Trip	Total	By Trip	Total	By Trip
HOV	$22,534.85	$0.52	$277,684.14	$2.49	$263,408.43	$3.22	$563,627.42	$2.38
Beltway	$28,013.44	$0.65	$341,725.61	$3.07	$385,844.43	$4.71	$755,583.48	$3.20
LRT	$1059.30	$0.02	$67,929.07	$0.61	$270,912.29	$3.33	$339,900.65	$1.44
Pricing	-$68,239.29	-$1.58	-$84,961.02	-$0.77	-$56,736.77	-$0.70	-$209,937.08	-$0.89
Pricing+LRT	-$156,762.22	-$3.60	-$108,232.79	-$0.97	$132,237.00	$1.63	-$132,758.01	-$0.56
Urban Reserve+Infill+LRT	$5,869.81	$0.14	$131,997.54	$1.19	$397,808.36	$4.92	$535,675.71	$2.28
Urban Reserve+Infill+LRT+pricing	-$61,388.90	-$1.41	-$39,346.48	-$0.36	-$305,576.43	-$3.78	-$406,311.80	-$1.73
UGB+LRT	$44,600.91	$1.07	$583,417.11	$5.39	$1,328,500.36	$16.76	$1,956,518.37	$8.53
UGB+LRT+pricing	$433.83	$0.01	$396,205.08	$3.67	$684,320.25	$8.70	$1,080,959.16	$4.72

Notes: the benefit measure captures change in travel cost and time for all modes from the base case scenario for the work trip purpose for the AM peak hour only; figures are in 1990 dollars; capital and O&M costs are not included in the benefit measure; additional monetary costs incurred (compared to the base case) are returned to travelers in the scenarios that include pricing policies.

Figure 1. The interaction of the land use and transportation markets in MEPLAN.



