GRAVITY-BASED LAND USE MODEL (G-LUM)

A Presentation for Texas MPOs

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Agenda

- Motivation
- Overview
- Model Specification & Logic
- Model Calibration & Application
- Installation Procedure
- Data Preparation
- Running G-LUM
- Viewing Results
- Case Study
- Conclusion

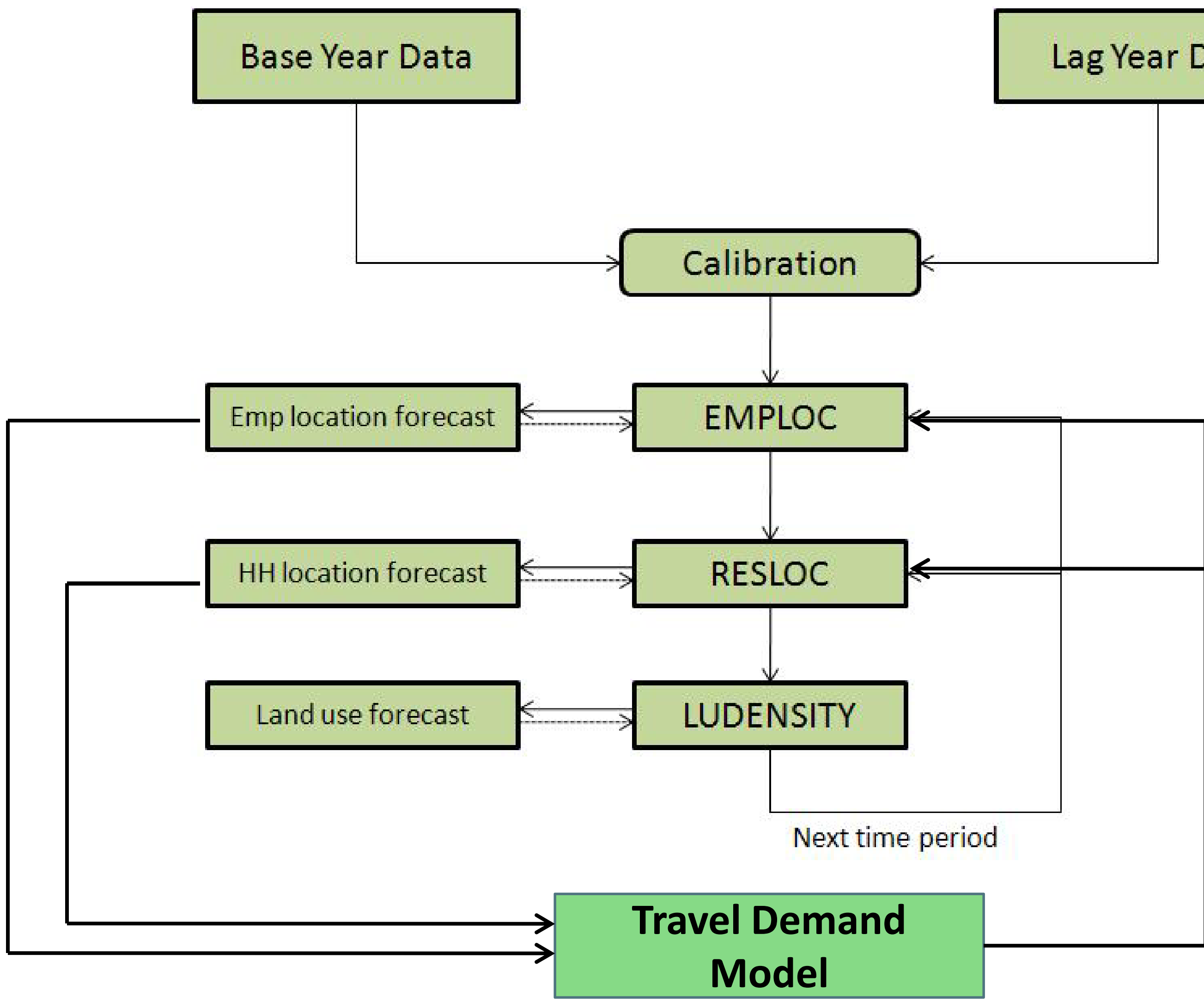
Motivation

- Travel and land use forecasting is critical to project development and National Environmental Policy Act (NEPA) processes.
- Long-term traffic forecasts require long-term land use forecasts.
- Forecasts provide information to planning organizations and decision-makers to determine plan-of-action.
- Land use forecasts provide important inputs for evaluating alternatives.

Overview

- Dominant model relies on a system of **gravity-based equations** (Steve Putman's ITLUP®).
- TELUM is FHWA's publicly available Transportation, Economic & Land Use Model, based on Putman's equations.
- UT Austin's Gravity-based Land Use Model (G-LUM) is also based on Putman's equations, & has been **coded in MATLAB**. It is freely available at http://www.ce.utexas.edu/prof/kockelman/G-LUM_Website/homepage.htm & is fully documented (open-source).
- Stand-alone G-LUM application **can run without MATLAB** license (supporting software is provided free via mail).
- G-LUM consists of three sub-models: **EMPLOC, RESLOC, & LUDENSITY.**
- G-LUM uses **entropy maximization and non-linear least square** principles (similar to maximum likelihood) to calibrate sub-models.

Model Flowchart



Model Specification

EMPLOC

Employment's spatial distribution is based on:

- **Accessibility to (all) households & jobs** of that type, across zones, in prior time periods,
- Zone-to-zone **travel costs**, &
- **Zone size**

$$E_{j,t}^{k} = \lambda^{k} \sum_{i} N_{T,i,t-1} A_{i,t-1}^{k} M_{j,t-1}^{k} c_{i,j,t}^{\omega^{k}} \exp(\rho^{k} c_{i,j,t}) + (1-\lambda^{k}) E_{j,t-1}^{k}$$

$$A_{i,t-1}^{k} = \left[\sum_{l} (E_{l,t-1}^{k})^{a^{k}} (L_{l})^{b^{k}} c_{i,l,t}^{\omega^{k}} \exp(\beta^{k} c_{i,l,t}) \right]^{-1}$$

$$M_{j,t-1}^{k} = (E_{j,t-1}^{k})^{a^{k}} (L_{j})^{b^{k}}$$

where E = #jobs (employment), N =#households, c = travel cost, L = land area, i & j = zones, k = job type, n = household type, t = year/time period

Specification (2)

RESLOC

Household spatial distribution is based on:

- **Access to households** in all categories & **Jobs** of all types in prior period,
- Zone-to-zone **travel costs**, &
- **Land use conditions** in prior period.

$$N_i^n = \eta^n \sum_j Q_j^n B_j^n W_i^n c_{i,j}^{\alpha^n} \exp(\beta^n c_{i,j}) + (1-\eta^n) N_{i,t-1}^n$$

$$Q_j^n = \sum_k a_{k,n} E_j^k \qquad B_j^n = \left[\sum_i W_i^n c_{i,j}^{\alpha^n} \exp(\beta^n c_{i,j}) \right]^{-1}$$

$$W_i^n = (L_i^v)^{q^n} (x_i)^{r^n} (L_i^r)^{s^n} \prod_{n'} \left[\left(1 + \frac{N_i^{n'}}{\sum_n N_i^n} \right)^{b_{n'}^n} \right]$$

Specification (3)

LUDENSITY

Land per household or job is based on:

- **Land use conditions** in current time period.
- **Share** of **households** & **jobs** by type in current period.

