AIR QUALITY IMPACTS OF TRANSPORTATION AND LAND USE POLICIES: A CASE STUDY IN AUSTIN, TEXAS

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ABSTRACT

The impacts of land use and transportation policies on emissions, ozone concentrations, and a metric for population exposure were examined for Austin, Texas. Three distinct transportation and land use scenarios were investigated using a gravity-based land use model and a standard travel demand model: a business-as-usual scenario, a road pricing policy that included a flat-rate carbon-based tax and congestion pricing of all Austin area freeways, and an urban growth boundary policy. Two scenarios, a business-as-usual scenario and a flat-rate carbon-based tax

and congestion pricing policy were also investigated using a novel, parcel-level land use change and land use intensity model and a standard travel demand model.

Transportation and land use policies were predicted to have substantial impacts on travel and emissions of ozone precursors. Emissions of ozone precursors decreased markedly for all 2030 scenarios due to the implementation of more stringent federal motor vehicle emission control programs, but transportation and land use policies were predicted to lead to even greater reductions of emissions of both ozone precursors relative to the business as usual scenario. The impacts of such policies on ozone concentrations and population exposure suggested varying effects. Lower exposure was typically predicted for the road pricing scenarios, but a penalty appeared to exist with relatively higher values of exposure predicted for the urban growth boundary on some episode days. The results of this analysis indicate the potential complexity of planning for urban growth and equity and the need for integrated modeling and policy evaluation efforts.

INTRODUCTION

Land use and land cover changes due to urbanization impact air quality through changes in biogenic and anthropogenic emissions, heat and energy balances and urban climate, and dry deposition of pollutants. Evaluating the impacts of urbanization on future emissions, air quality, and human exposure to pollution requires consideration of transportation, land use, and environmental policies, technological advances, and changes in demographics and human activity patterns. Previous studies have examined the effects of uncertainty in population and employment control totals on vehicle emissions (Rodier and Johnston, 2002), as well as the effects of certain land use and transport policies (Rodier et al., 2002) on such emissions. Other studies have examined the effects of land use change on future air quality by isolating the impacts due to changes in surface meteorology and/or anthropogenic and biogenic emissions under one or more growth scenarios (Wang et al, 2007; Civerolo et al., 2007; Song et al., 2008).

Song et al. (2008) explored the impacts of alternative regional development patterns on anthropogenic and biogenic emissions of ozone precursors and ozone concentrations using four visions of future land use in Austin, Texas. Although all visions were based on an assumed doubling of population in 20-40 years from 2001, they assumed different spatial patterns of development ranging from a continuation of the region’s historical trend of low density, separate use development, to corridor-oriented development, to high-density, balanced-use development and redevelopment in existing areas. Emissions and their spatial allocation were determined for each development pattern and used to predict hourly ozone concentrations under the same meteorological conditions. Differences in hourly ozone concentrations due to changes in emissions between 2007 and the future case scenarios were primarily due to more stringent federal motor vehicle emission control programs, including the EPA’s Tier 2 and heavy-duty 2007 rules. These differences in the magnitude of emissions produced greater changes in air quality than differences in regional development patterns between the four scenarios although the effects of urbanization patterns were distinguishable. Using the same four visions of future growth, McDonald-Buller et al. (2008) found that concentrated high-density development in existing towns with balanced-use zoning produced lower exposure to high ozone concentrations in the Austin area than a more typical urban sprawl pattern.

Future emission scenarios prepared for air quality planning typically account for changes in the magnitude of emissions due to recognized environmental regulations, technological changes and forecasted population growth, but do not consider regional transportation and land use policies. The five-county Austin – Round Rock Metropolitan Statistical Area (MSA), including Travis, Williamson, Bastrop, Hayes, and Caldwell Counties, is representative of many rapidly growing urban areas in the United States that are challenged with improving air quality that is on the cusp of attainment with the National Ambient Air Quality Standard for ozone while considering the spatial patterns and equity of future growth. In the work of Song et al. (2008), the air quality impacts of different urban growth scenarios based on a community-driven visioning process known as Envision Central Texas (ECT) were compared. In our continued focus on the Austin-Round Rock MSA, two integrated transportation-land use models (ITLUMs) that were developed by Zhou and Kockelman (2008) and Zhou et al. (2008) are used in conjunction with the Comprehensive Air Quality Model with Extensions (CAMx; ENVIRON, 2004) to evaluate the impacts of transportation and land use policies on emissions of nitrogen oxides (NOx) and volatile organic compounds (VOCs), and daily maximum and hourly episodic ozone concentrations. Three policies were considered: a business-as-usual scenario (BAU), congestion pricing-plus-carbon tax scenario (CPCT), and an urban growth boundary (UGB) scenario.

