HOW DOES UPZONING IMPACT LAND USE AND TRANSPORT: A CASE STUDY OF SEATTLE

Naifu Fan
PhD Candidate
Key Laboratory of Road and Traffic Engineering of the Ministry of Education
College of Transportation Engineering
Tongji University
1810973@tongji.edu.cn

Kara M. Kockelman, Ph.D., P.E.
(Corresponding Author)
Dewitt Greer Professor in Engineering
Department of Civil, Architectural and Environmental Engineering
The University of Texas at Austin
301 E. Dean Keeton St, Stop C1761, Austin, TX, 78712
kkockelm@mail.utexas.edu
Tel: 512-471-0210

Peter Caballero
Puget Sound Regional Council
PCaballero@psrc.org

Jason Hawkins, PhD
Assistant Professor
Department of Civil & Environmental Engineering
University of Nebraska Lincoln
jason.hawkins@unl.edu

Xiaohong Chen, PhD
Professor
Key Laboratory of Road and Traffic Engineering of the Ministry of Education
College of Transportation Engineering
Tongji University
tongjicxh@163.com

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ABSTRACT

This work simulates the long-term land use and transportation impacts of upzoning in the city and region of Seattle, Washington. The simulations use UrbanSim, an open-source model for micro-simulating land use change at the parcel level (annually from 2014 to 2050), with the Puget Sound Regional Council's agent-based travel demand model (SoundCast) being run every 10 years. Scenario results are compared, to illuminate differences in a Business-as-Usual future (BAU) versus Upzoning scenarios that upzone all single-family-use residential parcels in the region to 3 dwelling units per parcel (when land area and setbacks permit it). Results indicate the region's housing shortage and associated price increases will intensify without upzoning or other policies and practices. Under BAU, the rise in household counts outstrips added housing units by 22K units the 36-year simulation period, while the region's home affordability index falls 20%, and (real) rents rise 6%. Average travel times and costs to the downtown rise by 21% and 29%, respectively.

In constrast, the region-wide upzoning policy delivers 68K more residential units by 2050, though with 29K fewer single-family homes (as compared to the BAU forecast), and affordability is 11% higher, than the BAU approach. Upzoning also improves the region's average accessibility, and the gap among neighborhoods falls 6%. If only the City of Seattle elects to upzone, housing supply in that city is predicted to rise 65% by 2050, while the number of single-family buildings fell by 2%. Other areas that do not apply upzoning policy increase the housing supply by only 52%, and 8% more single-family buildings are needed.

Keywords: Integrated land use-transportation modeling, upzoning, forecasting urban futures, UrbanSim, Seattle, parcel data, single-family zoning

MOTIVATION

Lack of affordable housing is one of the most significant problems growing cities face. Supply constraints of housing and rising population drive up central-area prices (and rents), with much housing development staying at the low-cost periphery [1, 2], resulting in longer travel distances, wider congestion, and greater emissions. First applied in 1916 in New York City - to help manage rapid, unplanned growth, land use zoning policies influence location and density choices, by residents and developers, businesses and immigrants [3]. With most cities across developed nations using zoning policies to plan land development, and long-term residents often protesting upzoning and/or lower-cost building regulations, zoning's long-term effects are often exclusionary, and unable to accommodate new residents near central cities. Outdated zoning policies regularly limit housing supply and increase housing prices, while exacerbating income inequality trends, homelessness, and gentrification of formerly affordable central neighborhoods [4]. Upzoning changes increase allowed densities to enable land use change, and more efficient use decisions. Simple upzoning of residentially zoned parcels and neighborhoods across wide areas (e.g., entire cities or regions) should enable more affordable housing for lower-income households over time. Such zoning changes may also improve jobs-housing balance near the core and improve the region's economy, by lowering access costs [5-7].

While apartment living is common in most world cities, the U.S. has long had a policy of incentivizing single-family housing (via lower interest rates and tax deductions), to serve as a major source of savings for the aged. Many US cities now have very poor affordability scores, including Seattle, which has been promoting inclusionary zoning and higher density, while lowering parking requirements [8]. While New York State's governor is promoting policy for developers to build more lower-income units [9], the City of Minneapolis has enabled taller and bigger housing complexes, while eliminating single-family (SF) zoning to allow up to three dwelling units (DUs) per SF parcel [10]. Governor Gavin Newsom signed California's Housing Opportunity and More Efficiency (HOME) Act to allow home owners to add a second unit anywhere in that state [11].

Real estate is a major source of stored wealth (and often income) for most Americans. Upzoning (for residential or other uses) can be popular on specific sites, in limited settings, with economic potential for site redevelopment [12, 13]. In these specific settings, upzoning comes with higher land and housing values, limiting its usefulness towards housing affordability [4, 14, 15]. Only Minnespolis and California have upzoned in a widespread nature, and the effects of those policies are still to be seen. But experts expect that large-scale upzoning will lower housing costs over time [12, 16] – though it may accelerate gentrification in some neighborhoods, in the short term [17]. The process of land use change, supply-demand dynamics, and rent/price movements is affected by migrations, evolving demographics, transportation networks, national and global economies, and a wide variety of related policies and practices, perceptions and promises. One way to anticipate upzoning policies' effects without waiting years to try and collect enough data and hope to disentangle or control for all these hundreds of effects is to simulate the demolition of existing structures, building of new structures, changes in population and jobs by location, property price bidding, travel choices, and traffic conditions.

The longer commutes and higher travel costs that come with low-density development strike low-income households especially hard, while raising the cost of doing business for everyone [18]. To appreciate the future of urban housing and living costs, one cannot ignore the impact of traffic – especially for lower-income travelers [19, 20, 21]. To this end, this paper uses an integrated model of land use (at the parcel level) and transportation (at the level of traffic analysis zones) to predict the far future of building and price changes, under in-migration for the four-county Seattle region, with and without upzoning (to 3 units per currently 1 residential-unit parcels) for a City of Seattle scenario, and then for parcels across the entire region. Before describing the data sets, equations, and results obtained, this paper digs deeper into past research on this topic.

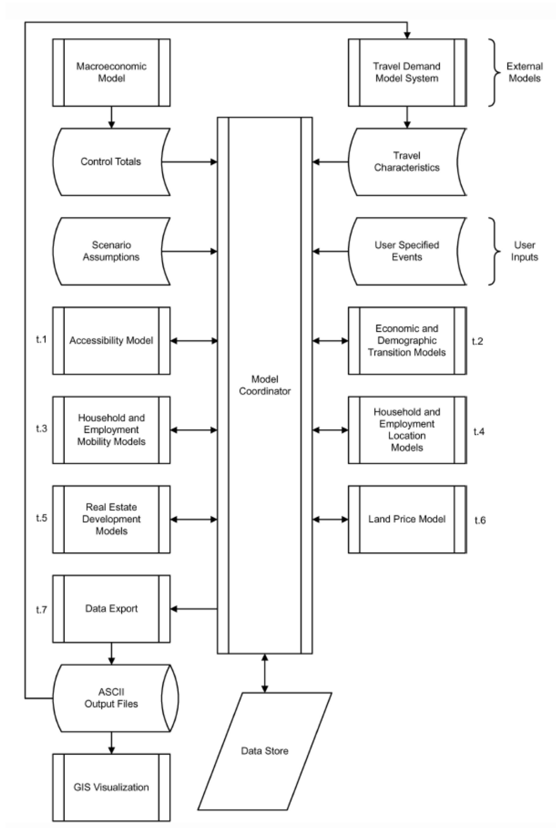
URBANSIM FOR LAND USE MODELING

Land use models have been developed and used for urban planning and resource distribution for decades [22]. Since urban systems are extremely complex, most models are confined to either land use or transport, producing a weak model integration between these systems. Without strong demographic and transport data analysis, it is difficult to accurately forecast future land use and real estate patterns. However, to meet the investment and policy needs of growing populations and evolving regions, it is necessary to pursue long-term urban planning, ideally with integrated models of land use and transport. Such needs and ambitions have led to the development of the multi-faceted model called UrbanSim [23-25]. UrbanSim's many equations seek to reproduce the mechanics of residential and work location choice, along with land development and land use change, which then affect travel times and access conditions (typically via a paired travel demand model).

