FORECASTING EMPLOYMENT & POPULATION IN TEXAS:
An Investigation on TELUM Requirements, Assumptions, and Results, including a Study of Zone Size Effects, for the Austin and Waco Regions

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Abstract

The FHWA's publicly available Transportation, Economic, and Land Use Model (TELUM) predicts the future spatial distributions of employment and households using Putman's Integrated Transportation Land Use Package (ITLUP) equations. TELUM was used here to generate the employment and household location forecasts for the Austin and Waco regions by district. While reasonably well documented, TELUM remains something of a black box, in that the research team could not duplicate its parameter predictions or its forecasts. It also is restrictive in application, requiring application at the district level, rather than any zone size (such as the more common, and smaller, traffic analysis zones [TAZs]).

The research team developed its own "open source" Matlab code, which will be referred to as Gravity Land Use Model (G-LUM). G-LUM is based on Putman's documentation of ITLUP equations as well as Caliper's own (not yet publicly available) ITLUP user manual. This was done in order to provide transparency, try to corroborate TELUM's results, and overcome TELUM's zone size restrictions. Parameters for all ITLUP equations (five for each household type, five for each employment type, and 19 for the land consumption model) are estimated by solving a non-convex, non-linear optimization problem, which maximizes the entropy and thus the likelihood of the data. In such cases the solution algorithm can get trapped at a local optimum, so our code solves the calibration problem using different starting assumptions on parameter values, thus reducing the chance of non-globally optimal solutions. TELUM does not address this issue. The estimation results of our code differ from those of TELUM and yield higher entropy values. An analysis of the two models' forecasts, from 2005 through 2030 (in 5-year increments), for the Austin and Waco regions is presented here. TELUM's employment and household predictions differ significantly from those of the G-LUM code for the Austin region. In the case of Waco, many similarities exist in the employment forecasts, across the models, but household forecasts differ considerably. Such distinctions engender analyst hesitation in pursuing the use of already compiled code, such as TELUM's. More transparency is needed, to deduce the source of such distinctions.

The influence of zone size on the forecast produced by the ITLUP equations also was investigated in this study. Future forecasts of the spatial distribution of employment and households by TAZ were obtained by using our own code for the Austin and Waco regions. These forecasts were aggregated by districts and then compared with the district-based forecasts. The comparison showed some stark differences. For example, in the case of Waco, forecasts by

district showed more total employment in the eastern and western parts, while forecasts by TAZ showed more total employment in southern parts of the region. Also the spatial distribution of low income households in Austin was completely different for district- and TAZ-based forecasts.

This report contains detailed descriptions and illustrations of applying both the TELUM and G-LUM to the three-county Austin region and the Waco region. The report begins with background on the ITLUP model, and then results from calibration are discussed as well as results from model runs. A summary of findings, including advantages and drawbacks of the model, concludes the report.

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1. Introduction

The spatial distributions of employment and households of the region are essential inputs to predict the travel time in a region. Travel time in turn influences employment and household locations in the future. Measures such as the total time spent by all users traveling in a network are used as indicators of congestion and hence, these measures are used to gauge the effectiveness of transportation policies. So it is necessary to develop a model that can make good forecast of the locations of employment and household to predict the travel time accurately in the future. The focus of this study is to analyze the employment and household location forecast given by the ITLUP equations proposed by Dr. Putman. The ITLUP equations were implemented using the TELUM software developed jointly by New Jersey Institute of Technology and S.H. Putman Associates, and also by a code developed independently by our team using Matlab, referred as Gravity Land Use model (G-LUM). G-LUM was developed to overcome restrictions imposed by TELUM and also to validate TELUM's results.

TELUM can be used to predict the impact of a planned transportation policy on the land use pattern of a region in both the short- and long-term. TELUM uses the regional residential and employment data from the current and lag years, and base year land cover data to forecast the future regional land use patterns. Professor Stephen H. Putman, developer of TELUM, proposed the ITLUP equations in early 1970s and used them to demonstrate the importance of the linkage between transportation policy and land use. ITLUP has since been applied to more than twenty metropolitan areas in the United States (User Manual: TELUM, 2005). The ITLUP equations have been extensively revised and updated since the initial work, particularly in light of the substantial advancement in computer technology over the past two decades. Specifically, Geographical Information Systems (GIS) have been developed and are now popular among planners.

In 1997, METROPILUS, a new land use modeling tool was developed by Putman. The entire modeling system along with Graphical User Interface (GUI) was embedded in the ESRI's ArcView GIS operating environment. It contained several models for location analysis and it could perform data analysis, statistical analysis and display mapping of the output. In 1999, Professor Putman began retooling METROPILUS as a land use component of Transportation Economic Land Use System (TELUS). The TELUS Land Use Model or TELUM can predict the location and the growth of the residential and nonresidential development for up to 30 years based on the analysis of current year and a lag year residential and nonresidential development, the locations of transportation improvements, and congestion in the system.

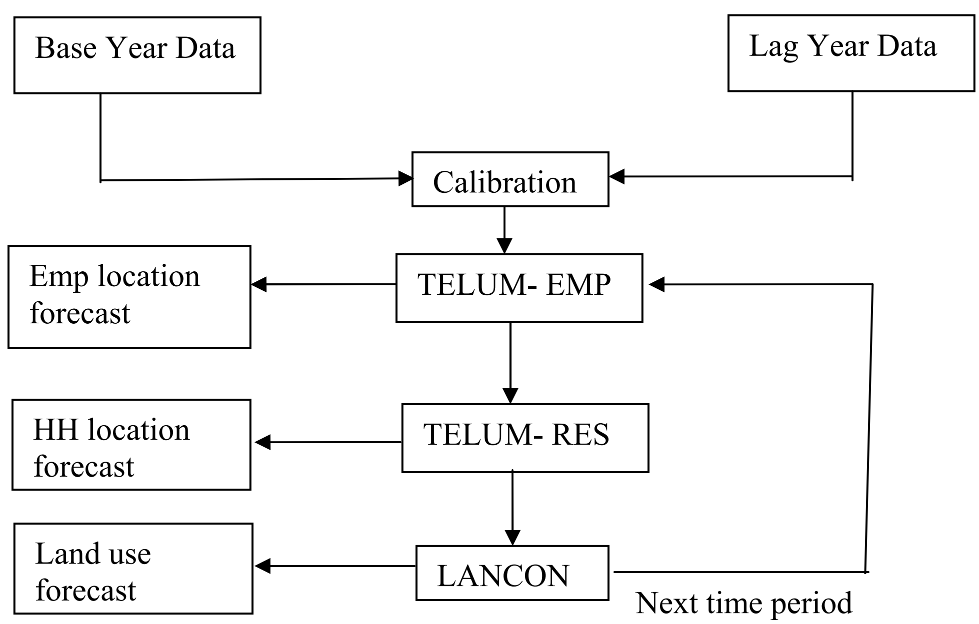
TELUM and G-LUM were used to generate the employment and household forecast at the district level for Travis, Hays, and Williamson counties of Austin. The traffic analysis zones (TAZs) of Austin do not satisfy the zonal requirements of TELUM due to restrictions on the size of zones. G-LUM doesn't impose any such restrictions. The objectives of this study are three-fold:

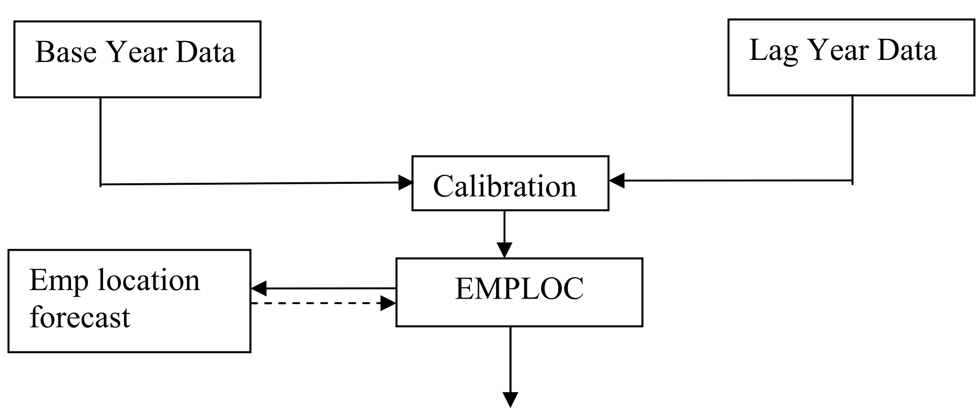
i) Implement TELUM for Austin and Waco, and provide a detailed account of our experience working with the software.

ii) Develop a code (G-LUM) that overcomes the restrictions of TELUM and also validate the TELUM results.
iii) Examine the influence of zone size on the forecast generated using G-LUM equations.

2. Sub-models & Data Requirements

TELUM consists of three sub-models namely EMPAL®, DRAM®, and LANCON. The corresponding sub-models in G-LUM are referred to as EMPLOC, RESLOC, and LUDENSITY. The equations involved in each of three sub-models are presented and discussed in Appendix A. Calibration determines the value of parameters that generate the best forecast for the base year based on the lag year data. Calibration of G-LUM is discussed in detail in the next section. Forecasts are generated in time increments of five years. A time step begins with the execution of the EMPLOC model, followed by RESLOC, and then LUDENSITY. The flowchart in Figure 1 indicates the steps involved in G-LUM. G-LUM will be described in this section, and a note will be made where TELUM differs.





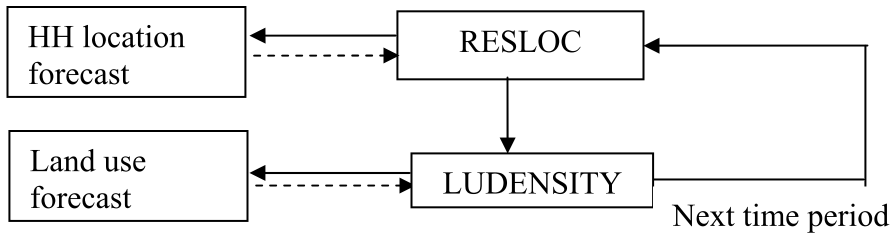


Figure 1: Block diagram of G-LUM

2.1 EMPLOC

EMPLOC forecasts the future spatial distribution of employment and was developed based on the EMPAL® model of ITLUP. EMPLOC does not have a limit on the number of employment sectors allowed, but EMPAL® requires a minimum of four and can incorporate up to eight employment sectors. The forecast of employment location of a type in a time period in a zone is based on four factors (Putman 2005):
i) The employment of that type in all zones in the previous time period
ii) Population of all types in all zones in the previous time period
iii) Total area per zone for all zones and
iv) Zone to zone travel cost

EMPLOC also requires the projected total employment of region for each employment category in all the forecast years. These control totals are used to normalize the output produced by EMPLOC.

2.2 RESLOC

RESLOC, developed based on the DRAM® model of ITLUP, forecasts the future residential development. RESLOC requires the classification of households into 4-5 groups usually based on income. The future location of a resident of a specified type in a zone in a time period is based on (Putman S.H, 2005):
i) Number of residents of all types in all zones in the previous time period
ii) Quantity of land used for residential purposes in that zone at previous time period
iii) Percentage of developable land in that zone that has already been developed in a previous time period
iv) Quantity of vacant developable land in that zone at a previous time
v) Zone to zone travel cost in the current time period
vi) Employment of all types in all zones in the current time period

RESLOC does not ask the user to explicitly input the number of households in each category for the forecast years, and instead it computes the control totals for each household category in each forecast year based on following inputs:
i) Total population of the region in each forecast year

ii) Total employment in the region for all categories in forecast years
iii) Average number of employees in each household category
iv) Matrix of Employment by household type in the base year

2.3 LUDENSITY

LUDENSITY computes the land consumption in all zones based on the demand for land for employment and residential purposes in each zone and the developable (supply) land in that zone. LUDENSITY requires the following inputs:

- i) Total land area in all zones
- ii) Usable land in all the zones
- iii) Unusable land in all the zones
- iv) Land used for basic employment in all the zones
- v) Land used for commercial employment in all the zones
- vi) Residential land in all the zones
- vii) Land used for street and highways for all the zones
- viii) Vacant developable in all the zones

3. Calibration

The calibration process involves fitting the G-LUM equations to the data of the region. The better the fit of the model, the more reliable are the forecasts. In EMPLOC and RESLOC five parameters have to be determined for each employment and household type respectively. The LUDENSITY model requires nineteen parameters to be determined empirically. Calibration is an important step in G-LUM since the forecast can vary significantly across different combination of parameter values.

Calibration entails generating a base year forecast from the lag year data using the G-LUM equations. The parameters that generate the best base year forecast (i.e., the forecast the most closely matches reality) are used to forecast the employment and household spatial distributions in the future. The parametric values of G-LUM are typically determined by solving an optimization formulation. The standard multiple regression techniques cannot be used to estimate the parameters of RESLOC and EMPLOC since the equations are non-convex, non-linear, and the regional data may not be normally distributed. The equations in the LUDENSITY model become linear equations if we take logarithm on both sides. So the parameters of LUDENSITY can be determined using linear regression.

The goodness of fit measure also has a significant influence in selecting the parametric values. Two commonly used goodness of fit criteria are R^2 and measures of likelihood. It has been shown by (Putman, 1983) using R^2 tends to produce a flat surface close to the local optimum. In comparison, use of the likelihood criteria generates a steeper surface close to the local optimum. So G-LUM uses the entropy based log likelihood function as the goodness of fit criteria. CALIBTEL is the procedure used by TELUM to determine the parametric values in the DRAM® and EMPAL® sub-models. CALIBTEL and G-LUM uses a gradient search technique to solve the optimization formulation. Linear regression is used to determine the parameters in LUDENSITY sub-model. TELUM does not allow users to fine-tune its parameters (evidently, to avoid "overtinkering" and misuse of the software), so further calibration simply is not feasible.

For employment and households distribution, TELUM and G-LUM solves the following entropy maximization formulation to determine the parametric values of ITLUP and G-LUM equations. This formulation is consistent with the theory given in Putman (1983).

$$\max \sum_{i \in I} N_i \ln\left(\hat{N}_i\right)$$
$$s.t. \sum_{i \in I} N_i = \sum_{i \in I} \hat{N}_i \qquad (1)$$

where I is the set of all zones, N_i is the count (of jobs or population) in zone i, and $\hat{N}_i$ is the estimated value (of jobs or households) in zone i.

The constraint in (1) ensures that the sum of the projected values is the sum of actual values. If the above constraint is not imposed then the objective may blow up. The above constraint can be imposed by normalizing all the predicted values by the ratio of sum of actual value to the sum of the predicted values. Hence, we can use an unconstrained optimization technique to solve the above formulation provided we calculate the objective function after normalizing the predicted values.

G-LUM (detailed in Appendix B) solves the above formulation using a built-in optimization program based on the “Nelder-Mead” method. The G-LUM equations are non-linear in nature, so there is always a chance of the program getting stuck at a local minimum. In order to overcome this problem, we have solved the above optimization formulation with multiple starting points. The set of parameters that yielded the lowest objective function value was chosen for implementation.

The effects of parameters that influence the household and employment spatial distributions but are not incorporated into G-LUM are captured in residuals. Residuals are computed as the difference between the actual data of the base year and the predictions generated by G-LUM for the base year using the lag year data. TELUM allows users to meet base year targets by retaining all residuals and adding these back in to the estimates (essentially as a suite of fudge factors, one per zone per job and household category). The effect of these is said to diminish, but users do not know to what extent these values actually diminish. The G-LUM code the team has developed assumes a 20% reduction in these residuals every 5 years.

4. Austin Metropolitan Region Implementation

TELUM and G-LUM have been used to generate the employment and household forecast for the Travis, Hays and Williamson counties of the Austin metropolitan region (Fig 2). Williamson County is located in the north, while Hays County is in the south of region. Travis County is in between Hays and Williamson Counties. The city of Austin is situated close to the center of Travis County. The three counties in total have 109 districts or 1074 TAZs. G-LUM produces forecasts both by district and by TAZ, while TELUM generates forecasts only by district.

