Comparisons from the Sacramento Model Testbed
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Three land use and transport interaction models were applied to the Sacramento, CA region by various teams of researchers. The results of these efforts were compared with each other and with the traditional transport demand model used by the regional government. This paper compares the results of the modeling efforts, focusing on how the design of the modeling frameworks and their application influenced the modeling results. A trend scenario was compared to three different policy scenarios, one involving HOV lane construction, one adding beltway construction as well as HOV construction, and a third involving light rail construction and limited pricing of automobile use. The results differ among the different models for the trend scenario, as well as for each model with respect to scenario-to-trend comparisons. The results show some of the limitations of aggregate models calibrated to cross-sectional data. The differences between the models provide important insight into how models should be calibrated and how their results should be used. Uncertainty in land use transport interaction models seems inevitable, and further research should investigate how to best use such modeling frameworks to understand the influence of policy in the face of uncertain futures.

INTRODUCTION

Background

The Sacramento Model Testbed research program was established to apply land use and urban economic models to transportation planning in the US. Teams of researchers agreed to participate by applying a modeling framework to the Sacramento region. Each team was provided with data describing the region's land use patterns, employment and household distributions, travel characteristics and transportation network.

The models were applied to analyze transport policy scenarios. The transport scenarios were composed of politically realistic changes to the supply of transport in the region. The changes included HOV lane construction, new freeway construction, LRT construction and changes to the costs of vehicle operation and parking. These scenarios were compared with a trend scenario so that the sensitivity of each model could be established independently of the basic behavior of the model.

The then-current version of the Sacramento Area Council of Government's transportation model, SACMET, was also applied to the scenarios for comparison purposes.

The intent of the program was to examine how model form influences model results, to provide a basis for further research and development, and to further inform how cities and regions can respond to transportation policy. The models were developed with existing data sources, and with small research budgets, as a demonstration of the nature and the potential of the frameworks. This paper focuses on the modeling results so far and discusses some implications of those results.

Sacramento Area

The models were applied to the region under the control of the Sacramento Area Council of Governments (SACOG). This is a region approximately 200 km east to west and 100 km north to south. The region consists of the City of Sacramento, with a reasonably dense CBD, and a number of smaller towns. Most of the development is lower density, and there is a substantial amount of developable land zoned for development, and substantial amounts of additional land where development is physically possible but is restricted through zoning.

The transportation system is primarily auto-based, and auto travel is comparatively inexpensive. The freeway system is fairly extensive, but at times congestion limits the mobility provided by the roadway network.

MODEL DESCRIPTIONS

Four models are compared in this paper

SACMET 96

The SACMET model is a model based on the 4-step modeling framework but with auto ownership added as a separate submodel (DKS Associates, 1994 [1]). For work trips, mode choice and destination choice are modeled jointly with a nested logit model. The SACMET model was developed by the Sacramento Area Council of Governments with the assistance of DKS associates. The model was built for local policy analysis and infrastructure planning, and so more resources were available to collect data, investigate data and construct and validate the model.

The SACMET model has considerably more detail in the description of conditions, with 11,159 roadway links and 8403 roadway lane miles. The zoning system is also finely detailed, with 1077 transport zones.

The other models relied on data that was gathered for the purpose of developing the 1994 version of the SACMET model (SACMET 94, which differs in only minor ways from the updated model, SACMET 96, described in this paper).

Land use is an exogenous input in SACMET. The model is a traffic equilibrium model, and so is run directly for the horizon year with no need to simulate intermediate time periods and the dynamics of changes in urban form and spatial arrangement of activities.

There is an explicit representation of truck movements in the model.

DRAM/EMPAL (with SACMET 96)

DRAM/EMPAL allocates employment (EMPAL) and residence location (DRAM) in a simultaneous logit allocation (Putman, 1983 [2], 1991 [3]). Six employment categories and five household categories are allocated to zones. There are a large number of attributes in the utility function, including travel conditions (composite utilities) from previous time periods in the transport model. The transport model used is the SACMET '96 model, and DRAM/EMPAL uses the predictions of travel conditions from the SACMET model to predict the arrangement of activity.

The DRAM/EMPAL model uses 127 land use zones, and uses the full set of transport zones and the full transport network in the SACMET model. Because this model system structure incorporates SACMET, i.e. SACMET is run both within and between time periods, it allows the location of households and employment both to affect and be affected by the levels of congestion on the region's transportation networks.

DRAM and EMPAL operate as a linked pair of quasi-dynamic models. The forecasts of employment and household location depend upon a mix of lagged and current variables. Changes in the population, employment and transport services are modeled in five year time steps. Within each five year time step the transport model and the land use model are iteratively run (3 times) to approach an equilibrium between transport conditions and the spatial arrangement of activity. There is no explicit representation of the development industry, nor of prices for developed space. In each time period the forecasts of employment and household location demand are followed by a reconciliation of competing demands, and a subsequent calculation of land consumption.

MEPLAN

The MEPLAN framework models aggregate quantities of activity by allocating activity to zones. The allocation is done based on the interdependencies described in an Input-Output matrix, with travel costs and disutilities from a transport assignment and mode choice model. It is a quasi-dynamic framework, where quantities in one time step can depend on quantities in the previous time step (5 years earlier) (Hunt and Echenique, 1993 [4].)

In the Sacramento model the activities in the region were divided into 11 economic types and 3 household sectors (Abraham and Hunt, 1999) [5]. The exogenous amounts of activity (a portion of each activity type, based mostly on the quantities of export from the Input-Output table) are specified in each zone in the base year, and the inputs required are allocated to further activity in other zones according to utility values that include input costs, space costs, transport costs and alternative specific constants. Space quantities are constrained in any one time period, representing the permanent nature of buildings. The price of space is determined so that the space demanded by activity in a zone is equal to the constraint. New space is created by developers between time periods in response to price signals, and new exogenous activity locates according to price signals and capacity. Five year time periods are used in the Sacramento MEPLAN model, with travel conditions from the previous time period influencing the spatial arrangement of activities in the next time period.

Nested logit models are used for allocations, and Dial's algorithm is used for network loading.

The MEPLAN model is a sketch planning model, and uses 65 large zones representing SACOG's "Regional Analysis Districts" (RADs). The network as modeled is a simplified network, with 1,578 roadway links and 4,898 roadway lane miles.

TRANUS

The TRANUS model of Sacramento uses the TRANUS modeling framework from Modelistica. TRANUS is very similar to MEPLAN, especially in the representation of spatial allocation of activity, with a focus on ease of application rather than on flexibility. The TRANUS model of Sacramento (Modelistica, 1996 [6], Johnston and de la Barra, 2000 [7]) uses 5 year time steps, 6 economic sectors and 3 household sectors. Allocation of activity to zones is performed using logit models.