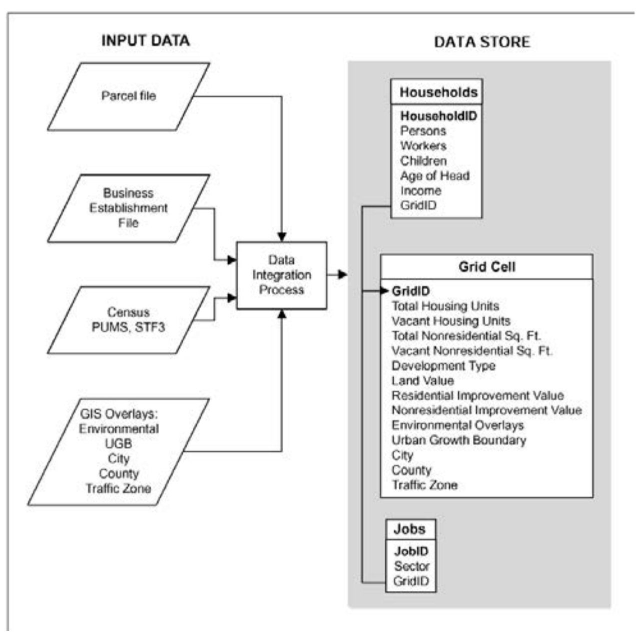
Model Structure

UrbanSim consists of several sub-models to "reflect the needs and choices of different stakeholders, including households, businesses, developers, and governments" [26]. As Figure 1 (a) suggests [27], UrbanSim has an accessibility model, economic and demographic transition models, household and employment mobility and location-choice models, a real estate development model, and a hedonic land price equation. This combination of sub-models supports many application scenarios. Research in Austin applied six scenarios to study the potential land use and travels impacts of different situations, including a No Travel Demand Model (NoTDM) scenario, a Business as Usual (BAU) scenario, an Urban Growth Boundary (UGB) scenario, a doubled Travel-Cost Sensitivity (TCS) scenario, an expanded highway capacity scenario (EXPAN), and an added state highway 130 (SH 130) scenario [28]. Multinomial logit models, ordered probit models, and linear regression models, are the basic statistical methods used in UrbanSim. Socioeconomic transition and demand models are also included in the model system of equations.

Figure 1 (b) [27] shows UrbanSim's data integration process. The input data (used to construct the model database) includes parcel files (from local tax assessor offices); business establishment files (from state unemployment insurance databases or commercial sources); US Census data; GIS overlays representing environmental, political, and planning boundaries; and a 150 by 150 meters grid for cell locations. These real data sets are combined with synthetic details for specific households, businesses, and some parcels.



(a)



(b)

Figure 1 UrbanSim model structure and data processing. [27]

Land Use Model Comparisons

UrbanSim differs from other urban planning models in several ways. In contrast to simpler microsimulation methods for land use change, UrbanSim adopts a "dynamic disequilibrium" method to adjust models at various rates [29]. Disaggregate methods are used to apply sub-models at a grid cell spatial resolution. Duthie et al. compared Putman's gravity-based Integrated Transportation Land Use Planning (ITLUP also known as DRAM-EMPAL) specification and application to UrbanSim [30,31]. As noted, UrbanSim requires much more extensive and disaggregate data and many more equations and predictions or outputs, every year (rather than every 5 or 10 years as in ITLUP). ITLUP models may be more suitable for small-scale planning with limited resources and data [32]. In comparison to past economic and spatial-interaction models (like MEPLAN and TRANUS) [33,34], which rely on cross-sectional equilibrium solutions using large geographic zones, UrbanSim is highly disaggregated, in space and time [27, 35]. More recently, Marko et al. [36] specified and applied a static-equilibrium framework, called Pirandello, and compared its results to UrbanSim, step by step, for various simulated policy scenarios like urban toll implementation and dramatic petrol price increase in Lyon, Franc. Pirandello has a rather sophisticated mechanism for employment location choices, while UrbanSim uses a possibility for agent relocations. Despite their differences, their predictions are comparable and interpretable.

Land Use Model Applications

Two decades have passed since UrbanSim was released, with many US applications (including regions and cities in California, Hawaii, Oregon, and Utah) [23]. For the city of Austin, Duthie et al. [30] used UrbanSim to simulate a commercial job space for the Austin sub-area in 2007. They compared it to the application of TELUM to find an appropriate model for MPOs of various resources and needs. Kakaraparthi and Kockelman [28] described the modeling of the Year 2030 land-use patterns of Austin. The comparison between different scenarios reflects the model's sensitivity to the application of various transport and land use policies. Waddell also applied the complete UrbanSim model in the San Francisco Bay Area for the Metropolitan Transportation Commission (MTC) and Association of Bay Area Governments (ABAG), for use in regional macroscopic plans [2]. In non-American cities, however, the integrated land use -transportation modeling may face different challenges and demands compared to the cases in the United States [37]. UrbanSim modeling treats developer behavior and the emergence of land prices as independent processes, Felsenstein and Ashbel studied the simultaneity between house prices and developer behavior in Tel Aviv [38]. Simultaneous estimation of these two processes can result in more significant outcomes and unstable trends. Similarly, the research of the Real Estate Price Model was also applied in Lyon [39]. Focusing on modeling residential locations in UrbanSim, Waddell briefly provided an overview of applications in numerous metropolitan areas and summarized the model system [40], while Jin and Lee [41] forecasted changes in household residential locations and derived policy implications for the local housing market in Suwon, Korea. Furthermore, UrbanSim was also implemented in the canton of Zurich as one of three case studies of the SustainCity project [42].

UrbanSim Limitations

While UrbanSim continues a microsimulation tradition in land-use transportation modeling extending the work from different subjects, it still has limitations. First, the disaggregate data required for UrbanSim makes it difficult to generate a complete input dataset. Patterson et al. [43] used the cases of Brussels, Belgium, and Lyon, France to study the possibility of using aggregate data to fit the UrbanSim system. Second, the model cannot predict isolated events that may occur during the study time. Third, model full calibration can hardly be done and is not sensitive enough to sudden policy changes. The uncertainty in model parameter estimates also has an impact on the outputs [44]. Fourth, the methodology for sub-models is pre-set, which is a methodological limitation in UrbanSim for research flexibility. Finally, as mentioned earlier, the situations in non-American countries are different. Adaptation and extension are needed when applying UrbanSim in various circumstances.