INTEGRATED TRANSPORTATION- LAND USE MODELING

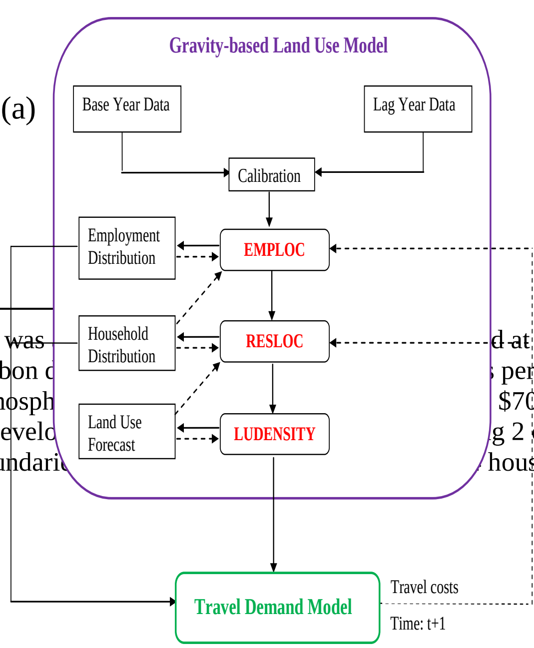
Year 2030 travel conditions and household and employment distributions for the Austin-Round Rock MSA were predicted using two ITLUMs, as described in detail by Zhou et al. (2008) and by Zhou and Kockelman (2008) and thus only briefly reviewed here. The first utilizes a gravity-based land use model (G-LUM) that is a variation of Steven Putman's Integrated Transportation-Land Use Package (ITLUP®) and a reasonably standard sequential travel demand model (TDM) largely based on Smart Mobility's specification. The second, a new land use change and land use intensity (LUC-LUI) model, examines land use change at the parcel level and applies systems of equations for land use intensity (household and employment counts by type) at the level of travel analysis zones (TAZs).

Figure 1a shows the interactions between the three G-LUM components and the TDM. In this integrated modeling framework, the Employment Allocation (EMPLOC) model runs before the Residential Allocation (RESLOC) model, followed by the Land Use Density (LUDENSITY) model and the TDM. The EMPLOC model output (employment by category by zone) serves as an input to the RESLOC. Predicted household and employment levels (by category/type) are LUDENSITY's primary inputs. The TDM is applied immediately after allocating households and jobs (and estimating land consumption levels), in order to update travel times between zones and the relative attractiveness of each zone. The model system predicts the spatial distributions of six household types (categorized by number of workers [0, 1 and 2+] and presence of children) and three employment categories (basic, retail and service jobs). Model data requirements and calibration are described by Zhou et al. (2008). The models were applied at five year intervals to obtain 2030 forecasts with the inclusion of several restrictions: (1) households and jobs in each TAZ were not allowed to fall by more than 5% in any (five-year) time interval; (2) growth in these counts was limited by land availability; and (3) in fully developed TAZs, households and jobs were not allowed to increase by more than 5% per time interval.

In addition to the G-LUM, a hybrid land use model system consisting of two model components operated on individual parcel and zonal levels was applied to the five-county Austin area. Figure 1 shows the model components and their relationship. The Land Use Change Model (LUC Model) determines how individual parcels evolve: whether an undeveloped parcel will subdivide into several smaller parcels during a specified time interval (e.g., 5 years in this study) (the Subdivision Model), how big these subdivided parcels are (the Parcel Size Model), and what land use types will emerge on each individual parcel (the Land Development Model). Land use change is generally associated with increases (or decreases) of land use intensity levels (household and employment counts), and the effect is aggregated at the level of TAZs to provide key inputs to a standard TDM. A Land Use Intensity Model (LUI Model) allocates households and employment by type, using a seemingly unrelated regression (SUR) with two spatial processes. Data availability and model specification, calibration and application are described in detail by Zhou and Kockelman (2006 and 2008). The LUC model, the LUI model, and a TDM formed a new integrated model that was applied to investigate the spatial distribution of households and jobs, along with travel conditions in 2030 across the Austin-Round Rock MSA. Iterative adjustments in the Land Development Model's alternative-specific constants according to region-wide land use forecasts and adjustments of household and job counts to match control totals, due to the inability to embed "targets" into the model system, were among the restrictions required to obtain reasonable results. The transportation and land use policy scenarios were simulated through year 2030 at five-year intervals.

Three transportation and land use policies were considered, as described in Zhou et al. (2008) and briefly reviewed here. The BAU scenario assumed that development trends observed over the five-year calibration would continue without imposition of new policies. The road pricing (CPCT) scenario combined congestion pricing with a gas (or carbon) tax. A congestion charge was set to equal the implicit cost of marginal delay (imposed per added vehicle-mile-traveled, assuming a $6.75/person-hour value of travel time) on all freeway segments in the network, and the carbon tax was assumed to be 4.55 cents per mile on all links in the network[1]. The BAU and CPCT scenarios were applied with both the G-LUM and the LUC-LUI models. The UGB scenario restricted all types of new development to a pre-defined set of largely contiguous zones, centered on existing population centers[2]. Zones outside of this "boundary" were not permitted any new residential, basic or commercial development as described by Zhou et al. (2008). This scenario was applied within the G-LUM, but could not be applied in the LUC-LUI model because the spatial econometric models used there are not readily adapted to zone

(a)



[1] It was [illegible] d at the pump is responsible for the emission of 26 pounds of carbon [illegible] per gallon of gasoline, and the cost of removing carbon from the atmosph[illegible] $70/ton.

[2] Develo[illegible] g 2 or more job-equivalents per acre, and any TAZs touching their boundari[illegible] households, since the region has 0.714 households per job.

