DEVELOPING CALIFORNIA INTEGRATED LAND USE/TRANSPORTATION MODEL

Shengyi Gao
Urban Land Use and Transportation Center
University of California
One Shields Ave.
Davis, CA 95616
sgao@ucdavis.edu
Phone: (530) 752-6303
Fax: (530)752-3350
Corresponding Author

Eric Lehmer
Urban Land Use and Transportation Center
University of California
One Shields Ave.
Davis, CA 95616
elehmer@ucdavis.edu
Phone: (530) 754-6212
Fax: (530)752-3350

Yang Wang
Urban Land Use and Transportation Center
University of California
One Shields Ave.
Davis, CA 95616
geowang@ucdavis.edu
Phone: (530) 752-6303
Fax: (530)752-3350

Michael McCoy
Urban Land Use and Transportation Center
University of California
One Shields Ave.
Davis, CA 95616
mcmccoy@ucdavis.edu
Phone: (530) 754-9171
Fax: (530)752-3350

Robert A. Johnston
Dept. of Environmental Science and Policy
University of California
One Shields Ave.
Davis, CA 95616
rajohnston@ucdavis.edu

John Abraham
HBA Specto, Inc.
Calgary, T2P 3P4, AB
Canada
jea@hbaspecto.com
Phone: (403)232-1060

Phone: (530) 582-0700

Fax: (403)232-1060

Fax: (530)752-3350

John Douglas Hunt

HBA Specto, Inc.

Calgary, T2P 3P4, Canada

jdhund@hbaspecto.com

Phone: (403)232-1060

Fax: (403)232-1060

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Abstract: We report on the multi-year process of developing the California PECAS statewide integrated land use/transportation model and the preliminary results of a sensitivity test. In the Trend 2030 Scenario, the model allocated economic activities and developed floorspace in a plausible pattern, when viewed statewide or regionally. In the High Fuel Cost Scenario, a more-compact development pattern was found. We conclude that the initial demonstration model performed reasonably well. The chief problems that we encountered are discussed and our future work is outlined.

INTRODUCTION

The conventional four-step travel demand forecast model has been criticized for failing to incorporate the impacts of land use on transportation which is proved to be statistically significant [1-2]. The emergence of land use models (MEPLAN, UPLAN, TRANUS, DELTA/START, UrbanSIM, PECAS, etc.) provided a possible solution to this problem in practice [1-9]. To many metropolitan planning organizations (MPO), a more direct impetus for the development of a land use model comes from the requirements of legislation. The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) strongly encourages MPOs to use land use models which are able to address the relationships among the economy, land use, and transportation. In California, SB375 requires that planning models and analytical techniques be able to assess the effects of policy choices, and address the relationship among land use, auto ownership, and vehicle-miles traveled (VMT).

Each land use model varies in complexity, data requirements, and development cycle and costs. Therefore, many MPOs and state transportation agencies find it difficult to choose a suitable land use model for their purposes. The California Department of Transportation (Caltrans) started in 2004 to seek a land use model that could address the relationships among the economy, land use, and transportation at the state level. After a careful review of all the available models, Caltrans finally chose the Production, Exchange, and Consumption Allocation System (PECAS).

After three years of effort, we have built a statewide PECAS model and integrated the model with a statewide travel demand forecast model. A preliminary sensitivity test showed that higher fuel costs affected land development patterns from 2010 to 2030 in reasonable ways. OVERVIEW OF CALIFORNIA PECAS

The California PECAS model has the same framework as reported in the literature [10-12]. The model has two modules: the Activity Allocation (AA)and Space Development (SD) modules. The AA module, whose nested logit choice structure is shown in Figure 1, allocates production and consumption activities across land use zones (LUZ). At its highest level, the locations of activities were represented by LUZs, which were aggregations of TAZs. At its intermediate level, the technology choice implies the production and consumption of commodities. Industry sectors produce goods and services at fixed rates while households produce labor with elastic rates. Industry sectors and households consumed goods and services at fixed rates but floorspace at elastic rates. Imports and exports were available for all commodities at fixed rates. The production and consumption rates were derived from IMPLAN (http: //www.implan.com) Social Accounting Matrices (SAM). At its lowest level, the total quantity of each commodity produced at the intermediate level was allocated among the exchange locations. The SD module simulates the space development at the 50 meter grid cell level, instead of the LUZ level (see Figure 2 for its nested logit choice structure). The AA and SD modules were internally integrated together (see Figure 8). The AA module priced all commodities, including different floorspace types for the SD module while the SD module produced quantity of floorspace by type for the AA module. The location allocation and price updating process in the AA module is shown in Figure 3.

Insert Figure 1 here

Insert Figure 2 here

Insert Figure 3 here

Insert Figure 4 here

A progressive strategy in the development of the California PECAS has been employed. The entire model development consists of three phases: Prototype, Demonstration, and Production. In the first phase, the goal was to develop a fully functional AA module with the minimum activities, commodities, and LUZs. The Prototype model had only 5 zones (San Diego Association of Governments (SANDAG), Southern California Association of Governments (SCAG), Association of Bay Area Governments (ABAG), Central California, and Northern California), four types of activities, six commodity types and two floorspace types. After coarsely calibrating the module and having it converge, an activity, a commodity, or a floorspace type was split to increase the complexity of the model. Through this method, we could track the changes of outputs caused by the increase of activities, commodities or floorspace types, identify problems in the process of disaggregation of activities, commodities, and floorspace types, and accumulate expertise about the model’s behavior. The last model of this phase ended with eighteen activities, twenty-two commodities, and ten floorspace types.

The goal of the second phase was to development a model with all planned activities, commodities, and floorspace types, which included 66 activities, 70 commodities, and 14 floorspace types, to coarsely calibrate the model, and to test the sensitivity of the model to some land use/transportation policy factors. The milestones of this phase included disaggregations of industry sectors, goods and services types, and floorspace types, building floorspace inventory in the base year (2000), synthesizing the base year parcels for the SD module, setting up new LUZs (from 5 to 58 then to 523 LUZs) and constraints at TAZ level, calculating travel costs by time and distance, and calibrating the AA and SD modules. The results reported in this paper were based on the Demonstration model in the second phase.

SYNTHESIZING THE BASE PARCELS

In the SD module, the floorspace of the entire state was represented by 50 meter grid cells. Each grid cell has a unique grid ID, a TAZ ID, a zoning code, an existing land use type, and a total quantity of floorspace. The zoning code represents land use policy and tells the model what type of development is allowed on a grid cell . The existing land use type is the actual land use in the base year, and might or might not be the same as that designated in the zoning code. The total quantity of floorspace is the total quantity of floorspace for the existing land use type on a grid cell. This database is stored in Microsoft SQL Server 2005.

To build this database, we firstly took a Geographic Information System (GIS) approach to synthesize the existing land use from the National Land Cover Dataset 2001 (NLCD 2001). NLCD 2001 was a raster derived from LandSat images (see http://www.mrlc.gov/nlcd.php). Its land cover classification system was mainly based on development intensity which was usually interpreted as the proportions of impervious surface. The classification system was not directly compatible with the system needed for PECAS. To convert the land cover types into PECAS land use types, we used county/city general land use plans (showing information on planned land use types, see Figure 4), statewide elevator data (recording all elevators in commercial and residential buildings in California), Geographic Data Technology (GDT) Dynamap 2000 street network (Spatial Insights, Inc.) (showing all the roads with functional classes), and 2003 InfoUSA data (InfoUSA, Inc.) (showing the locations and numbers of all employees). Figure 5 shows a synthesized land use map for 2000 in the Los Angeles area. The planners in SCAG thought the synthesized land use map was adequate. Secondly, using Solver in Microsoft Excel, and 2000 U.S. Census Block Group Data, the Public-Use Microdata Sample (PUMS) 1% Survey, the 2003 InfoUSA data, and the zonal input table of the California statewide travel demand forecast model developed by Cambridge Systematics, Inc in 2006, we imputed the floorspace inventory for each TAZ. We then, assigned the total inventory to each grid cell with a synthesizer [13-14]. Figure 6 shows the synthesized land use intensity map for the Log Angeles area. The densities looked similar to those on GoogleEarth©.