This work synthesizes the upzoning problem with urban land use evolution over years at the parcel level, using improved UrbanSim models and an advanced travel demand model, considering the change in households, employment, and real estate prices. Compared to other upzoning research, the forecasted changes in this study benefit from the UrbanSim simulation, which will be important for long-term urban planning. The transitions of households and jobs are not mentioned in most past research, which suggests that they implicitly reflect the original residents' willingness to live in the planned area. Further, the changes in house prices and residential units after decades will show the true beneficiaries of this policy. What's more, the incorporation between the land use model and travel model captures the evolution of travel demand and travel cost over time, which deeply affects the travel patterns and location choices of residents.

SEATTLE APPLICATION

The study takes Seattle and its surrounding areas as the study area. With a population of 741,251 in 2020, Seattle is the largest city in the U.S. state of Washington, and one of the nation's fastest growing big cities [45]. To meet the housing demand and lower residents' cost of living, the mayor of Seattle has signed laws to build more affordable and denser housing in 27 neighborhoods [46]. Restrictions are set to limit developers and builders, so they have to choose between constructing more affordable houses and paying the extra city fund. Upzoning buildings, although mainly for low-income groups, may affect the real estate market and population migration of the whole city.

This study uses parcel-level land use and demographic data and zone-level travel data obtained by the Puget Sound Regional Council (PSRC) for Seattle and surrounding areas (including King, Kitsap, Pierce, and Snohomish counties), shown in Figure 2. The land use and demographic data contain the information of 1.2M parcels, 1.6M households, 1.2M buildings, 2.0M jobs, 3.7M persons, and land use and development template data of the study area, collected in 2014. The travel data contains 3700 travel analysis zones (TAZs), and relies on estimates of travel time and distance between zones in peak hours.

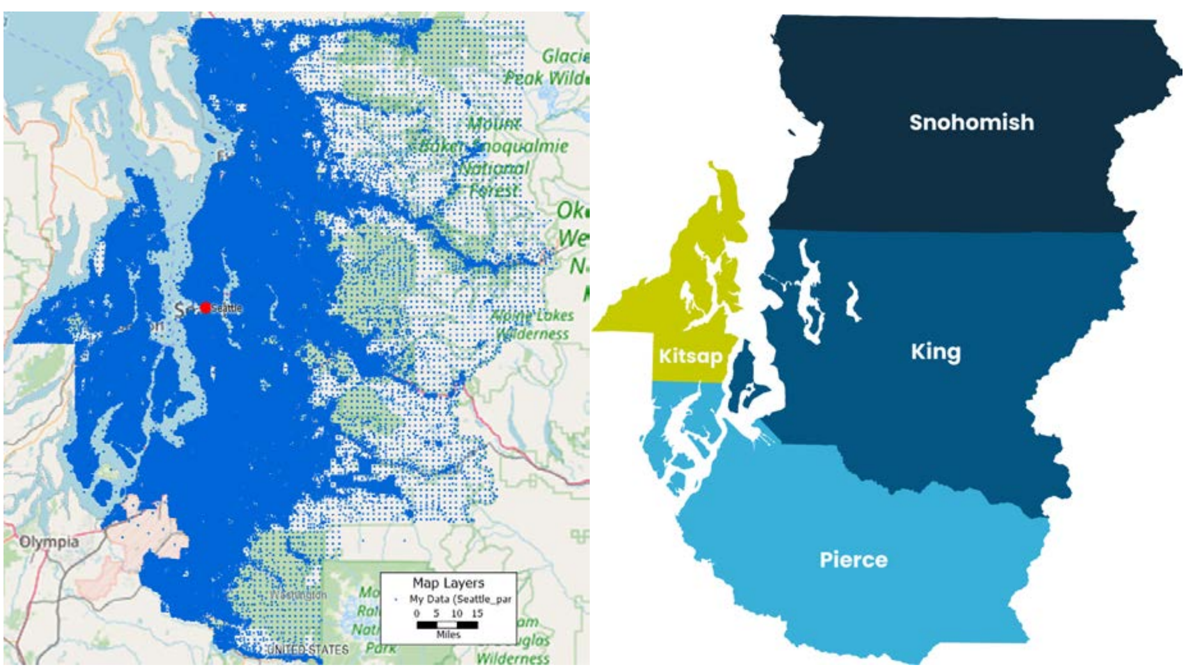


Figure 2. Seattle's four counties and parcel-level intensities [source: 47]

Figure 3 shows various regional features in year 2014. As evident, most households and jobs are located on the western side of Pierce County and the eastern side of Snohomish County. Many jobs alos exist on both sides of King County. The region enjoys a rather level of jobs density, thanks to mountain ranges and waterways limiting growth, plus the region's long-time Pacific Coast port city function.

Since almost 10% of dwelling units are unoccupied across the region (which is similar for many US cities and regions), each household corresponds to 1.09 residential units (in year 2014). One TAZ (#632 in the City of Seattle) has 3.5 units per household (due to what? Tiny, old apartments no one wants?), while TAZs 3409 through 3700 (in Kitsop and Pierce Counties) have a 1 to 1 ratio (so every unit is considered occupied, signalizing little flexibility in those locations' housing markets). For the total land value, the results are formatted in dollar values by acre. Figure 3's final graphic shows land values, in total dollars divied by total acres per TAZ, with values highest in the City of Seattle and adjacent zones.