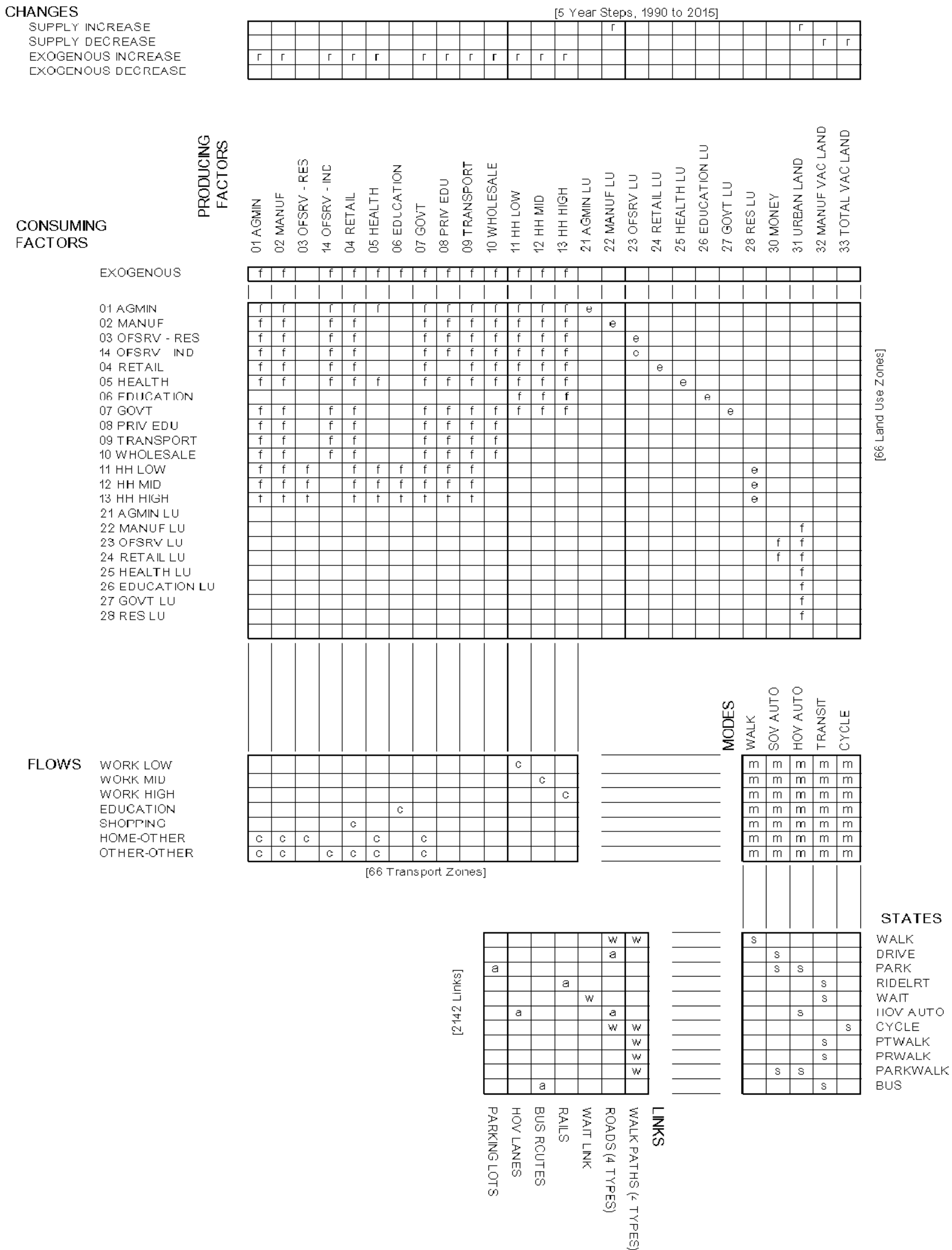


Figure 2. The "Hunt" Diagram of the Sacramento MEPLAN Model

Figure 3. Map of the HOV and beltway networks.

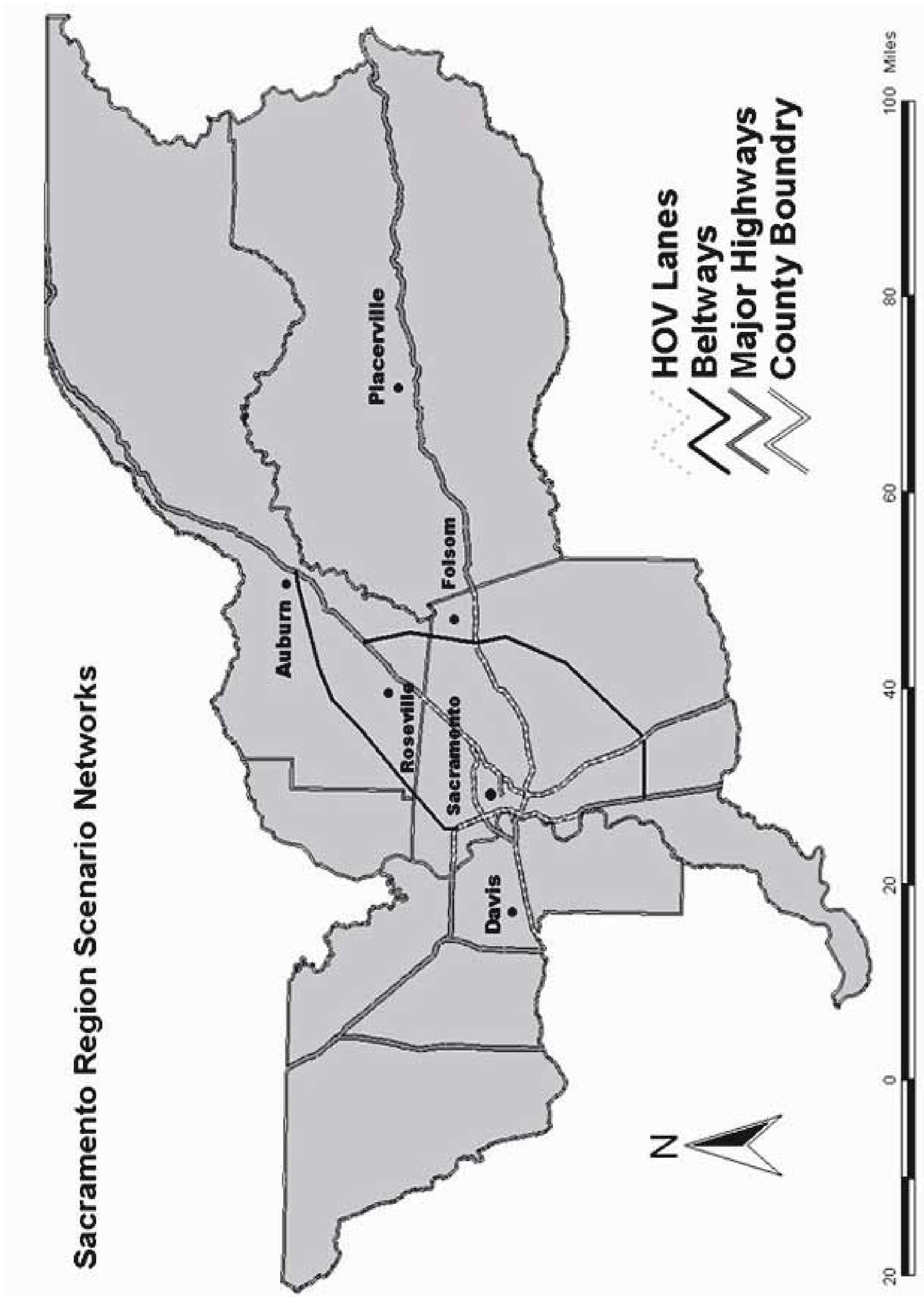


Figure 4. Map of the LRT network.