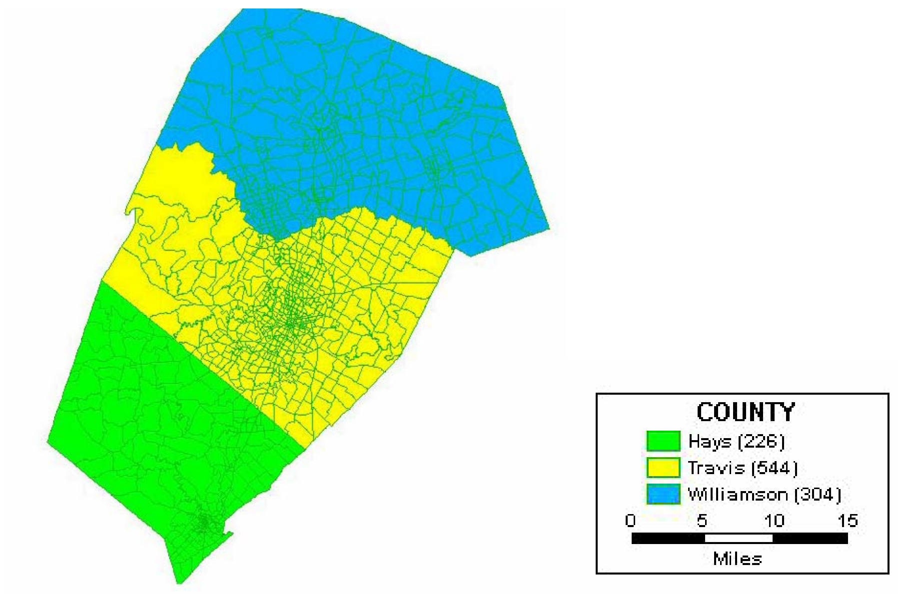


Figure 2: Three-county Austin metropolitan region

The employees in the three-county region were classified into the following categories:

i) Basic employment (Bas)
ii) Services employment (Serv)
iii) Retail employment (Ret)
iv) Airport employees (Air)
v) Employees in colleges (ED1)
vi) Employees in school (ED2)

The households were classified as:

i) Low income (Low): Annual income less than $25,000
ii) Below average (BAvg): Annual income between $25,000 to $40,000
iii) Above average (AAvg) Annual income between $40,000 to $75,000
iv) High income (High): Annual income more than $75,000

2005 was chosen as the base year for implementation. Since TELUM makes predictions in five year increments, data from year 2000 was used for calibration. The employment data and the total number of households in each zone were obtained from the Capital Area Metropolitan Planning Authority (CAMPO). The households were then divided into the above mentioned income categories based on year 2000 Census data. It must be noted that TELUM requires household data by type only for the base year while the total number of households in a zone is enough for the lag year. The land cover data for 2005 was obtained from the Capital Area Council of Governments (CAPCOG). The forecasts were generated by the TELUM and G-LUM codes using travel times from the base year 2005. The travel times are not updated based on the forecast of the previous iteration.

4.1 Base Year and Lag Year Data

4.1.1 Basic Employment

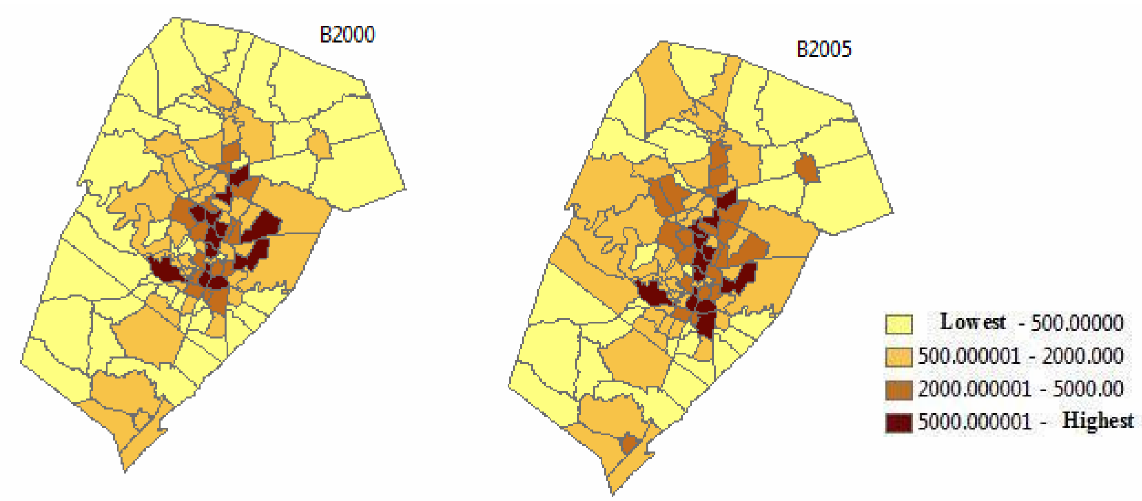


Figure 3: Spatial distribution of basic employment in base and lag years for the three-county Austin region

The basic employment is high in the city Austin and its surrounding zones in 2005. Some zones in Hays County and most of the zones in the outskirts of the city witnessed an increase in the basic employment from 2000 to 2005.

4.1.2 Retail Employment

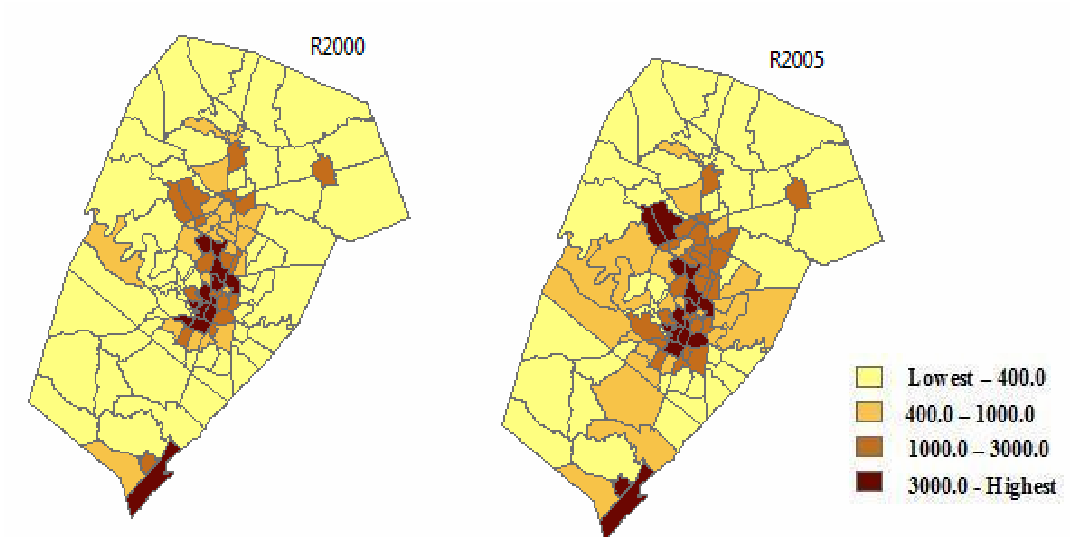


Figure 4: Spatial distribution of retail employment in base and lag years for the three-county Austin region

Retail employment was concentrated mainly in the Austin city area in 2000 and its magnitude reduces as we move away from the city. The growth in retail employment from 2000 to 2005 is again mainly in the outskirts of the city. A couple of zones in Hays County also registered a high increase in the retail employment.

4.1.3 Service Sector Employment

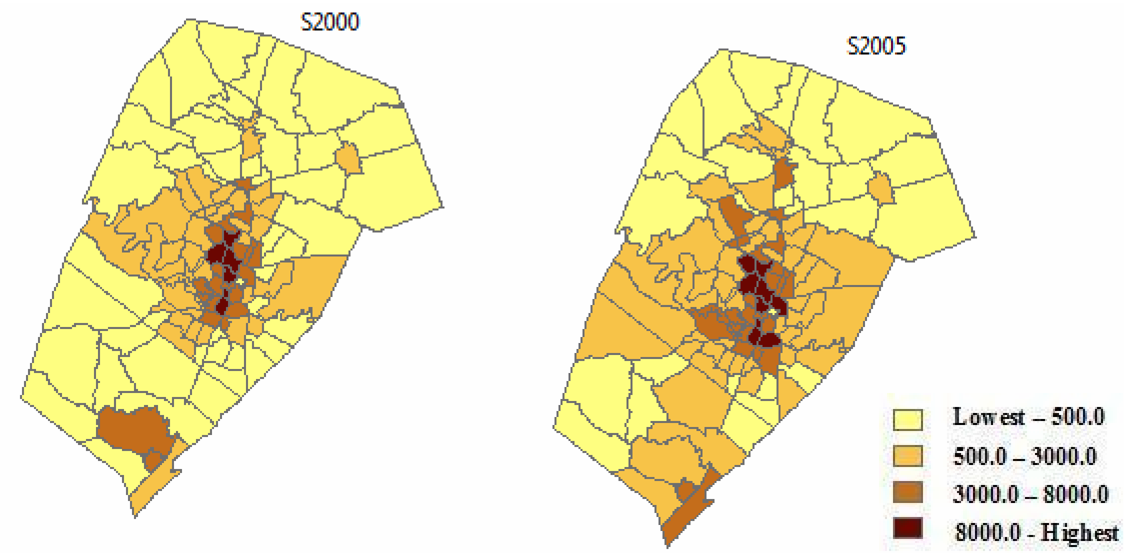


Figure 5: Spatial distribution of service sector employment in base and lag years for the three-county Austin region

Service sector employment is uniformly distributed across Travis County with the magnitude being higher in the city. The major growth areas were zones in Travis County located away from the city. Interestingly, some zones in the city and its outskirts witnessed a decrease in the service employment.

4.1.4 Total Employment

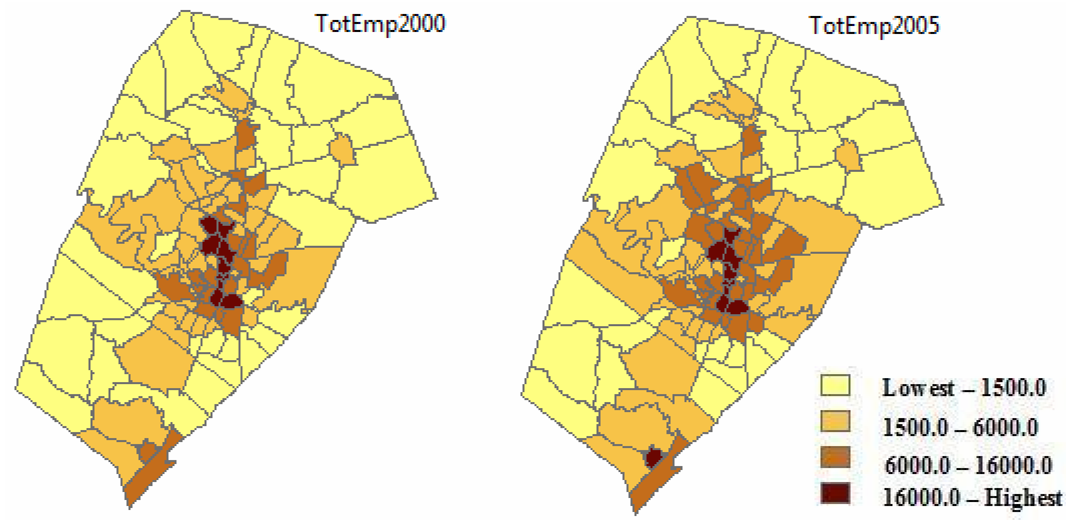


Figure 6: Spatial distribution of total employment in base and lag years for the three-county Austin region

The total employment is at its maximum in the city of Austin and then reduces as we move away from the city. An interesting trend that was observed from 2000 to 2005 is that the zones with high total employment in the city have reduced while total employment in zones located in the outskirts of the city has increased.

4.1.5 Low Income Households

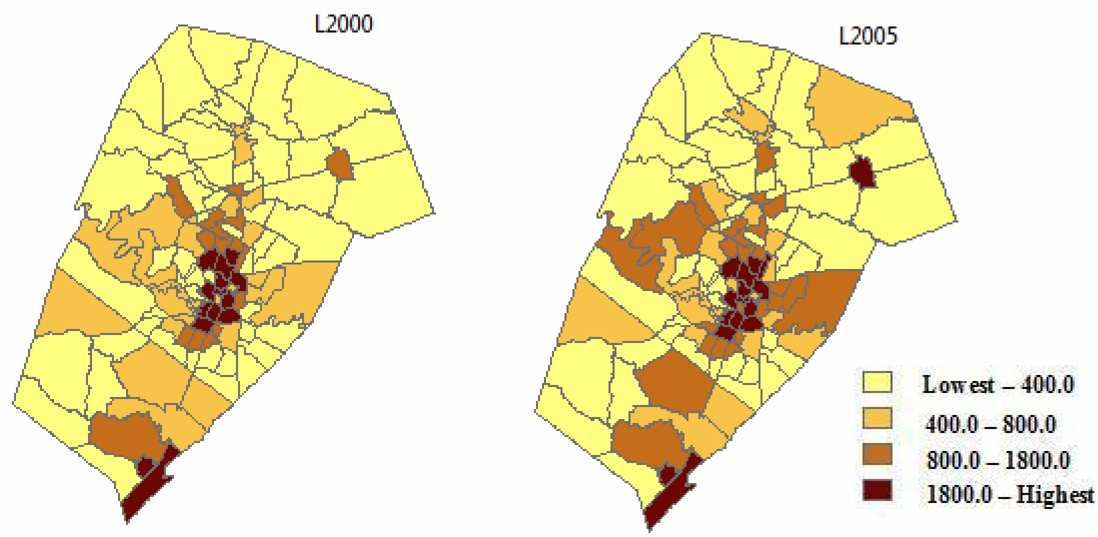


Figure 7: Spatial distribution of low income households in base and lag years for the three-county Austin region

There are a large number of low income households close to the city. These are likely to be students at the University of Texas and other institutions. The number of low income households in the outskirts of the city has increased considerably from 2000 to 2005. This may be because low income households prefer to stay in outskirts of city due to the low cost of living.

4.1.6 Below Average Income Households

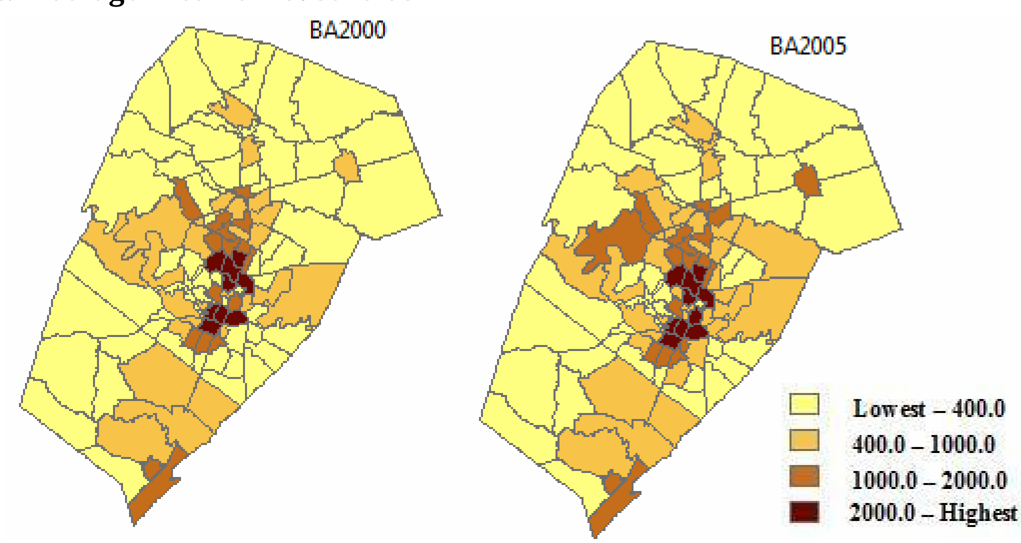


Figure 8: Spatial distribution of below average income households in base and lag years for the three-county Austin region

This category of household is densely populated in the zones close to city and the density reduces as we move away from city. A sizeable population of these households is located in Hays County. There has been an increase in the number of below average households in a couple of zones in the outskirts of the city between 2000 and 2005, but no major changes have occurred in the spatial distribution of this category of households.

4.1.7 Above Average Income Households

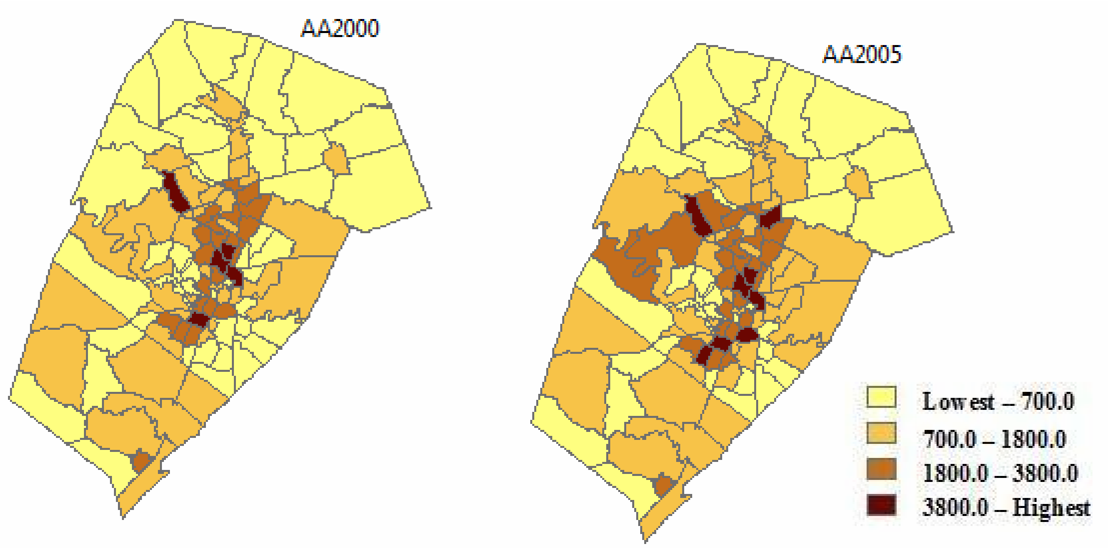


Figure 9: Spatial distribution of above average income households in base and lag years for the three-county Austin region

Most of the zones in Travis and Hays County have a number of above average income households. These households have increased in a couple of zones in the Austin city and also in a number of zones in the outskirts of the city. There were no major changes in the spatial distribution of these households in Williamson and Hays counties between 2000 and 2005.