The network assignment algorithm in TRANUS uses a path enumeration technique. In the Sacramento implementation there is no separate mode choice model; rather the choice of modes is integral to the types of links chosen during the path. TRANUS uses “scaled utilities logit” for allocation rather than the standard logit model.

The TRANUS model was the first in the project to be completed and applied to the scenarios. The MEPLAN model benefited from having access to analysis and processed data from the development of the TRANUS model. In particular, the simplified representation of the roadway network in MEPLAN was taken from the TRANUS model. The TRANUS model also uses the 65 RADs as zones.

	Observed	MEPLAN	TRANUS	SACMET	SACMET +DRAM/ EMPAL
total person trips	4,810,800	4,843,600	2,276,879	6,700,000	6,700,000
trips per household	8.67	8.73	4.10	12.58	12.58
total vehicle trips	3,380,600	3,119,800	1,662,609	4,089,100	4,500,000
vehicle trips per household	6.09	5.62	3.00	7.68	8.45
total VMT		23,943,700	32,581,509	32,289,500	34,600,000
average distance per vehicle trip		7.68	18.90	8.87	7.69
transit share of person trips (%)	2.47	2.35	5.55	1.00	1.00
walk & bike share of person trips (%)	10.40	9.94	5.61	8.70	8.70
average speed (mph)		33.2	37.1	39.7	39.7
total households	554,900	554,860	554,900	532,600	532,600
households in Sacramento CBD	60,600	60,662	60,700	58,100	58,100
households in Inner Suburbs	238,300	238,303	238,300	228,700	228,700
households in Citrus Hgts & Roseville	62,700	62,711	62,700	60,200	60,200
households in Rancho Cordova & Folsom	43,900	43,915	43,900	42,200	42,200
households in Outer Ring (remainder)	149,400	149,269	149,300	143,400	143,400
total employment	632,100	632,069	632,000	609,900	597,700
employment in Sacramento CBD	167,700	170,295	167,700	160,600	158,100
employment in Inner Suburbs	218,700	212,580	218,700	214,900	211,800
employment in Citrus Hgts & Roseville	70,300	72,173	70,300	62,100	55,700
employment in Rancho Cordova & Folsom	83,100	84,222	83,100	69,700	70,900
employment in Outer Ring (remainder)	92,300	92,798	92,200	102,600	101,200
number of roadway links		1,578	1,578	11,159	11,159
total roadway miles		3,630	3,630	6,423	6,423
total roadway lane-miles		4,898	4,898	8,403	8,403
number of zones		65	65	1,077	127 & 1,077
time period for link capacities		16 hours	24 hours	24 hours	24 hours

Table 1: Characteristics of the models as calibrated for their base years

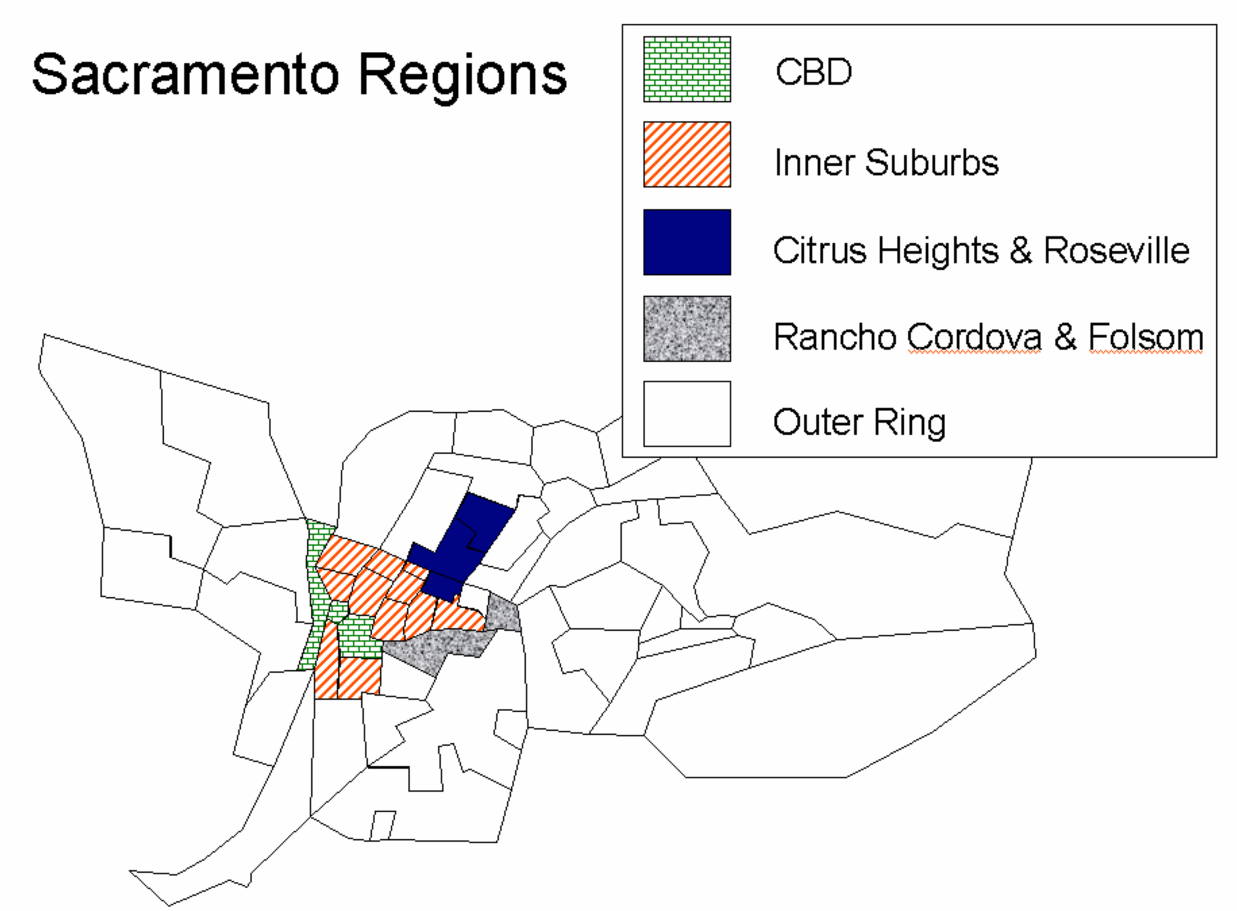

Figure 1: Areas of the Sacramento region identified in the tables

1990 CALIBRATION

Table 1 shows the results from the base year for each of the models, the household and employment distribution numbers refer to the areas of the region identified in Figure 1.