Insert Figure 5 here

Insert Figure 6 here

IMPUTING TRAVEL COSTS

Travel costs were used to calculate the transport utility of buying and selling commodities [13] at the lowest level of the nested logit choice in the AA module. Two types of travel costs were used in the AA module: travel distance based travel cost and travel time based cost. The former was an arithmetic product of the total travel distance and its unit travel cost (dollar cost to move one dollar value for a mile) while the latter was an arithmetic product of the total travel time and its unit travel cost (dollar cost to move one dollar value for a minute). We used the U.S. Commodity Flow Survey (CFS) 2002 National Data Table 7 (http://www.bts.gov/publications/commodity_flow_survey/2002/united_states/html/table_07.html), 2000-2001 California Statewide Travel Survey Weekday Travel Report (http://www.bls.gov/oes/current/oes_CA.htm#b11-0000), and IMPLAN SAM to calculate the unit travel costs. Eq. 1 and Eq. 2 were used to compute the two travel unit costs for goods movement, respectively; Eq. 3 and Eq. 4 were for services and labor movement:

$$-1 * \frac{\text{transport cost}}{\text{truck-mile}} * \frac{1}{\frac{\$\text{ of goods}}{\text{ton}} * \frac{\text{ton}}{\text{truck}}} \qquad (1)$$

where transport cost was the total travel cost; truck-mile was the truck miles traveled; $ of goods/ton was the total value of goods per ton; ton/truck was the capacity of a truck;

$$-1 * \frac{\text{transport cost}}{\text{truck-minute}} * \frac{1}{\frac{\$\text{ of goods}}{\text{ton}} * \frac{\text{ton}}{\text{truck}}} \qquad (2)$$

where truck-minute was the truck time traveled; others were the same as defined in Eq. (1)

$$-1 * \frac{\text{transport cost}}{\text{persontrip-mile}} * \frac{1}{\frac{\$\text{ of service}}{\text{day}} * \frac{\text{day}}{\text{persontrip}}} \qquad (3)$$

where transport cost was the total travel costs for providing services; persontrip-mile was the total miles of person service trips; $ of service was the dollar value of the service; day was the number of work days per year; persontrip was the total person service trips per year;

$$-1 * \frac{\text{transport cost}}{\text{persontrip-minute}} * \frac{1}{\frac{\$\text{ of service}}{\text{day}} * \frac{\text{day}}{\text{persontrip}}} \qquad (4)$$

where persontrip-minute was the total travel time by minute for providing services; others were the same as defined in Eq. 3;

CALIBRATING AA AND SD MODULES

In this phase, the AA and SD modules were calibrated separately. For the SD module, we focused on the calibration of transition constants (in the cells with Yes in Table 1) which determined the quantity of floorspace transition from one land use type to another. To rationalize the efforts on the calibration of the SD module at this phase, we chose ten counties (Amador, Fresno, Imperial, Inyo, Orange, Placer, Sacramento, San Diego, San Francisco, and Shasta Counties) with different floorspace development patterns to represent the entire state, and set up targets for each transition. The floorspace prices used in the calibration were the “observed” prices in the base year. The iterative calibration (see Figure 8) was automated through a Python script.

Insert Table 1 here

Insert Figure 7 here

The calibration of the AA module focused on option size terms for technology choice and the buying/selling dispersion parameters for commodities. The option size term was a component of the utility of technology options. The utility of a technology option was a component of the utility of location choice. Therefore, it influenced not only the total quantities of production and consumption of commodities (including floorspace), but also the quantities of activities in location choice. The target values of technology option size of activities were expected to be the total make and use of commodities (i.e. goods, services, labor, and floorspace) in the base year. We derived the target values for the production and consumption of commodities from IMPLAN and PUMS data. Like in the calibration of SD, the prices of floorspace were the “observed” prices in the base year. The calibration of technology option size terms was automated through a Python script as well.

The buying and selling dispersion parameters, as their names imply, determine the dispersion of buying and selling commodities. A tighter (i.e. larger value) dispersion parameter reduces the range of buying and selling locations. In other words, the trip distance of buying and selling became shorter if a tighter dispersion parameter was applied, when other inputs were fixed. Therefore, the buying and selling dispersion parameters could be calibrated by setting up with targets for the trip lengths of commodity flows (i.e. goods) and labor travel flows (i.e. services). The datasets used to set up these targets were the same as those in computing the travel costs.

INTEGRATING PECAS WITH THE STATEWIDE TRAVEL MODEL

The statewide travel model was developed by Cambridge Systematics, Inc. in 2006. The motivation for developing this model was to forecast the interregional travel demand with and without the proposed high speed rail system. The trips within the boundaries of ABAG, SCAG, and SANDAG were defined as intrazonal trips and were fixed in the travel model. If this model was directly integrated with PECAS, the travel pattern within the three MPOs' boundaries would not be affected by land use, and likewise the spatial pattern of land use would not be influenced by the travel model. To fix this problem, we factored the trips up and down based on the zonal changes in total employment and households at the transportation forecasting year (every five years from the base year in the AA and SD modules), and assigned the trips to the highway network. The integration of PECAS and the travel model is shown in Figure 8.

From the figure, we can see that the time step of the AA module and SD was one year while it was five years for the travel model. The AA module reads the skims of distance and time from the travel model (to calculate transport utility of buying and selling) in the base year and continues to use those skims until 2005. The AA activities in 2005 were aggregated up to the TAZ level. The travel model uses the changes in employment and households to factor up the trips in the trip table and then assigns the trips to the highway network. The new distance and time skims were then used by the AA module in 2006. This process was repeated every 5 years.

Insert Figure 8 here

PRELIMILARY SENSITIVITY TEST

Following the flow chart in Figure 8, we ran a trend scenario. In the base year (2000), we set up activity constraints (the number of employees by industry sector and number of households by income and size) for each TAZ to force the AA module to replicate the spatial pattern of activities and to generate a zonal utility constant for each LUZ. The activity total for each activity in each year was exogenous and the annual growth rate for all activites was fixed at 1.2% (the average annual growth rate from 1990 to 2000). The highway network was kept unchanged in the time span (2000 to 2030). We hypothesized the following model responses:

- Agriculture land area would monotonically decrease over time.
- The trend in development of floorspace in manufacturing, commercial, and residential would be consistent with that of employment and households.
-
- Floorspace prices would reflect the demand and supply of floorspace at the LUZ level.

As shown in Table 1, agriculture space was allowed to be converted into all other space types. Not surprisingly, total agriculture space decreased over time due to the growth of population and employment. Resources land area represented military space in the AA module and SD modules, and was designed for military bases only. Thus, the quantity didn't change over time. The total quantities of other space types grew at different rates over time (see Figures 9 and 10). Single family separate (ResType5) and shared entrances (ResType6) had higher growth rates. This was plausible because these two types of floorspace took higher proportions in the total inventory in the base year, and their growth rates were influenced more by the size term. Also, urban land became more scarce.