4.1.8 High Income Households

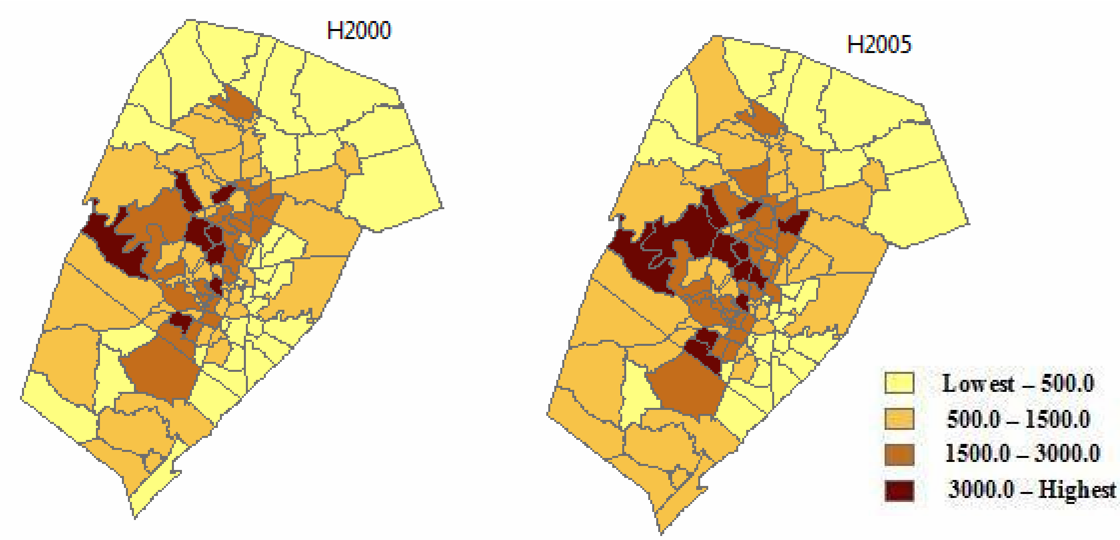


Figure 10: Spatial distribution of high income households in base and lag years for the three-county Austin region

High income households are mainly concentrated on the outskirts of the city and their number in these zones continued to increase from 2000 to 2005. Hays and Williamson counties also has a sizeable number of high income households. However distribution of these households in the counties has not changed much between the years 2000 to 2005.

4.2 District Implementation

ITLUP equations were implemented at the district level to generate employment and household forecasts from 2010 to 2030 using both the TELUM and G-LUM codes. The calibration results and the maps indicating the spatial distribution of the forecast given by the TELUM and G-LUM codes is given below.

4.2.1 Calibration Results

The values of parameters in the sub-models determined using TELUM and G-LUM developed are presented below. The entropy value is the measure of the goodness of fit of the model used in both the models. In order to make a comparison of the goodness of fit of parameters calculated by TELUM and G-LUM, the entropy values are also displayed. The equations corresponding to these parameters can be found in the Appendix A.

4.2.1.1 TELUM calibration results

The readers are referred to the Appendix A for an explanation of each of these parameters.

Table 1: DRAM® parameters – calibrated using TELUM for Austin districts

Parameters	Low-HH	BAvg-HH	AAvg-HH	High-HH
η	0.493	0.27	0.195	0.381
α	1.297	1.348	1.013	0.989
β	-0.186	-0.206	-0.056	-0.03
q	-0.064	-0.044	0.085	-0.013
r	0.43	0.5	0.42	0.435
s	0.359	0.342	0.105	0.244
B (HHtype,Low)	5.773	-0.549	-4.088	-3.36
B (HHtype, BAvg)	4.39	8.633	1.66	0.195
B (HHtype,Aavg)	-1.097	0.459	8.262	3.258
B (HHtype,High)	-3.003	-3.787	-0.365	5.239
Entropy	8.15E+05	6.11E+05	1.25E+06	1.08E+06

Table 2: EMPAL® parameters – calibrated using TELUM for Austin districts

Parameters	Basic	Retail	Serv	Air	College	ED1	ED2
λ	0.3132	0.3477	0.3306	0.146	0.3764	0.2308	0.3132
α	2.8096	2.8105	2.8103	2.8106	2.8102	2.809	2.8096
β	-0.009	-0.0086	-0.0108	-0.0062	-0.0178	-0.0093	-0.009
a	0.6172	0.6052	0.6067	0.7651	-0.0044	0.5669	0.6172
b	0.1176	0.1424	0.1157	0.0876	0.2787	0.0436	0.1176
Entropy	1.78E+06	1.04E+06	3.00E+06	2.03E+04	1.35E+05	2.02E+05	1.78E+06

Table 3: LANCON parameters – calibrated using TELUM for Austin districts

Parameters	Residential	Industry	Commercial
Constant	0.089726	0.014728	0.026702
PerDev	0.7311	0.095	-0.551
PerBas	-0.297	0.633	0.951
PerComm	-0.565	-0.379	-0.898
PerLI	0.026	0.983	0.516
PerHI	-0.057	0.399	0.05
Developable	0.743		
Entropy	3.35E+06	1.16E+05	1.62E+05

4.2.1.2 Matlab code parameters

Table 4: RESLOC parameters – calibrated using G-LUM for Austin districts

Parameters	Low-HH	BAvg-HH	AAvg-HH	High-HH
η	0.0004	0.000215	0.000236	0.000106
α	1.2382	0.89818	0.88763	0.89606
β	-0.0501	-0.04884	-0.04864	-0.04873
q	0.0896	0.011473	0.011458	0.010031
r	0.488	0.66018	0.65734	0.65772
s	0.4214	0.20567	0.20496	0.20391
B (HHtype,Low)	0.6935	-0.50495	-2.003	-3.1126
B (HHtype, BAvg)	0.6598	8.5297	5.019	0.21482
B (HHtype,Aavg)	0.5699	5.6832	8.8308	3.2166
B (HHtype,High)	0.4857	1.0617	-0.48058	9.3381
Entropy	9.30E+05	6.78E+05	1.32E+06	1.21E+06

Table 5: EMPLOC parameters – calibrated using G-LUM for Austin districts

Parameters	Basic	Retail	Serv	Air	College	ED1	ED2
λ	0.5177	0.0905	0.1895	0.2734	0.0283	0.0041	0.5177
α	0.2123	2.5664	4.9848	3.6195	3.8403	1.1559	0.2123
β	-0.0005	-0.0012	-0.0016	-0.0011	-0.0007	-0.0005	-0.0005
a	0.8209	0.4449	0.4455	1.0396	0.0046	0.0697	0.8209
b	-0.0701	0.2248	-0.1079	0.1503	-0.033	-0.4992	-0.0701
Entropy	1.79E+06	1.05E+06	3.03E+06	24271	1.45E+05	2.21E+05	1.79E+06

Table 6: LUDENSITY parameters – calibrated using G-LUM for Austin districts

Parameters	Residential	Industry	Commercial
Constant	1.13E-05	1.0914	0.0495
PerDev	0.9725	0.4303	-1.19
PerBas	0.3983	0.77	0.3021
PerComm	0.0648	1.3301	-0.9004
PerLI	-0.3253	-0.2558	0.037
PerHI	-0.3544	0.7768	0.3942
Developable	1.2438		
Entropy	3.53E+06	1.12E+05	1.61E+05

The entropy value of the parameters calculated by G-LUM is greater than the parameters computed by TELUM in all the cases. So parameters computed by G-LUM are likely to give more accurate predictions than TELUM using ITLUP equations for the three-county Austin region.

4.2.2 Comparison of TELUM & G-LUM Forecasts

A comparison of the outputs produced by TELUM and G-LUM is presented in this section. The spatial distributions of three main employment classes and total employment along with the spatial distributions of all the four household classes in the forecast years produced by TELUM and G-LUM are discussed here.

4.2.2.1 R^2 and weighted R^2 values

The R^2 value and the weighted R^2 value for all the employment and household types in the forecast years are also calculated. The R^2 value is an indicator of the difference in the spatial distribution of the forecast year and the base year.

Table 7: EMPLOC parameter R^2 values using G-LUM for Austin districts

Years	Basic	Retail	Services	Air	ED1	ED2
2010	0.943	0.922	0.984	0.999	0.798	0.974
2015	0.874	0.790	0.949	0.999	0.616	0.957
2020	0.825	0.682	0.907	0.999	0.496	0.956
2025	0.798	0.595	0.865	0.999	0.405	0.949
2030	0.776	0.527	0.826	0.999	0.289	0.950

Table 8: RESLOC parameter R^2 values using G-LUM for Austin districts

Years	Low	BAvg	AAvg	High
2010	0.65	0.824	0.847	0.423
2015	0.624	0.772	0.796	0.398
2020	0.604	0.733	0.756	0.376
2025	0.594	0.781	0.735	0.365
2030	0.595	0.716	0.735	0.365

Table 9: Weighted EMPLOC parameter R^2 values using G-LUM for Austin districts

Years	Basic	Retail	Services	Air	ED1	ED2
2010	0.958	0.915	0.989	0.999	0.672	0.933
2015	0.9	0.765	0.964	0.999	0.441	0.908
2020	0.852	0.623	0.927	0.999	0.237	0.907
2025	0.818	0.479	0.881	0.999	0.061	0.885
2030	0.78	0.337	0.824	0.999	0.002	0.886

Table 10: Weighted RESLOC parameter R^2 values using G-LUM for Austin districts

Years	Low	BAvg	AAvg	High
2010	0.498	0.678	0.646	0.213
2015	0.443	0.57	0.529	0.174
2020	0.404	0.496	0.451	0.149
2025	0.386	0.561	0.417	0.139
2030	0.386	0.463	0.416	0.138

Table 11: EMPAL® parameter R^2 values using TELUM for Austin districts

Years	Basic	Retail	Services	Air	ED1	ED2
2010	0.959	0.936	0.987	0.999	0.867	0.989
2015	0.849	0.728	0.928	0.999	0.623	0.915
2020	0.708	0.462	0.788	0.999	0.431	0.648
2025	0.573	0.257	0.56	0.999	0.31	0.27
2030	0.46	0.136	0.318	0.999	0.235	0.078

Table 12: DRAM® parameter R^2 values using TELUM for Austin districts

Years	Low	BAvg	AAvg	High
2010	0.682	0.874	0.865	0.418
2015	0.643	0.832	0.866	0.445
2020	0.535	0.709	0.793	0.439
2025	0.358	0.5	0.609	0.37
2030	0.177	0.259	0.371	0.251

Table 13: Weighted EMPAL® parameter R^2 values using TELUM for Austin districts

Years	Basic	Retail	Services	Air	ED1	ED2
2010	0.973	0.932	0.99	0.999	0.807	0.972
2015	0.889	0.685	0.94	0.999	0.563	0.811
2020	0.755	0.355	0.799	0.999	0.415	0.431
2025	0.598	0.136	0.55	0.999	0.33	0.141
2030	0.446	0.042	0.292	0.999	0.277	0.042

Table 14: Weighted DRAM® parameter R^2 values using TELUM for Austin districts

Years	Low	BAvg	AAvg	High
2010	0.546	0.764	0.703	0.221
2015	0.486	0.685	0.68	0.236
2020	0.287	0.418	0.481	0.189
2025	0.096	0.16	0.226	0.103
2030	0.018	0.036	0.087	0.048

4.2.2.2 Forecast from 2010 to 2030

This section presents the mapped output produced by TELUM and G-LUM and a discussion on these results. The forecast are produced in increments of five years. The zones have been classified into four classes based on the number of employment and household types present in that zone. Each class is assigned a different color.

Basic employment

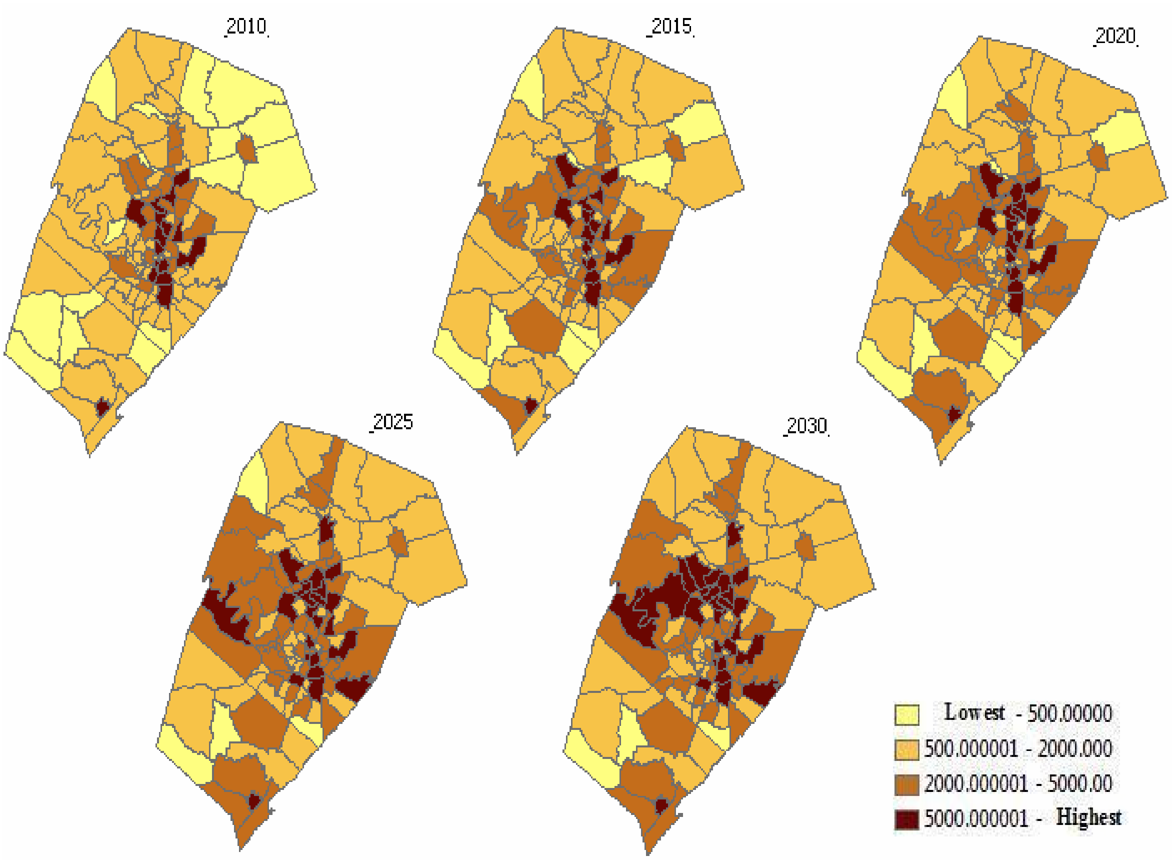


Figure 11: TELUM forecast by district for basic employment for the three-county Austin region

TELUM predicts that the basic employment will increase in almost all the zones in the three-county region. The basic employment is predicted to be high in the outskirts of the Austin city particularly in the zones west of the city by 2030.

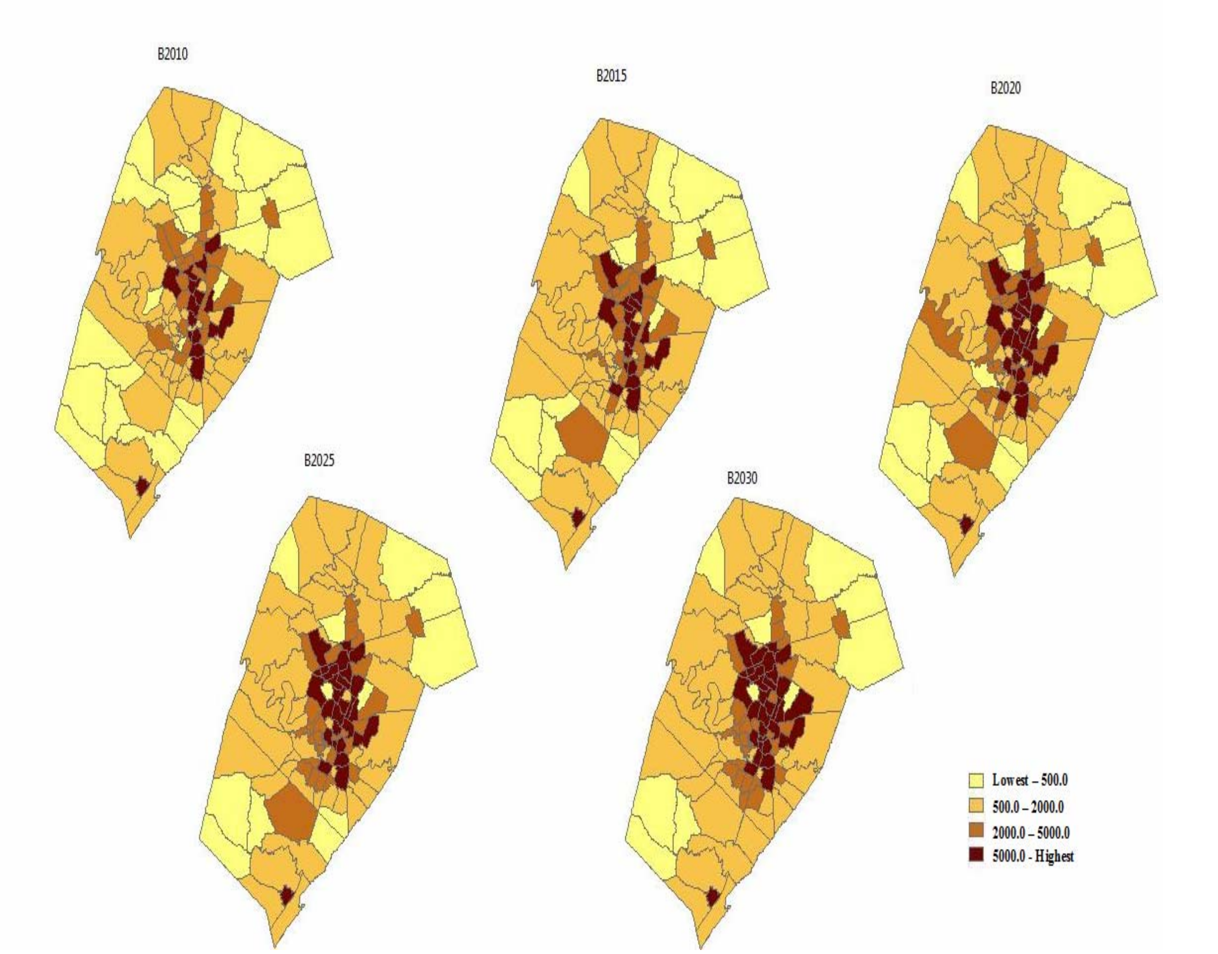


Figure 12: G-LUM forecast by district for basic employment for the three-county Austin region

G-LUM, on the other hand, predicts that the distribution of basic employment would be high in central Austin. The majority of growth areas are located close to the city and only a few zones in Hays and Williamson counties are predicted to experience a high increase in basic employment.