$$\frac{L_{r,i,t}}{N_{T,i,t}} = k_0 L_{D,i,t}^{k_1} \left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{k_2} \left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{k_3} \left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{k_4} \left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{k_5} \left(\frac{N_{2,i,t}}{N_{T,i,t}}\right)^{k_6} \left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{k_7} \left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{k_8} \left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{k_9} \left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{k_{10}}$$

$$\frac{L_{b,i,t}}{E_{b,i,t}} = g_0 \left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{g_1} \left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{g_3} \left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{g_4} \left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{g_5} \left(\frac{N_{2,i,t}}{N_{T,i,t}}\right)^{g_6} \left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{g_7} \left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{g_8} \left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{g_9} \left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{g_{10}}$$

$$\frac{L_{c,i,t}}{E_{c,i,t}} = p_0 \left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{p_1} \left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{p_3} \left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{p_4} \left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{p_5} \left(\frac{N_{2,i,t}}{N_{T,i,t}}\right)^{p_6} \left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{p_7} \left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{p_8} \left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{p_9} \left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{p_{10}}$$

Model Calibration

EMPLOC

$$E_{j,t}^{k} = \lambda^{k} \sum_{i} N_{T,i,t-1} A_{i,t-1}^{k} M_{j,t-1}^{k} c_{i,j,t}^{\omega^{k}} \exp(\rho^{k} c_{i,j,t}) + (1-\lambda^{k}) E_{j,t-1}^{k}$$

$$A_{i,t-1}^{k} = \left[\sum_{l} (E_{l,t-1}^{k})^{a^{k}} (L_{l})^{b^{k}} c_{i,l,t}^{\omega^{k}} \exp(\rho^{k} c_{i,l,t}) \right]^{-1}$$

$$M_{j,t-1}^{k} = (E_{j,t-1}^{k})^{a^{k}} (L_{j})^{b^{k}}$$

RESLOC

$$N_{i}^{n} = \eta^{n} \sum_{j} Q_{j}^{n} B_{j}^{n} W_{i}^{n} c_{i,j}^{\alpha^{n}} \exp(\beta^{n} c_{i,j}) + (1-\eta^{n}) N_{i,t-1}^{n}$$

$$Q_{j}^{n} = \sum_{k} a_{k,n} E_{j}^{k}$$

$$B_{j}^{n} = \left[\sum_{i} W_{i}^{n} c_{i,j}^{\alpha^{n}} \exp(\beta^{n} c_{i,j}) \right]^{-1}$$

$$W_{i}^{n} = (L_{i}^{v})^{q^{n}} (x_{i})^{r^{n}} (L_{i}^{r})^{s^{n}} \prod_{n'} \left[\left(1 + \frac{N_{i}^{n'}}{\sum_{n} N_{i}^{n}} \right)^{b_{n'}^{n}} \right]$$

Calibration (2)

LUDENSITY

$$\frac{L_{r,i,t}}{N_{T,i,t}} = k_0 L_{D,i,t}^{k_1} \left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{k_2} \left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{k_3} \left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{k_4} \left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{k_5} \left(\frac{N_{2,i,t}}{N_{T,i,t}}\right)^{k_6} \left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{k_7} \left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{k_8} \left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{k_9} \left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{k_{10}}$$

$$\frac{L_{b,i,t}}{E_{b,i,t}} = g_0 \left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{g_1} \left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{g_3} \left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{g_4} \left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{g_5} \left(\frac{N_{2,i,t}}{N_{T,i,t}}\right)^{g_6} \left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{g_7} \left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{g_8} \left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{g_9} \left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{g_{10}}$$

$$\frac{L_{c,i,t}}{E_{c,i,t}} = p_0 \left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{p_1} \left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{p_3} \left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{p_4} \left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{p_5} \left(\frac{N_{2,i,t}}{N_{T,i,t}}\right)^{p_6} \left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{p_7} \left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{p_8} \left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{p_9} \left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{p_{10}}$$

Calibration (3)

- Calibration process finds parameters that best predict the base year data using lag (past) year data.
- **Entropy maximization** principle is used to estimate all parameters in each equation:

$$\max \sum_{i=1}^{n} N_i \ln(\hat{N}_i) \text{ such that } \sum_{i=1}^{n} N_i = \sum_{i=1}^{n} \hat{N}_i$$

- The constraint ensures that sum of actual values equals sum of predicted values across all zones (thanks to adjustment of initial predictions, via scaling).
- **MATLAB's in-built optimization techniques** are used here, to produce all sets of parameter estimates.

Simulation

- Simulation starts by using calibrated parameters to **predict base-year** population, jobs, & land use (based on lag year data).
- Predicted totals are then **scaled to match actual totals in base year**.
- **Residuals** are the difference between actual & predicted values in each zone.
- They help **capture other key factors** influencing spatial distribution jobs & population.
- Residuals are **retained & used to adjust forward predictions**.

Model Application

EMPLOC

$$E^k_{j,t} = \lambda^k \sum_i N_{T,i,t-1} A^k_{i,t-1} M^k_{j,t-1} c^{\omega^k}_{i,j,t} \exp(\rho^k c_{i,j,t}) + (1-\lambda^k) E^k_{j,t-1}$$

$$A^k_{i,t-1} = \left[\sum_l (E^k_{l,t-1})^{a^k} (L_l)^{b^k} c^{\omega^k}_{i,l,t} \exp(\rho^k c_{i,l,t}) \right]^{-1}$$

$$M^k_{j,t-1} = (E^k_{j,t-1})^{a^k} (L_j)^{b^k}$$

RESLOC

$$N^n_i = \eta^n \sum_j Q^n_j B^n_j W^n_i c^{\alpha^n}_{i,j} \exp(\beta^n c_{i,j,t}) + (1-\eta^n) N^n_{i,t-1}$$

$$Q^n_j = \sum_k a_{k,n} E^k_j$$

$$B^n_j = \left[\sum_i W^n_i c^{\alpha^n}_{i,j} \exp(\beta^n c_{i,j,t}) \right]^{-1}$$

$$W^n_i = (L^v_i)^{q^n} (x_i)^{r^n} (L^r_i)^{s^n} \prod_{n'} \left[\left(1 + \frac{N^{n'}_{i,t-1}}{\sum_n N^n_{i,t-1}} \right)^{b^n_{n'}} \right]$$

Application (2)

LUDENSITY

$$\frac{L_{r,i,t}}{N_{T,i,t}} = k_0 L_{D,i,t}^{k_1} \left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{k_2} \left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{k_3} \left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{k_4} *$$

$$\left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{k_5} \left(\frac{N_{2,i,t}}{N_{T,i,t}}\right)^{k_6} \left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{k_7} \left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{k_8} \left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{k_9} \left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{k_{10}}$$

RESLOC

EMPLOC

$$\frac{L_{b,i,t}}{E_{b,i,t}} = g_0 \left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{g_1} \left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{g_3} \left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{g_4} *$$

$$\left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{g_5} \left(\frac{N_{2,i,t}}{N_{T,i,t}}\right)^{g_6} \left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{g_7} \left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{g_8} \left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{g_9} \left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{g_{10}}$$

$$\frac{L_{c,i,t}}{E_{c,i,t}} = p_0 \left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{p_1} \left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{p_3} \left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{p_4} *$$

$$\left(\frac{N_{1,i,t}}{N_{T,i,t}}\right)^{p_5} \left(\frac{N_{2,i,t}}{N_{T,i,t}}\right)^{p_6} \left(\frac{N_{3,i,t}}{N_{T,i,t}}\right)^{p_7} \left(\frac{N_{4,i,t}}{N_{T,i,t}}\right)^{p_8} \left(\frac{N_{5,i,t}}{N_{T,i,t}}\right)^{p_9} \left(\frac{N_{6,i,t}}{N_{T,i,t}}\right)^{p_{10}}$$