One important observation from Table 1 is that the models were not calibrated identically. The "observed" values are, for the most part, from the home based survey factored up to match the population. The number of person trips in the SACMET model was further factored up to match ground counts, under the assumption that person trips were under-reported in the home based survey, and perhaps to represent greater commercial trips.

Ground counts on the simplified networks (used by TRANUS and MEPLAN) were not available. MEPLAN was calibrated to trip length distributions, to properly represent the effect of distance on location choice. The VMT in MEPLAN is lower than the VMT in other models, as the trip lengths (in minutes) were respected but the number of trips was lower and the network was a simplified network. The speed-volume relationships for predicting congested travel times on links were not calibrated to observed data in TRANUS or MEPLAN. TRANUS was calibrated to match VMT values, leading to long lengths for auto trips. TRANUS does not include intra-zonal trips, and since the zones used (RAD's) are quite large this led to larger average trip lengths and further differences in mode split.

It is difficult to compare the mode share of transit trips in the TRANUS model with the values from the other models. In Tranus the mode choice was implemented as a choice of competing routes; the mode shares reported for transit are based on transit boardings, not trips, so transfers effectively increase the reported trip portions. In SACMET the dedicated school buses are not counted as "transit", while in MEPLAN they are, and the mode choice was further adjusted in SACMET to match ground counts.

The differences in travel measures between SACMET alone and SACMET with DRAM/EMPAL are caused by running the SACMET model differently. With DRAM/EMPAL population relocations lead to household composition changes, and where DRAM/EMPAL runs SACMET using Method of Successive Averages on link speeds to, while SACMET on its own adjusts the trip tables instead of link speeds to feedback travel conditions to equilibrium.

These differences in calibration are caused by the differences in the teams building the models, differences in the data supplied, different decisions made regarding ways to deal with data inconsistencies, the "demonstration" nature of the comparison project, and the lack of direct connection between the modeling teams and the data management at the University of California at Davis and within SACOG. In general it can be expected that the SACMET calibration is the more appropriate calibration for the transport model since:

- The SACMET development was a commercial modeling exercise with a significant budget and staff resources,
- SACOG is located in Sacramento and owns much of the available data and has staff who understand the intricacies of the data,
- The SACMET model, in both its stand-alone use and its use integrated with DRAM/EMPAL, has a more complete network representation. The more complete transport supply representation allowed a more complete representation of transport demand, and
- The Tranus and MEPLAN modeling teams were encouraged to create their own models separate from the policy concerns faced by SACOG. The focus was on demonstrating the nature of the modeling framework or developing methods to make such modeling easier in a USA context, not on reproducing network conditions. (In contrast, the initial application of DRAM/EMPAL to the region was funded by SACOG prior to this comparison project.)

SCENARIOS

Trend Scenario

The "Trend" scenario consists of expected regional population growth, and a financially constrained infrastructure and service plan based on the latest transportation improvement plan. Reasonable amounts of new roadway capacity are constructed to 2005, with no substantial improvements between 2005 and 2015.

The development of land in MEPLAN and TRANUS is such that land rents grow at about 1% per year in real terms. In MEPLAN this 1% was a region-wide average, with development allocated to zones based in part on prices in the previous time period. In TRANUS the land in each zone was developed so that each zone's prices would not increase by more than 1% as long as remaining developable (and appropriately zoned) land was available.

The other scenarios all included the basic infrastructure changes and amount of development as the Trend scenario, but included some additional transport infrastructure and price changes.

HOV Scenario

The "HOV" Scenario includes (in addition to the base network improvements in the Trend scenario) new HOV construction on radial freeways in the region. The HOV lanes shown by the dashed lines in Figure 2 are constructed.

HOV and Beltway Scenario

The "HOV and Beltway" Scenario involves the same HOV additions as the HOV scenario, but also involves further orbital beltways. The beltway additions are not a complete regional beltway, extending only to the North, South and East. The additional HOV lanes and beltways are shown in Figure 2.