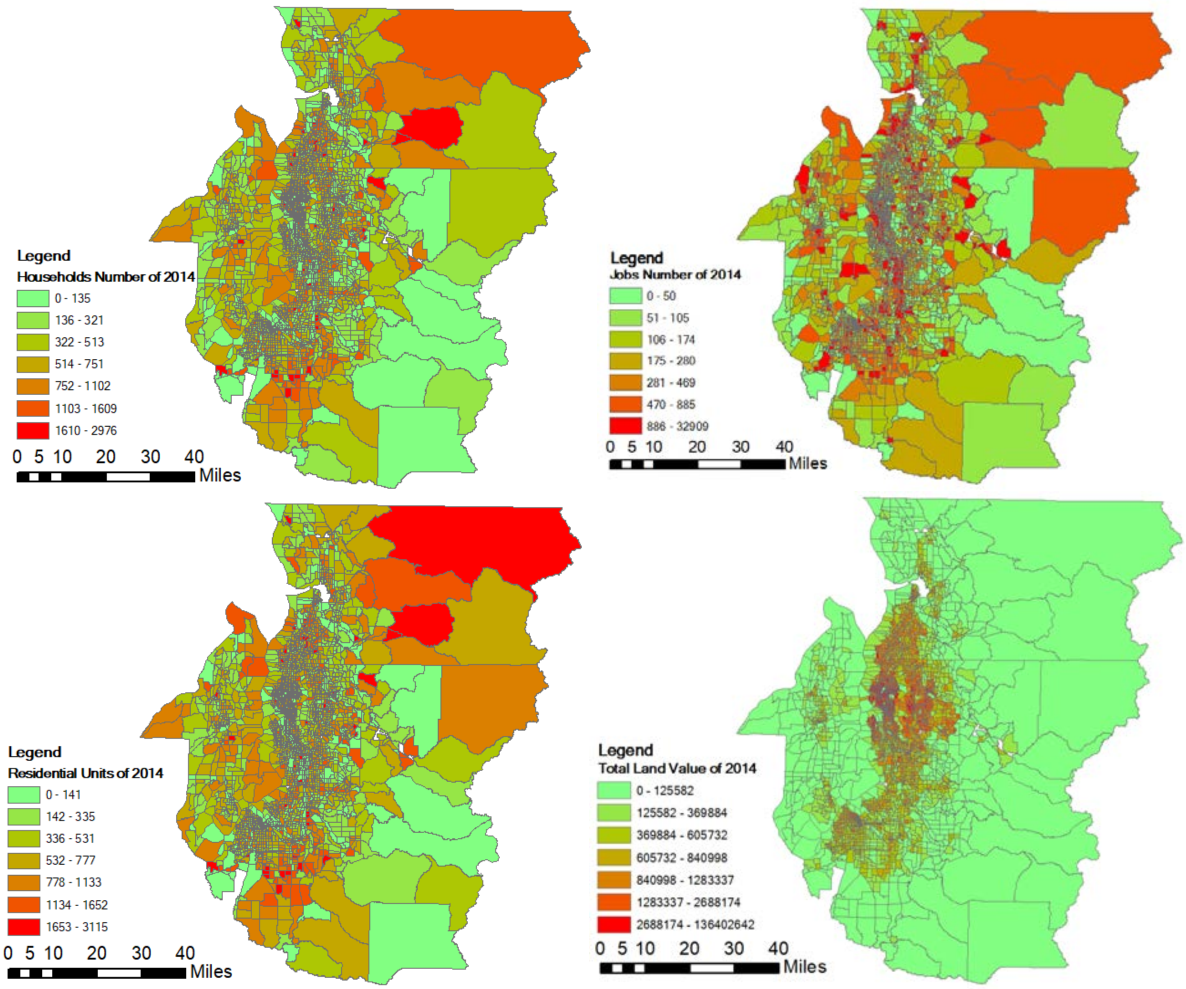


Figure 3. Household, Jobs, Residential Unit Counts and Land Value per Acre across the Seattle Region's 3,700 TAZs

3.2 Scenarios Description

Four scenarios were simulated over 26 years: from 2014 through 2050. First is a business-as-usual but No Travel Demand Model (BAU-NoTDM) scenario that we run UrbanSim without TDM integration or upzoning. The travel cost remains the same as the base year 2014. This scenario reflects the impact of incorporation between UrbanSim and travel demand model (SoundCast). Second is a business-as-usual (BAU) scenario in which we simulate changes in the study area over time without upzoning. All the parcels' DU remain the same as the base year. TDM is applied in this scenario. This BAU scenario is set as the control group of the upzoning cases. Third is an All-upzoning (AU) scenario in which we upzone every parcel in the study area. We increase the allowable maximum density for single-family parcels to 30 dwelling units per acre. This zoning policy means that residents are allowed to upzone their single unit up to a maximum of three units. AU scenario reflects the case of applying upzoning policy at the whole four counties (about 4.4M acres). The last is a Seattle-upzoning (SU) scenario in which we only upzone the city of Seattle (about 53K acres), and the process of upzoning is the same as the last scenario. This can represent the result of upzoning the core region of these counties, showing the differences between the downtown and the peripheral area.

3. 3 Model Specification

This research contains three parts: regional economic forecasts, land use forecasts, and travel forecasts. Outputs from UrbanSim and the TDM, including land development, change of real estate price, household and employment location choice, transition and construction, and accessibility of TAZs were used during iteration. The following discussion describes information from the key sub-models.

Land Price Model

UrbanSim's land price model predicts changes in the real estate market. The total property value is equal to the parcel's land value if vacant, and land plus buildings' (improvement) value for developed parcels. Every (simulated) year, the model updates market value estimates and its outputs serve as inputs to the land development and household and employment location models.

Hedonic regression is used to estimate property value, as shown in Eq. 1:

$$P = f\left(\overrightarrow{LA}, \vec{S}, \vec{N}, \vec{E}\right) \tag{1}$$

where P is the total property price (land plus any built improvements), $\overrightarrow{LA}$ is a vector of location and access attributes, $\vec{S}$ are building attributes (like square footage and age of structure), $\vec{N}$ are neighborhood characteristics, and $\vec{E}$ are local environmental factors.

Here, key attributes include generalized cost and travel time of accessing employment and population by different traffic modes, retail jobs density, population density, total employment density, number of nearby schools and their quality scores, distance to the nearest arterial roadway and to the nearest highway, parcel size, building size, number of dwelling units, average income of resident households, age of building, share of impoverished residents, building density, developable capacity, presence inside the regional urban growth boundary, waterfront status, and park area within walking distance.

Housing affordability indexes help one appreciate whether the median Seattle household can own the median-priced house [48], with equations as follows:

$$MP = HP \cdot 0.8 \cdot \frac{\frac{IR}{12}}{1 - \left(\frac{1}{\left(1 + \frac{IR}{12}\right)^{360}}\right)} \tag{2}$$

$$NI = \left(\frac{MP \cdot 12}{MI}\right) \cdot 100 \tag{3}$$

$$QI = MP \cdot 4 \cdot 12 \tag{4}$$

$$HA = \left(\frac{MI}{QI}\right) \cdot 100 \tag{5}$$

where MP is the monthly payment, $HP$is the average housing price, IR is the interest rate; NI is the necessary monthly income, MI is the median income; QI is the qualifying income, and HA is the housing affordability. Rent affordability is also considered in the following results.

Household/Employment Location Choice Model

UrbanSim's household/employment location choice model contains a transition model, location choice model, and relocation model, for both households and businesses or individual jobs. The transition model determines the number of households and jobs that will be added to (or subtracted from) the region each year. Demographic, accessibility, and land use factors are used to allow the household and jobs counts to meet the annual regional control totals. Then the relocation model determines the probability of households/jobs changing their current location, and this process is based on the exogenous relocation rate. A pool of vacant spaces and unassigned households/jobs is set. Finally, the location choice model selects households and jobs from the unassigned pool and matches them to possible locations through a multinomial logit (MNL) model. Various explanatory variables are selected to run the household location choice model. The utility or overall attractiveness of locations is also involved in the choice and match process. Table 1 is an example of the coefficients of the HLCM.

Table 1 Coefficients used in the household location choice model.