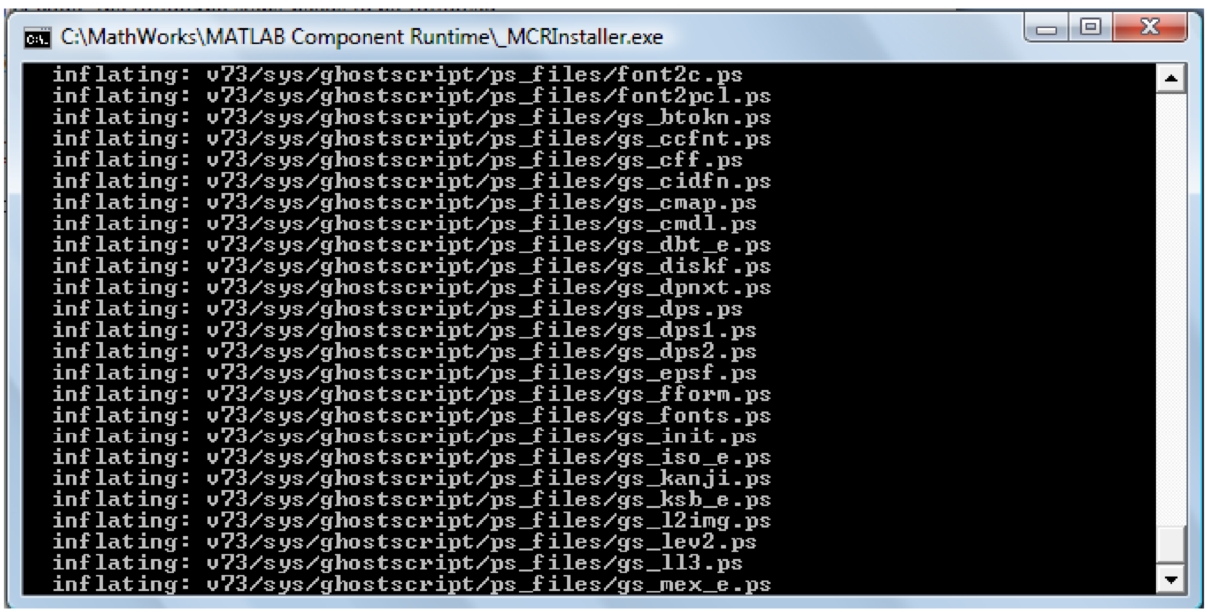
Prediction Process

- Involves **prediction** of households, jobs, & land use in each zone using **calibrated parameters**.
- Each time-period's jobs and households estimates are **scaled to match the actual totals** (provided by the user).
- Land use predictions are **scaled to match the total developable land** in each time period.
- Next, the **residuals are added** into the estimates, to reflect the base-year targets.
- **One-quarter (25%) reduction in base-year residuals** is used, after each time increment (till zero adjustment made to estimates, in the 5^{th} time step).

Model Installation

Required only for the stand-alone application

- Step 1: Install the MCRInstaller.exe from the downloaded folder.
- Step 2: In Windows Vista Navigate to the folder C:\Programfiles\ & copy the Math Works folder into C:\ folder.
- Step 3: Run the file _MCRInstaller.exe.



Installation (2)

Step 3:

a) Click on the Start button in the task bar.

b) Right click on 'My Computer' & select 'Properties'.

c) In *Windows XP, click on the advanced settings tab.*

In *Windows Vista, click on 'Advanced System Settings' present on the left side of the window.*

d) Click on the 'Environmental Variables' button.

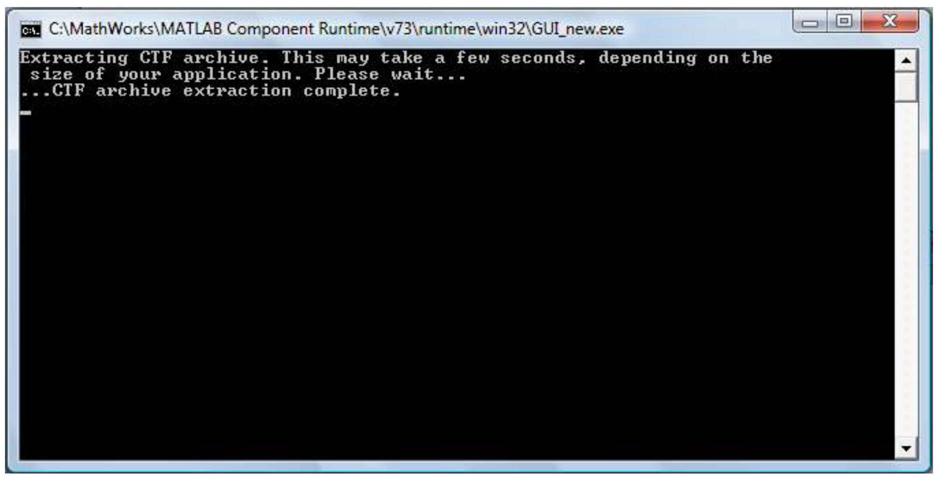
e) In system variables window, go to the 'path' present in the list of system variables.

f) Edit the path by appending the ";C:\Program files\MathWorks\MATLAB Component Runtime\v73\bin\win32".

Installation (3)

Step 4: Copy the GUI_brenda.exe & GUI_brenda.ctf present in the 'GUI code for G-LUM' folder of the website to the folder C:\MathWorks\MATLAB Component Runtime\v74\runtime\win32.

Step 5:Double Click on the file GUI_brenda.exe.



Step 6: Unzip the G-LUM Finale folder present in the 'GUI code for G-LUM' folder into the C- drive.

Data Preparation

14 input files are required for calibration & prediction.

- **Employment:** Jobs by sector type (basic, retail, service) for each zone (e.g., TAZ).
  1. EMP_lag.txt
  2. EMP_base.txt
- **Households:** Number of households by type (1-6) in each zone.
  3. HH_lag.txt
  4. HH_base.txt
- **Link Impedance:** Travel times (or travel costs) between each pair of zones in the base year.
  5. TT.txt

Note: Data columns for jobs (by sector) & households (by type) should be separated by tabs or spaces. Moreover, the data for each zone should be on a new line & listed in the same order across data input files.

Data (2)

- **Land use:** Amount of land dedicated for various uses in each zone.

  6. ZoneSize.txt: **Area of each zone** in the base year.
  7. Landb.txt: Amount of land dedicated to **basic jobs** in base year.
  8. Landc.txt: Amount of land dedicated to **commercial** jobs in base year.
  9. Landd.txt: Amount of undeveloped but **developable** land in each zone in base year.
  10. Landu.txt: Amount of **unusable land** in each zone in the base year.
  11. Lands.txt: Land dedicated to **streets & highways** in each zone in base year.
  12. Landr.txt: Amount of land dedicated for **residential** use in each zone in base year.