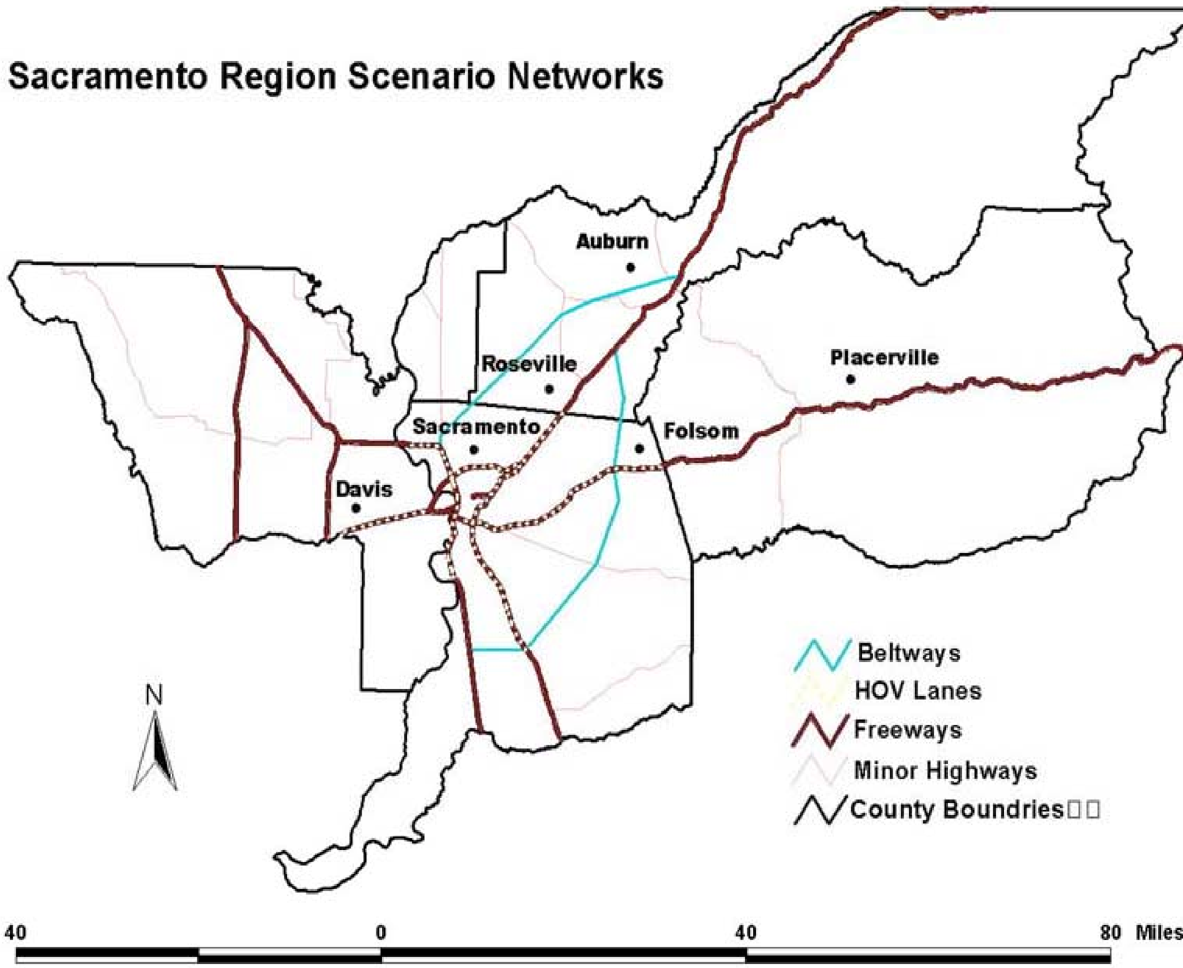

Figure 2: Proposed HOV lanes for the "HOV" scenario and proposed beltways for the "HOV and Beltway" scenario

LRT and Pricing Scenario

The "LRT and Pricing" Scenario involves extending LRT on various lines, and imposing a tax that increases the operating cost of private vehicles by 30%. The parking rates are increased in the CBD by $4.00 for work trips and by $1.00 for other types of trips. Figure 3 shows the LRT extensions in this scenario.

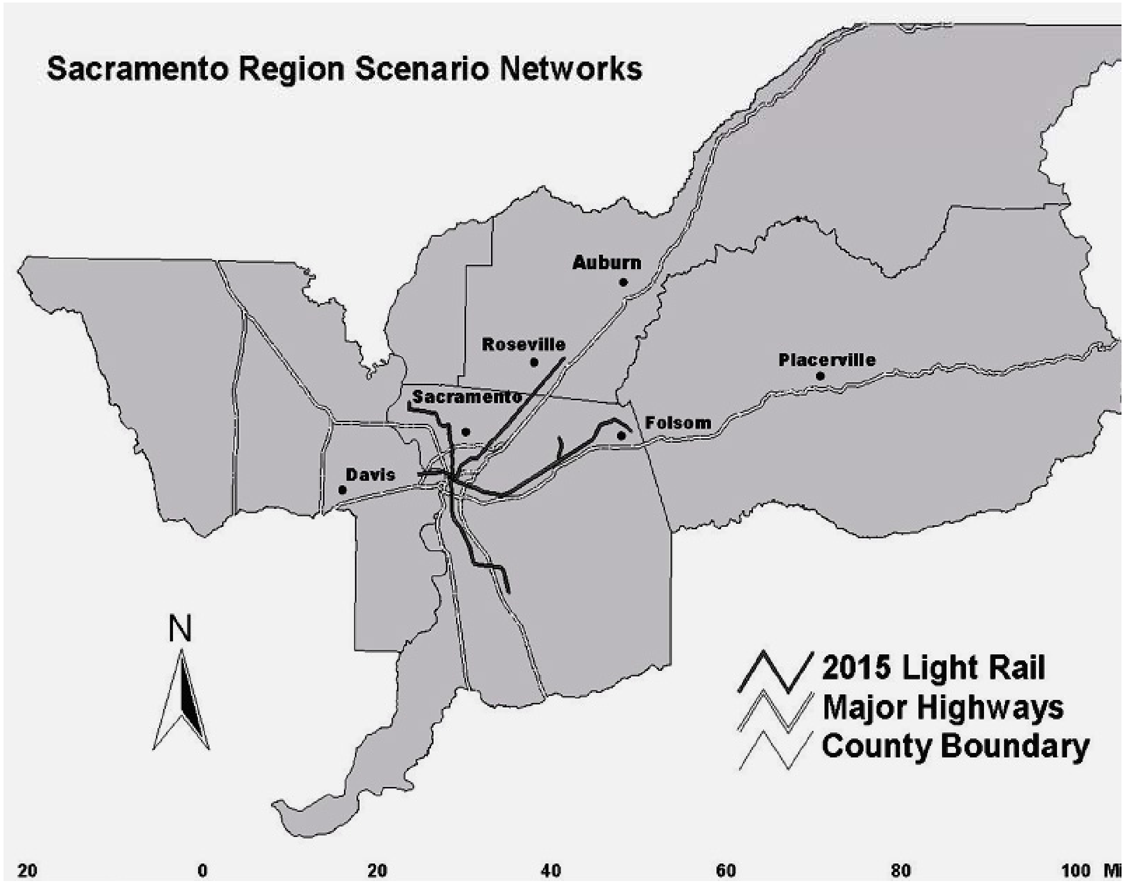

Figure 3: LRT extensions in the LRT Scenario

MODEL RESULTS FOR CHANGES OVER TIME

2015 was used as a horizon year for future predictions, although some DRAM/EMPAL results were reported for 2020. Table 2 shows the model predictions for the Trend scenario together with the percentage change between the 1990 calibration and the horizon year prediction for each of the models, and the maximum variation between scenarios as a percentage of the trend scenario values. The percentage change and variation values separate out the effect of the different calibrations and show the behavior of the models. There is a wide variation among the different models; generally much larger than the variation between scenarios within each model. Thus, there is a large effect attributed to the alternative specific constants (ASCs) and also to the general model elasticities, differences in calibration methods and the differences in the way activity location and the development industry are represented. The differences in the level of detail of network representation may confound some of these comparisons -- the large transportation zones and aggregate networks in Tranus and MEPLAN provide a more abstract representation of travel conditions than provided by the SACMET model.