Insert Figure 9 here

Insert Figure 10 here

Insert Figure 11 here

Insert Figure 12 here

The Base Scenario in Figures 11 and 12 supported our assumptions about spatial changes in floorspace. The suburban or exurban zones had higher growth rates than those in the inner urban areas. The vacant land and residential floorspace supply in those zones was abundant and the price was lower. It looked like the impacts of travel cost were not substantial in this case. The growth pattern of the commercial low-density space was the opposite, i.e., higher growth rates in the inner urban areas than in the suburban or exurban zones. Access costs are more important to commercial activities.

To test the sensitivity of the AA and SD modules to changes in travel costs, we increased the general travel cost by 1.9 times, to represent High Fuel Costs, and kept all other inputs the same as in the Trend Scenario). We hypothesized that:

- The higher travel cost would make development more compact.
- The average trip lengths for services trips and work trips (commuting) would be shorter.
- Floorspace prices in zones with higher accessibility would be higher.

From Figures 11 and 12, we can see that the land use patterns in the High Fuel Cost Scenario were similar to those in the Trend Scenario, i.e., residential (Residential Medium Density Separate Entrance) had higher growth rates in the suburbs while Commercial Low Density had higher growth rates in the inner urban areas. Comparing the two scenarios with the, we did find the changes we hypothesized, however.

Figure13 shows the absolute differences between the two scenarios in households and employment for the entire state. The dots in blue and green indicated an increase in households and employment, respectively, in those zones, while the dots in brown and red represent decreases. In general, the model predicted the hypothesized changes. According to the dot density, employment was more sensitive to the higher travel cost than were households. Figure 14 shows more details in the differences between the scenarios in the Los Angeles area. It sshows the impacts of higher travel costs, in more spatial detail. Comparing Figure 14 with Figures 9 and 10, we can see that, albeit households grew faster in the suburbs than in the inner urban areas in the High Fuel Cost Scenario, they grew more slowly than in the suburbs than in the Trend Scenario. This implies that the model performed as was expected.

CONCLUSIONS

The development process for the PECAS California integrated land use and transportation model has been complicated and time-consuming. The requirements for data quality, calibration, and time were different in the different phases. Therefore, it was critical to use a progressive strategy to set up goals and to identify potential problems, at each timeline within each phase. Following this strategy, we developed and calibrated the Demonstration model. The preliminary analysis of the results, reported here, show that the performance of the Demonstration model met our initial expectations, under a severe deadline.

As a complex econometric model, California PECAS was data hungry. Data availability and quality were two major factors that influenced the progress of model development. In the demonstration model, we had to impute or synthesize some historic data by using limited information. The imputation of data saved time and lowered the development costs of the model. For a demonstration model that focused more on developing methods and identifying potential problems, than on the usefulness of the outputs, this approach was found to be cost-effective.

The main lesson we learned in this phase was the need for data consistency. In the AA module, the production and consumption rates of activities were derived from IMPLAN. The activity constraints were based on the InfoUSA dataset. The base parcels were based on county/city general plans. These datasets were carefully reviewed and were thought to be consistent during data preparation. When they were put into the model, however, inconsistencies emerged. In IMPLAN, the relative size of each activity was fixed. This relative size was distorted by the activity constraints and the available floorspace in the base parcels. The distortion of the relative size largely increased the difficulty of calibration.

The next phase of the statewide integrated model development will be Production. In this phase, the development will focus on the improvement of data quality and calibration of the integrated PECAS and travel model. In terms of the travel model, it will be improved to become a tour-based model with dynamic zonal assignment for all trips.