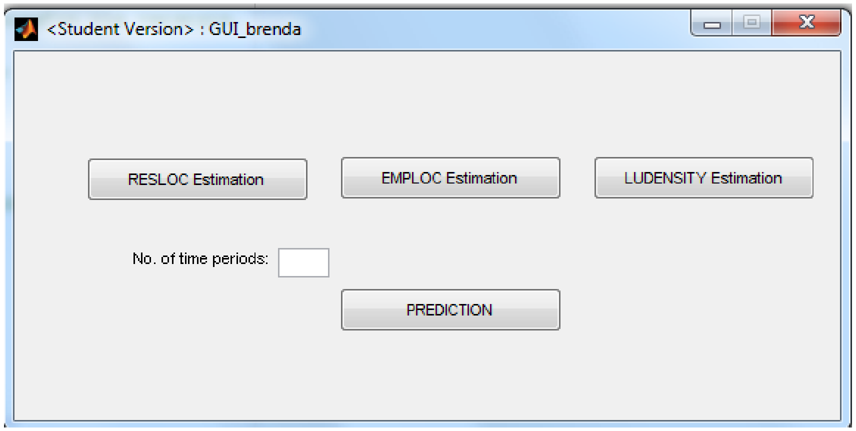
- **Control totals:** Assumption regarding increase in # jobs & # households.

  13. EmpProj.txt: **Control totals for jobs** over the prediction time period.
  14. HHProj.txt: Control **totals for households** over the prediction time period.

  Note: Data should be listed in same order across all the files with consistent units.

Running G-LUM

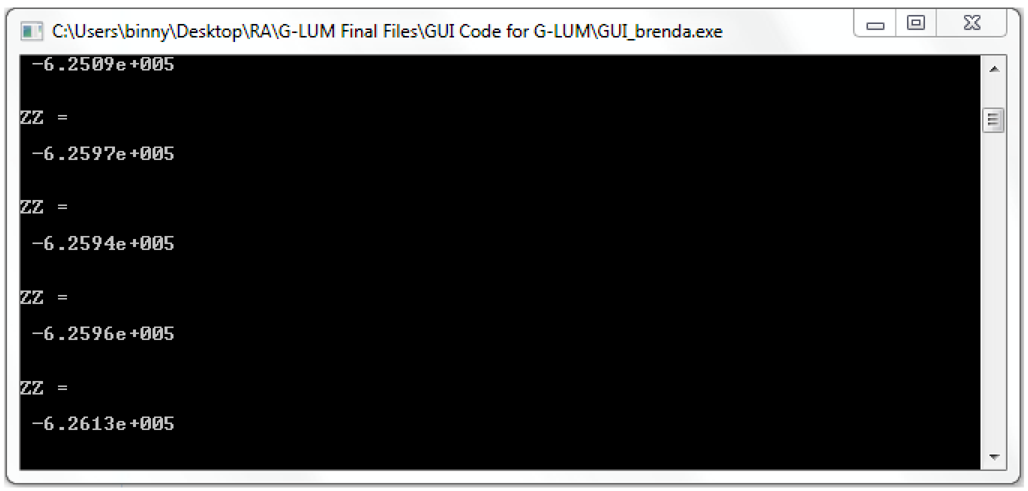
- G-LUM can be directly run using MATLAB or running the stand-alone application.



- Selecting RESLOC Estimation, EMPLOC Estimation, & LUDENSITY Estimation runs the RESLOC, EMPLOC, & LUDENSITY calibration modules, respectively.
- **PREDICTION button starts the forecasting process** for the analyst-entered number of time periods.
- For Dual core, 2.66 GHz, 4GB RAM machine, **RESLOC & EMPLOC calibrate in around 70 minutes**, while **LUDENSITY takes around 10** minutes. **PREDICTION takes another 5 minutes**.

Goodness of Model Fit

- G-LUM reports a goodness of fit in terms of ZZ value for each iteration of EMPLOC, RESLOC, & LUDENSITY.
- ZZ values pop-up in the MATLAB window or command prompt window.



- Lower ZZ values indicate better estimates (via lower squared errors).
- Analyst should note the last ZZ value for each module run.

Setting Initial Values

- RESLOC, EMPLOC, & LUDENSITY equations are highly non-linear & often lead to local optima.
- Analysts can change the initial values in the **initial_values.txt** & aim for a lower ZZ value.
- initial_values.txt is located in C:\G-LUM Finale\Prediction\Input\ folder.
- The columns of initial_values.txt in the first 6 rows correspond to *eta* (η), *alpha* (α), *beta* (β), *q, r, s,* & b_n parameters of the RESLOC equation.
- Rows 7 to 12 correspond to *lambda* (λ), *omega* (ω), *rho* (ρ), *aa,* & *bb* parameters of EMPLOC equation.
- The last row corresponds to the *k, g, p* parameters of the LUDENSITY equation.

Calibration through Prediction

Step 1: Prepare all the data files & copy in the required folders.

- First 12 files go into the C:\G-LUM Finale\Calibration\Input\ folder.
- 13th & 14th input files go into the C:\G-LUM Finale\Prediction\Input\ folder including first 12 files.

Step 2: Run the RESLOC, EMPLOC, & LUDENSITY calibration by pressing the respective buttons.

Step 3: Copy all the files in the C:\G-LUM Finale\Calibration\Output\ folder, & paste into the C:\G-LUM Finale\Prediction\Input\ folder.

Step 4: Push the PREDICTION button to forecast for required number of years.

Step 5: Open C:\G-LUM Finale\Prediction\Output\ folder to view the forecasts for different time periods.

Viewing Results

- **Forecasts are outputted** to C:\G-LUM Finale\Prediction\Output\ folder in the following order:

  - ***EMP_timepdx.csv***: contains the forecasted number of jobs across all zones, for each job type after time period *x*.

  - ***HH_timepdx.csv***: contains the forecasted number of households across all zones, for each household type after time period *x*.

  - ***Lb_timepdx.csv***: contains the forecasted amount of land allocated for basic jobs in all zones after time period *x*.

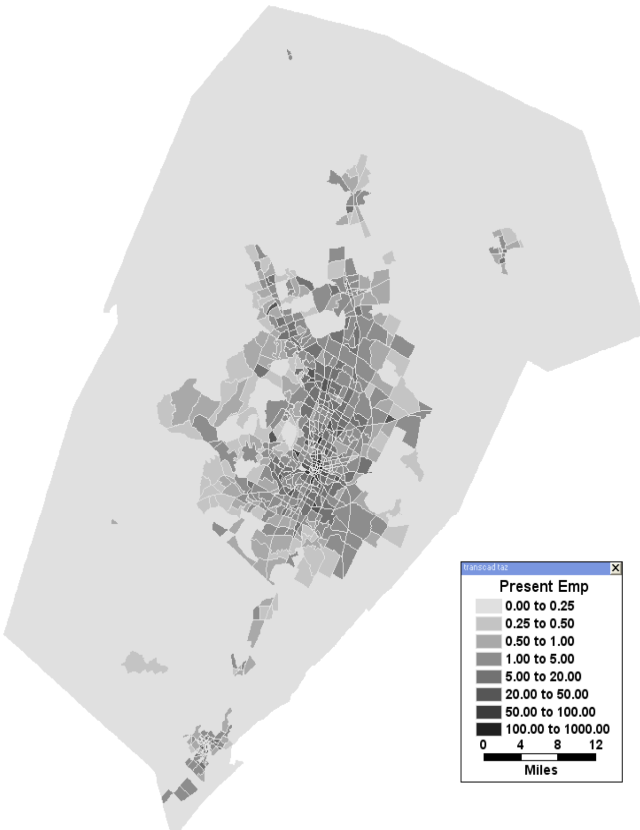
  - ***Lc_timepd.csv***: contains the forecasted amount of land allocated for commercial jobs in all zones after time period *x*.

  - ***Lr_timepd.csv***: contains the forecasted amount of land allocated for residential use in all zones after time period *x*.
- **Output data can be viewed in ArcGIS or TransCAD** by mapping the output data with a spatial layer.