	MEPLAN	% change from 1990	% variation between Scenarios	TRANUS	% change from 1990	% variation between Scenarios	SACMET	% change from 1990	% variation between Scenarios	DRAM/ EMPAL 6-9 AM 2020	% change from 1990	% variation between Scenarios
	TREND			TREND			TREND			TREND		
total person trips	8,084,500	66.9	0.46	3,900,000	71.3	0.00	9,800,000	46.3	0.00			
trips per household	8.61	-1.3	0.12	4.08	-0.6	0.01	11.05	-12.2	0.00			
total vehicle trips	5,186,900	66.3	3.22	3,700,000	122.5	18.92	6,800,000	66.3	0.00	1,362,400	63.6	0.37
vehicle trips per household	5.53	-1.7	3.74	3.87	29.2	18.92	7.67	-0.1	0.00	1.41	-9.8	0.38
total VMT	37,966,900	58.6	18.42	61,200,000	87.8	23.86	62,200,000	92.6	5.14	13,219,000	67.9	4.84
average distance per vehicle trip	7.32	-4.7	16.57	16.54	-12.5	6.85	9.15	3.1	5.14	9.70	2.6	4.78
transit share of person trips (%)	1.79	-23.8	27.93	4.20	-24.3	131.0	0.70	-30.0	28.57			
walk & bike share of person trips (%)	10.83	9.0	9.88	6.00	7.0	283.3	7.50	-13.8	4.00			
average speed (mph)	27.1	-18.4	6.38	15.8	-57.4	72.78	38.7	-2.5	2.84	31.5	-18.6	6.35
total households	938,565	69.2	0.50	956,000	72.3	0.01	887,000	66.5	0.00	968,400	81.8	0.01
households in Sacramento CBD	76,428	26.0	1.59	109,500	80.4	2.56	82,300	41.7	0.00	67,400	16.0	11.28
households in Inner Suburbs	311,734	30.8	1.53	401,200	68.4	2.24	301,200	31.7	0.00	313,800	37.2	4.24
households in Citrus Hgts & Roseville	98,559	57.2	1.67	109,400	74.5	1.46	100,600	67.1	0.00	163,200	171.1	5.39
households in Rancho Cordova & Folsom	83,254	89.6	1.68	75,300	71.5	2.79	62,700	48.6	0.00	83,300	97.4	33.37
households in Outer Ring (remainder)	368,589	146.9	0.97	260,600	74.5	2.65	340,200	137.2	0.00	340,700	137.6	7.19
total employment	1,059,486	67.6	0.49	1,088,900	72.3	0.03	1,031,600	69.1	0.00	1,126,000	88.4	0.02
employment in Sacramento CBD	230,487	35.3	7.22	289,800	72.8	0.86	247,100	53.9	0.00	218,600	38.3	1.33
employment in Inner Suburbs	336,506	58.3	2.58	382,600	74.9	0.84	287,800	33.9	0.00	370,800	75.1	1.73
employment in Citrus Hgts & Roseville	124,460	72.4	7.12	118,500	68.6	1.35	123,800	99.4	0.00	216,600	288.9	3.09
employment in Rancho Cordova & Folsom	123,034	46.1	15.67	138,000	66.1	2.75	128,300	84.1	0.00	105,400	48.7	3.42
employment in Outer Ring (remainder)	245,000	164.0	13.08	160,000	73.5	2.31	244,600	138.4	0.00	214,600	112.1	1.86

Table 2: Predictions for future trend scenarios, percentage change from calibration year (1990), and percentage variation between policy scenarios

Trips

The growth in person trips was generally comparable between models, with numbers of trips growing as the economy grows. The growth of person trips was lower in SACMET as SACMET included an assumption of smaller household sizes in the future. In TRANUS and MEPLAN the household sizes were assumed to be the same through time, and the growth in households was assumed to be the same as the growth of population.

The growth in vehicle trips was also generally comparable between models; however the TRANUS model showed significant differences between the scenarios. The TRANUS model had quite large mode choice elasticities compared to the other models, with mode changes in future scenarios being quite significant, leading to changes in the number of vehicle trips between the scenarios.

VMT

The SACMET model shows the largest increases in VMT over all scenarios. The models with an endogenous land use component (the other three models) all predict lower VMT growth than the SACMET model. The TRANUS result is, however, only slightly different from SACMET, while both MEPLAN and DRAM/EMPAL produce substantially smaller increases in total VMT. The SACMET model has, as input, assumptions of how much growth will occur where. The other three models show activities adjusting their locations in various ways in response to congestion as the region grows.

All of the models show significant differences in VMT growth between the scenarios.

Mode Choice

All of the models show a general trend downward in the number of trips served by transit. TRANUS shows a substantial increase in transit trips for the LRT and Pricing scenario. TRANUS shows substantial mode choice elasticity, with large differences between the scenarios. The Walk and Cycle mode share is fairly stable across scenarios in all of the models except the TRANUS model, where there are substantial differences between scenarios. This is partially because TRANUS does not include intra-zonal trips, but it also seems that the calibration of TRANUS left it with substantial mode choice elasticity.

Average Speeds

Average speeds for private auto travel are very stable in SACMET. In the other models there are reductions in average speed over the period from 1990 to 2015. The three land use models show people choosing locations where congestion is higher or where lower-speed roads are more dominant, leading to lower speeds (except in the HOV and Beltway Scenario with the MEPLAN model). This is not surprising, as the land use inputs to the SACMET model were crafted together with the network policy inputs, and so in the SACMET model there is an imposed match between activity location and the location of new transport facilities. In the other three models the land use activity patterns respond to the facility locations.

This illustrates a substantial difference between the way traditional transport models are used and the way land use and transport models should be used. In a traditional transport model the spatial arrangement of activity is forecasted exogenously, and in advance, and then the model is used to design a travel network that will serve that arrangement of activity. With a land use and transport modeling system various network configurations and zoning policies can be tested. The linked model will provide forecasts of resulting land use patterns and network facility usage. Thus with a linked land use model facilities can be planned to match spatial patterns that are forecasted together with travel patterns.

The average speeds in MEPLAN and TRANUS show greater variation between scenarios than the average speeds in the SACMET model with or without DRAM/EMPAL. This is likely due to the fact that MEPLAN and TRANUS only represent a portion of the roadway network, and so changes in transport demand have a larger effect when modeled over a smaller network of roads. Further, the network of roads in TRANUS and MEPLAN consist of proportionally more freeways, where congestion is the primary limitation on travel speeds, and proportionally fewer smaller roads, where speeds are limited more by geometry and less by the effects of congestion.

Location changes

The changes in employment and households by zone from 1990 to 2015 are quite different among the different models. The differences between the models are much larger than the differences between the scenarios analyzed with any one of the models. In part this is caused by the modest nature of the scenarios – the proposed changes in infrastructure plans and transport prices over 25 years are small changes compared to the inertia caused by the existing patterns of development, activity location and travel. It is also caused by the nature of the data and resources available to the project – no time series data on floorspace development was available and no budget was available to collect such data. Land price data were available, but without data on floorspace quantities the price data was difficult to interpret. Without such data to provide, in calibration, the information on how activity location responds to price and accessibility changes, the TRANUS and MEPLAN modeling teams were forced to use “rule-of-thumb” parameters and to rely extensively on the cross-sectional analysis of conditions in 1990 to imply the location response.