Sub-Model ID	Variable	estimate	T-stat	StErr
1	Avg. network distance (miles)	-0.029	-2.59	0.011
1	Max commute logsum	0.849	12.52	0.068
1	Location	0.566	7.90	0.072
1	Multi-family residential? (yes = 1)	0.297	2.44	0.122
1	Multi-family building type?	1.162	12.67	0.092
1	Range of housing	-0.328	-5.51	0.059
1	Residual of price	0.397	15.75	0.025
1	Per capita income x household size	-0.044	-9.40	0.005
1	One-person household & Is not single-family residential	1.243	10.83	0.115
1	Households with more than 3 people and do not live in Seattle	0.895	2.95	0.303
1	Owner of the house & Is not single-family residential	2.210	17.30	0.128
1	Retail density within walking distance	0.542	8.39	0.065
2	Multi-family building type	1.571	12.12	0.130
2	Range of housing	-0.599	-5.77	0.104
2	Residual of price	0.573	12.96	0.044
2	Per capita income x household size	-0.032	-2.77	0.012
2	One-person household & Is not single-family residential	1.770	5.83	0.303
2	Owner of the house & Is not single-family residential	2.475	8.53	0.290
2	Retail density within walking distance	0.718	5.39	0.133
2	Households with less than 3 people and do not live in Seattle	1.633	16.15	0.101

Integration with SoundCast Travel Demand Model

UrbanSim is used here in tandem with PSRC's activity-based model system called SoundCast [49]. UrbanSim has been used with various TDMs, including MATSim and TransCAD [50, 51]. Compared to the traditional four-step model, SoundCast applies DaySim to represent various aspects of travel [52]. An integrated system of discrete choice models is used to simulate long-term choices of each household, daily travels, and activities. The other two main components include submodels commercial travel and network assignment.

SoundCast inputs include land use, travel impedance, and household and person data. The travel impedance data contains the zone-to-zone OD matrixes that reflect peak hour travel behaviors for different transport modes and people groups, as shown in Table 2.

Table 2 The input zone-to-zone travel matrixes.

Indicator Name	Description
am_single_vehicle_to_work_travel_time	Car travel time to work in peak hour.
am_single_vehicle_to_work_toll	Car travel toll to work in peak hour.
single_vehicle_to_work_travel_distance	Car travel distance to work in peak hour.
single_vehicle_to_work_travel_cost	Car travel cost to work in peak hour.
am_walk_time_in_minutes	Walk travel time in minutes.
am_pk_period_drive_alone_vehicle_trips	Number of vehicle trips in peak hour.
am_total_transit_time_walk	Walk time to transit in peak hour.
logsum_hbw_am_income_1-4	Logsum index of home-based-work travel for people with different incomes.

The generalized travel cost is acquired considering travel cost, travel time, and tolls, as shown in Eq. 2 [53]:

$$TC = \beta_{tt} \cdot TT + \beta_{td} \cdot TD + \beta_{ttoll} \cdot TToll \tag{2}$$

where β_{tt} is the marginal (dis)utility of travel time, TT is travel time, β_{td} is the marginal (dis)utility of travel distance TD, and β_{ttoll} is the marginal utility of travel toll $TToll$.

The logsum index is labeled "logsum_hbw_am_income", since it is for home-based-work (HBW) trips only, in the AM Peak period of day (approximately 7 to 9 am on weekdays), and by income category. Logsum terms (shown in Eq. 3) are a valuable measure of access since they reflect the tradeoffs between all potential modes and destinations [54,55].

$$A_i = ln \sum_j e^{V_{ij}} \tag{3}$$

where i is origin TAZ, j is (possible) destination TAZ, and V_{ij} is the "utility" of travel between i and j (which grows more negative as time and cost grow).

SoundCast provides forecasts of travel between all parcels (not just TAZs), and time-of-day and mode-specific trip matrices, which can be used for traffic assignment and to estimate access indices for different TAZs. Since travel costs and access affect land use decisions, these outputs are input into UrbanSim to serve as variables each year for an entire decade of land use simulation, as shown in Figure 4. SoundCast is used 3 times: years 2030, 2040, and 2050, due to its heavy computing costs.

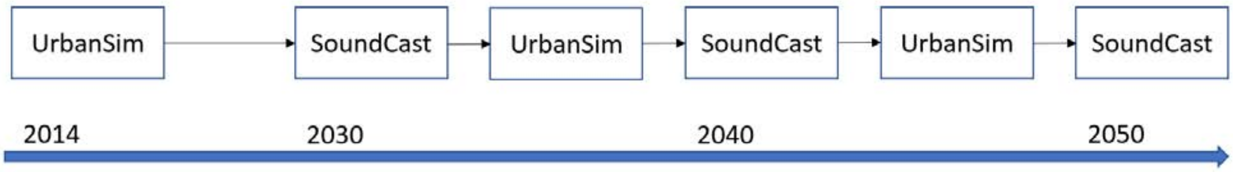
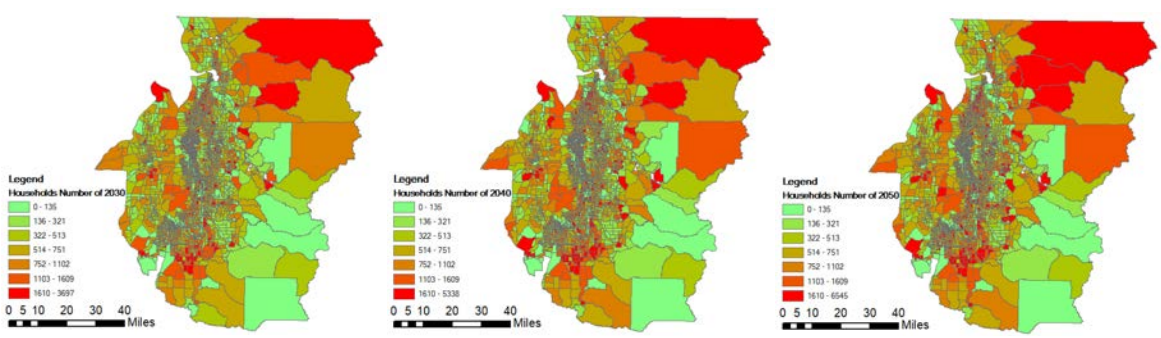


Figure 4. Sequence of SoundCast (Transportation) and UrbanSim (Land Use) Model Application

RESULTS

Four scenarios were used to evaluate the impacts of upzoning policies, and the incorporation of UrbanSim and SoundCast: BAU-NoTDM, BAU, AU, and SU. The BAU-NoTDM scenario reflects the difference between adopting and not adopting the TDM in the simulation process, by comparing with the BAU scenario. The BAU scenario shows the forecast result of the study area with no upzoning policies. The AU scenario demonstrates the impacts of implementing a broad upzoning policy, and the SU scenario shows the effects of an upzoning policy applied in Seattle only.

Compared to the BAU-NoTDM scenario, the BAU scenario incorporates the land use model UrbanSim with TDM SoundCast in years 2030, 2040, and 2050. This process affects the forecast of hedonic regression and location choice, and the development results of increases in households, jobs, and population remain the same. Figure 5 (a) and (b) illustrate the BAU forecast result of BAU households and jobs in 2030, 2040, and 2050. Population grows from 3.7M in 2014 to 5.7M in 2050. Households and jobs in the northeast and southwest of the study area increased the fastest. Total households grow by 61% (from 1.51M in 2014 to 2.42M in 2050). Total jobs grow from 2.00M in 2014 to 3.34M in 2050, which slightly exceeds the increase in worker growth (from 1.84M in 2014 to 2.85M in 2050), indicating that the jobs supply growth can meet the needs of workers. Figure 5 (c) shows the growth trend for total land value and total residential units. Note that the sudden decrease in total land value from 2030 to 2035 is caused by the interaction of UrbanSim and SoundCast. These interactions will also slightly reduce the forecast result of residential units, for the result of BAU in 2050 is 1.2K less than the BAU-NoTDM. For the housing ratio (residential units/households) in BAU, the value decreases from 1.09 in 2014 to 1.04 in 2050. The number of residential units grows by 890K, which is less than the growth of households by 912K. This change indicates that the housing shortage in the study area will increase in the future if no measures are taken. In addition, the total land value will continue to rise, especially in King County.