Retail employment

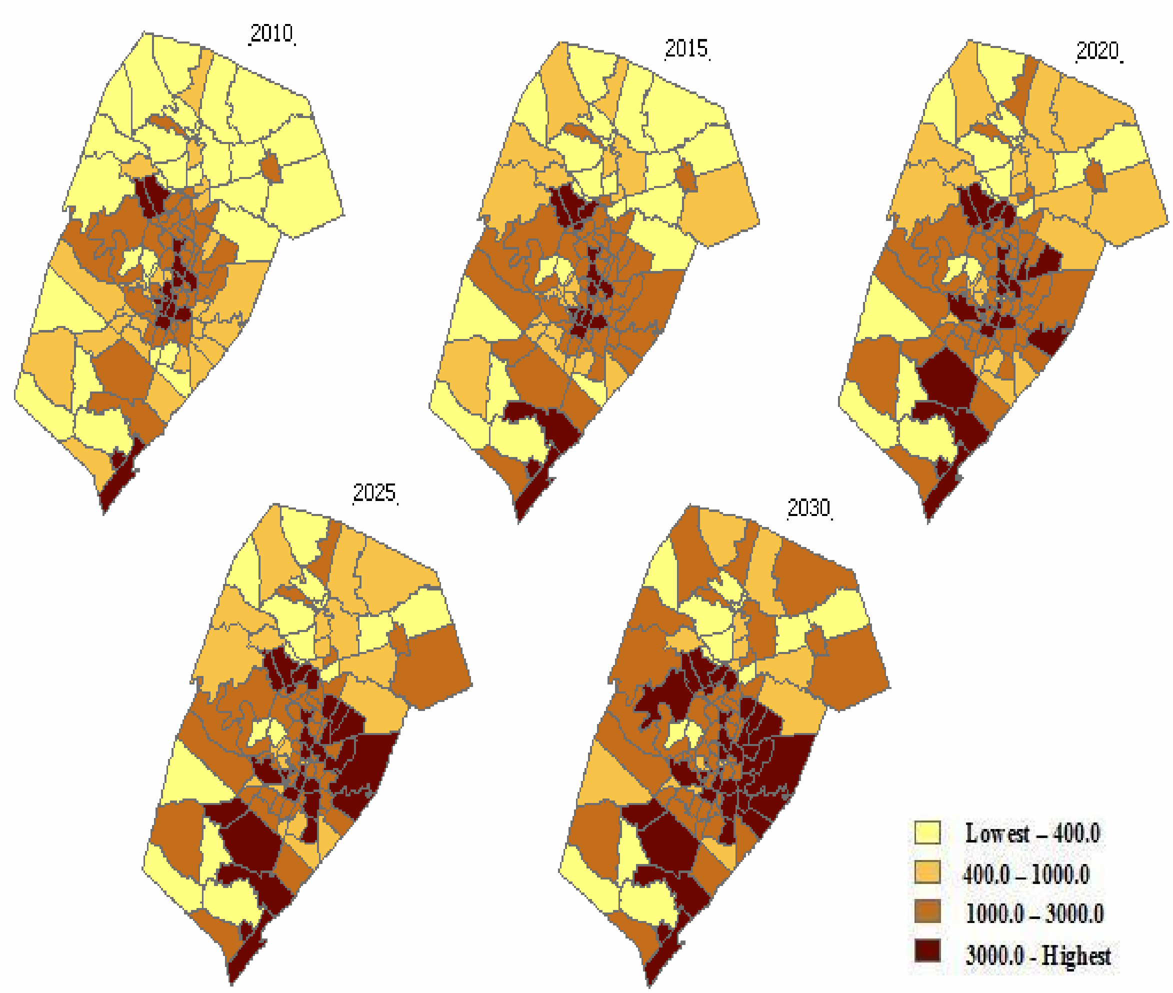


Figure 13: TELUM forecast by district for retail employment for the three-county Austin region

Almost all zones in Travis County are predicted by TELUM to experience a huge increase in retail employment. By 2030, the outskirts of the city are forecasted to have high numbers of retail employment. Some of the zones in Hays and the Williamson counties are also predicted to witness a large increase in retail employment.

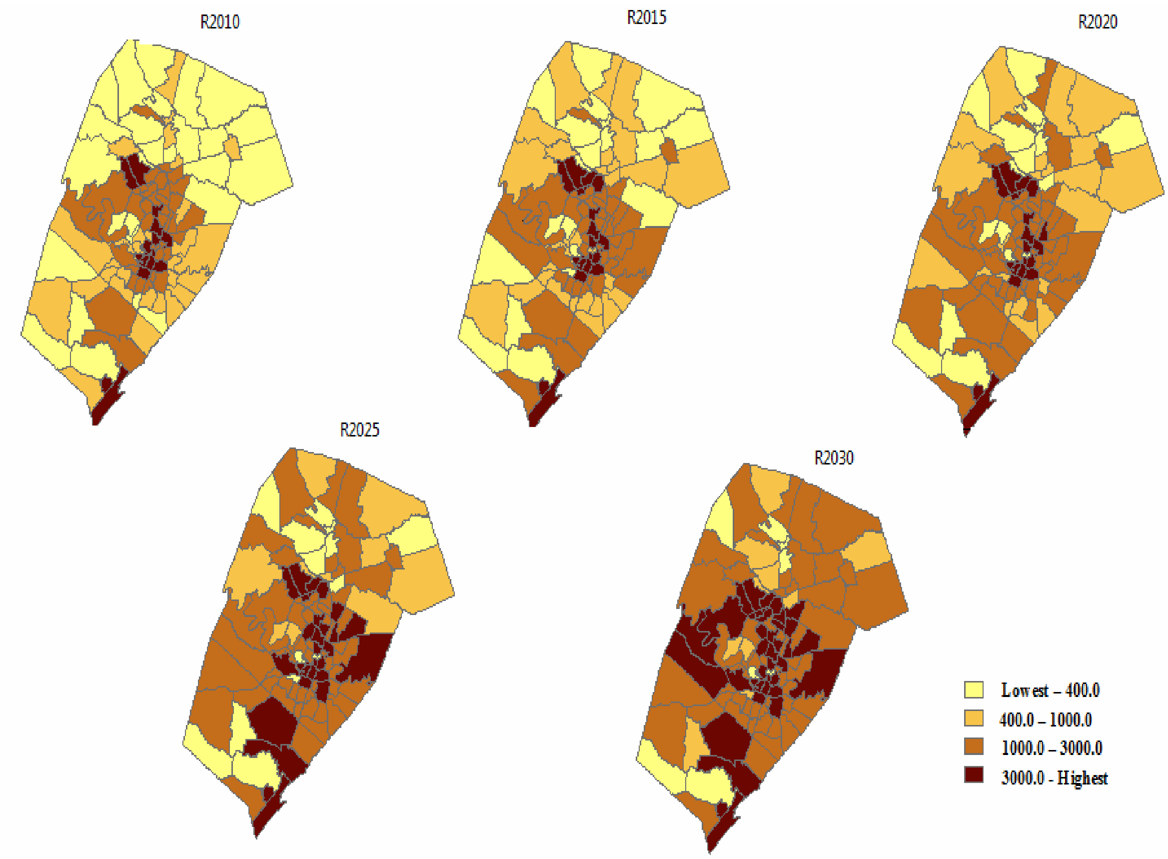


Figure 14: G-LUM forecast by district for retail employment for the three-county Austin region

G-LUM also predicts a huge increase in the retail employment in the outskirts of the city. However the spatial distribution of the retail employment predicted by both G-LUM and TELUM are substantially different. G-LUM forecasts that the west of the city will become high retail employment while TELUM, on the other hand, predicts the retail employment to increase mainly east of city. The forecast of retail employment in Hays and Williamson counties by TELUM matches with G-LUM predictions.

Services employment

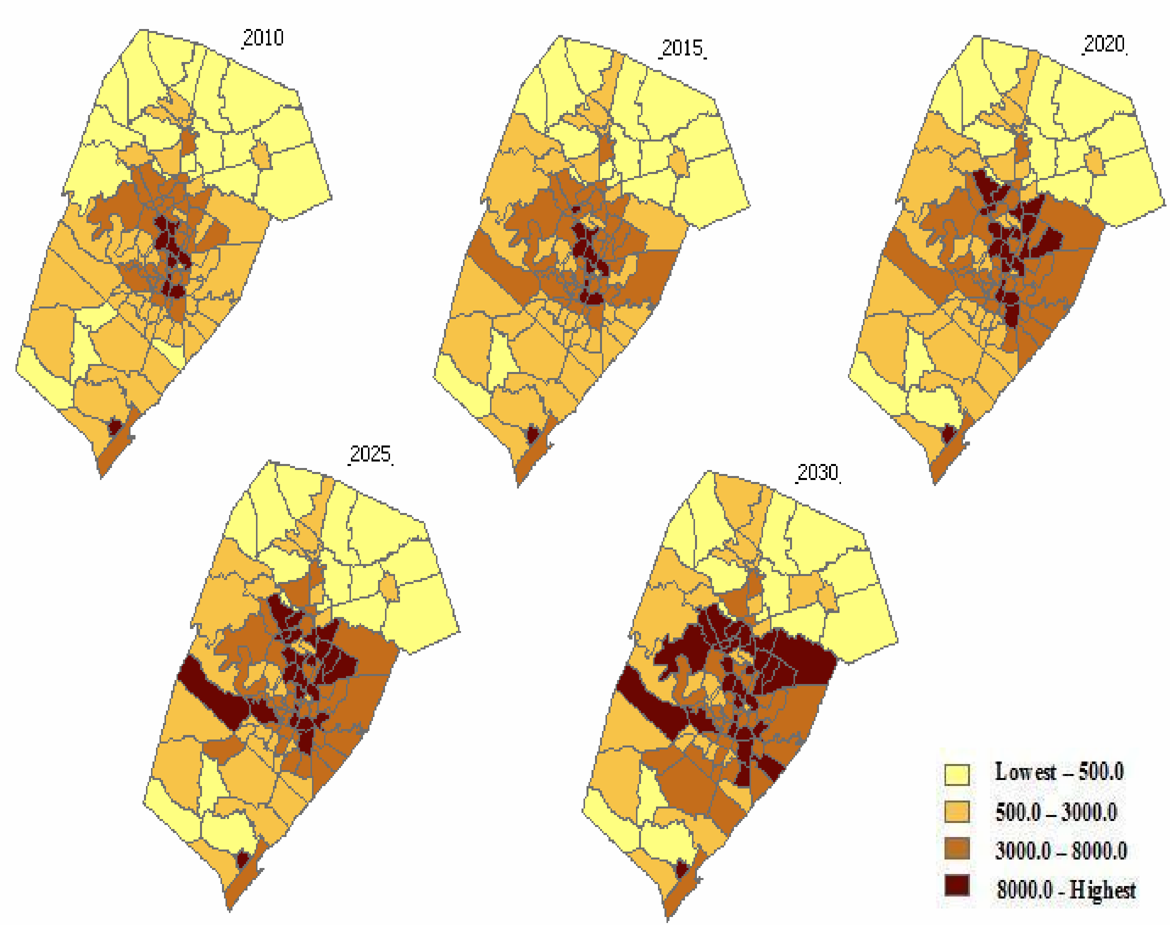


Figure 15: TELUM forecast by district for service employment for the three-county Austin region

Service sector employment is predicted by TELUM to be high in districts located to the north of the city by 2030. A couple of zones to the south of city and in Hays County are also predicted to experience huge increase in service employment. The zones in Williamson County are predicted to have only small changes in service employment.

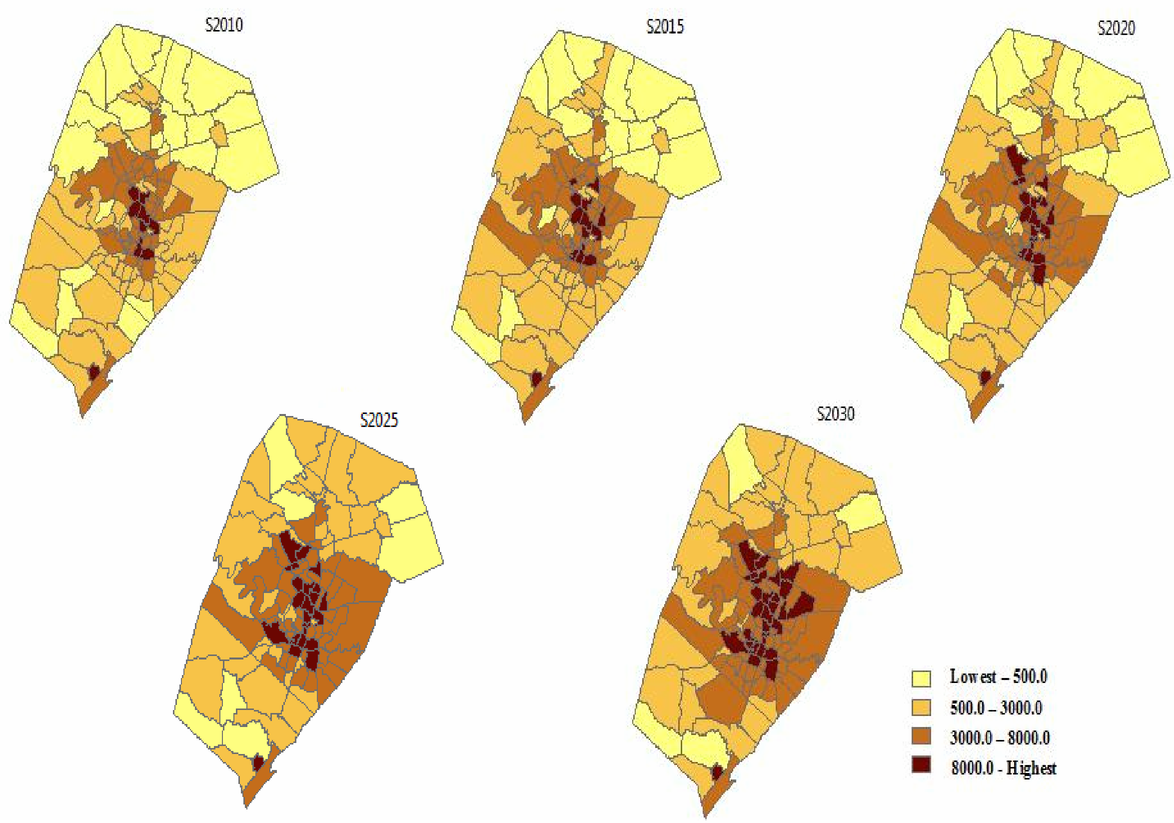


Fig 16: G-LUM forecast by district for services employment for the three-county Austin region

G-LUM predicts central Austin to have high levels of service employment by 2030, but TELUM forecasts this growth to happen north of the city center. The G-LUM predictions and TELUM predictions are nearly the same for the zones in the Hays County. However their predictions differ significantly for the Williamson County. G-LUM forecasts that there will be a significant increase in the levels of service employment for zones in Williamson County but TELUM predicts only small increases in service employment for these zones.