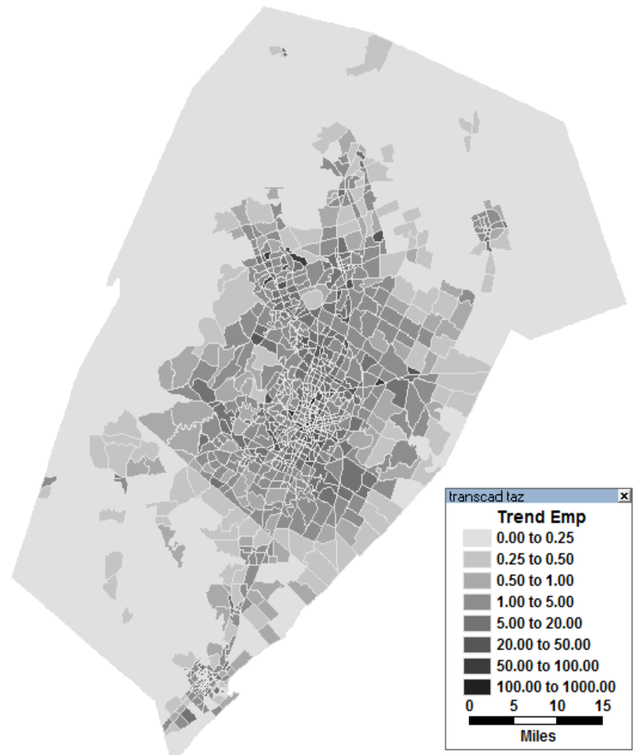
Austin Case-Study

- Data came from Capital Area Metropolitan Organization (CAMPO) for **1,074 TAZs**.
- Lag year = **2000** & Base year = **2005**
- **Forecasts** made for five time periods (2010, 2015, 2020, 2025 & **2030**).
- **3 employment** types **& 4 household** types.
- **Three Scenarios:**
  - TT150: Increased travel time (by 50%).
  - HH150: Increased household control totals (by 50%).
  - EMP150: Increased employment control totals (by 50%).

Results: *Trend Scenario*, Job Density



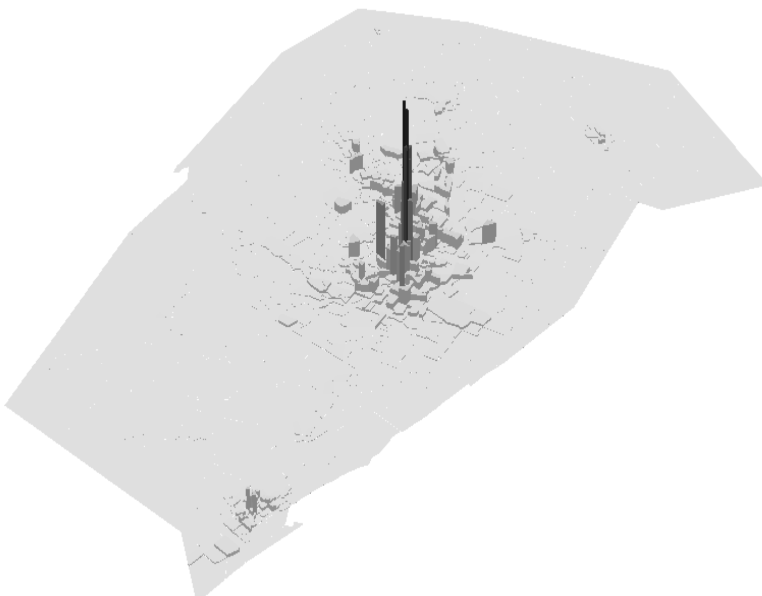
Year 2005



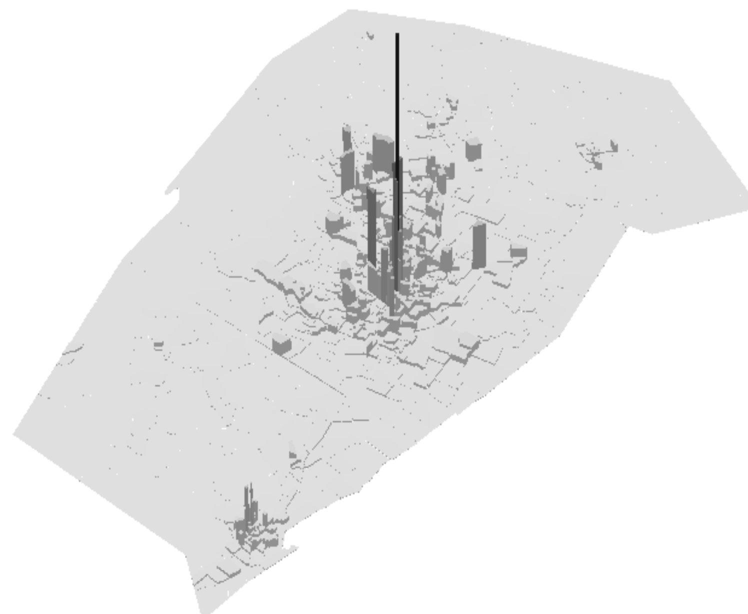
Year 2030

Densities are jobs per acre.

3D Job Density



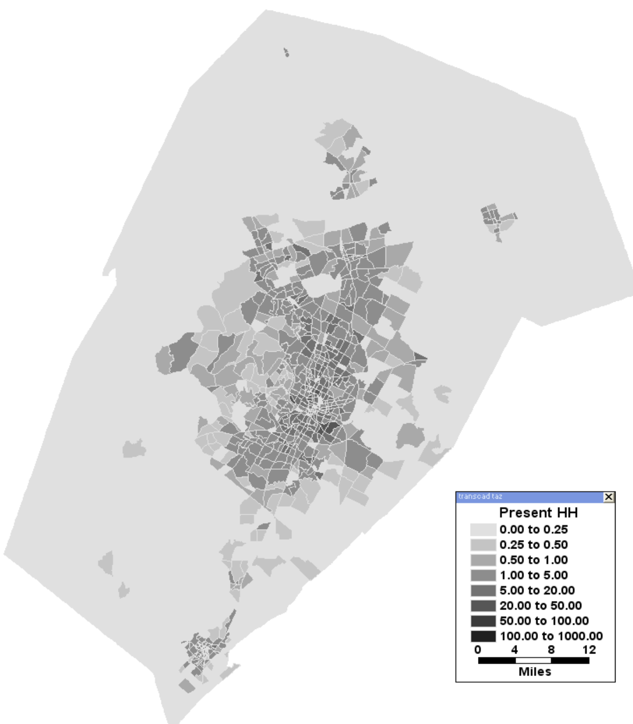
Year 2005



Year 2030

Densities are jobs per acre.