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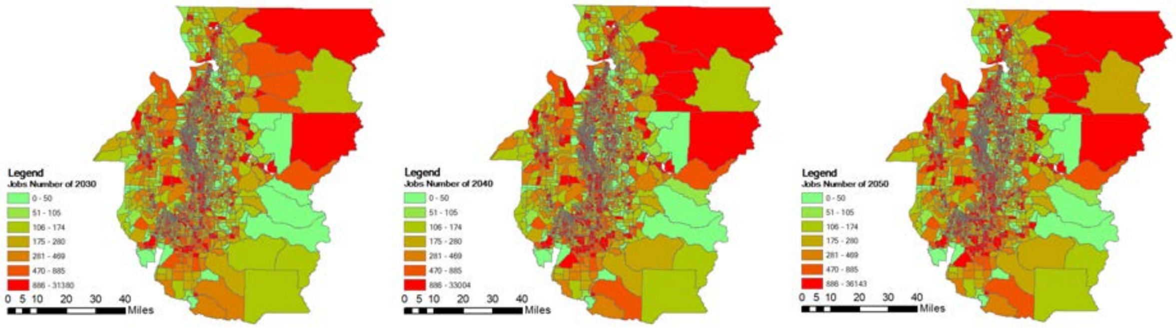

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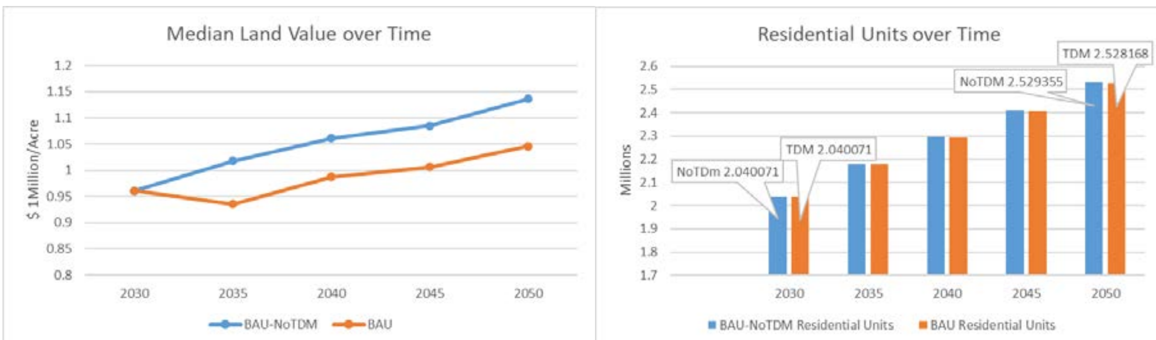


(c)

Figure 5. BAU Simulation Results over Time: (a) number of households per zone, (b) number of jobs per zone, (c) median land value per acre, and (4) number of residential units per zone

Table 3's first two rows illustrate the change in housing affordability index of the study area in the BAU scenario. Note that this simulation relies on data acquired from county assessors (of property values), so the affordability calculation is based on assessed value (not market or sales data). The U.S. mortgage (home lending) rate is set at 5.44% (as of May 19, 2022) and the home-price-to-rent ratio is set at 24.6% [56,57]. The reason for the decline in the median household income is that new households continue to be created, while UrbanSim assumes that the existing income of each household remains unchanged. Inflation and price changes are not considered in this study. The average number of workers in year 2014 households was 1.22, and is 1.17 for new households, which also results in a lower median income over time. Year 2050 housing prices are much here than those in the base (2014) year, with the region's housing affordability index falling: from 75.3 to 60.6.

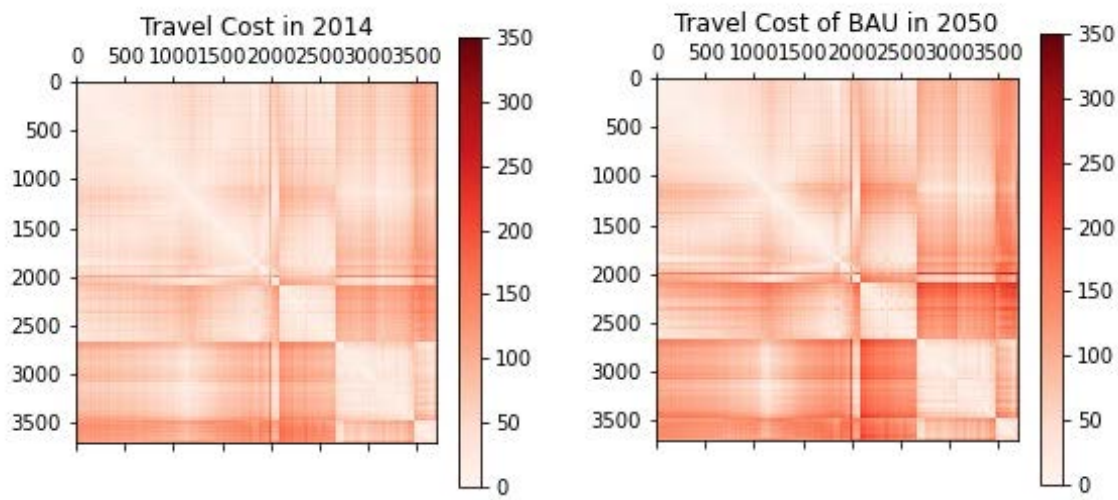
As expected, housing pressure keeps rising for this popular region. In 2050, the median buyer is predicted to use 41% of its household income to repay the mortgage loan, while renters need to use 31% of their income to pay rent, under the BAU scenario. It becomes increasingly difficult for low-income and mid-income families to afford a house iin the region. Upzoning policies appear needed, to moderate such effects. The all-region (AU) policy studied here suggests upzoning SF parcels from 1 to 3 DUs should temper the fall in affordability index by about half, with (real, not nominal) income levels just $8,259 higher (in 2050) to qualify for median home purchase, rather than $19,296 higher.

Table 3 Housing Affordability Index Calculations for Seattle Region

Scenario & Year	Average Dwelling Unit Price	Avg. Monthly Payment to Own Home	Mortgage Payment as % of Median HH Income	Median Household Income	Qualifying Household Income	Home Affordability for Buyers	12-month Rent	Rent as a % of Regional Median Income
BAU/2014	$420,754/DU	$1898/mo.	33.19%	$68,610	$91,090	75.32	$17,104	24.9%

BAU/2050	$509,885/DU	$2300/mo.	41.27%	$66,870	$110,386	60.58	$20,727	31.0%
AU/2050	$458,902/DU	$2070/mo.	37.14%	$66,874	$99,349	67.31	$18,655	27.9%

Figure 6 and Table 4's first two rows access changes between 2014 and 2050, across TAZs under the BAU scenario. As evident, travel costs between the 3700 TAZs rise significantly over the 36-year period, with travel costs between Snohomish County (TAZs 2090-2669), and Kitsap and Pierce Counties (TAZs 2670-3700) always the highest. For daily travelers, the average bumps in travel cost and time from each TAZ to the Seattle CBD are 29% and 17%, respectively. Many low-income household members rely on public transit, and thus spend more time in daily travel. The average travel cost for residents of low-income TAZs (those in the bottom 20%) is predicted to rise 32%. Furthermore, logsum changes suggest that traveler benefits fall each year, with the spread (or standard deviation) in costs rising over time. The travel cost imbalance between TAZs appears aggravated over time, with too-few housing units being built, and higher-income households always enjoying the best access values, on average.