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FIGURES AND TABLES

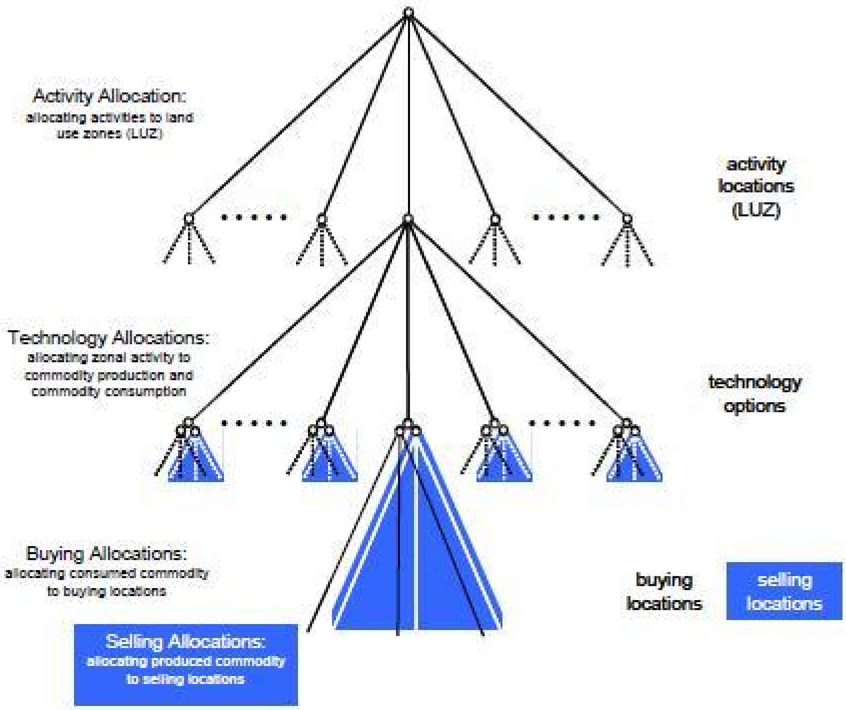


Figure 1 Nested Logit Structure in AA

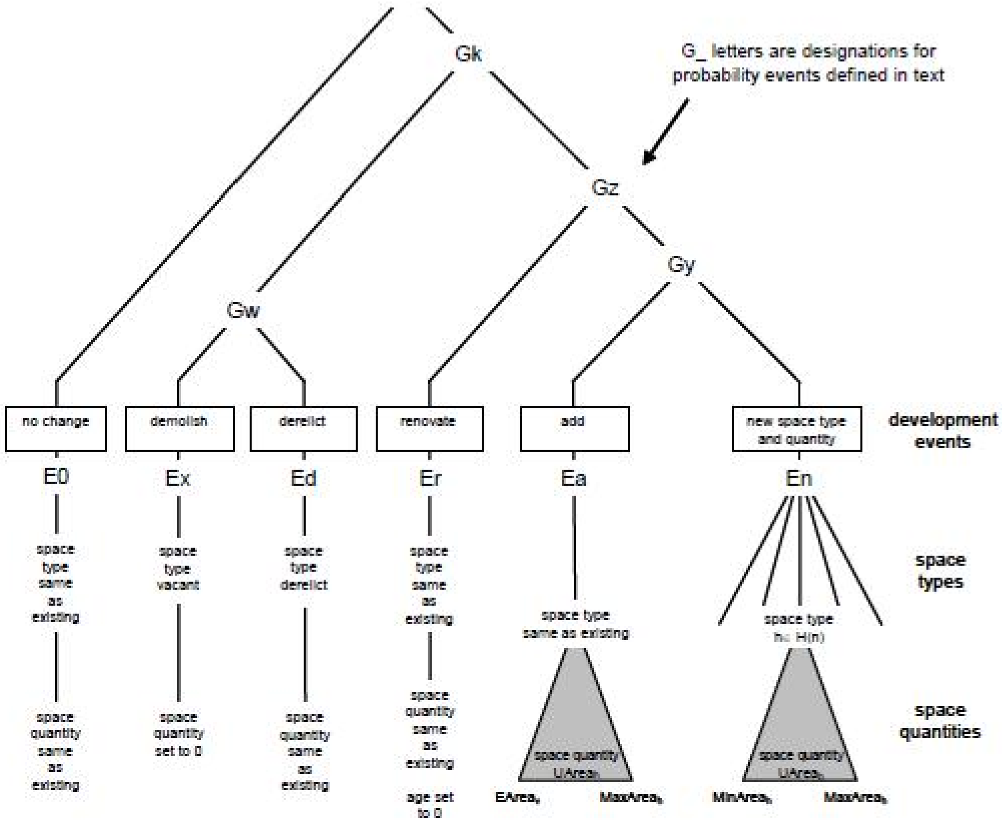


Figure 2 Nested Logit Structure in SD

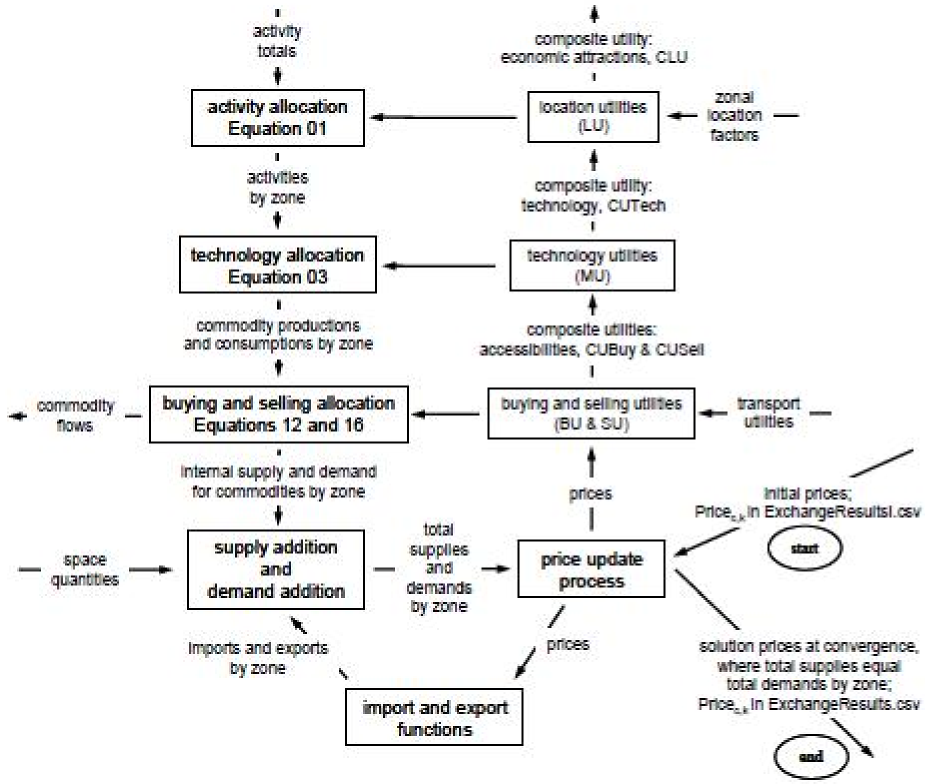
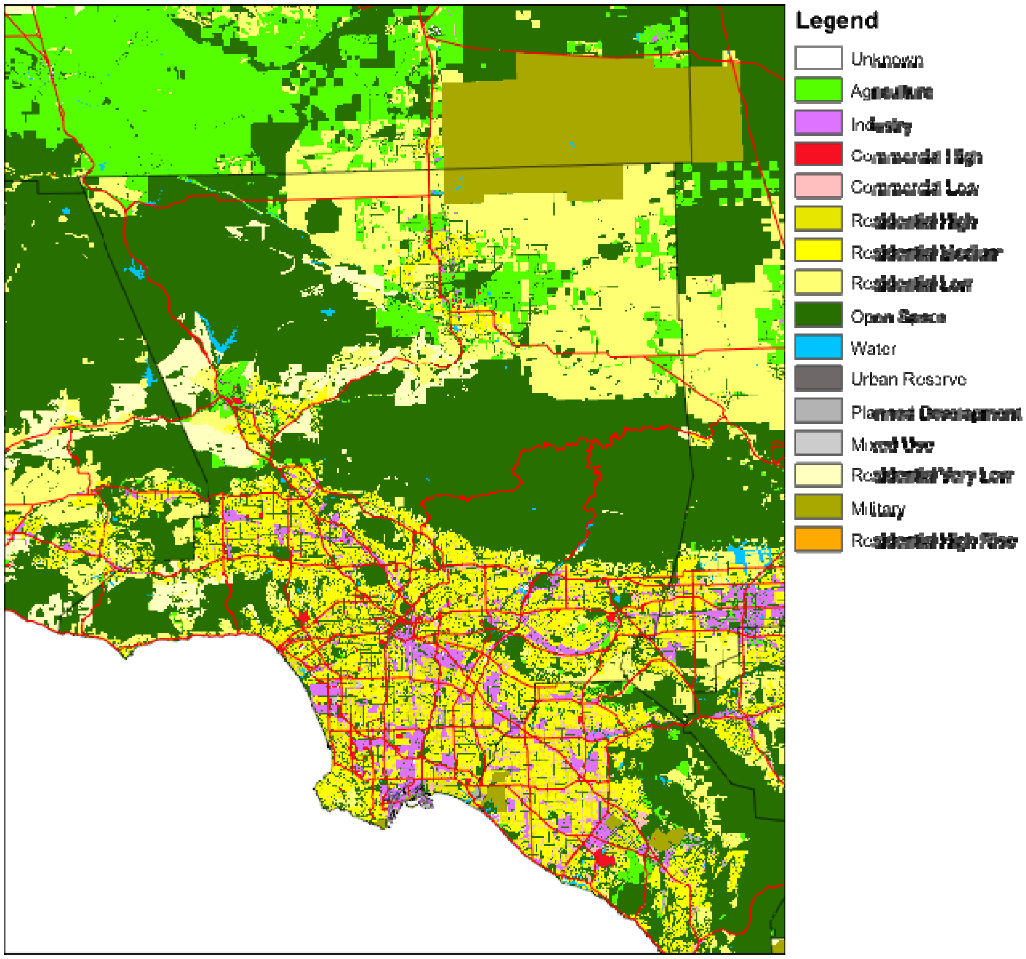


Figure 3 Allocation and Price Updating Process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Industry
Commercial High
Commercial Low
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Water
Urban Reserve
Planned Development
Mixed Use
Residential Very Low
Military
Residential High Rise