Total Employment

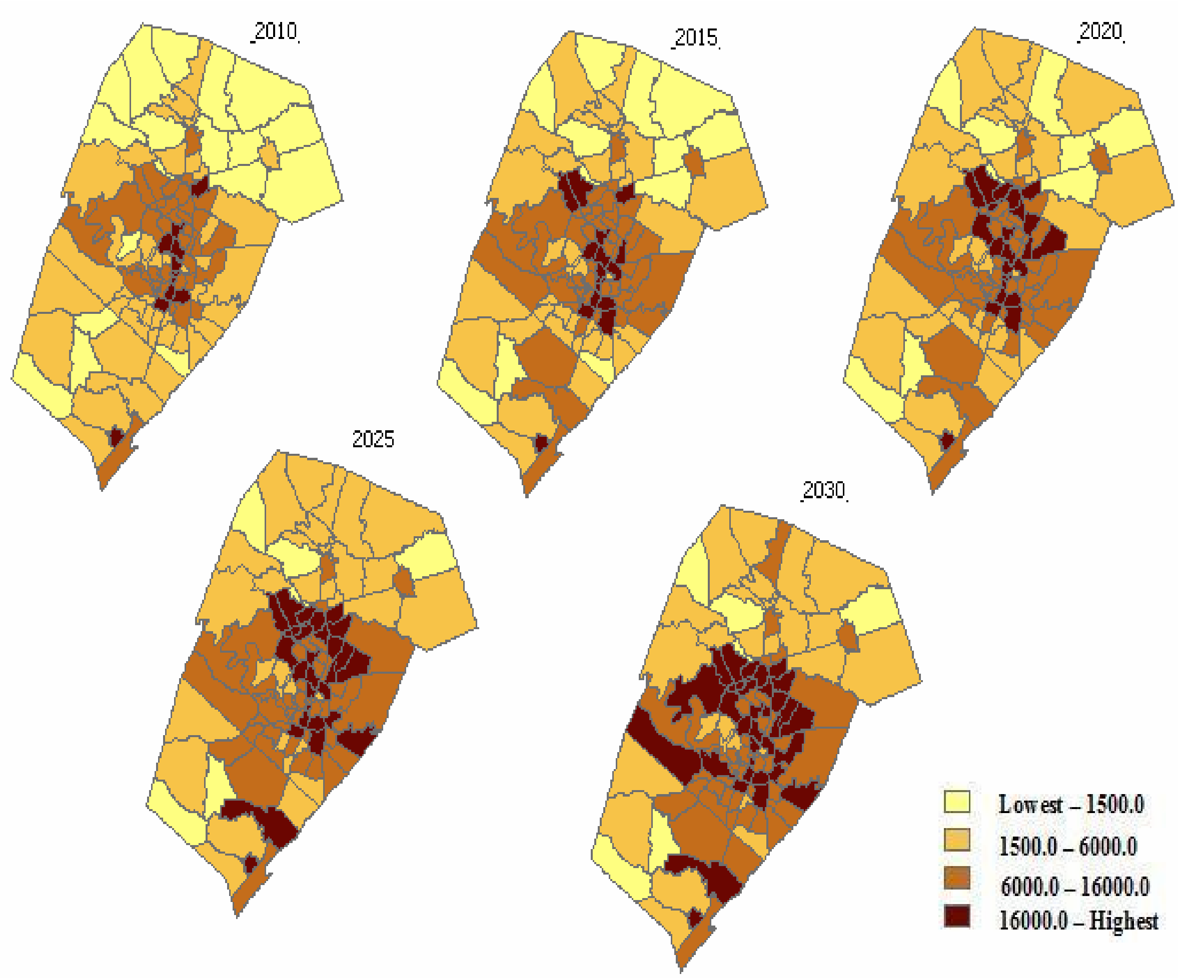


Figure 17: TELUM forecast by district for total employment for the three-county Austin region

The total employment is predicted to increase in almost all the zones in the three-county region. In particular, total employment in the zones north of Austin city and zones located in the city and in the outskirts of the city is predicted to increase rapidly.

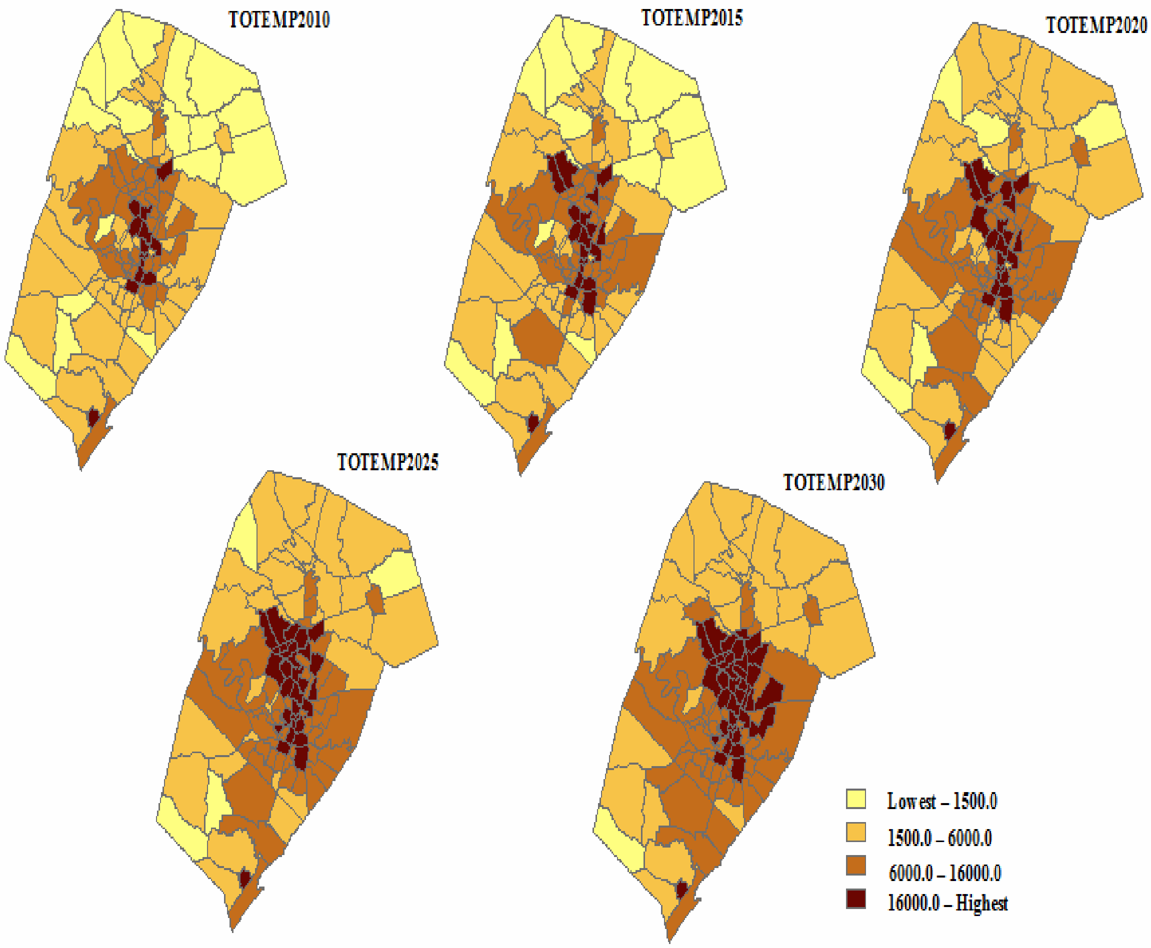


Figure 18: G-LUM forecast by district for total employment for the three-county Austin region

G-LUM, on the other hand, predicts a more uniform increase in the total employment. The high employment zones are located in the city center and to the north of the city. The major difference in the forecasted spatial distribution of G-LUM and TELUM is in the zones of Williamson County. TELUM predicts only small increases in total employment in most of the zones of Williamson County. G-LUM, on the other hand, predicts substantial increases in the total employment in almost all the zones in the Williamson County.

Low income households

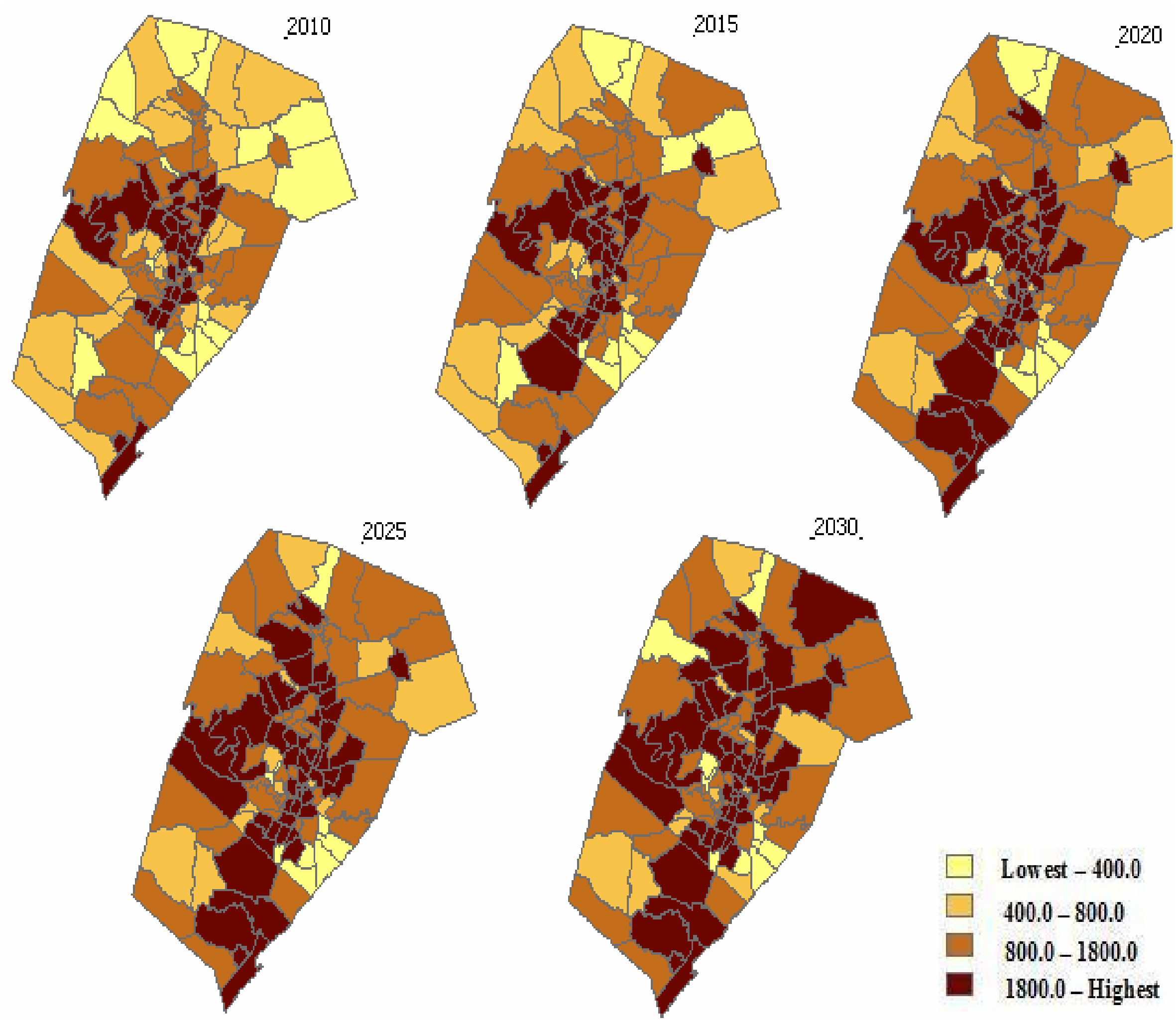


Figure 19: TELUM forecast by district for low income households for the three-county Austin region

TELUM predicts the number of low income households to increase in most of the zones. A large number of these households are predicted to be located in zones close to Austin city center and to the west of the city. Some zones in Hays and Williamson counties are also predicted to have a high number of low income households by 2030.

Figure 20: G-LUM forecast by district for low income for the three-county Austin region

The G-LUM forecast matches the TELUM forecast for most of the zones in Travis and Hays counties. In Williamson County, G-LUM predicts small changes in the number of low income households. TELUM, on the contrary, predicts a large increase in the number of low income households here.

Below average income households

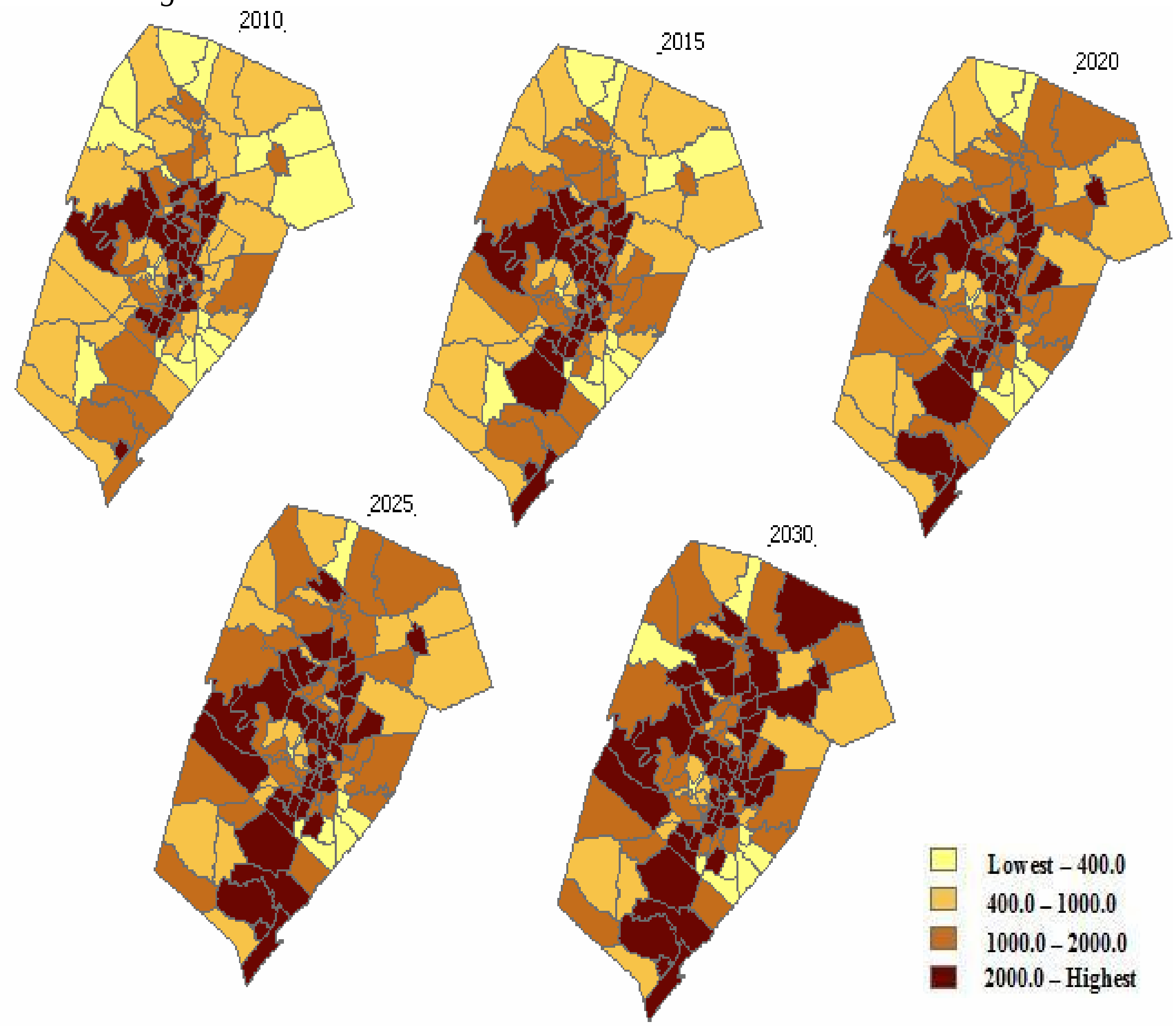


Figure 21: TELUM forecast by district for below average income households for the three-county Austin region

Below average income households are predicted to increase in most of the zones in the three-county region by TELUM. Zones close to city center and to the west, along with a couple of zones in Williamson and Hays counties, are predicted to have a high number of these households by 2030.