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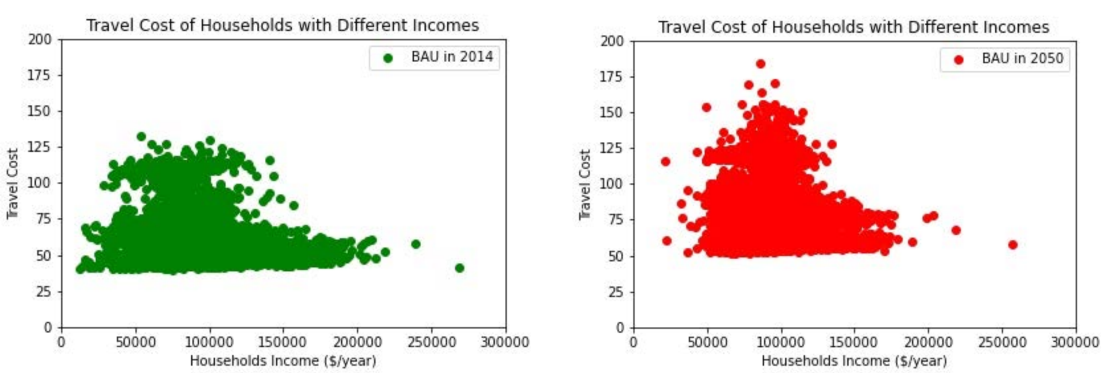


(b)

Figure 6. Travel Costs between All TAZs and by Income under BAU in Years 2014 and 2050

Table 4. Travel Times and Logsum Access Values for BAU and AU Scenarios

Scenario &Year	Avg. Travel	Avg. Travel	St Dev of Travel Cost	Avg. Travel Cost for Low-income TAZs	HBW Travel	HBW Travel	HBW Travel	HBW Travel

	Cost to CBD	Time to CBD	between TAZs		Logsum of Class 1	Logsum of Class 2	Logsum of Class 3	Logsum of Class 4
BAU/2014	54.04	52.03	18.71	70.22	-3.49	-3.21	-2.86	-2.57
BAU/2050	69.87	60.99	23.56	92.55	-3.54	-3.27	-2.98	-2.66
AU/2050	69.18	60.34	22.08	91.21	-3.55	-3.28	-2.98	-2.66

Upzoning policy is applied in AU scenario and SU scenario, and the zoning restrictions on single-family residential parcels are relaxed. Compared to scenario BAU, upzoning policy won't change the growth tendency of demographic factors and immigration situation, which were set up before simulation. As a result, the upzoning forecast results of these indexes are very close to BAU's.

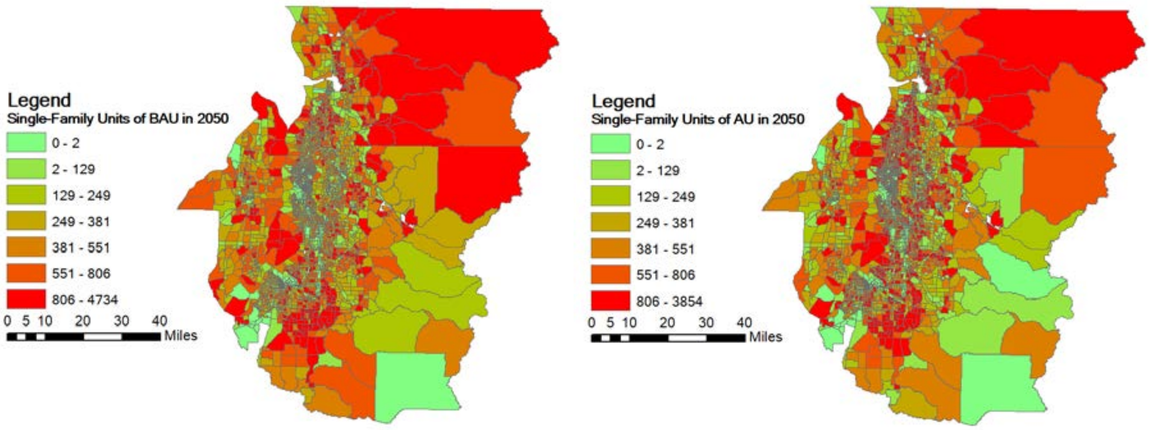
For AU scenario, all four counties' single-family residential parcels are allowed to be upzoned, and this impacts the housing condition and real estate market forecasts, as shown in Table 5 and Figure 7a. The total building count in scenario BAU in 2050 is 37K higher than that in scenario AU, and the number of single-family buildings in BAU in 2050 is 29K higher than in AU scenario. The single-family buildings in King County and Pierce County are most affected by this policy. Over 339K buildings that have more than one dwelling unit are in previously single-family residential zoned parcels – i.e., upzoned parcels. In addition, 68K more residential dwelling units are supplied in 2050 under the upzoning policy. These indicate that upzoning policy can provide more housing while reducing the long-term need for new buildings.

Figure 7 b and the last two rows of Table 3 illustrate the impact of upzoning policy on real estate market and residents' living conditions. In 2050, the AU housing value is significantly lower than in BAU, especially in the regions that have fewer single-family units. The average housing price in AU is $50K less than in BAU, and this leads to lower monthly payments to own a house or to pay the rent. For AU scenario, buyers need to use 37% (4.1% less than BAU) of their income to repay their loan, and renters need to use 28% (3.1% less than BAU) of their income to pay rent. Although the buying affordability of AU in 2050 (67.31) is still lower than BAU in 2014's (75.32), it is much higher than the buying affordability of BAU in 2050 (60.58). Therefore, upzoning policy can effectively slow down the growth of housing prices and increase housing affordability. This measure will make it easier for citizens to afford their daily living expenses.

Table 4 also illustrates the accessibility differences between AU scenario and BAU scenario. The All-upzoning scenario is associated with lower travel cost and travel time to CBD. Although the logsum of each group stays roughly the same, the travel cost reduction of low-income TAZs indicates an improvement. What's more, the standard deviation of travel cost between TAZs decreases by 6%. The gap in travel accessibility among TAZs becomes smaller. These results indicate that upzoning policy can make overall accessibility higher, and can benefit to promote more equitable transportation.

Table 5 The comparison of housing conditions between BAU scenario and AU scenario.