The use of a single “horizon year” in forecasts from dynamic models (or quasi-dynamic models) is also problematic. Land patterns take time to adjust, and the spatial regional economy may continue to respond to policy changes for several decades. A transport model is generally an equilibrium model, because the transportation system is expected to reach a stable state relatively quickly. A land use and transport interaction model has some representation of dynamics or “lags” in the locational response to transport conditions. Thus for a land use and transport model the outputs in a single future year do not show the full influence of policy.

Table 2 shows the relative growth predicted by each of the models from the calibration year (1990) to 2015 (2020 for DRAM/EMPAL.) Growth rates in TRANUS are essentially constant across the region. This may be related to the way development was simulated in TRANUS, with each zone’s supply of floorspace increased in each time period to keep floorspace rents approximately constant; or it may be related to how the amount of floorspace influenced the size terms in the logit utility functions for activity allocation.

The other models consistently predict large growth rates in the outer region at the expense of growth in the CBD area and the Inner Suburbs. The growth of the larger established communities (Citrus Heights/Roseville, Rancho Cordova/Folsom) are predicted differently by the different models. For example the DRAM/EMPAL model predicts a high growth rate in the Citrus Heights and Roseville area. DRAM/EMPAL has the capability to account for a pattern of activities preferring to locate near concentrations of similar activities (e.g. high income households prefer zones where a higher percentage of prior residents are high income households). This serves as a surrogate for a more comprehensive, explicit, representation of land markets. TRANUS and MEPLAN only represent the location preferences in their economic consumption functions and related travel; non-market externalities are not represented in the Sacramento implementations of these modeling frameworks. The market and travel relationships in MEPLAN can also be self-reinforcing in a zone, but it is directly modeled as a savings in transport costs due to complimentary activities, not as a term in an allocation utility function.

Shifts in activity in MEPLAN and TRANUS need to fit within the floorspace. If there is a large demand for space in a zone and a shortage of space, the price of space in the zone will rise forcing people to locate elsewhere. In the next time period, developers respond to the price signals, providing more space for activity. Thus changes take time to develop in these models because of the need for prices to be established in one time period to influence the development patterns between time periods.

DRAM/EMPAL has no such explicit representation of space. Households and employment are allocated directly to zones, with a subsequent land consumption procedure that accounts for density changes. In the case of extremely large demands, the model provides for the use of maximum constraints to eliminate large, unrealistic, shifts. No such constraints were used in the Sacramento tests. This approach is a less explicit representation of behavioral patterns and perhaps is less realistic, and could be the cause of DRAM/EMPAL predicting such substantial growth in the Citrus Heights/Roseville area. On the other hand, no data were made available on the development of space over time, so the MEPLAN and TRANUS models are sure to be inaccurate in their representation of development, even if the frameworks are more behavioral. The DRAM/EMPAL model does not require such data and could very well be more accurate when such data are not available. Finally, note that Citrus Heights and Roseville are currently experiencing substantial growth (in reality, since 1990).

The growth rates in the SACMET model are established in a manual way, when the inputs to the model are generated. They can be considered to be a judgement regarding how the region may grow.

In both MEPLAN and DRAM/EMPAL the differences in employment growth rates are larger than the differences in household growth rates. In MEPLAN this is partially caused by the lack of floorspace data. The model was designed with only one type of floorspace for commercial activities, making it easy for the model to swap the locations of different activity types. For instance, the conversion of warehouses (with few employees) to retail space (with many employees) can occur very easily (over one time period) in the current MEPLAN design, even though in reality there would be some redevelopment costs.

MODEL RESULTS FOR DIFFERENCES AMONG SCENARIOS

Since the models differed substantially in their base year calibration and in their trend predictions it is difficult to see the influence of the scenarios when absolute future year predictions from different models are compared. Instead, future year predictions for the scenarios can be compared with trend scenario predictions for each model, to show the sensitivity of the models. Table 3 shows the differences between the three policy scenarios and the trend scenario, as a percentage change, for each of the three models.

Location differences

The land use patterns in SACMET do not vary between scenarios, as SACMET has no land use model.

The household location changes in DRAM/EMPAL are larger than those from the other models. The employment location changes are larger in MEPLAN than in the other models. The large household location changes in DRAM/EMPAL are likely the result of its lack of a development model. Residential development is a slow process, dampening the rate of possible change in aggregate residential location. The larger employment location changes in MEPLAN are likely the result of having only one type of commercial space. The model too readily predicts the swapping of space by different types of employment, and since different employment types use different amounts of space this can lead to larger changes in the aggregate amount of employment. This may be an incorrect representation of the *time scale* of redevelopment – when MEPLAN is run to 2040 the employment changes seem much more reasonable in comparison to the magnitude of population changes.

In the LRT and pricing scenario, the parking surcharge drives employment out of the CBD in both TRANUS and MEPLAN. In MEPLAN the effect is large enough to lower the price of real estate in the CBD, and households move in to take advantage of the lower prices. In TRANUS, however, the direct effect of non-residential parking charges in the CBD makes the CBD *less* attractive to households.

The overall changes in location patterns between scenarios are quite small, even though the different models predict substantial differences in general growth patterns. This suggests that the influence of these simple transport supply scenarios are quite small in comparison to the other factors in the urban region. These other factors are all contained in the ASCs for different activities in different zones. The magnitude of the ASCs is, in a sense, too large – meaning that the models do not include explicit representation of enough of the important influences on the evolution of urban form. For instance, there is no notion of school quality, of property tax revenue and the ability to spend property taxes to improve a community, the notion of crime or the diversity of housing quality. All these things end up being "rolled into" the ASCs.

Although the overall changes between scenarios are small, Rodier *et al* [8] show that for the MEPLAN model the location changes between scenarios make a substantial contribution to the differences in travel conditions.

Travel differences

HOV Scenario

In the HOV Scenario the TRANUS model predicts a dramatic drop in transit usage and walk/bike usage. This is because the model is predicting a shift to HOV vehicles. The MEPLAN model, using the same travel network, is calibrated to have substantial less mode choice elasticity. In the MEPLAN framework the observed mode split under thousands of different conditions (by zone pair) were used to calibrate the elasticity to observed patterns (Abraham, 1998 [9]). In MEPLAN the increase in VMT is fairly substantial, but the increase is caused by longer average trip lengths not mode shifts to HOV Auto.