(b)

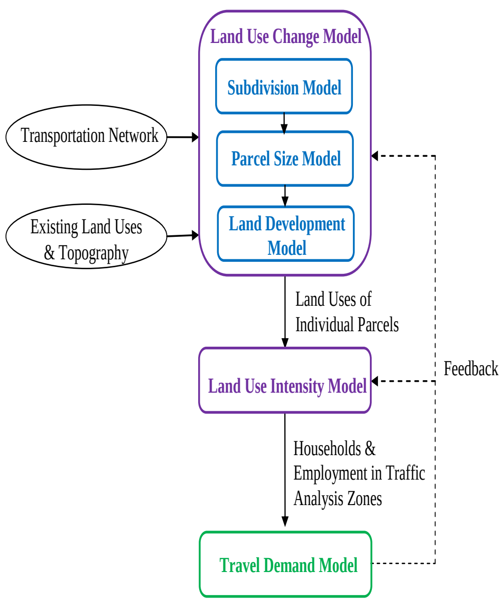


Figure 1. Model logic of the (a) Gravity Land Use Model and the (b) Land Use Change and Land Use Intensity Model.

exclusions (where certain zones are "excluded" from model prediction), such as zoning constraints or prior knowledge of development (Webb et al., 2008).

EMISSION INVENTORIES

Methodology

Biogenic emissions of hydrocarbons dominate the overall emission inventory in eastern Texas, but their spatial distribution is heterogeneous (Wiedinmyer et al., 2000 and 2001). Portions of central Texas including the Austin area represent transition zones where both biogenic and anthropogenic emissions are significant, and accurately characterizing the spatial distribution of biogenic emissions is an important element in understanding air quality and the effectiveness of emission control strategies. Urbanization patterns and the accompanying changes in vegetative cover can alter a region's biogenic emissions.

The Global Biogenic Emissions and Interactions System (GloBEIS) version 3.1 was used to develop biogenic emission inventories for a September 13th to September 20th, 1999 modeling episode (Yarwood et al., 2003; Song et al., 2008). The photochemical modeling domain was a nested regional/urban scale 36-km/12-km/4-km grid with 12 vertical layers from the surface to 3.9 km; the five-county Austin area was included within the 4-km domain. GloBEIS and similar models rely on accurate spatial mappings of land cover and on meteorological parameters including temperature, photosynthetically active radiation (PAR), wind speed, and humidity to obtain biogenic emission estimates. Biogenic emission estimates were developed for the ITLUM scenarios using the methodology described by Song et al. (2008) for the Envision Central Texas scenarios. According to this approach, ECT planners estimated the fraction of impervious cover for each ECT land use type, which was used to adjust the fraction of original vegetation expected to exist in that land use category. Assumptions about the remaining vegetation after development were based on visual studies of development impacts on tree cover using orthophotography from 1995 and 2002, and on local knowledge of development practices (Song et al., 2008). However, in contrast to the ECT land use and land cover databases which included estimates of impervious cover for each land use type, the classifications used in the G-LUM and LUC-LUI models did not directly provide information that could be used to estimate the fraction of original vegetation remaining after application of each scenario. Instead, the classifications used in the models were mapped to one of the ECT development types as shown in Tables 1 and 2. Each TAZ polygon was classified as central business district (CBD), urban, suburban or rural as follows:

$$DF_{TAZ} = P_{TAZ} + B(\frac{E_{TAZ}}{A_{TAZ}})$$

CBD: $DF_{TAZ} >= 50$
Urban: $50 > DF_{TAZ} >= 10$
Suburban: $10 > DF_{TAZ} >= 1$
Rural: $1 > DF_{TAZ} >= 0$

where *DF* is a density factor, *P* is the population in the TAZ, *E* is the employment in the TAZ, *A* is the acreage of the TAZ, and *B* is the ratio of the study area population to the study area employment (Alliance 2003). The reclassified ITLUM scenarios were then overlaid on the original land cover data for the region from Wiedinmyer et al. (2000, 2001) and used to modify the original vegetation density which was used in GloBEIS to obtain estimates of biogenic emissions.

Dry deposition, which is the dominant physical loss mechanism for air pollutants in central Texas, is a strong function of land use/land cover type and is most frequently estimated based on the model of Wesely (1989). Deposition rates are estimated as a series of mass transfer resistances to deposition. Land cover estimates for input into the dry deposition algorithms of CAMx were developed using the reclassified ITLUM scenarios and the methodology described by Song et al. (2008).

Forecasts of the growth of point source emissions have been small relative to other anthropogenic sources in the region; hence, these emissions were assumed to be constant through 2030. Anthropogenic emission estimates for on-road mobile, non-road mobile, and area sources were developed for the ITLUM scenarios using the methodology of Song et al. (2008). MOBILE6.2 was used to calculate emission factors (grams mile-1) for volatile organic compounds (VOC), carbon monoxide (CO), and nitrogen oxides (NOx) and included default federal motor vehicle control programs (FMVCP) for the year 2030. Population and household count data for each scenario were used in conjunction with the EPA's NONROAD Model version 2005 (NONROAD 2005) to obtain 2030 non-road mobile source inventories.

Table 1. Assumed fraction of vegetative cover remaining after development for each G-LUM and corresponding ECT classification.