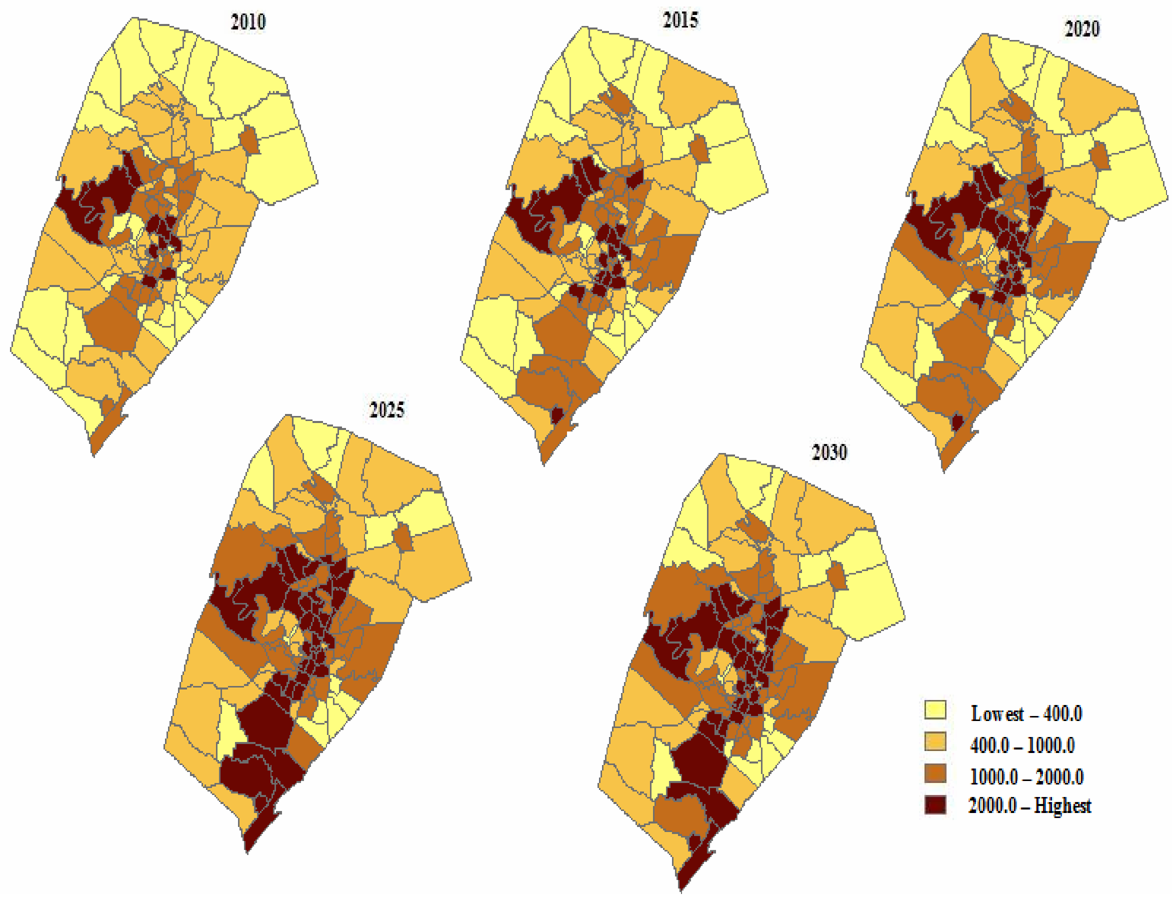


Figure 22: G-LUM forecast by district for below average income households for the three-county Austin region

G-LUM also forecasts the below average income households to be concentrated in zones to the west of city and in some zones in Hays County. However the predictions from G-LUM are significantly different from the TELUM predictions for zones in Williamson County and zones located to the east of the city. TELUM predicts the number of below average income households in these zones to be much higher than the G-LUM predictions.

Above average income households

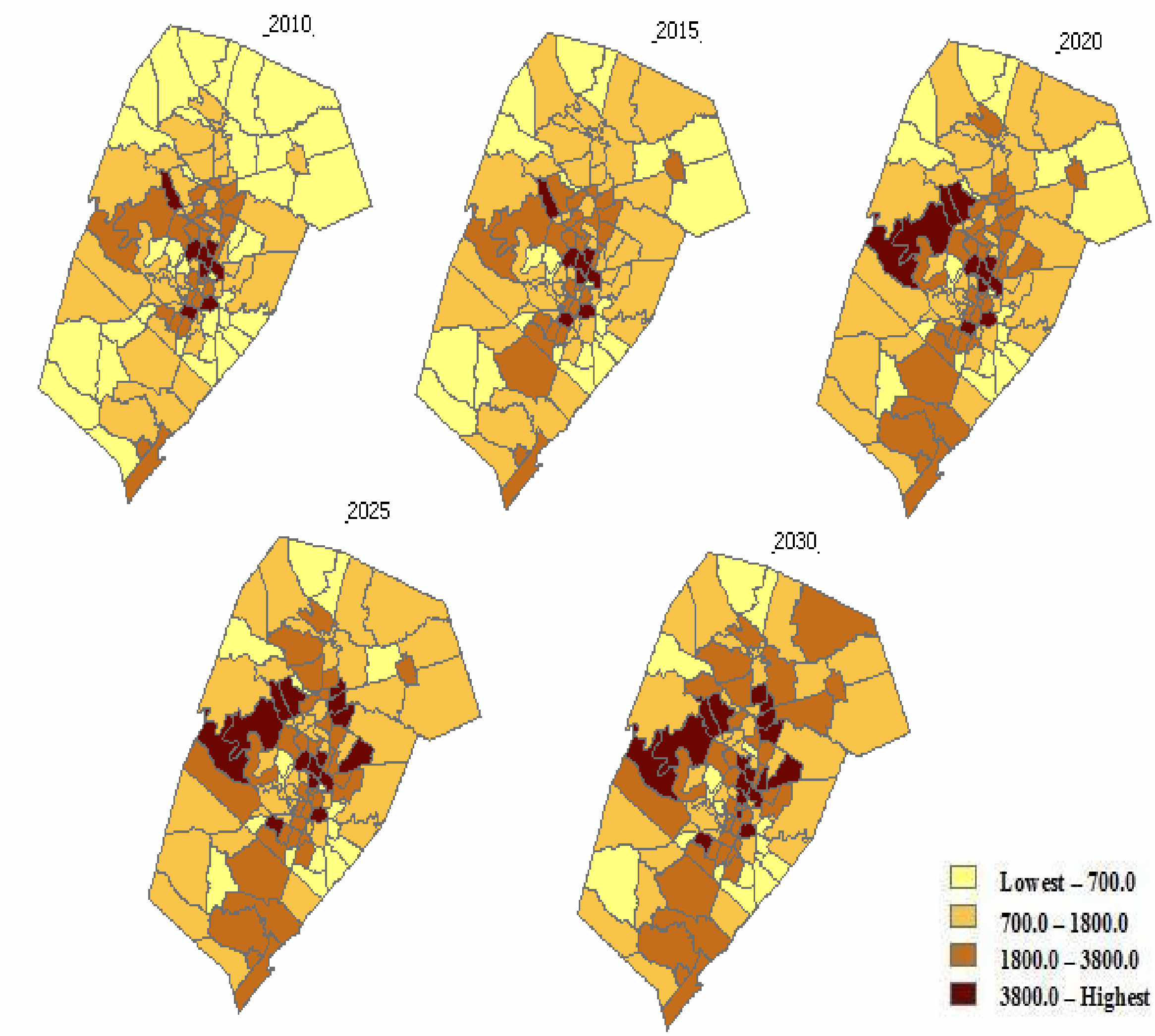


Figure 23: TELUM forecast by district for above average income households for the three-county Austin region

The number of above average income households is also predicted by TELUM to increase in most of the zones. A large number of above average households are predicted by TELUM to be located to west and north of Austin city in 2030.

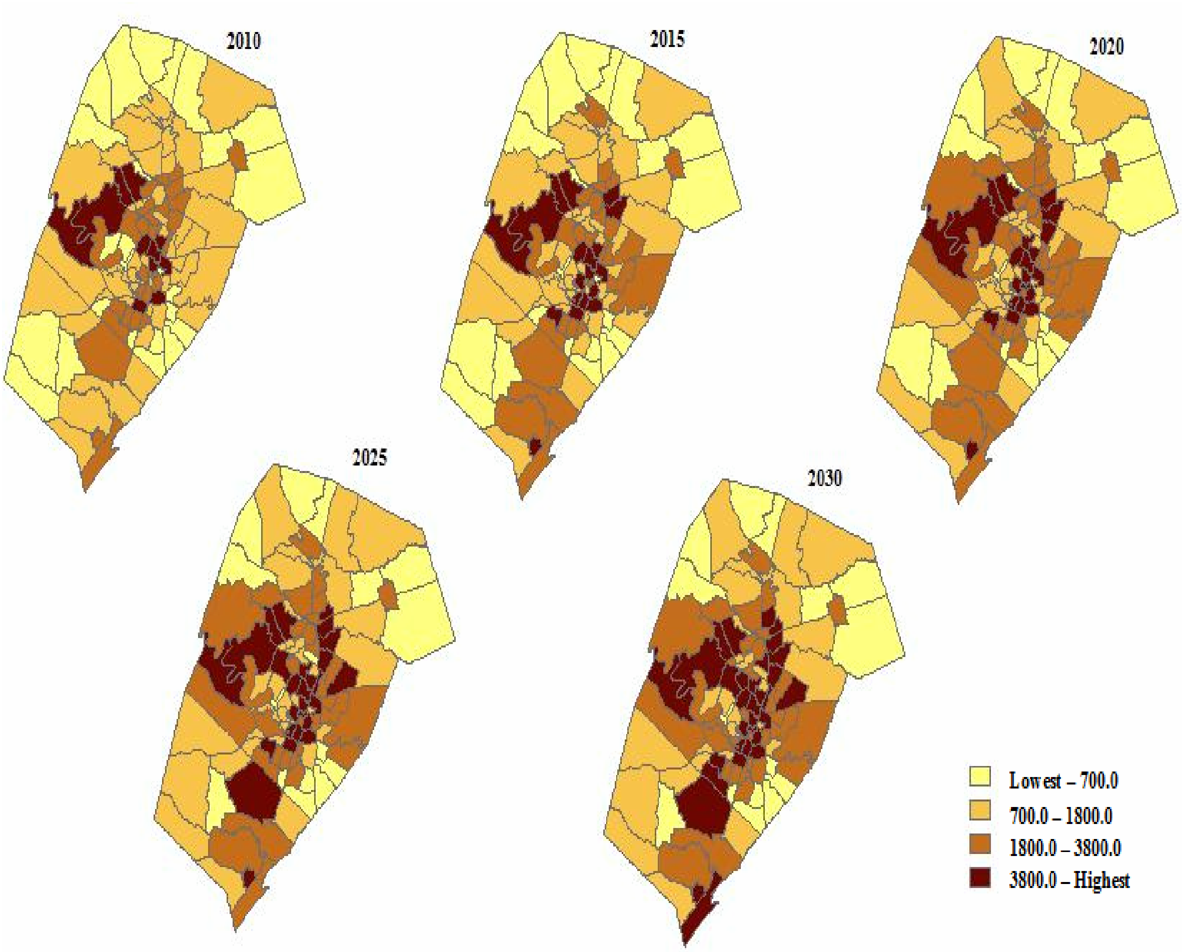


Figure 24: G-LUM forecast by district for above average income households for the three-county Austin region

The forecast of spatial distribution of the above average income households by G-LUM matches the TELUM forecast for most of the zones in Travis County. G-LUM predicts a couple of zones in Hays County to have large number of these households but TELUM does not. G-LUM also predicts small changes in the number of above average income households in Williamson County but TELUM on the other hand predicts significant change in the number of above average income households in these zones.

High income households

Figure 25: TELUM forecast by district for high income households for the three-county Austin region

A large number of high income households are predicted by TELUM to be located in central Austin, some zones to the west of Austin city and in a couple of zones in Hays County by 2030. TELUM also predicts the number of high income households to increase in most of the zones.

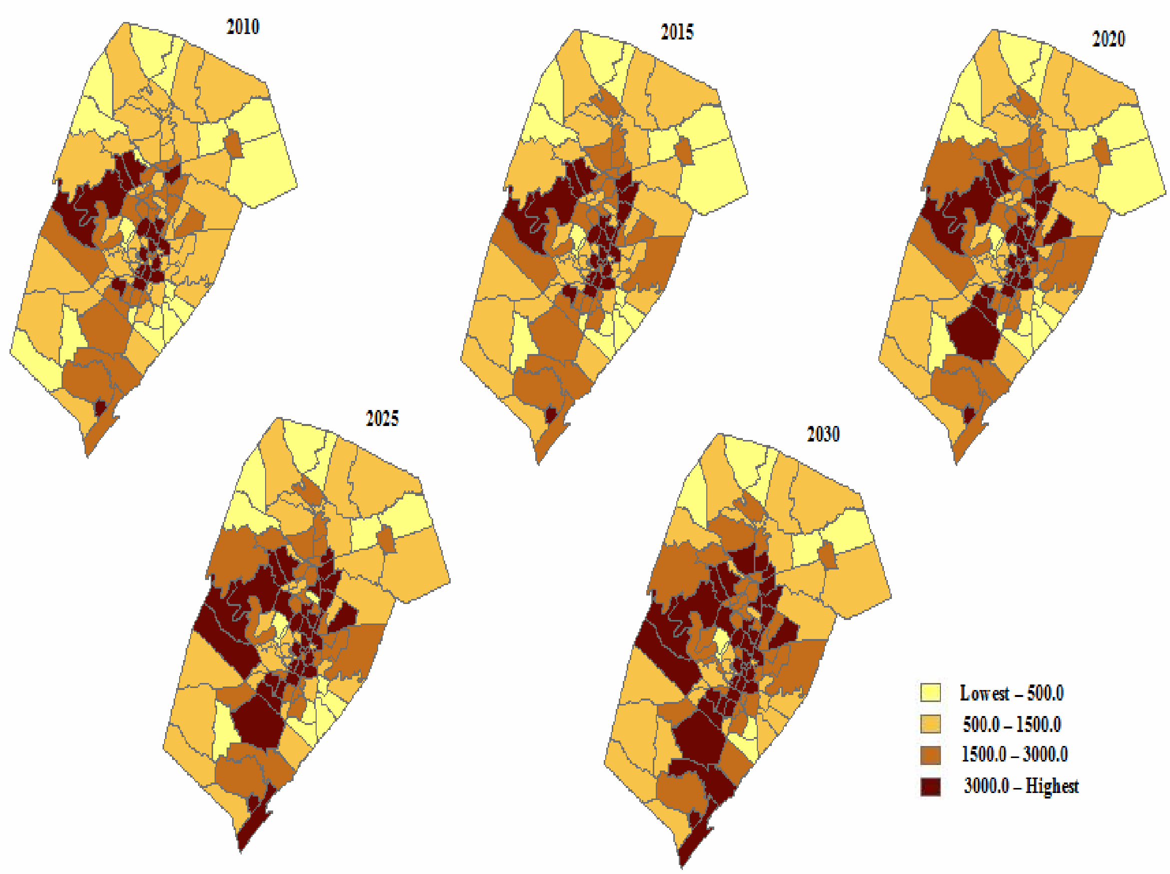


Figure 26: G-LUM forecast by district for high income households for the three-county Austin region

The predictions of the spatial distribution of the high income households of G-LUM are nearly the same as the TELUM predictions. The difference is again in some zones of Williamson County where TELUM predicts the number of high income households to be more than the G-LUM predictions.

4.2.2.3 Density Variation in Forecast Years

Density of a zone is the ratio of the number of jobs or households of a particular type present in the zone to the total land area of that zone. The density variation across the three county region predicted by TELUM and G-LUM during the forecast years is depicted using a series of maps. The zones are classified into four classes based on the magnitude of the density of the zone and each class is distinguished by a different color.

Total Employment

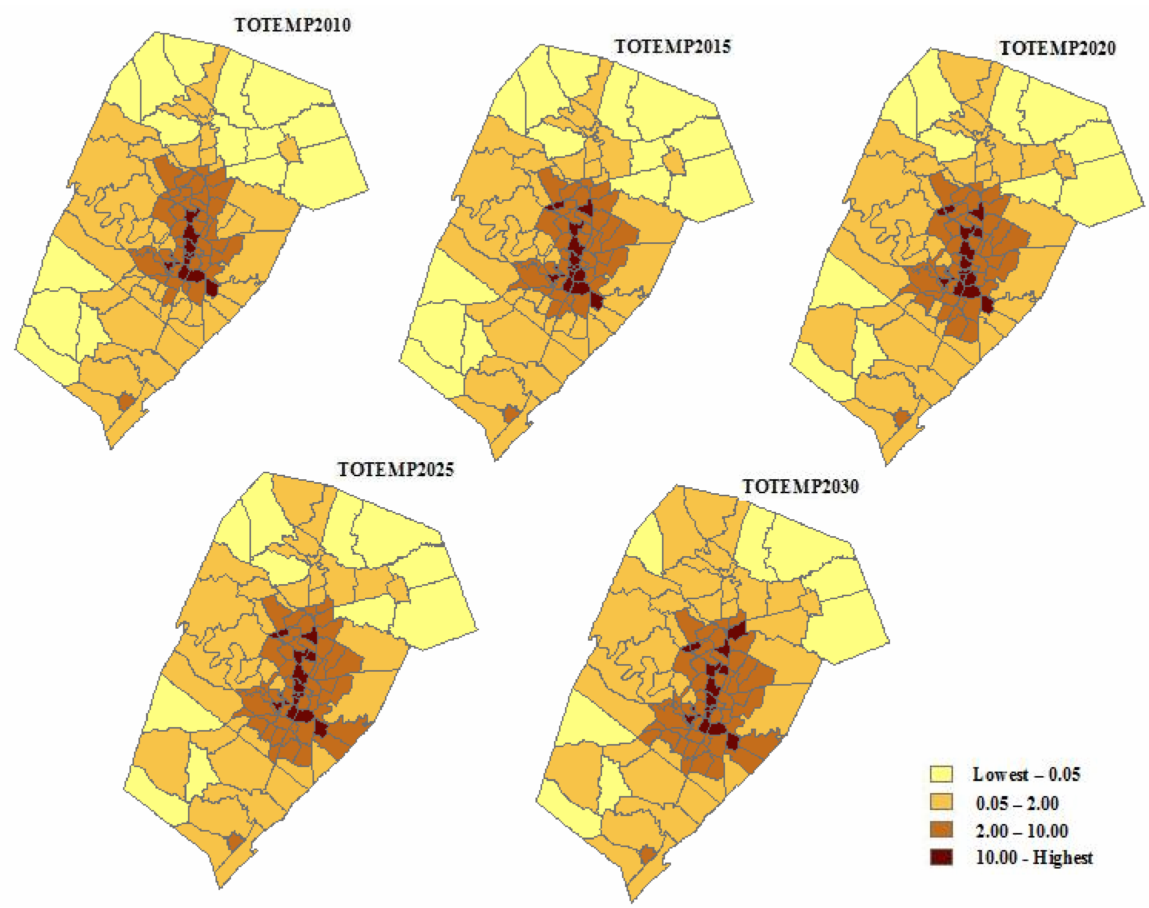


Figure 27: TELUM forecast by district for density of total employment for the three-county Austin region

The zones with high density of total employment in 2030 are predicted to be located in Austin city center and its outskirts, and also in few zones to the east of the city in the TELUM forecast. The major change across the forecast year is the increase in total employment density in many zones of Williamson County and also in few zones in the city and west of Austin.