TRANUS shows substantial increases in average speeds, even though the vehicle trips and VMT only decrease slightly. MEPLAN shows small changes in average speeds.

HOV & Beltway Scenario

In the HOV and Beltway scenario TRANUS shows a substantial drop in transit and walk/bike mode shares, and an increase in average speeds. This may be because of the simpler network representation, so that an increase in roadway capacity is a greater increase in TRANUS *relative to the overall network capacity*. It is also generally the case that TRANUS has substantially larger mode share elasticity.

In MEPLAN the trip lengths increase in this scenario. The calibrations are quite different between MEPLAN and TRANUS. MEPLAN's mode choice elasticity and trip lengths were a focus of the calibration to the observed data from 1990, and so MEPLAN's trip length and mode choice results seem more reasonable.

DRAM/EMPAL did not report mode shares, so a complete comparison is difficult. DRAM/EMPAL suggests that average speed will go down with the construction of the beltways and HOV lanes.

LRT & Pricing Scenario

The high mode choice elasticity in TRANUS is readily apparent in the LRT and Pricing scenario. MEPLAN, DRAM/EMPAL and SACMET all confirm the reduction in VMT and the increase in speeds predicted by TRANUS, but with much smaller changes in mode split.

Percent Change in Travel HOV vs Trend	MEPLAN	TRANUS	SACMET	DRAM/EMPAL
total person trips	0.26	0.00	0.00	
trips per household	0.07	0.01	0.00	
total vehicle trips	-0.85	-2.70	0.00	-0.14
vehicle trips per household	-1.02	-2.69	0.00	-0.14
total VMT	6.05	-1.96	1.77	3.31
average distance per vehicle trip	6.97	0.76	1.77	3.45
transit share of person trips (%)	-0.56	-19.05	14.29	
walk & bike share of person trips (%)	-3.88	-30.00	-1.33	
average speed (mph)	3.32	18.99	1.03	-1.90

Percent change in Households: HOV vs Trend	MEPLAN	TRANUS	SACMET	DRAM/EMPAL
Region total	0.19	-0.01	0.00	0.00
CBD	0.59	-0.46	0.00	-2.08
Inner Suburbs	1.27	-0.35	0.00	-2.55
Citrus Heights and Roseville	1.67	0.27	0.00	3.13
Rancho Cordova & Folsom	-1.04	-0.13	0.00	8.16
Outer region	-0.93	0.61	0.00	-0.73

Percentage change in Employment HOV vs Trend	MEPLAN	TRANUS	SACMET	DRAM/EMPAL
Region total	0.32	-0.02	0.00	0.01
CBD	3.35	0.03	0.00	-0.27
Inner Suburbs	2.00	0.08	0.00	-0.05
Citrus Heights and Roseville	-5.93	0.08	0.00	0.74
Rancho Cordova & Folsom	15.67	-0.07	0.00	-0.38
Outer region	-9.39	-0.38	0.00	-0.14

Percent Change in Travel Belt+HOV vs Trend	MEPLAN	TRANUS	SACMET	DRAM/EMPAL
total person trips	0.33	0.00	0.00	
trips per household	0.07	0.01	0.00	
total vehicle trips	-1.11	-2.70	0.00	0.17
vehicle trips per household	-1.38	-2.69	0.00	0.18
total VMT	11.49	-3.76	3.54	0.42
average distance per vehicle trip	12.74	-1.08	3.54	0.25
transit share of person trips (%)	1.12	-42.86	14.29	
walk & bike share of person trips (%)	-8.40	-43.33	-2.67	
average speed (mph)	6.38	40.51	2.84	-5.40

Percent change in Households: Belt+HOV vs Trend	MEPLAN	TRANUS	SACMET	DRAM/EMPAL
Region total	0.29	-0.01	0.00	-0.01
CBD	0.71	-1.92	0.00	-11.28
Inner Suburbs	1.53	1.89	0.00	-1.47
Citrus Heights and Roseville	1.12	0.82	0.00	5.39
Rancho Cordova & Folsom	-0.21	-1.59	0.00	33.37
Outer region	-0.97	-2.03	0.00	-7.19

Percentage change in Employment Belt+HOV vs Trend	MEPLAN	TRANUS	SACMET	DRAM/EMPAL
Region total	0.36	-0.03	0.00	0.02
CBD	3.79	-0.14	0.00	-0.96
Inner Suburbs	2.47	-0.52	0.00	-0.84
Citrus Heights and Roseville	1.19	0.00	0.00	2.86
Rancho Cordova & Folsom	14.10	-0.72	0.00	3.04
Outer region	-13.07	1.94	0.00	-1.86

Percent Change in Travel Rail+Pricing vs Trend	MEPLAN	TRANUS	SACMET	DRAM/EMPAL
total person trips	0.46	0.00	0.00	
trips per household	-0.04	0.00	0.00	
total vehicle trips	-3.22	-18.92	0.00	-0.21
vehicle trips per household	-3.74	-18.92	0.00	-0.21
total VMT	-6.93	-23.86	-1.61	-1.53
average distance per vehicle trip	-3.82	-6.09	-1.61	-1.33
transit share of person trips (%)	27.37	88.10	28.57	
walk & bike share of person trips (%)	1.48	240.00	1.33	
average speed (mph)	1.11	72.78	0.26	0.95

Percent change in Households: Rail+Pricing vs Trend	MEPLAN	TRANUS	SACMET	DRAM/EMPAL
Region total	0.50	0.00	0.00	0.00
CBD	1.59	-2.56	0.00	-0.30
Inner Suburbs	1.20	-0.27	0.00	1.69
Citrus Heights and Roseville	1.33	1.46	0.00	0.67
Rancho Cordova & Folsom	0.64	1.20	0.00	3.00
Outer region	-0.58	0.54	0.00	-2.55

Percentage change in Employment Rail+Pricing vs Trend	MEPLAN	TRANUS	SACMET	DRAM/EMPAL
Region total	0.49	0.00	0.00	0.02
CBD	-3.43	-0.83	0.00	0.37
Inner Suburbs	2.58	-0.76	0.00	0.89
Citrus Heights and Roseville	-0.07	1.35	0.00	-0.23
Rancho Cordova & Folsom	3.68	2.03	0.00	0.00
Outer region	0.01	0.56	0.00	-1.58

Table 3: Percentage change in model outputs as a result of policy scenarios

CONCLUSIONS

This paper compared the model results from four different models of the Sacramento Region. There were substantial differences between the models, showing the differences in model form and in model calibration.