Trend Scenario: **Household** Density

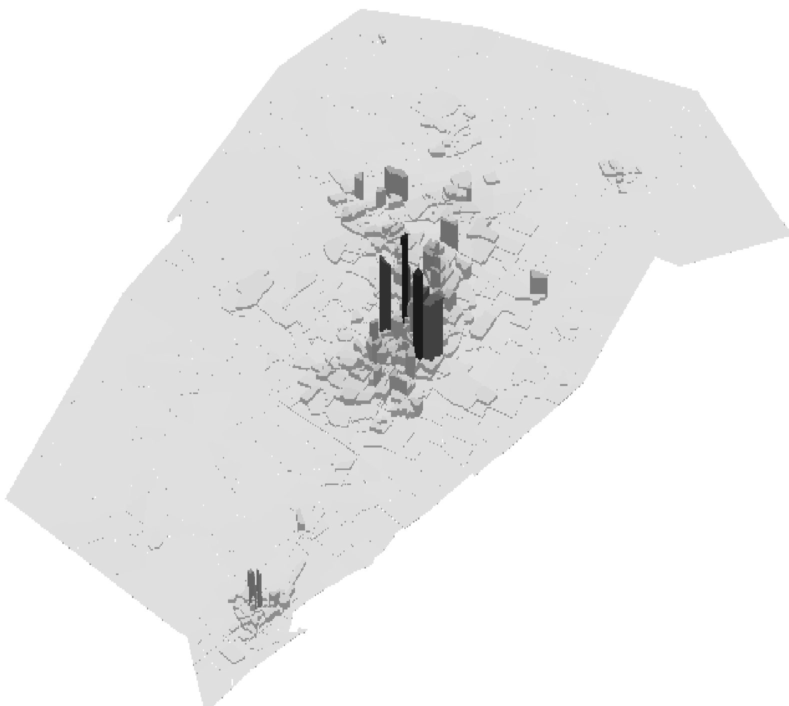


Year 2005

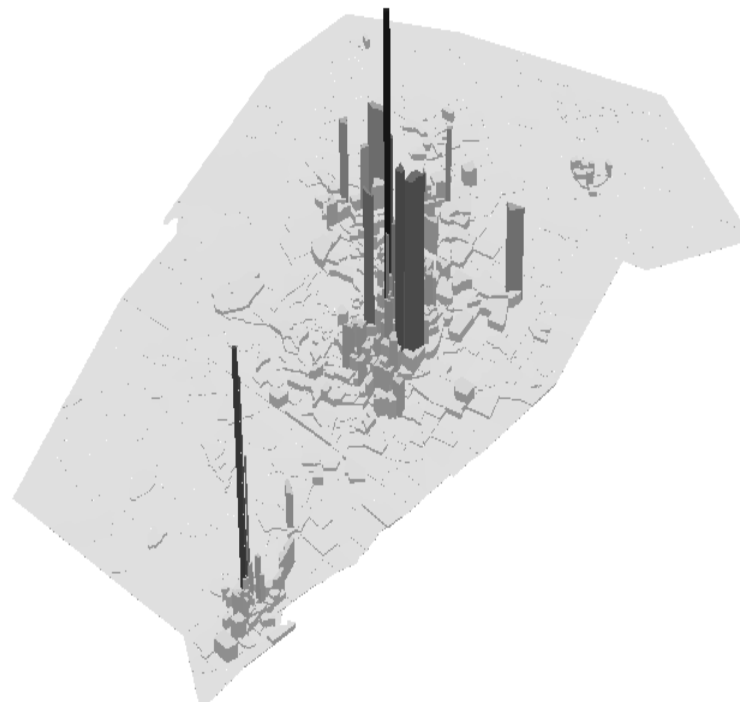
Year 2030

Densities are households per acre.

3D Household Density



Year 2005



Year 2030

Densities are households per acre.

Results: *50% Higher Travel Times*

(TT150 Scenario)

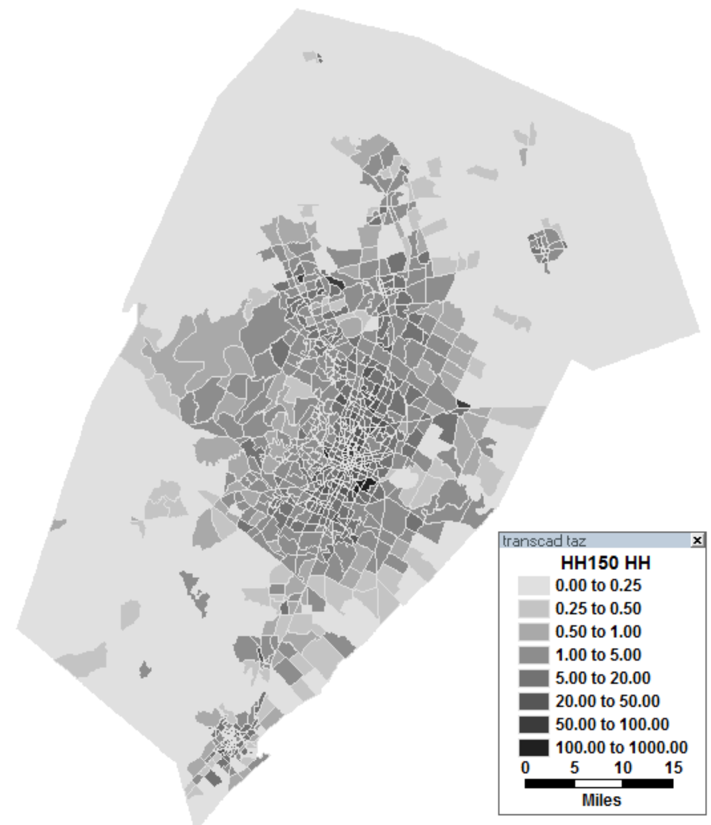
Job Density forecast in Year 2030

Household Density forecast in Year 2030

Densities are jobs & households per acre.

50% Higher HH Count
(HH150 Scenario)

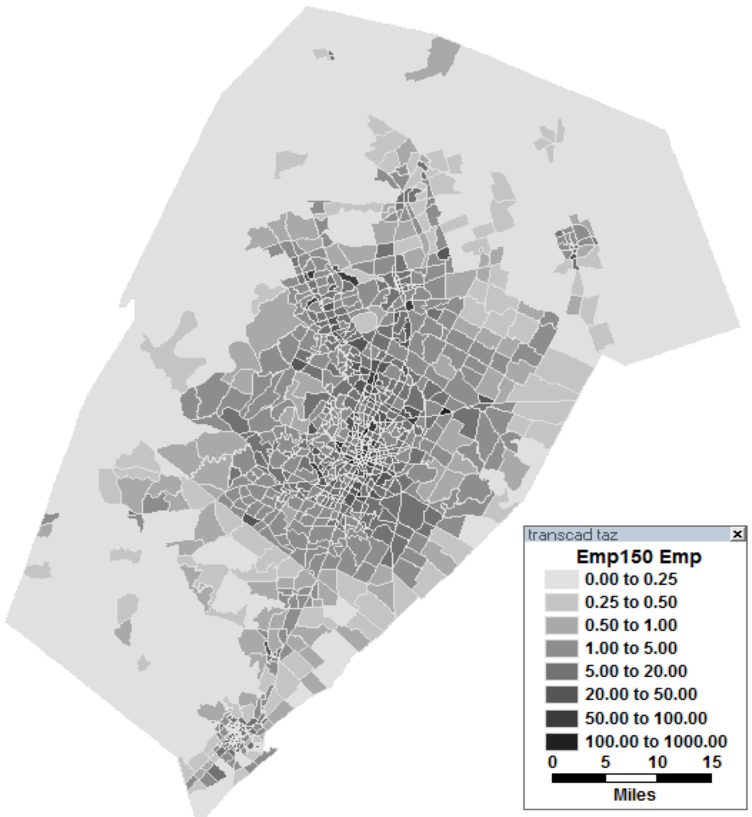
Job Density forecast in Year 2030



Household Density forecast in Year 2030

Densities are in counts per acre

50% Higher Jobs Totals
(EMP150 Scenario)