Gravity Land Use Model (G-LUM) Classification	Envision Central Texas (ECT) Classification	Assumed Fraction of Vegetative Cover Remaining
CBD Residential	Downtown	0.023
CBD Basic Employment	Downtown	0.023
CBD Commercial Employ.	Downtown	0.023
Urban Residential	Town	0.171
Urban Basic Employment	Activity Center	0.042
Urban Commercial Employ.	Activity Center	0.042
Suburban Residential	Residential Subdivision	0.363
Suburban Basic Employment	Industrial/Office Park	0.144
Suburban Commercial Employ.	Industrial/Office Park	0.144
Rural Residential	Rural Housing	0.763
Rural Basic Employment	Industrial/Office Park	0.144
Rural Commercial Employ.	Industrial/Office Park	0.144

Area source emission inventories for each scenario were developed by projecting 2007 base year area emissions using human population growth and applying federal and state emission standards (Song et al., 2008). Typically, for Texas and other states that routinely prepare and update State Implementation Plans, spatial allocation factors and surrogates remain the same between the base year and future attainment year. Song et al. (2008) accounted for the spatial differences in emissions from the different development patterns under the ECT scenarios. A

Table 2. Assumed fraction of vegetative cover remaining after development for each LUC-LUI and corresponding ECT classification.

Land Use Change-Land Use Intensity (LUC-LUI) Model Classification	Envision Central Texas (ECT) Classification	Assumed Fraction of Vegetative Cover Remaining
CBD LLSF	Downtown	0.023
CBD SF	Downtown	0.023
CBD MF	Downtown	0.023
CBD Commercial/Office	Downtown	0.023

CBD Industrial	Downtown	0.023
CBD Civic	Downtown	0.023
Urban LLSF	Large Lot	0.493
Urban SF	Residential Subdivision	0.363
Urban MF	Town	0.171
Urban Commercial/Office	Activity Center	0.042
Urban Industrial	Activity Center	0.042
Urban Civic	Activity Center	0.042
Suburban LLSF	Large Lot	0.493
Suburban SF	Residential Subdivision	0.363
Suburban MF	Town	0.171
Suburban Commercial/Office	Industrial/Office Park	0.144
Suburban Industrial	Industrial/Office Park	0.144
Suburban Civic	Industrial/Office Park	0.144
Rural LLSF	Rural Housing	0.763
Rural SF	Rural Housing	0.763
Rural MF	Town	0.171
Rural Commercial/Office	Industrial/Office Park	0.144
Rural Industrial	Industrial/Office Park	0.144
Rural Civic	Industrial/Office Park	0.144

similar approach was applied in this work in order to spatially allocate non-road and area sources emissions under the ITLUM policy scenarios. Housing and population values used in the projections and spatial allocation of anthropogenic emissions for the ITLUM scenarios are summarized in Tables 3 and 4, respectively. As expected, the different land use models result in different housing and population projections at the county level, which will influence emission estimates.

Inventory Summaries and Comparisons

Predictions of biogenic and anthropogenic emissions for the ITLUM scenarios were compared to predictions from a 2007 Base Case largely based on emission inventories developed for Austin's Early Action Compact. A summary of vehicle miles traveled (VMT) and NOx and VOC emissions from major source sectors for the 2007 Base Case and each ITLUM scenario is presented in Table 5. Similar results are presented for the 2007 Base Case and ECT scenarios (based on work by Song et al. (2008) and Webb et al. (2008)) in Table 6, for comparison purposes.

Table 3. Year 2001 housing units and year 2030 projected households for each ITLUM scenario by county (in thousands).

Austin Area County	2001 Housing Units (U.S. Census)	Average Household Size (U.S. Census)	G-LUM BAU HHs	G-LUM CPCT HHs	G-LUM UGB HHs	LUC-LUI BAU HHs	LUC-LUI CPCT HHs
Bastrop	22.7	2.87	64.4	65.5	49.4	65.2	62.6
Caldwell	12.2	2.98	30.4	31.4	26.0	55.7	55.0
Hays	37.9	2.92	87.0	87.0	73.3	94.3	93.7
Travis	353.3	2.53	512.2	510.6	582.5	495.3	496.7
Williamson	98.1	2.88	237	236	200	220	223
Total	524	-	931	931	931	931	931

Note: G-LUM = gravity-based land use model; LUC-LUI = parcel-level land use change and land use intensity model; BAU = business-as-usual scenario; CPCT = congestion pricing-plus-carbon tax scenario; UGB = urban growth boundary scenario.

Table 4. 2001 human population and year 2030 projected human population for each ITLUM scenario by county (in thousands).

Population	2001 (U.S. Census)	G-LUM BAU	G-LUM CPCT	G-LUM UGB	LUC-LUI BAU	LUC-LUI CPCT
Bastrop	61.5	185	188	142	187	179.6
Caldwell	33.8	90.6	93,6	77.4	166.1	163.9
Hays	104	254.1	254	214	275.2	273.7
Travis	842.3	1,295.9	1,291.8	1,473.6	1,253.1	1,256.7
Williamson	277	681	679.7	575	634.2	641.2
Total	1,319	2,507	2,507	2,482	2,516	2,515

Note: G-LUM = gravity-based land use model; LUC-LUI = parcel-level land use change and land use intensity model; BAU = business-as-usual scenario; CPCT = congestion pricing-plus-carbon tax scenario; UGB = urban growth boundary scenario.