Figure 4

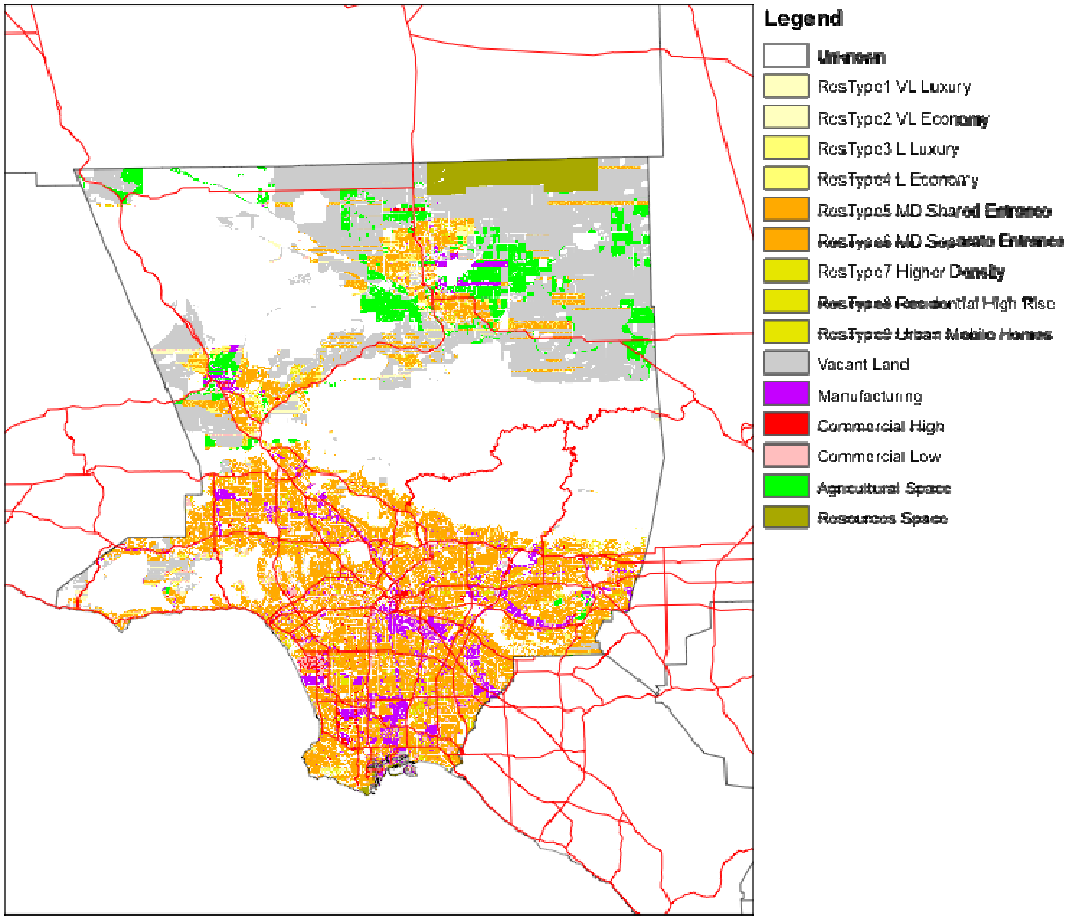


Figure 5 Synthesized Existing Land Use in 2000 (Los Angeles Area)

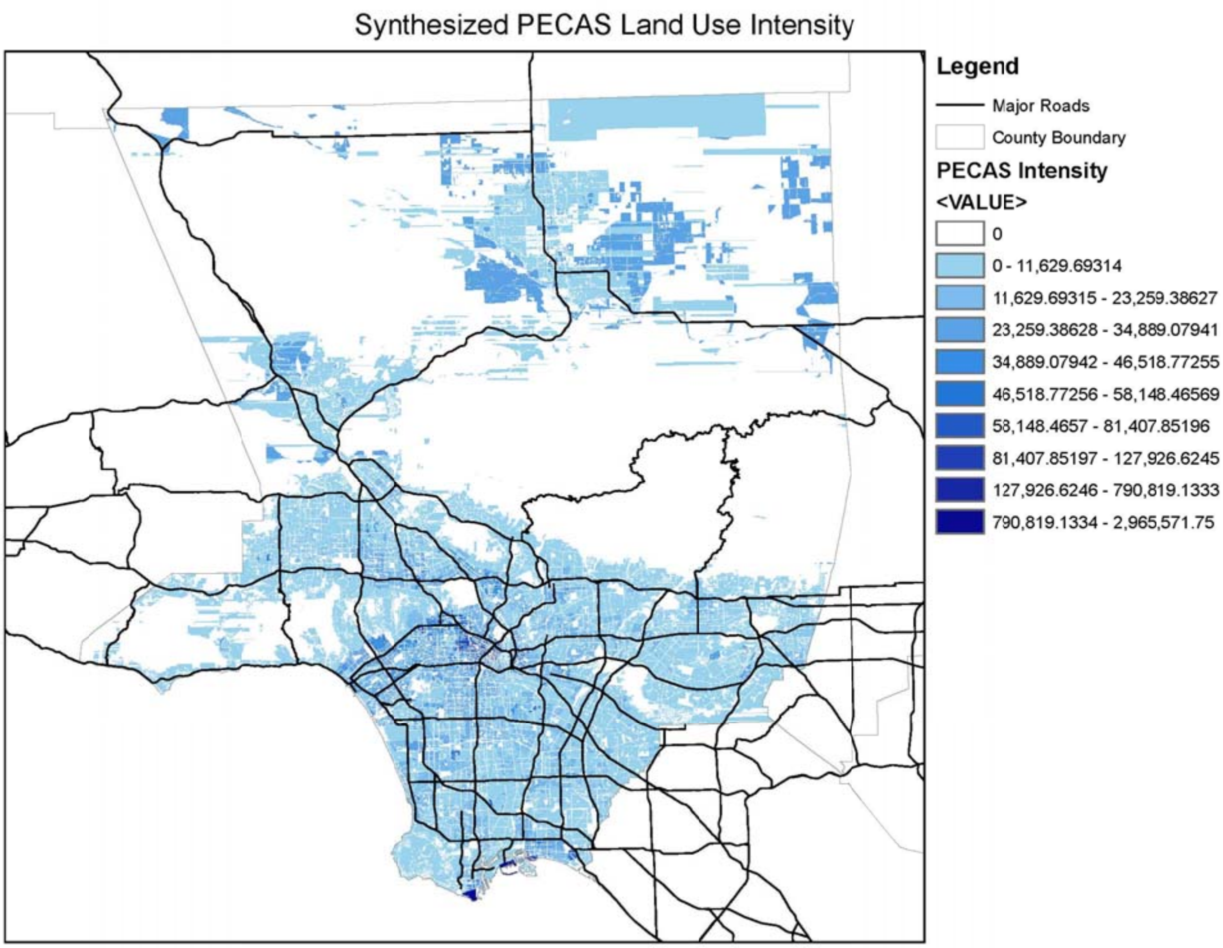


Figure 6 Synthesized Land Use Intensity in 2000 (Los Angeles Area)