The partial representation of transport supply caused difficulty. Changes to the most important links in a network will have a greater effect in a model that omits the less important links. Using a model with a "sketch" network is difficult and proper consideration should be given to how partial supply is represented and whether demand should be similarly scaled. In sketch planning models networks are usually simplified by removing the less important links manually. There is surprisingly little research into more automated and more robust ways of simplifying networks so that the fundamental capacity and configuration of the network is respected as much as possible. Without a rigorous and algorithmic network simplification process it may be better to choose to model with as complete a network representation as is possible, given constraints on computing resources.

The type of modeling frameworks affects the model results. The presence of land development models in MEPLAN and TRANUS limits the speed with which the spatial economy can adapt. The use of mode split "on the network" in TRANUS makes understanding the mode choice results more difficult, and could influence model results.

The vast majority of the investment into the permanent spatial arrangement of a region is done by floorspace developers. These developers respond to price and other signals in unique ways, suggesting that a good model of floorspace development is appropriate. Unfortunately none of the Sacramento models have floorspace development models calibrated to actual development data, because no development data were provided to the modeling teams. Given the importance of development it seems essential that planning organizations collect such data and make it available for analysis.

One of the problems in representing development in aggregate models like these is the unique nature of development and the site-specific variations that cause developers to choose one specific site for development. An aggregate model with large zones can never do a particularly good job of representing these issues, yet these issues may be essentially important for transportation issues such as parking, transit use and attractiveness to pedestrians. The microsimulation models under development (for example the Oregon Transportation Land Use Model Improvement Program (TLUMIP)) will be inherently more able to accurately represent developer behavior.

Predicting the future of a city is a bit of a fool's game – there is really no hope that a mathematical model can ever accurately predict what will happen 25 years in the future given all the uncertainty in demographics, national economies, technological shifts and social changes. If land use modelers could accurately predict the future form of a city they would all spend their time on real estate speculation, not planning! It is perhaps more important to focus on the *influence* of various policies on the *probabilities* that conditions will change in certain ways into the future. A comprehensive model with behavioral components can provide insight into this when its predictions, and the mechanisms leading to those predictions, are investigated in detail without the attention to aggregate quantities that is necessary in this paper. Another way to focus on the influence of policy would be to set up a system where uncertain inputs are sampled according to assumed distributions, and the models run hundreds or thousands of times to see the *range* of possible futures that a model would predict. It is very possible that if these set of four models were run in this way they could have similar (large) ranges in their future predictions, and a paper comparing the models could more easily (and appropriately) focus on what the models predict about the *impacts of policy*, rather than what the models predict the future will hold in absolute.

The large growth in certain areas under certain conditions illustrates the positive feedback caused by agglomeration economies. The models are able to simulate *bifurcations* in the system, where small changes in initial conditions lead to dramatically different outcomes in future states. This points to the chaotic nature of urban systems, as described in Allen (1997) [10]. This reinforces the notion that dynamic models with positive feedback should not be used to provide a single forecast for the future. Instead they should be used to explore the range of possible futures and the impact that policy actions today can have on the conditions in the future.

Running models to understand the uncertainty in their forecasts (as described) would provide better ways of dealing with the uncertainty caused by conditions not under planning control. But it is still appropriate to try to reduce that uncertainty as well. Aspects that led to uncertainty in the Sacramento models were the large impacts of Alternative Specific Constants for specific activities in specific zones, and the nature of the interactions between firms, institutions and households.

Data collection (and research) can help to understand the size and nature of the non-transport influences on neighborhood attractiveness and these should be integrated into models to reduce the size of the Alternative Specific Constants and improve overall accuracy. Stated Preference surveys can be especially useful for this (Hunt, 1997 [11], Hunt *et al*, 1994 [12], Hunt *et al*, 1995 [13]). The ASCs should be recognized as "catch all" terms, and model calibration should attempt to minimize the size of the ASCs to include as much information as possible in the model's behavioral parameters (Abraham, 2000 [14] p 144)

The interactions between industry and between firms and households should be investigated specifically, rather than relying on an aspatial Input/Output matrix developed for other purposes. Surveys of a random sample of firms could be especially useful to understand the variation between firms and within industries, and such sample data may be especially useful in the new generation of micro-simulation models.

Land use and transport models provide an indication of the rich set of complex interactions that can occur in a regional economy. The simplified analysis in this paper cannot show the full set of interactions and hence this paper, by necessity, does a poor job of demonstrating the myriad ways in which land use and transport models can be used. The model results from a single zone often provide insight that can lead to a useful exploration of policy alternatives.

The calibration of the models affects their results dramatically. A "good framework" does not provide a "good model" unless it is properly calibrated to appropriate data. The TRANUS model was the first one developed as part of this work, and the emphasis was on providing a complete model quickly to demonstrate the potential for such models. The MEPLAN model was calibrated much more rigorously, but only to certain types of data. Model calibration (both parameter estimation for model portions and overall calibration of the full system) should be a rigorous exercise and a large portion of any modeling project's budget. Appropriate calibration methods (Abraham, 2000 [15]) and semi-automated search routines can help produce accurately calibrated models. The development of semi-automatic search routines that allow an interactive exploration of lack-of-fit and its causes (Abraham, 2000 [14]) will make it easier to calibrate models to multiple year data sets and floorspace development data. Semi-automatic calibration and interactive exploration of lack-of-fit were developed with the Sacramento MEPLAN model, and so this model is particularly well-positioned to be recalibrated when new data are available.

Land use and transport models attempt to represent how a regional economy evolves over time. It should be obvious that time-series data on urban form are necessary to make such a model accurate. Nonetheless, much can be done with cross-sectional data. If time series data are not available it may be possible to construct an initial model with cross-sectional data while collecting the data on spatial change that is necessary to make the model better, as was done in this project. But while waiting for such data it might be best to adjust the various elasticities of model response to match expert opinion, to avoid seemingly unrealistic elasticities.

Future model comparison projects might consider testing the models with larger policy shifts, rather than only modeling politically realistic policy alternatives. The small variation in policy scenarios in this project made it difficult to separate out the policy response of the model from the base behavior of the model. The focus of the Sacramento Model Testbed was not to compare numerical results, but such a comparison would be easier if the calibration targets were more rigorously specified to the modeling teams and if data inconsistencies were dealt with carefully and centrally, not separately by the different teams.

Finally, it should be noted that the three land use models tested so far are all fairly similar – they represent aggregate quantities of activity in zones and allocate the activity using logit models that include transport disutilities. It would be informative and interesting to consider a wider range of frameworks. A more rigorous data depository is planned (augmented with new data on development and containing data from both 1990 and 2000) so that other existing (or future) models can be more easily applied to the region.

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