Biogenic sources and, because they have been projected using human population, area sources are predicted to remain the most significant sources of VOC emissions in the five-county area. Zhou and Kockelman (2008) and Zhou et al. (2008) found that the CPCT and BAU scenarios result in similar land use patterns, with CPCT predicted to influence travel behavior but not location choice. The biogenic emissions predictions for the BAU and CPCT scenarios for each model are consistent with this finding. However, biogenic emission estimates for the G-LUM BAU and G-LUM CPCT scenarios are considerably lower than for the LUC-LUI scenarios. The G-LUM scenarios forecast large changes in undeveloped land, particularly in rural zones, resulting in large reductions in vegetative cover as compared to the Base Case. The increased development rates, due to model limitations and no constraints on maximum developable land, result in unrealistic predictions of vegetative cover loss and over-predictions of urbanization in those zones. In contrast, the G-LUM UGB scenario predicts concentrated growth in households and employment within the predefined boundary, resulting in very modest consumption of vegetative cover and changes in biogenic emissions primarily within Travis County and southern Williamson County. With the exceptions of the G-LUM BAU and CPCT scenarios, the range of differences in the magnitude of biogenic hydrocarbons between the ITLUM scenarios and the 2007 Base Case was comparable to the 2-6% reductions in daily biogenic emissions between the ECT four scenarios and the 2007 Base Case across the 5-county Austin MSA.

Table 5. Emissions of VOC and NOx (tpd) for the 2007 Base Case and each year 2030 ITLUM scenario (gray).

Categories	2007 Base Case VMT = 45*		G-LUM BAU VMT = 85*		G-LUM CPCT VMT = 71*		G-LUM UGB VMT = 70*		LUC-LUI BAU VMT = 84*		LUC-LUI CPCT VMT = 71*	
	VOC	NOx	VOC	NOx	VOC	NOx	VOC	NOx	VOC	NOx	VOC	NOx
On-road mobile	34	62	23	24	19	20	19	20	22	24	19	20
Non-road mobile	22	22	23	9	23	9	23	9	23	9	23	9
Area	111	10	224	22	226	22	215	20	254	23	254	23
Point	3	3	3	3	3	3	3	3	3	3	3	3
Biogenic	211	20	150	20	151	20	206	20	201	20	202	20

Note: ITLUM scenario emissions are calculated for a future year of 2030.
G-LUM = gravity-based land use model; LUC-LUI = parcel-level land use change and land use intensity model; BAU= business-as-usual scenario; CPCT = congestion pricing-plus-carbon tax scenario; UGB = urban growth boundary scenario.
*VMT is given in units of 10^6 miles per day in the 5-county Austin area.

Area source VOC emissions in Austin were primarily due to solvent utilization, service stations, and industrial processes, while NOx emissions were associated with agricultural production and stationary source fuel combustion. The relative contribution of emissions from these source categories did not change in future years. However, the magnitude of emissions increased relative to the 2007 Base Case because area sources emissions were grown with population.

Emissions from most on-road and non-road mobile source categories decreased for the ITLUM scenarios relative to the Base Case due to more stringent federal emission controls. Non-road mobile source NOx emissions for all ITLUM scenarios were approximately 9.4 tpd and were nearly identical to the ECT scenarios suggesting that implementation of EPA’s Tier 4 engine standards has a more significant influence than regional development patterns and the imposition of policies. VOC emissions remain nearly the same or increase slightly between the

2007 Base Case and the 2030 ITLUM and ECT scenarios largely attributed by Song et al. (2008) to the growth in lawn and garden equipment, which tracked population growth.

Table 6. Emissions of VOC and NOx (tpd) for the 2007 Base Case and each ECT scenario (gray) from Song et al. (2008) and Webb et al. (2008).

Categories	2007 Base Case VMT = 45*		ECT A VMT = 82*		ECT B VMT = 72*		ECT C VMT = 70*		ECT D VMT = 66*	
	VOC	NOx	VOC	NOx	VOC	NOx	VOC	NOx	VOC	NOx
On-road mobile	34	62	22	18	19	16	19	16	17	14
Non-road mobile	22	22	23	10	24	10	24	10	23	10
Area	111	10	214	21	238	22	262	24	236	22
Point	3	3	3	3	3	3	3	3	3	3
Biogenic	211	20	199	20	205	20	205	20	208	20

Note: ECT scenario emissions are calculated for a future year of 2030. ECT Scenario A assumes low-density, segregated-use development based on extensive highway provision; ECT Scenario B assumes concentrated, contiguous regional growth within 1-mile of transportation corridors; ECT Scenario C concentrates growth in existing and new communities with distinct boundaries; and ECT Scenario D assumes high-density development in existing towns and cities with balanced-use zoning.

*VMT is given in units of 10^6 miles per day in the 5-county Austin area.

The G-LUM BAU, LUC-LUI BAU, and ECT A (a continuation of the current trend of low density, segregated use development) scenarios predicted nearly a doubling of VMT (i.e., 85% to 90% increase) by 2030, relative to the 2007 Base Case. VMT differences for the CPCT, UGB, and ECT B, C, and D scenarios relative to the 2007 Base Case indicated that transportation and land use policies as well as smart growth styled development can have substantial impacts on travel, increasing VMT by only 48% to 60%. VOC and NOx emissions decreased markedly for all 2030 scenarios due to the implementation of more stringent federal motor vehicle emission control programs, including the EPA’s Tier 2 and heavy-duty 2007 rules (Song et al., 2008). Smart growth strategies and transportation and land use policies were predicted to lead to greater reductions of emissions of both ozone precursors. For the G-LUM, CPCT and UGB policies were predicted to lead to approximately a 16% decrease in emissions of VOC and NOx relative to the BAU scenario. Similarly, the LUC-LUI model predicted approximately a 15% decrease of both NOx and VOC emissions for the CPCT scenario relative to the BAU scenario. Song et al. (2008) found reductions in NOx and VOC emissions for the ECT B (corridor-oriented development), ECT C (clustered development in new and existing areas), and ECT D (high-density mixed use development and redevelopment) scenarios ranging from 13% to 22%, relative to ECT A, which represented a continuation of current development trends.