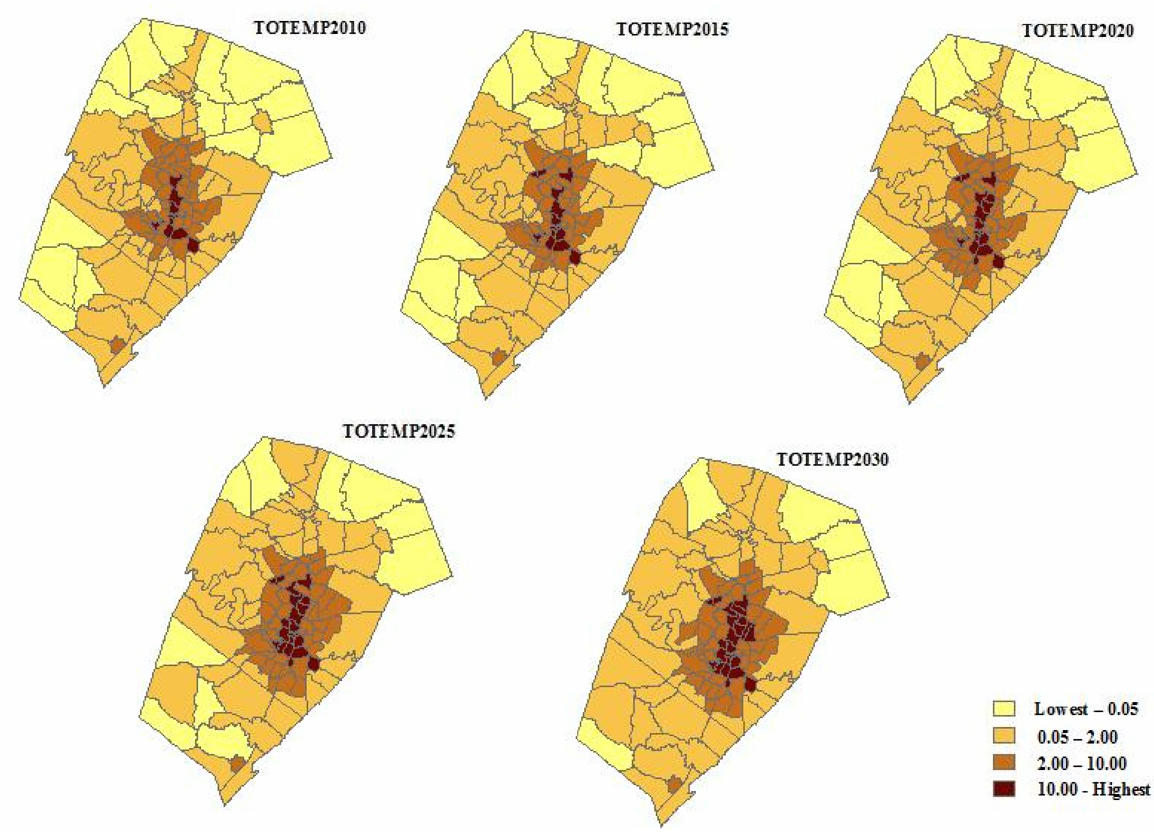


Figure 28: G-LUM forecast by district for density of total employment for the three-county Austin region

The G-LUM forecast for total employment density in the three-county region has a lot of similarities with the TELUM forecast. G-LUM predicts the number of high density zones in Austin city to be more than TELUM forecast. TELUM predicts the total employment to increase in a few zones to west of Austin city while G-LUM does not. Both forecasts are similar for the remaining zones.

Total Households

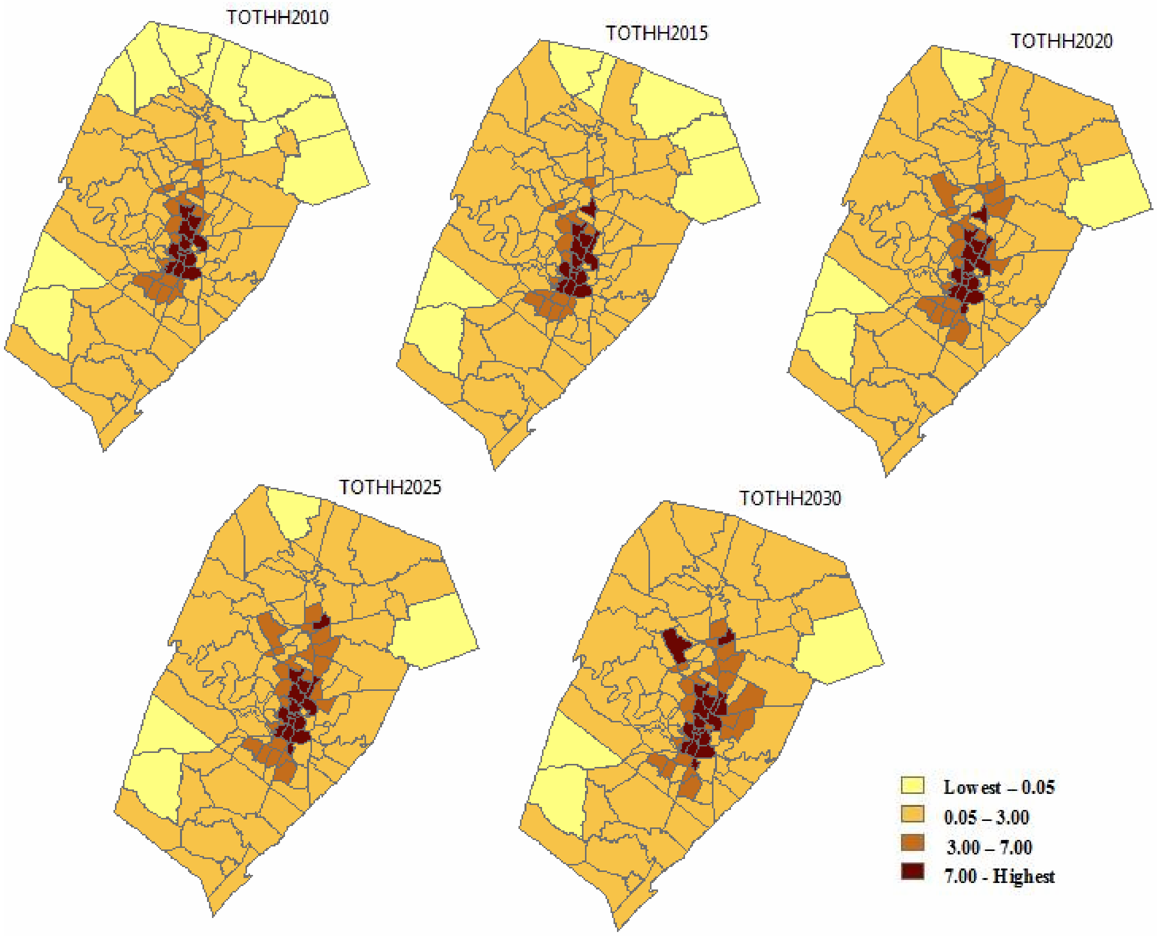


Figure 29: TELUM forecast by district for density of total households for the three-county Austin region

The high density zones of total households are predicted by TELUM to be located in Austin city and also in few zones in the outskirts. TELUM predicts that, during the forecast years, the total household density would increase in many zones of Williamson County. A few zones located to north of the city are also predicted to experience an increase in density.

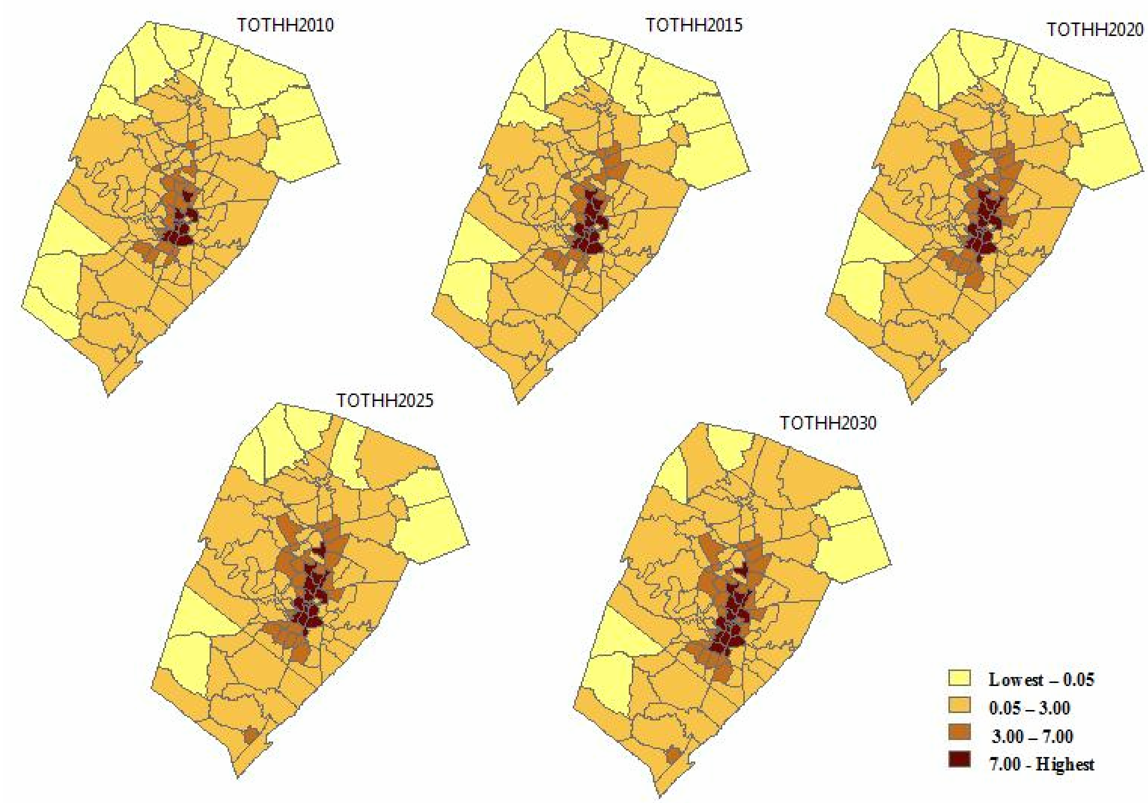


Figure 30: G-LUM forecast by district for density of total household for the three-county Austin region

G-LUM predicts the density of total household to be lower that of TELUM forecasts for a few zones located north of the city and in Williamson County. The G-LUM forecast for household density in the remaining zones of the region are very similar to the TELUM forecast.

4.2.2.4 Summary

TELUM predicts an increase in total employment in most of the zones in Travis County while G-LUM predicts an increase only in zones in the City of Austin. G-LUM predicts a significant increase in total employment in many zones of Williamson County but TELUM does not. The spatial distribution of low income households and below average income households predicted by TELUM is completely different from that of G-LUM. However, there were close similarities between the forecasts of TELUM and G-LUM for above average income and high income households. Hence, in general, there is a significant difference in the spatial distribution of employment and household forecasted by TELUM and G-LUM. The source for such distinctions is very likely from the unknown formulation of LANCON in TELUM. The user manual of TELUM missed LANCON's specification, and G-LUM follows the formulas in Putman's book to create LUDENSITY (1991).

4.3 TAZ Implementation

G-LUM was used to forecast the future distributions of employment and households in the Austin region by TAZ to investigate the influence of zone size on predictions generated by the G-LUM equations. TELUM cannot generate the forecast of Austin region by TAZ since the average population of a TAZ in the three-county region is less than 3000. The developers of TELUM have concluded that TELUM works best when the average population of each zone lies between 3,000 and 10,000.

4.3.1 Calibration results

The G-LUM results from calibrating RESLOC, EMPLOC and LUDENSITY sub-models using the three-county data by TAZ are presented in this section. The entropy corresponding to each set of parametric values is also displayed.

Table 15: RESLOC parameters – calibrated using G-LUM for Austin TAZs

Parameter	Low-HH	BAvg-HH	AAvg-HH	High-HH
η	3.47E-07	5.17E-08	8.49E-08	2.96E-08
α	0.85136	0.90659	0.87422	0.86866
β	-0.04816	-0.04942	-0.05021	-0.05147
q	0.1205	0.11889	0.10843	0.10308
r	0.43879	0.44434	0.451	0.45126
s	0.54101	0.53079	0.51165	0.50224
B (HHtype,Low)	0.60071	0.5956	0.67225	0.67098
B (HHtype, BAvg)	0.53976	0.52214	0.53548	0.52955
B (HHtype,Aavg)	0.66588	0.6682	0.66292	0.53555
B (HHtype,High)	0.58261	0.56927	0.57092	0.66366
Entropy	6.66E+05	4.88E+05	9.63E+05	8.98E+05

Table 16: EMPLOC parameters – calibrated using G-LUM for Austin TAZs

Parameter	Basic	Retail	Serv	Air	College	ED1	ED2
λ	0.052775	0.0896	0.1699	0.0617	0.5483	0.0034	0.052775
α	9.7433	5.4862	8.4699	4.1188	5.0226	1.6718	9.7433
β	-0.00285	-0.0017	-0.0026	-0.001	-0.002	-0.016	-0.00285
a	0.14071	0.303	0.3307	1.0643	0.7473	1.2671	0.14071
b	4.07E-07	0.0505	3.07E-07	0.0013	2.07E-07	0.0205	4.07E-07
Entropy	1.46E+06	7.81E+05	2.32E+06	2.43E+04	-334.169	1.93E+04	1.46E+06

Table 17: LUDENSITY parameters – calibrated using G-LUM for Austin TAZs

Parameter	Residential	Industry	Commercial
Constant	0.002	0.1824	0.6041
PerDev	0.8177	0.1043	0.9285
PerBas	-0.0776	0.005	-0.0281
PerComm	-0.1007	0.5438	-1.6159
PerLI	-0.0396	-0.0534	-0.0721
PerHI	-0.0329	0.0167	-0.0359
Developable	0.8698		
Entropy	3.49E+06	6.38E+04	2.89E+06

4.3.2 G-LUM Forecast by TAZs

The forecast is generated by G-LUM from 2010 to 2030 in increments of five years. The output generated by the G-LUM is mapped using Arc GIS for two employment and household categories. The forecast produced by G-LUM is also aggregated to the district level to facilitate a comparison with the forecast generated by G-LUM by district for the three-county region of Austin. The R^2 and weighted R^2 value of the forecast years for each of the employment and household type are also computed.

4.3.2.1 R^2 and weighted R^2 values

Table 18: EMPLOC parameter R^2 values using G-LUM for Austin TAZs

Forecast Year	Basic	Retail	Services	Air	ED1	ED2
2010	0.947	0.913	0.928	0.999	0.978	0.988
2015	0.873	0.818	0.853	0.999	0.829	0.964
2020	0.813	0.739	0.788	0.999	0.515	0.946
2025	0.776	0.691	0.74	0.999	0.227	0.945
2030	0.776	0.674	0.719	0.999	0.063	0.944

Table 19: RESLOC parameter R^2 values using G-LUM for Austin TAZs

Forecast Year	Low	BAvg	AAvg	High
2010	0.971	0.929	0.935	0.919
2015	0.917	0.811	0.819	0.784
2020	0.875	0.721	0.728	0.689
2025	0.85	0.418	0.685	0.641
2030	0.85	0.678	0.685	0.641

Table 20: Weighted EMPLOC parameter R^2 values using G-LUM for Austin TAZs

Forecast Year	Basic	Retail	Services	Air	ED1	ED2
2010	0.949	0.906	0.933	0.999	0.953	0.983
2015	0.891	0.81	0.886	0.999	0.763	0.95
2020	0.841	0.728	0.842	0.999	0.45	0.923
2025	0.809	0.691	0.813	0.999	0.199	0.922
2030	0.81	0.696	0.803	0.999	0.058	0.922

Table 21: Weighted RESLOC parameter R^2 values using G-LUM for Austin TAZs

Forecast Year	Low Inc	BAvg Inc	AAvg Inc	High Inc
2010	0.976	0.956	0.944	0.903
2015	0.93	0.87	0.831	0.724
2020	0.896	0.796	0.737	0.596
2025	0.876	0.442	0.689	0.53
2030	0.876	0.757	0.689	0.53

4.3.2.2 Forecasts from 2010 to 2030

This section contains the forecasts generated by G-LUM for the three-county region by TAZs. The TAZs are then aggregated to districts to make a comparison with the forecasts generated by G-LUM by districts for the same region. The zones are again classified into four types based on the magnitude of employment and household type present in the zone.