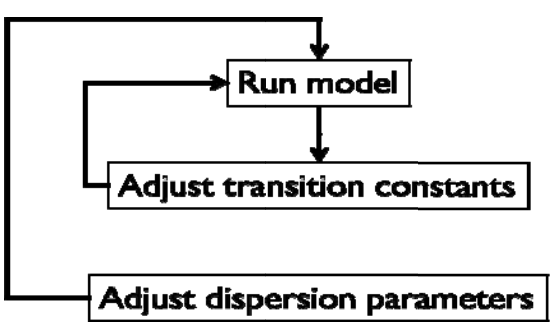


Figure 7 Iterative SD Calibration

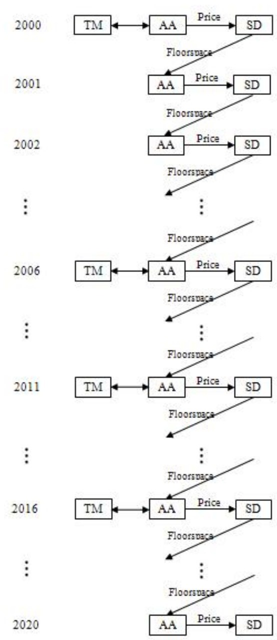


Figure 8 AA, SD and Travel Model Integration

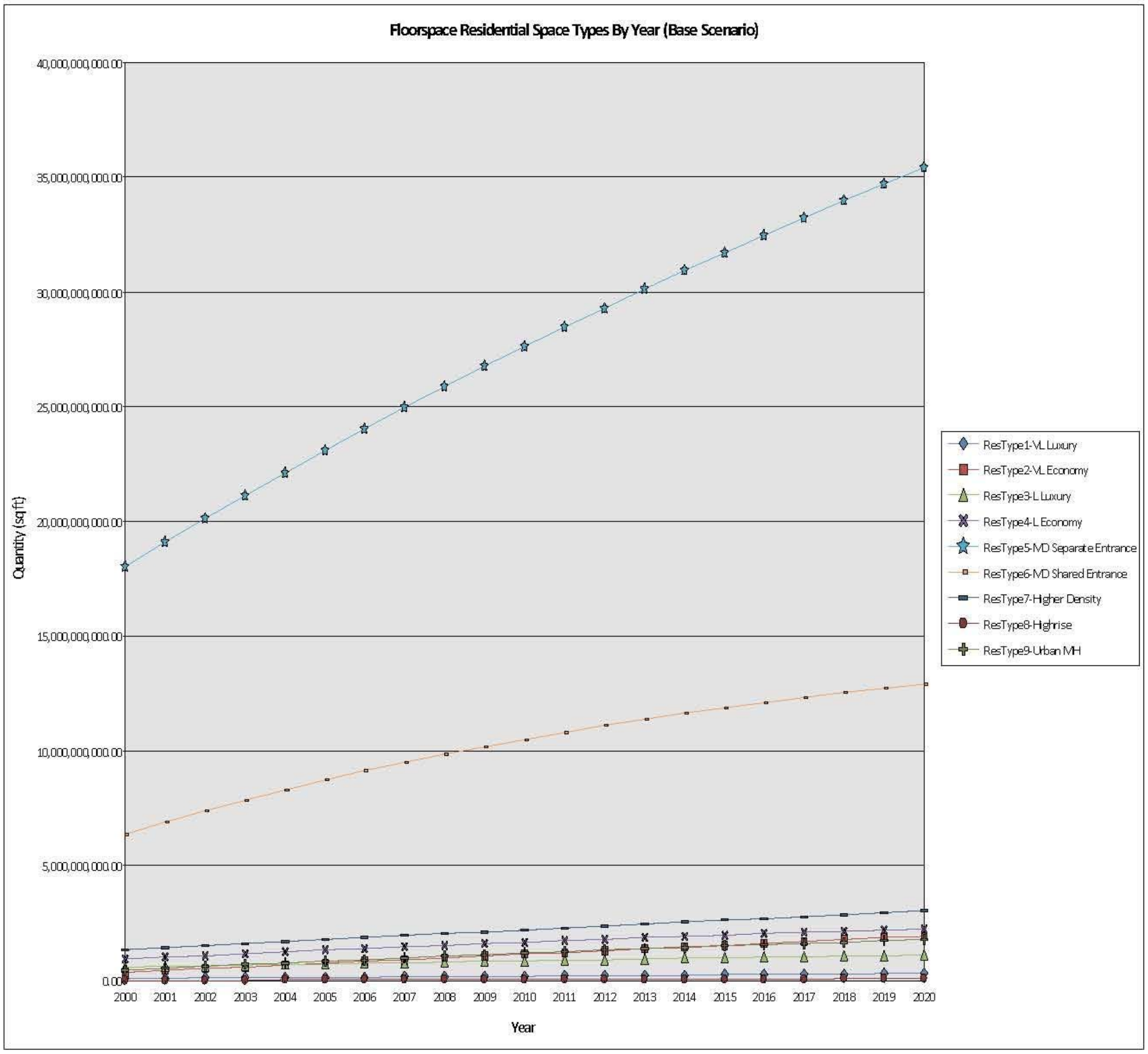


Figure 9 Trend of Residential Floorspace Over Time (2000 -2020)

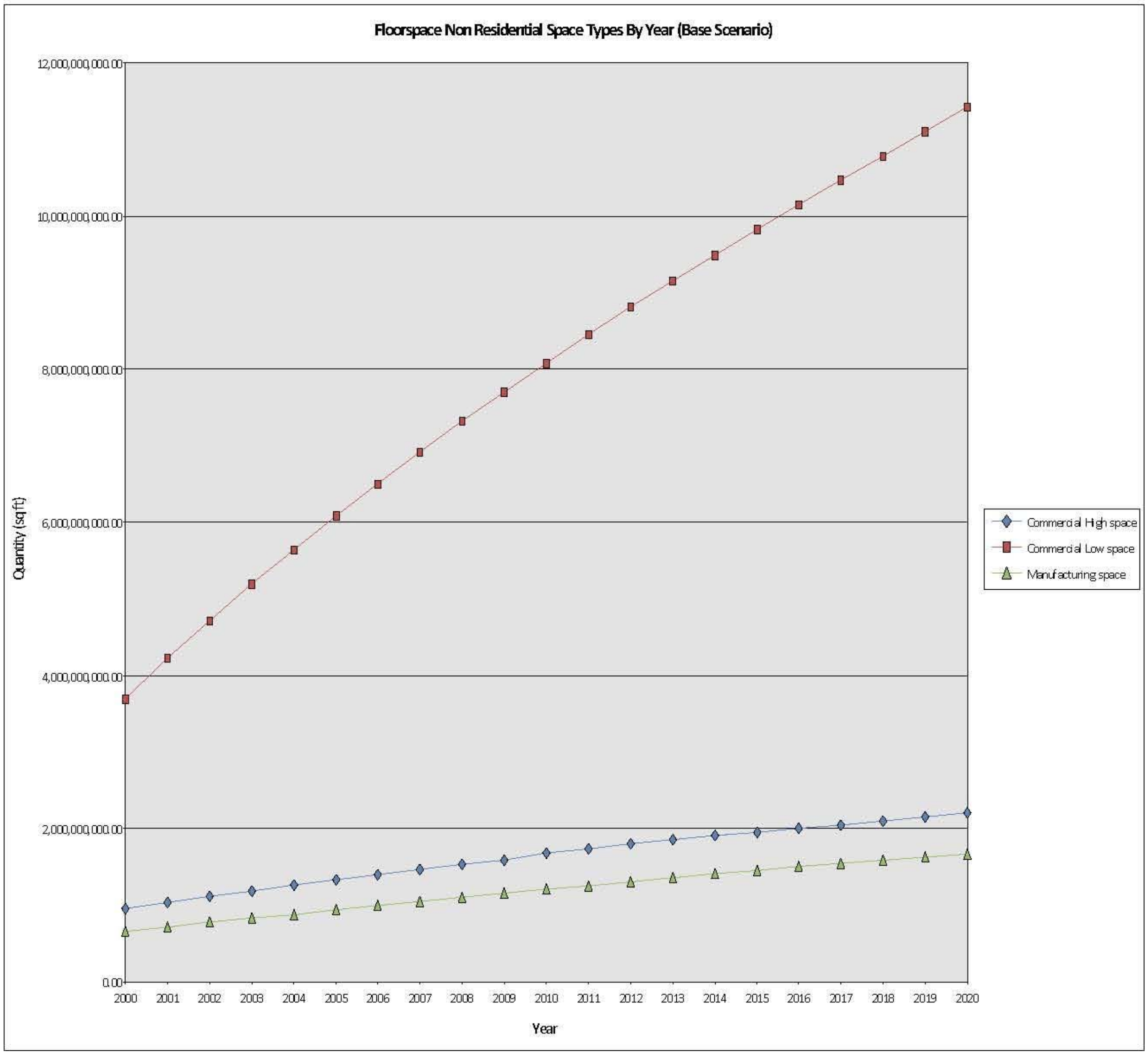
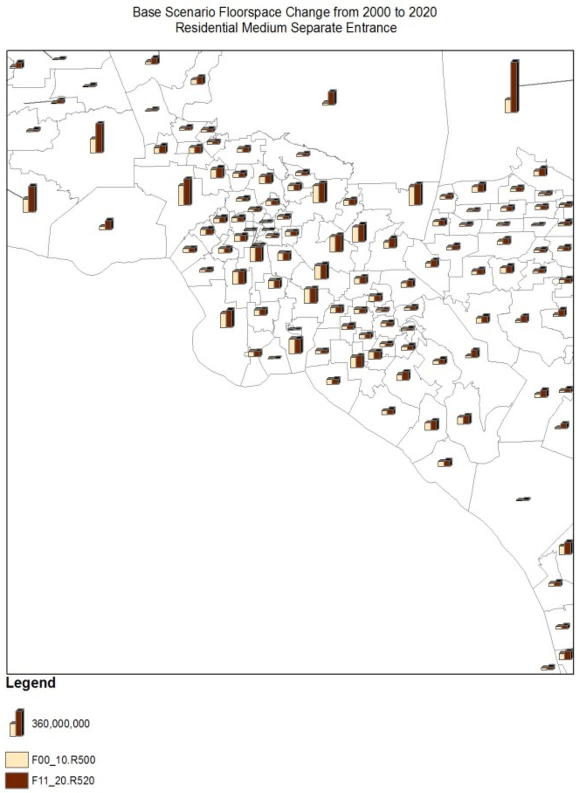