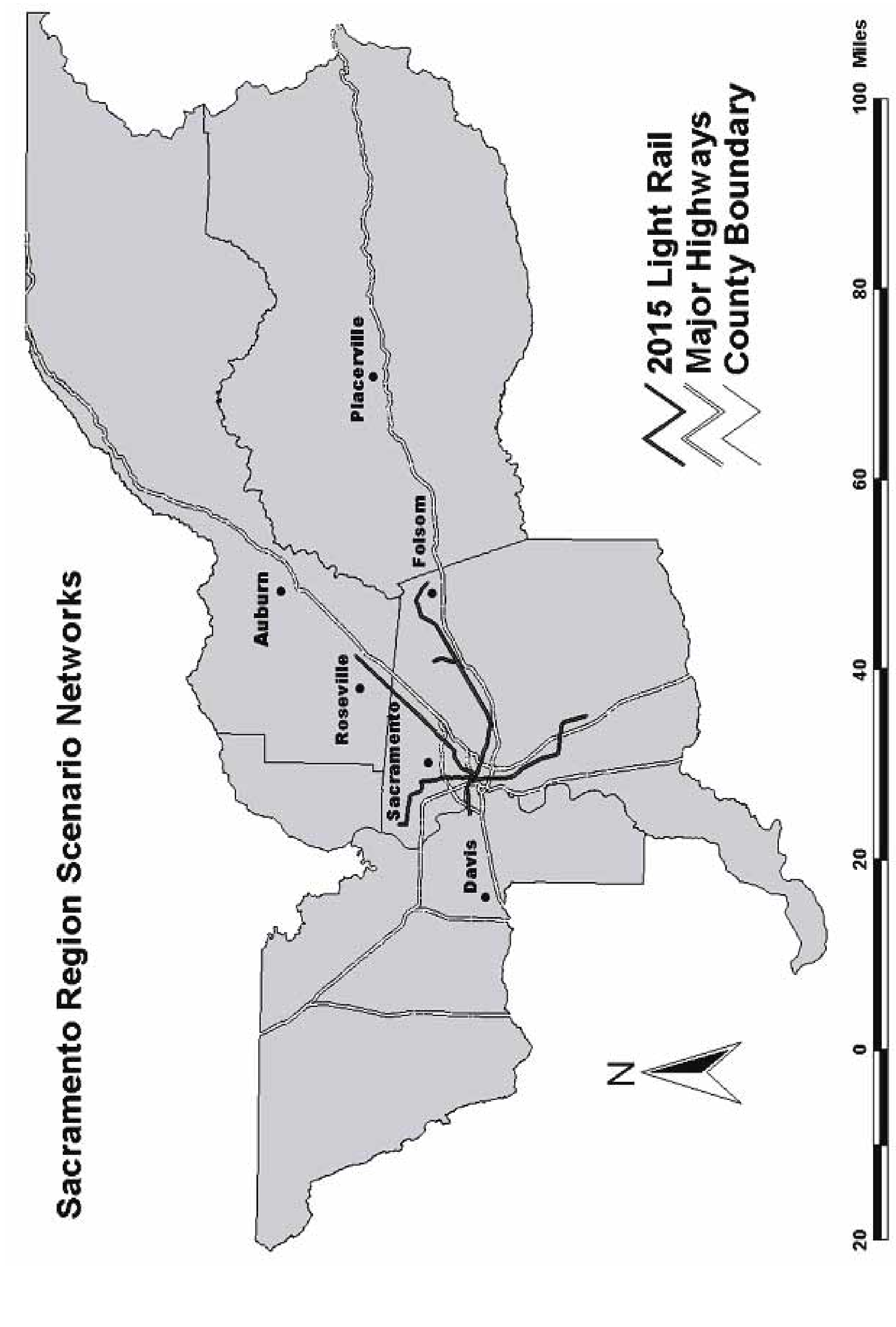


Figure 5. Map of the urban growth boundary.