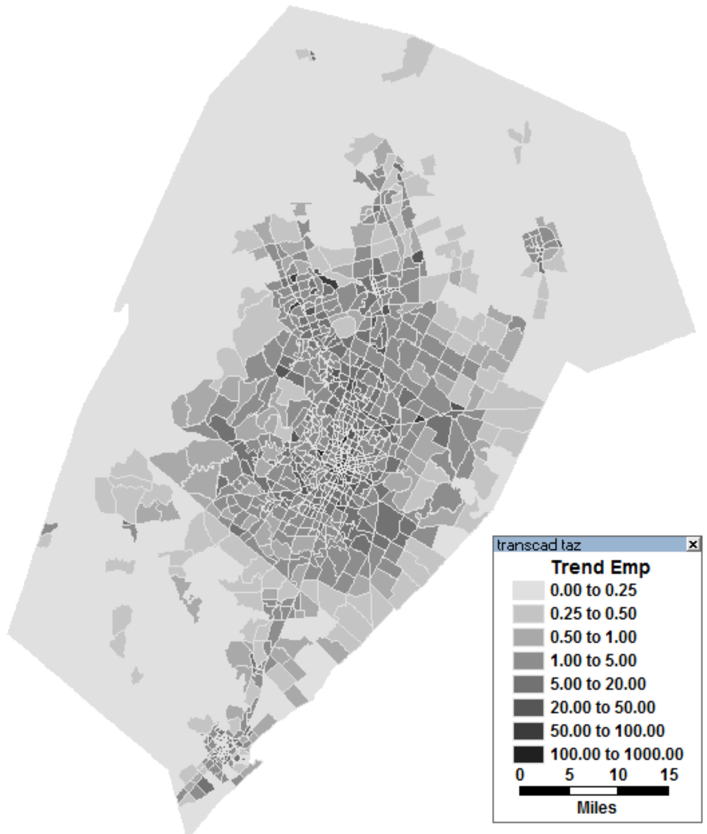


Job Density forecast in Year 2030

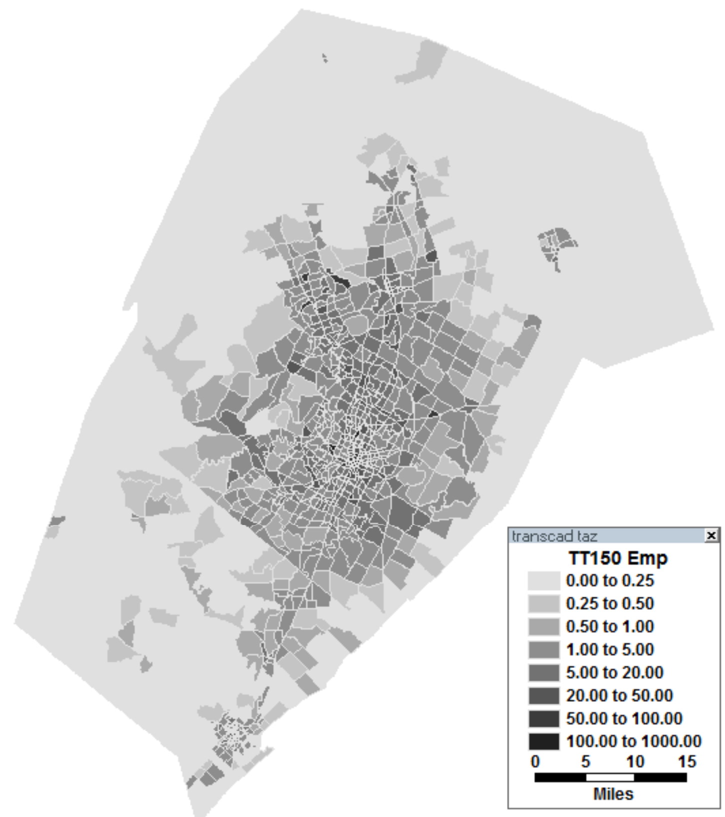
Household Density forecast in Year 2030

Densities are in counts per acre

Trend vs. TT150: Job Density



Job Density forecast in Year 2030



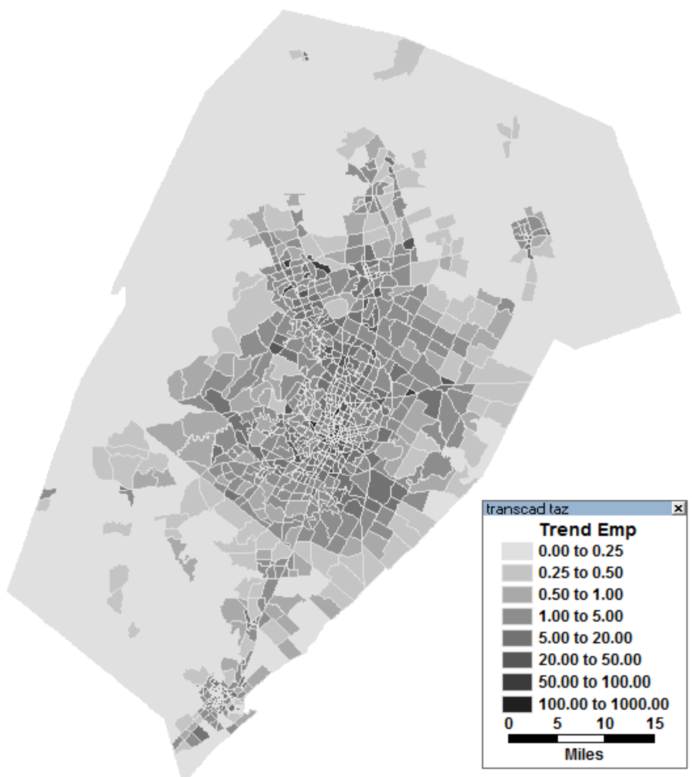
Job Density forecast in Year 2030

Trend vs. TT150 – HH Density

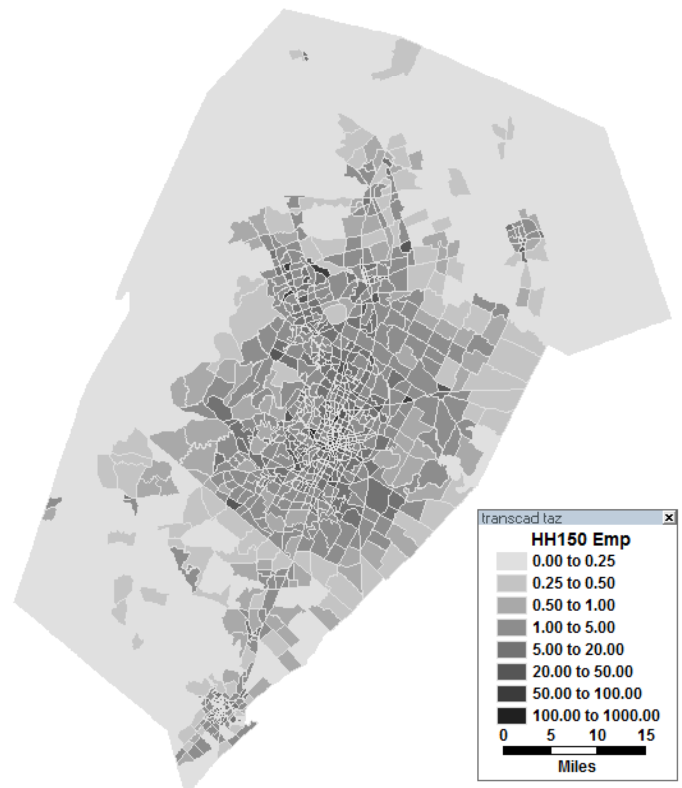
Job Density forecast in Year 2030

Job Density forecast in Year 2030

Trend vs. HH150 – Job Density



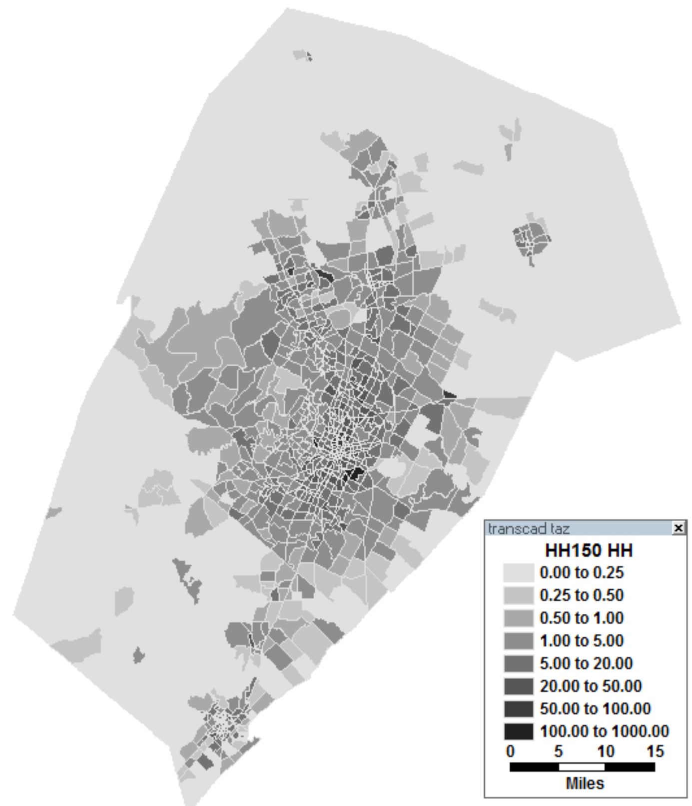
Job Density forecast in Year 2030



Job Density forecast in Year 2030

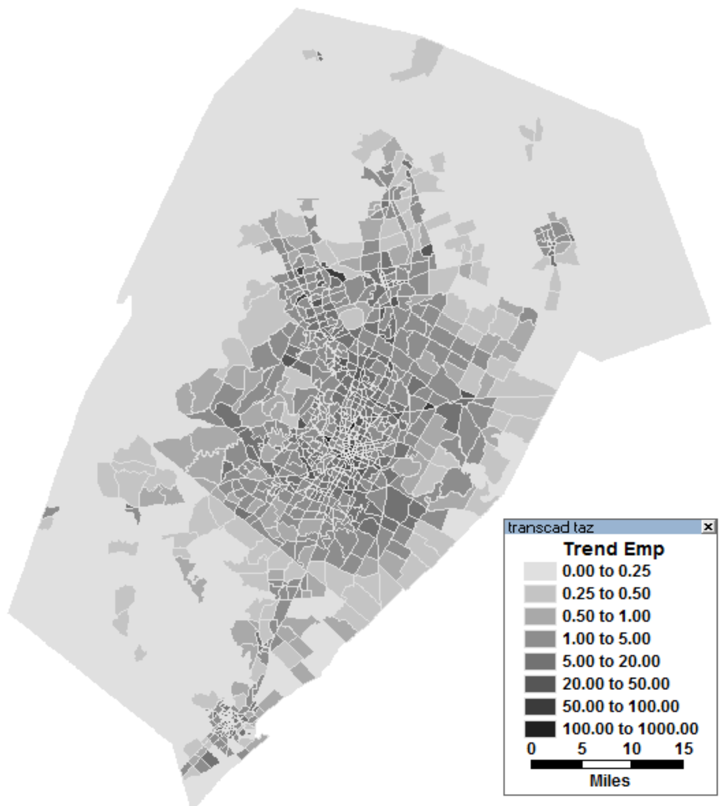
Trend vs. HH150 – HH Density

Job Density forecast in Year 2030

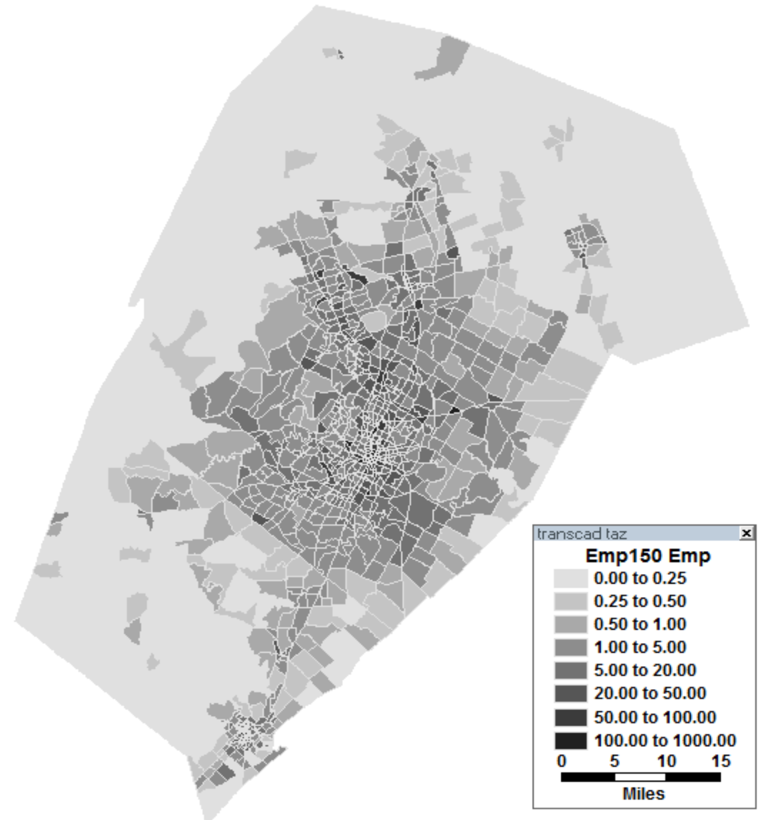


Job Density forecast in Year 2030

Trend vs. EMP150 – Job Density



Job Density forecast in Year 2030



Job Density forecast in Year 2030

Trend vs. EMP150 – HH Density

Job Density forecast in Year 2030

Job Density forecast in Year 2030

Scenario Comparisons

- Spatial distribution of jobs & households