Figure 10 Trend of Manufacturing, Commercial High and Low Floorspace Over Time (2000 -2020)



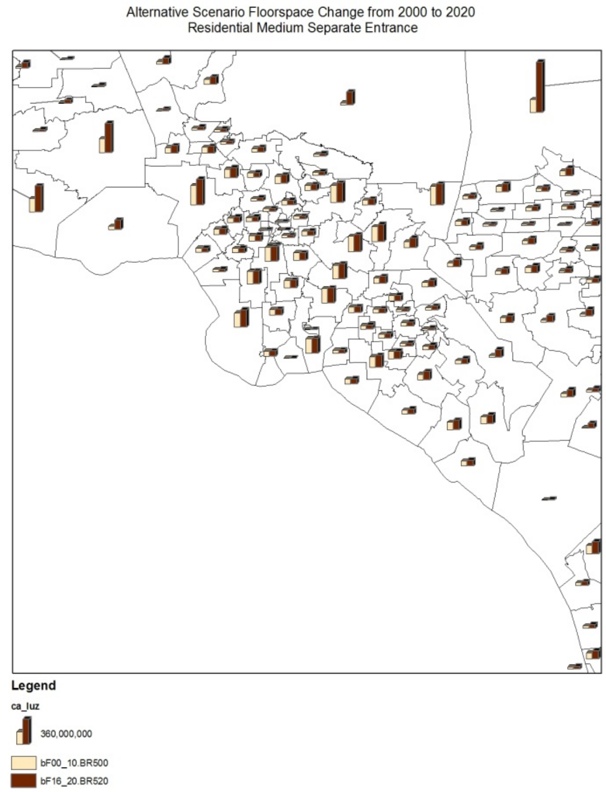


Figure 11 Residential Medium Separate Entrance Floorspace in 2000 and 2020 in the Base Scenario and Gasoline Scenario

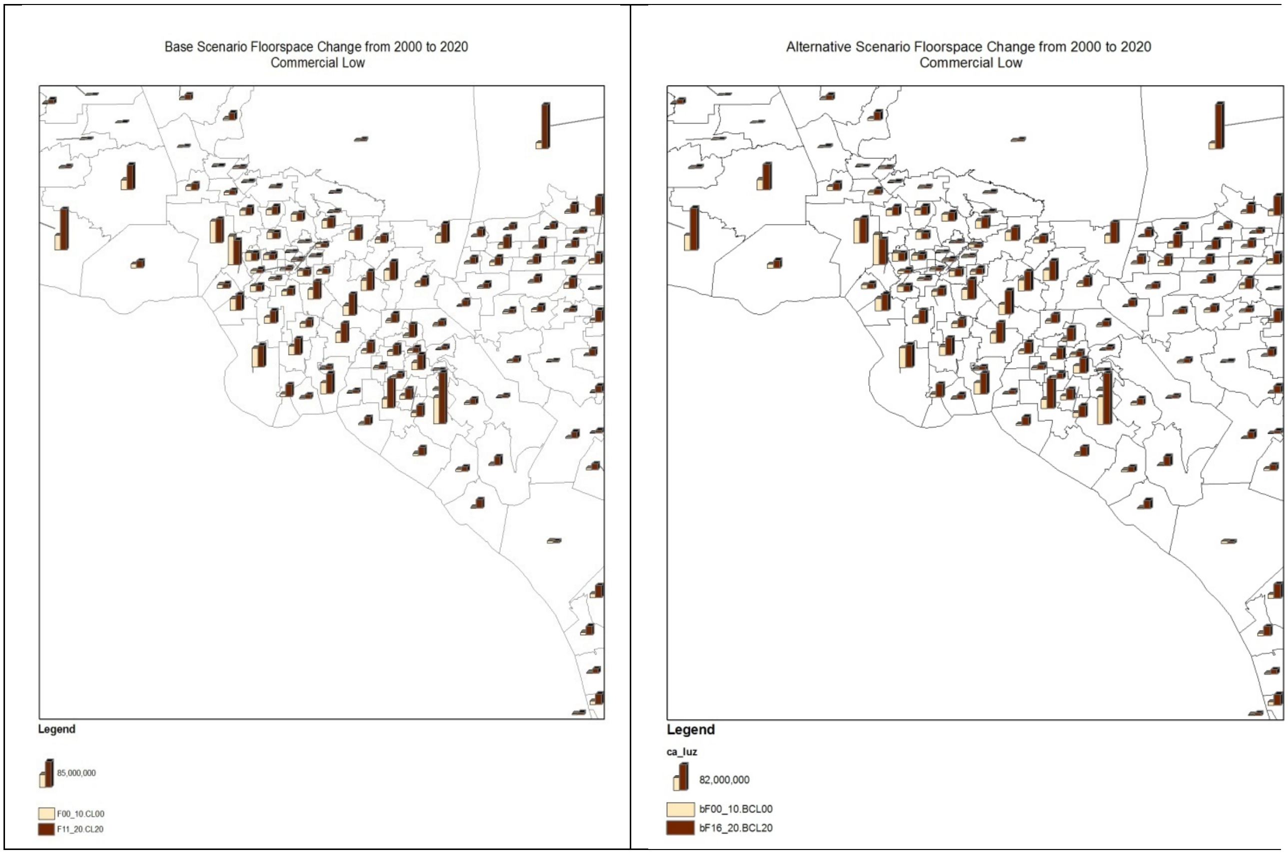


Figure 12 Commercial Low Floorspace in 2000 and 2020 in the Base Scenario and Gasoline Scenario