AIR QUALITY MODELING AND EXPOSURE PREDICTIONS

The ITLUM scenarios were compared to each other as well as to the predictions from the 2007 Base Case based on their impacts on daily maximum 1-hour ozone concentrations, hourly episodic ozone concentrations, and population exposure. CAMx simulations for the ITLUM scenarios were identical to those of the 2007 Base Case except for changes in biogenic and anthropogenic emissions and dry deposition velocities.

Predicted 1-hour averaged daily maximum ozone concentrations for the 2007 Base Case ranged from 72 ppb to 90 ppb across the episode. Differences in daily maximum 1-hour ozone concentrations due to the combined changes in dry deposition, biogenic emissions, and anthropogenic emissions from on-road mobile, non-road mobile and area sources for the ITLUM scenarios ranged from -10 to -2 ppb with typical values of -5 ppb as shown in Table 7. On most episode days, reductions in the daily maximum 1-hour averaged ozone concentrations due to the CPCT and UGB scenarios were comparable to or slightly greater than the reductions between the BAU scenarios and the 2007 Base Case.

Table 7. Daily maximum 1-hour ozone concentrations for the Base Case and differences in the daily maximum ozone concentrations relative to the Base Case.

Episode Day	Base Case Daily Max. O_3 Conc. (ppb)	G-LUM BAU	G-LUM CPCT	G-LUM UGB	LUC-LUI BAU	LUC-LUI CPCT
9/15	80.5	-4.1	-4.9	-4.4	-4.9	-5.6
9/16	72.0	-1.5	-1.6	-2.2	-2.1	-2.2
9/17	85.8	-6.5	-6.5	-6.4	-6.9	-6.9
9/18	86.2	-3.9	-3.9	-4.1	-4.1	-4.1
9/19	90.4	-6.0	-7.3	-5.5	-6.1	-7.5
9/20	90.5	-8.3	-9.7	-8.0	-8.6	-10.1

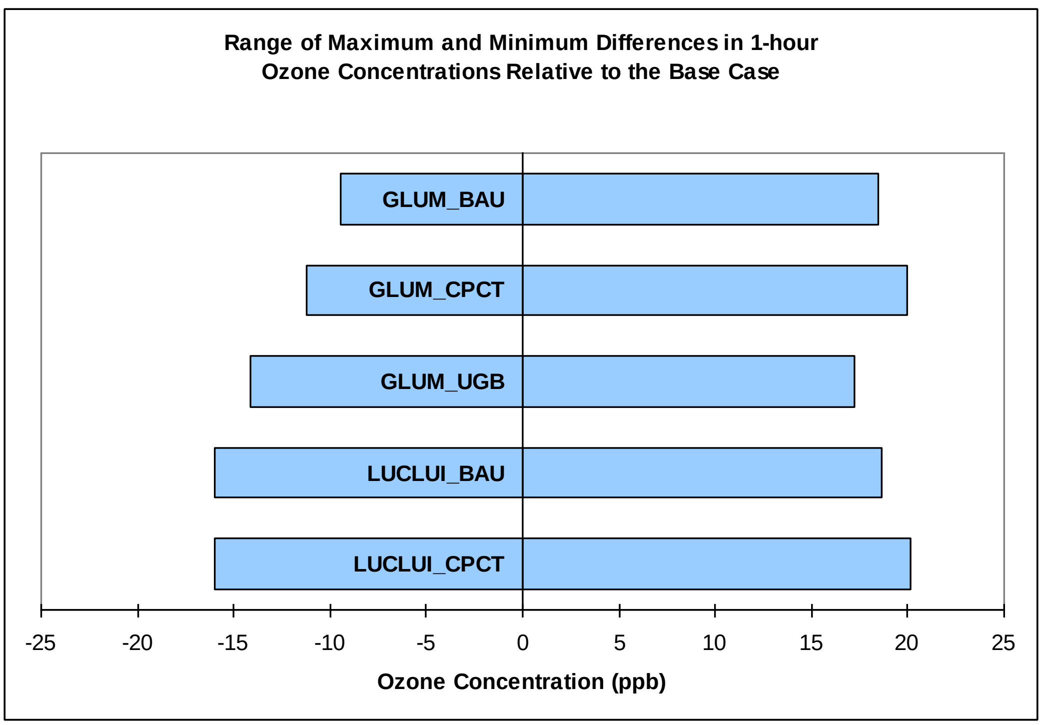
Note: G-LUM = gravity-based land use model; LUC-LUI = parcel-level land use change and land use intensity model; BAU= business-as-usual scenario; CPCT = congestion pricing-plus-carbon tax scenario; UGB = urban growth boundary scenario.