$$Count\text{-}weighted\ density = \sum \frac{HH_i \times HHDens_i}{TotalHouseholds}$$

$$AccessibilityIndex = AI = \sum_i \frac{Count_i}{DistToCBD_i}$$

	Job Density (count-weighted)	**HH Density** (count-weighted)	**Job AI** (from CBD)	**HH AI** (from CBD)
Lag (2000)	28.81	4.59	202,351	142,161
Base (2005)	26.49	4.84	223,620	172,332
Trend (2030)	21.08	13.4	360,287	297,469
Emp150 (2030)	35.97	13.57	562,845	293,957
HH150 (2030)	16.33	19.33	345,296	442,497
TT150 (2030)	21.53	14.17	389,929	301,458

Conclusions

- G-LUM's **straightforward** structure & simple Graphical User Interface (GUI) makes it very **user-friendly**.
- G-LUM involves fewer steps & **moderate input data needs**.
- G-LUM enjoys **fast run times** for its modules.
- G-LUM was implemented for **Austin, El Paso, San Antonio, and Waco.**
- G-LUM **mimics the trend** in lag and lead year very well.
- Need to watch out for **extreme events & temporary trends** which might be captured by the parameters.
- Inclusion of a **travel demand model will enhance** the results.

Thank You!

Questions & Suggestions?

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