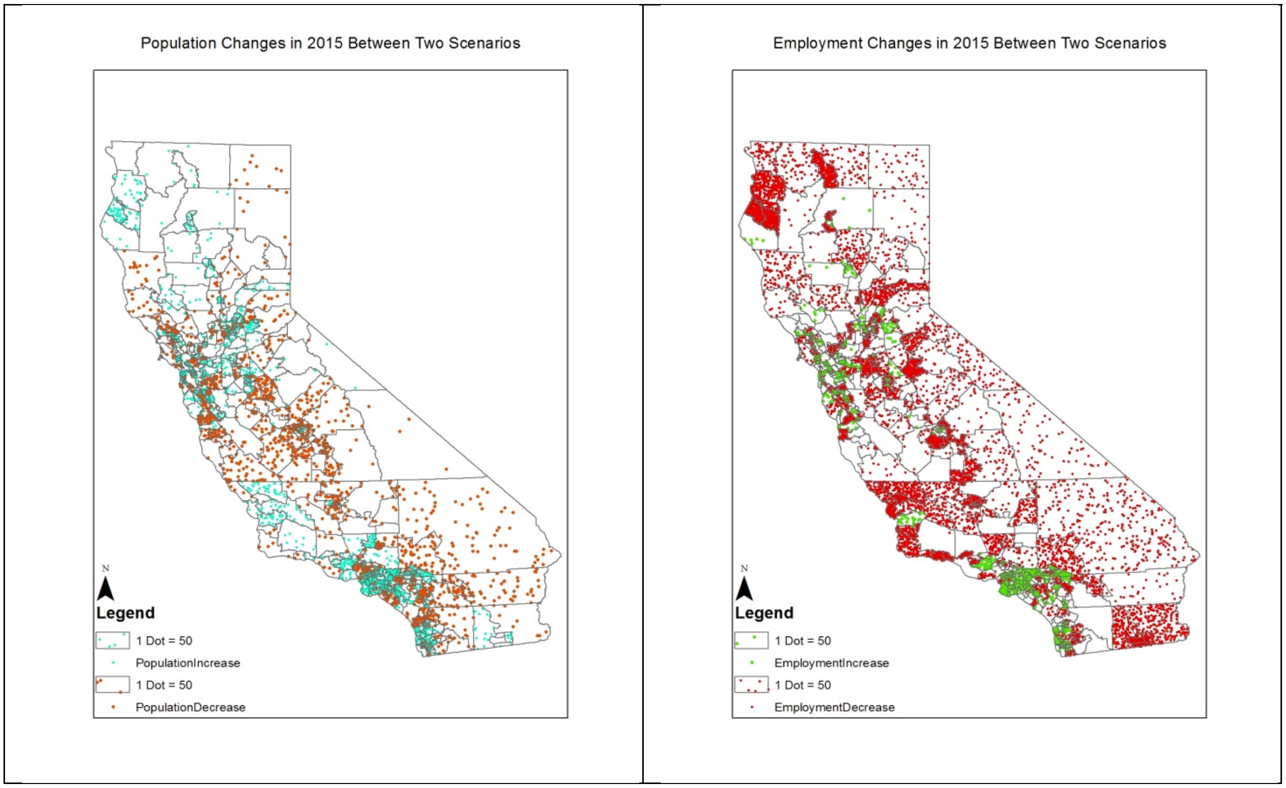
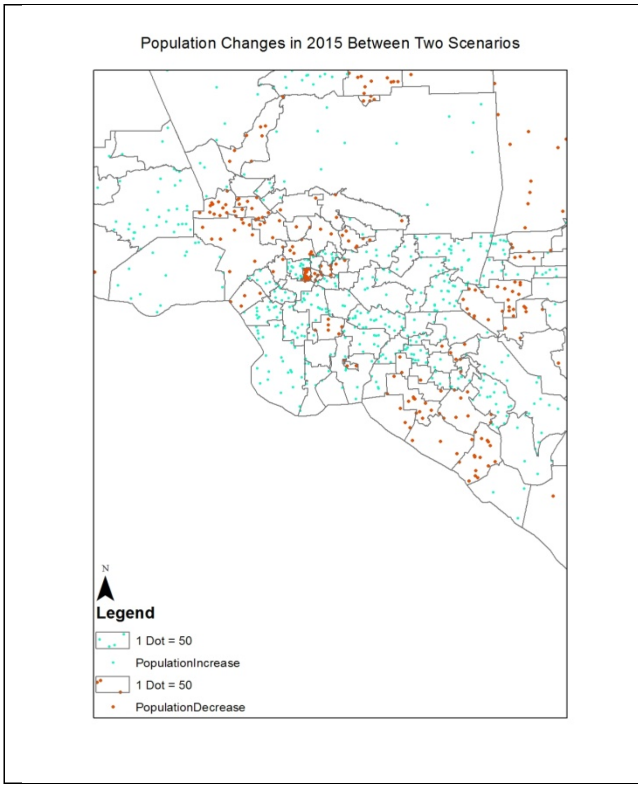


Figure 13 Differences of Households and Employments Between the Scenarios



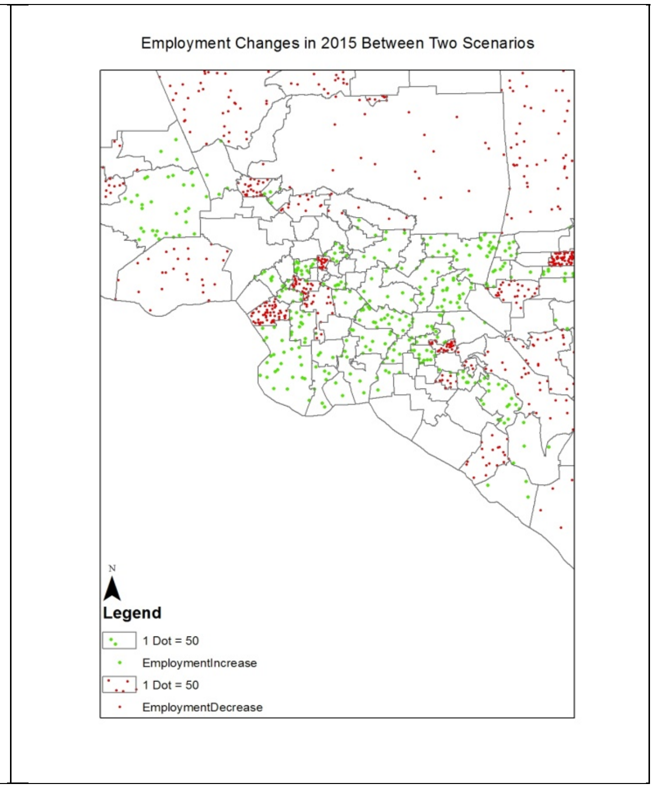


Figure 14 Differences of Households and Employments Between the Scenarios (Los Angeles Area

Table 1 Transition of Land Use Types*

From	ResType 1	ResType2	ResType3	ResType4	ResType5	ResType6	ResType7	ResType8	ResType9	Vacant	Manufacturing space	CH space	CL space	AG space	Resources space
ResType1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	No
ResType2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	No
ResType3	No	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	No
ResType4	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No
ResType5	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
ResType6	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
ResType7	No	No	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No
ResType8	No	No	No	No	No	No	No	Yes	No	Yes	Yes	Yes	Yes	No	No
ResType9	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No
Vacant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No
Manufacturing space	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
CH space	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
CL space	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
AG space	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Resources space	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes

*ResType1: Very Low Density Luxury

ResType2: Very Low Density Economy

ResType3: Low Density Luxury

ResType4: Low Density Economy

ResType5: Medium Density Separate Entrance

ResType6: Medium Density Shared Entrance

ResType7: Higher Density

ResType8: Highrise

ResType9: Urban Mobile Home

CH space: Commercial High space

CL space: Commercial Low space