Maximum and minimum differences in 1-hour ozone concentrations that occurred across the region regardless of time of day or magnitude were also evaluated. Figure 2 shows the range of changes in 1-hour ozone concentrations between the ITLUM scenarios and the 2007 Base Case due to changes in biogenic and anthropogenic emissions and dry deposition for each scenario. Similar to the findings of Song et al. (2008), increases occurred primarily during the morning hours not during afternoon periods with peak ozone concentrations and are associated with reductions in on-road mobile source emissions along transportation corridors in the Austin urban core that result in less titration of ozone by NOx emissions. Maximum decreases of as much as 16 ppb were predicted in the LUC-LUI scenarios. The G-LUM UGB scenario resulted in decreases of as much as 14 ppb as compared to 9.5 ppb in the G-LUM BAU scenario. Differences in hourly ozone concentrations between the future development scenarios and a 2007 base case were more pronounced than differences due to regional transportation and land use policies. However, evaluated with the findings of Song et al. (2008), the magnitude of the impacts of transportation and land use policies and smart-growth oriented strategies on ozone concentrations are generally within the range of several parts per billion and have the potential to be significant in particular in regions on the cusp of attainment with the NAAQS.

In addition to metrics based on ozone concentration, McDonald-Buller et al. (2008) examined total daily population-weighted exposure above a threshold ozone concentration (ppb) for the ECT scenarios:

$$M_{pop} = \sum_h \sum_g \frac{p_g}{p_t} s_{g,h}$$

where p_t is the total population in the five-county Austin area for the scenario, p_g is the population in each grid cell g and $s_{g,h}$ is the ozone concentration (ppb) over the threshold c_{thresh} for each grid cell g at hour h, $s_{g,h} = \left\{ \begin{array}{c} 0, c_{g,h} \le c_{thresh} \\ c_{g,h} - c_{thresh}, c_{g,h} > c_{thresh} \end{array} \right\}$. Using the same approach for each ITLUM scenario, this metric was evaluated for various threshold values and estimated for each grid cell, summed over the Austin area modeling domain, and over all hours of the day. Although population exposure based metrics do not affect a region's attainment status, they do facilitate a more comprehensive assessment of the impacts of urban growth strategies.



Note: G-LUM = gravity-based land use model; LUC-LUI = parcel-level land use change and land use intensity model; BAU= business-as-usual scenario; CPCT = congestion pricing-plus-carbon tax scenario; UGB = urban growth boundary scenario.

Figure 2. Range of changes in hourly ozone concentrations (ppb) between the ITLUM scenarios and the Base Case across the 5-county Austin area.

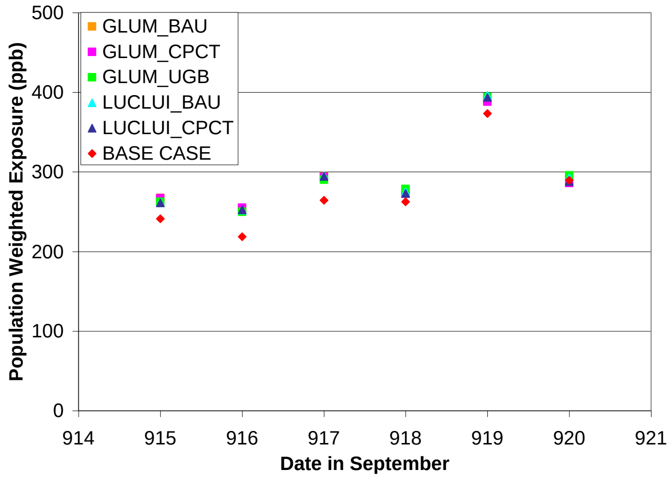
As shown in Figure 3a, for a threshold value of 40 ppb, all ITLUM scenarios exhibited greater exposure than the Base Case due to additional increases in ozone and population in newly developed areas. This finding was consistent with results for the ECT scenarios at a 40 ppb threshold concentration indicating an overall increase in exposure with population growth. The impacts of land use and transportation policies, smart-growth strategies and regulatory emissions controls become more pronounced at larger threshold ozone levels. Figure 3 shows the variation in exposure over the episode for higher threshold values of 60 ppb (3b) and 80 ppb (3c). As the threshold value increases, predicted exposure generally decreased for the ITLUM scenarios relative to the Base Case consistent with lower peak ozone concentrations. Predicted exposure was generally lower for the road pricing scenarios, but higher for the urban growth boundary scenario where population was more concentrated. Interestingly, the influence of the G-LUM UGB policy on exposure relative to the BAU scenario were in contrast to the impacts on ozone concentrations and emissions of its precursors; the UGB appeared to offer benefits for reducing emissions and ozone concentrations as well as VMT, but may have a penalty with respect to the proximity and density of the population in areas with higher ozone concentrations. McDonald-Buller et al. (2008) found that consistent with the trends in daily maximum ozone concentrations, population exposure to ozone concentrations above a 60 ppb threshold was lower for the future ECT development scenarios. Concentrated high-density development in existing towns with balanced-use zoning (ECT D) produced lower exposure to high ozone concentrations than a more typical pattern of urban sprawl (ECT A).