Scenario + Year	# Buildings	Residential Units	Single-Family Buildings
BAU2014	1,205,497 buildings	1,637,862 DUs	979,133 SF buildings
BAU2050	1,280,960	2,528,168	1,036,715
AU2050	1,244,430	2,596,632	1,007,913



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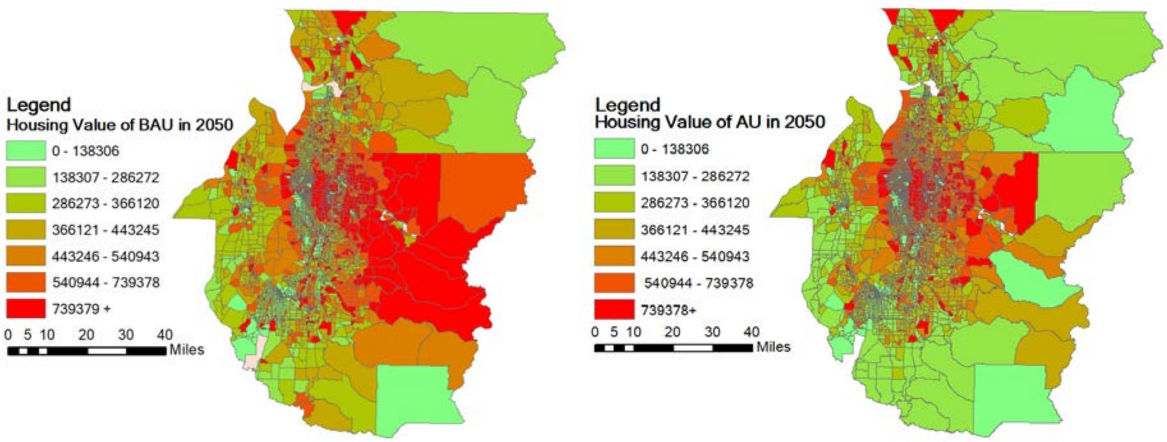
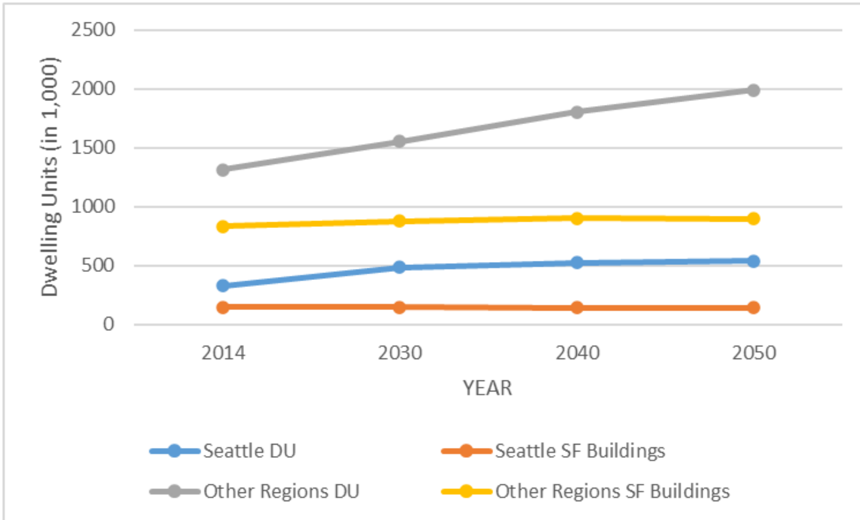


(b)

Figure 7. Seattle Region Home Count and Housing Value Predictions under the BAU and AU scenarios in Year 2050

For SU scenario, only the parcels in Seattle City are allowed to be upzoned, while the parcels in other areas follow the old zoning policy. As shown in Figure 8 (a), residential dwelling units in Seattle City grow from 326K in 2014 to 539K in 2050, and single-family buildings in Seattle City decrease from 145K in 2014 to 142K in 2050. For other regions that do not apply upzoning policy, residential dwelling units grow from 1.3M to 2.0M, and single-family buildings keep growing from 834K to 899K. The residential unit growth rate in Seattle City (65%) is higher than other regions (52%), while there is no need for Seattle City to build new single-family buildings to provide housing for new households. Upzoning policy can save land use while ensuring housing supply.

Figure 8 (b) shows the comparison of Seattle City housing value in 2050 between BAU and SU scenarios. In 2050, price per dwelling unit of Seattle City in SU is \$0.745M, which is lower than the \$0.768M in BAU. As shown below, although Seattle City remains a high construction density and less developable land, the housing value of residential land in the suburbs of SU is not as high as BAU. We note that upzoning can be considered an effective means to alleviate the housing price crisis in high-density cities.



(a)

(b)

Figure 8 (a)Forecast result of housing condition differences between Seattle City and other regions of AU scenario; (b)differences between Seattle City housing value of BAU scenario and SU scenario.

CONCLUSIONS

This study has demonstrated an approach to incorporate a land use model (UrbanSim) and travel model (SoundCast) to investigate the impact of upzoning policy on urban development in Seattle. Four scenarios are used to simulate demographic factors, land use, housing affordability, and travel accessibility from 2014 to 2050. The business-as-usual (BAU) scenario demonstrates the intensification of housing and raising home prices without changes in zoning policy, transportation regulation, and investment. The continuous population growth leads to increasing demand. Rising living expenses will bring a great financial burden to residents, and deteriorating travel cost will cause inconvenience. The BAU-no-travel-demand-model (BAU-NoTDM) scenario illustrates that the incorporation between UrbanSim and TDM (SoundCast) will decrease forecast results of land value and residential units. For all-upzoning (AU) and Seattle-upzoning (SU) scenarios, houses on single-family parcels are allowed to be upzoned up to a maximum of three residential dwelling units. AU predicts more dwelling units and fewer new buildings compared to BAU. The results also suggest higher housing affordability and better travel accessibility by 2050. SU reflects the simulation differences between Seattle City, which apply upzoning policy, and other regions that maintain the old zoning restriction. This scenario identifies a faster dwelling unit growth rate in Seattle City than in other regions. The number of single-family residential buildings in Seattle City may even decline. In addition, the upzoning policy has a more significant effect on alleviating the rise in house prices in the suburbs of Seattle City.

This study provides insights for policymakers to understand the necessity and benefits of implementing upzoning policy. Based on model outcomes, this paper contributes from the following aspects. First, the results of long-term simulation suggest that current zoning policy can not remedy the land shortage, housing problems, and declining travel accessibility. Similar results were found in other works [58, 59]. The future development trend is also predicted for Seattle on parcel-level. Second, large-scale upzoning policy is implemented and proved to be an effective method to solve these obstacles to urban development. As mentioned before, most studies on upzoning focus on short-term changes in small areas [13, 14]. Third, UrbanSim and SoundCast are applied based on a large amount of high-quality data, which backs up the authenticity of the research. In addition, we examined the impact of the interaction between UrbanSim and travel model on the results, and this is ignored by past research [48, 52].

Overall, results provide support for upzoning policy as a bright road for high-density big cities. Improvements to this work may include research on traffic policy suitable for upzoning. For instance, the increase in development density may lead to higher traffic flow in certain areas. Future studies can focus on how to balance the traffic system.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: N. Fan, K. Kockelman; data collection: P. Caballero; analysis and interpretation of results: N. Fan, P. Caballero; draft manuscript preparation: N. Fan, K. Kockelman, J. Hawkins, X. Chen. All authors reviewed the results and approved the final version of the manuscript.

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