CONCLUSIONS

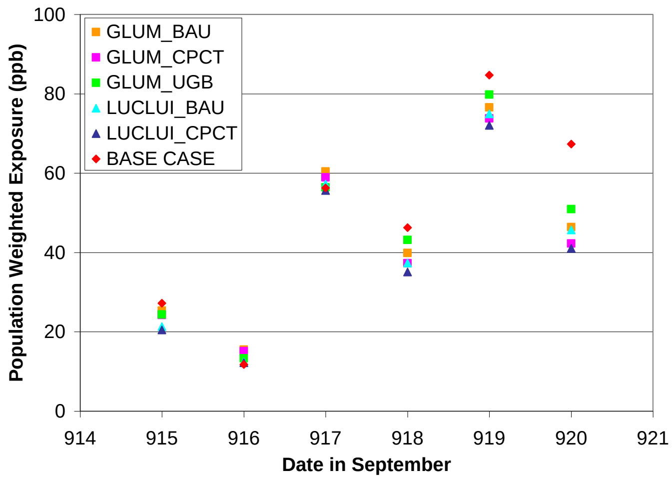
The impacts of land use and transportation policies on emissions, ozone concentrations, and a metric for population exposure were examined using Austin, Texas as a case study. Austin is typical of many urban areas of the United States that are on the cusp of non-attainment with the NAAQS for ozone. Three transportation and land use scenarios were investigated using a gravity-based land use model and a standard travel demand model: a business-as-usual scenario, a road pricing policy that included a flat-rate carbon-based tax and congestion pricing of all Austin area freeways, and an urban growth boundary policy. Two scenarios, a business-as-usual scenario and a flat-rate carbon-based tax and congestion pricing policy were also investigated using a novel, parcel-level land use change and land use intensity model and a standard travel demand model. The prices, tolls and boundary locations considered in this work represented reasonable scenarios if such policies were to be pursued by community stakeholders.

Transportation and land use policies were predicted to have substantial impacts on travel and emissions of ozone precursors. The business-as-usual scenario predicted an 85%-90% increase in VMT in 2030 relative to a 2007 Base Case. In contrast, the increase in VMT under the road pricing and urban growth boundary policies was only 60%. Emissions of ozone precursors decreased markedly for all 2030 scenarios due to the implementation of more stringent federal motor vehicle emission control programs, but transportation and land use policies were predicted to lead to even greater reductions, by about 15%, of emissions relative to the business-as-usual scenario.

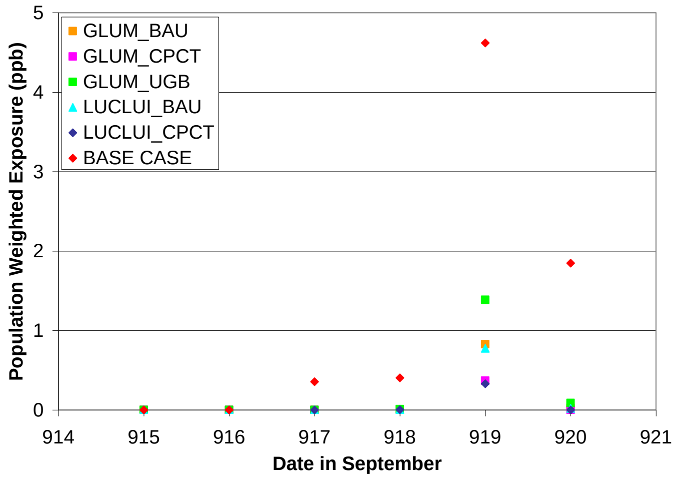
(a)


GLUM_BAU
GLUM_CPCT
GLUM_UGB
LUCLUI_BAU
LUCLUI_CPCT
BASE CASE
Population Weighted Exposure (ppb)
0
100
200
300
400
500
914
915
916
917
918
919
920
921
Date in September

(b)


GLUM_BAU
GLUM_CPCT
GLUM_UGB
LUCLUI_BAU
LUCLUI_CPCT
BASE CASE
Population Weighted Exposure (ppb)
0
20
40
60
80
100
914
915
916
917
918
919
920
921
Date in September

(c)



Note: G-LUM = gravity-based land use model; LUC-LUI = parcel-level land use change and land use intensity model; BAU= business-as-usual scenario; CPCT = congestion pricing-plus-carbon tax scenario; UGB = urban growth boundary scenario.

Figure 3. Total daily population-weighted exposure using a (a) 40 ppb, (b) 60 ppb, and (c) 80 ppb threshold for the ITLUM scenarios and the 2007 Base Case.

The impacts of such policies on ozone concentrations and population exposure suggested varying effects. Daily maximum 1-hour ozone concentrations were predicted to decrease under the future scenarios with changes ranging from -10 ppb to -2 ppb, with typical values of -5 ppb. The benefits of transportation and land use policies and smart-growth oriented strategies for reducing ozone concentrations were generally within the range of several parts per billion, which suggests that these policies have the potential to be significant in particular in regions on the cusp of attainment with the NAAQS. Lower exposure was typically predicted for the road pricing scenarios, but a penalty appeared to exist with relatively higher values of exposure predicted for the urban growth boundary on some episode days. Future work should examine the relative impacts on 8-hour ozone concentrations, explore the impacts of urban growth and transportation and land use policy scenarios on greenhouse gas emissions, examine new scenarios (such as density floors on new development), allow for new vehicle and power-generation technologies (such as plug-in electric vehicles and a greater share of renewable electricity feedstocks) and accommodate other land use model specifications.

The results of this analysis indicate the potential complexity of planning for urban growth and equity and the need for integrated modeling and policy evaluation efforts. This project was conducted by a team with expertise spanning urban and regional planning, transportation and land use modeling, emission inventory development, air quality modeling and data analysis. Although all of the primary team members had long histories of working with the State of Texas and Austin area stakeholders, this project was the first that synthesized our efforts. While expertise in these areas is not unique within the realm of many metropolitan planning organizations, departments of transportation, city governments, and state environmental agencies, there is a need for better collaboration between fields during community and regulatory decisionmaking processes to allow more comprehensive assessments of urbanization and its environmental impacts.

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