Basic employment

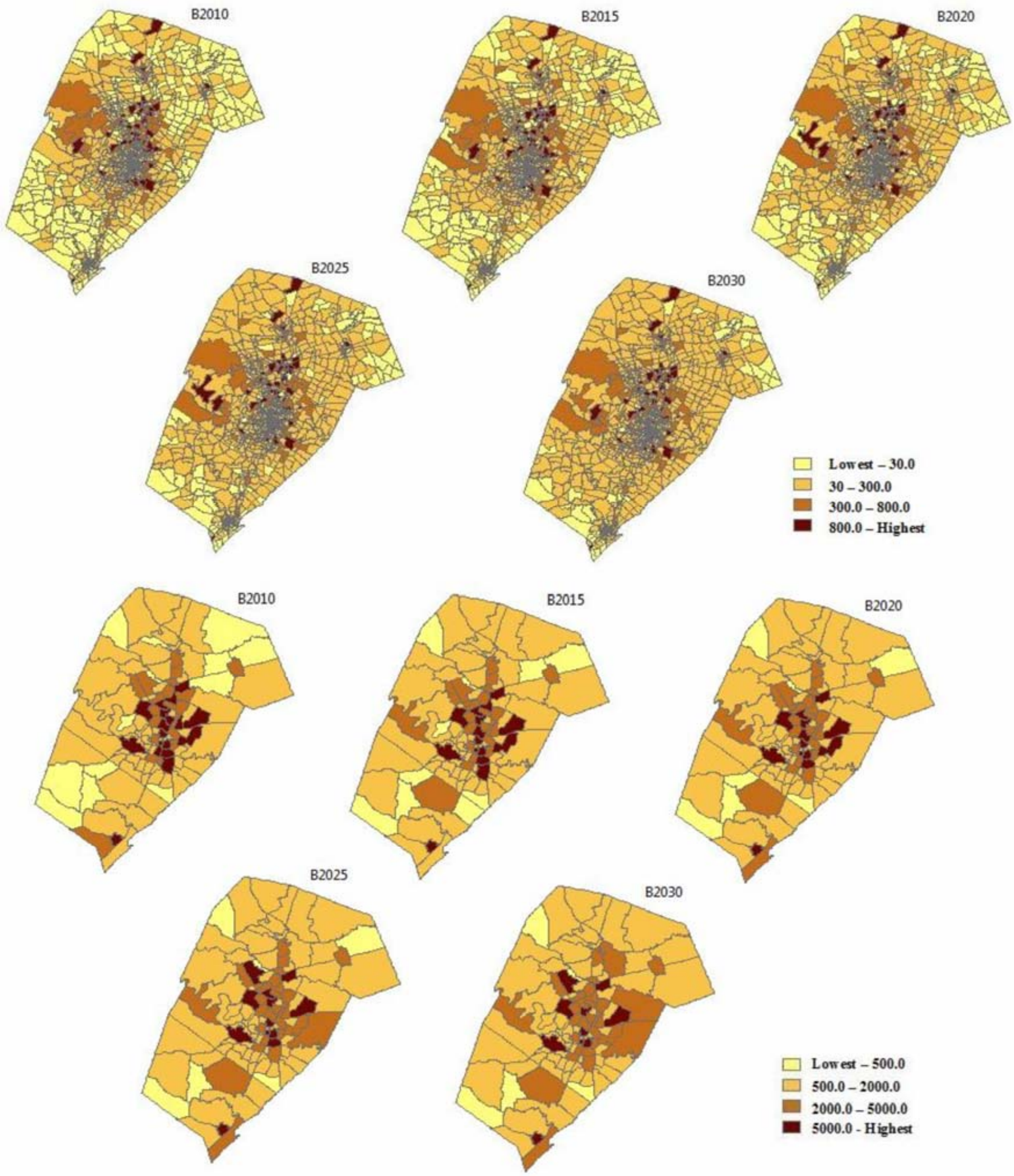


Figure 31: G-LUM code forecast by TAZ for basic employment for the three-county Austin region

G-LUM predicts that the basic employment in zones in the City of Austin would decrease while the zones situated east of the city would experience significant increase. Most of the zones in Hays and Williamson counties are projected to experience an increase in basic employment. In comparison, G-LUM predictions by district suggest that increase in basic employment would be mainly concentrated in the central districts of Travis County.

Total employment

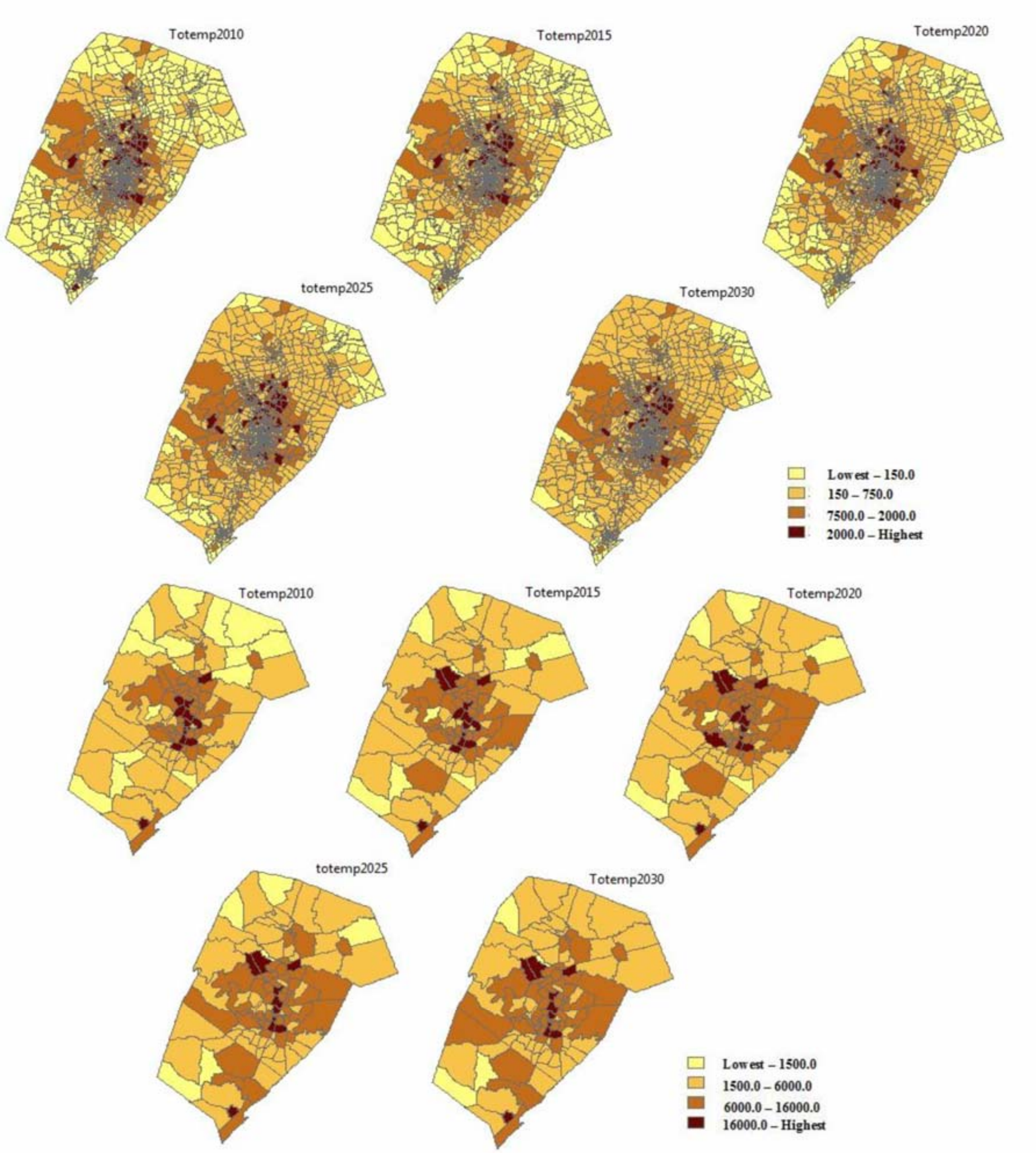


Figure 32: G-LUM forecast by TAZ for total employment for the three-county Austin region

The total employment in predictions generated by G-LUM by TAZ is concentrated mainly in the central and eastern districts of Travis County and in a few districts to the east of Hays County. The rest of the districts are predicted to experience a uniform increase in the total employment. On the other hand, there is a high level of total employment in many districts in central Travis County in G-LUM predictions by district. The predictions are roughly the same for the rest of the districts.

Low income households

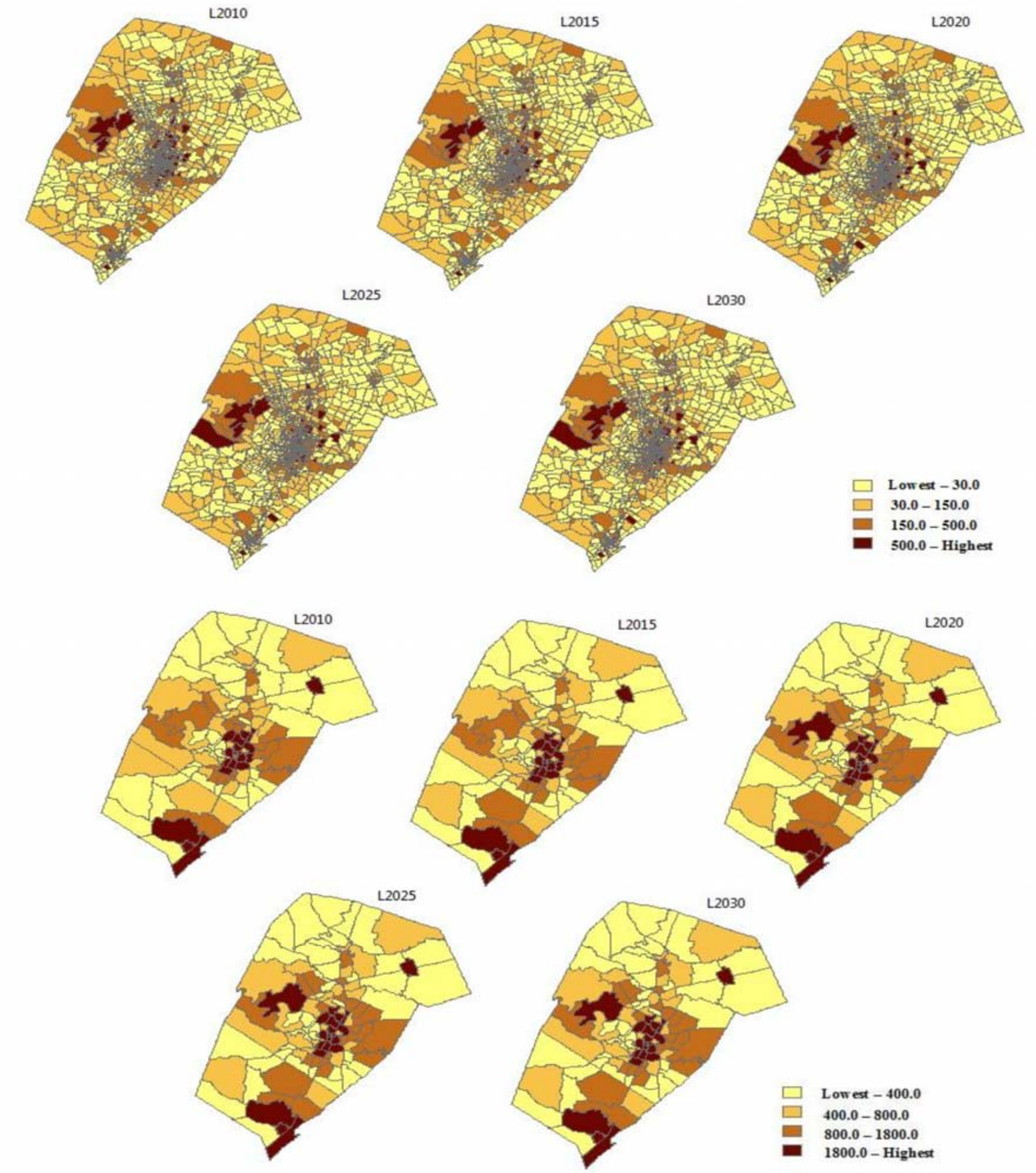


Figure 33: G-LUM forecast by TAZ for low income households for the three-county Austin region

By 2030, few zones in central Austin and in Hays County are predicted to have many low income households the in G-LUM forecast by TAZs. A significant number of low income households are also predicted in zones to the east of Travis County and also in a few zones in Hays County. The rest of the zones have a low number of low income households. While in the G-LUM forecast by district there is a high number of low income households in zones that are in central Travis and Hays counties and also in a few zones in the east and west of Travis County.

High income households

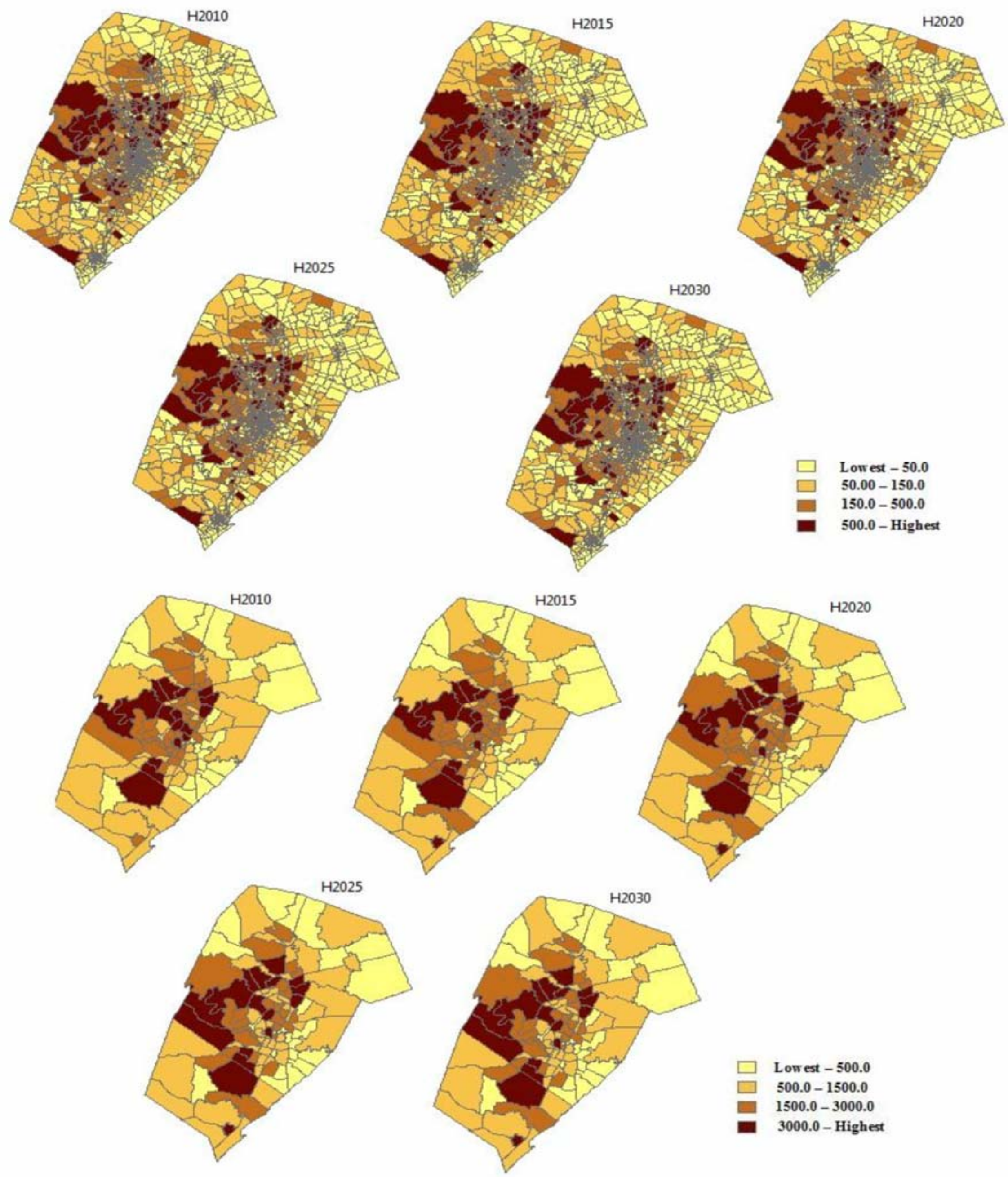


Figure 34: G-LUM forecast by TAZ for high income households for the three-county Austin region

The G-LUM predictions by TAZ suggest that high income households would be located densely in zones in the west of Travis County by 2030. The district level G-LUM predictions also produce similar output. The difference in the two forecasts lie in zones that are in the center of Travis County, which is predicted to have a large number of high income households in G-LUM predictions by districts. In comparison in the G-LUM prediction by TAZ these zones do not have a high number of high income households.

4.3.2.3 Density Variation in Forecast Years

The density variation in G-LUM forecasts by TAZ from 2010 to 2030 is presented in a series of maps. Each map represents the spatial distribution of density across the three-county region. The zones are classified into four classes depending on the magnitude of density and the classes are assigned different colors.

Total Employment

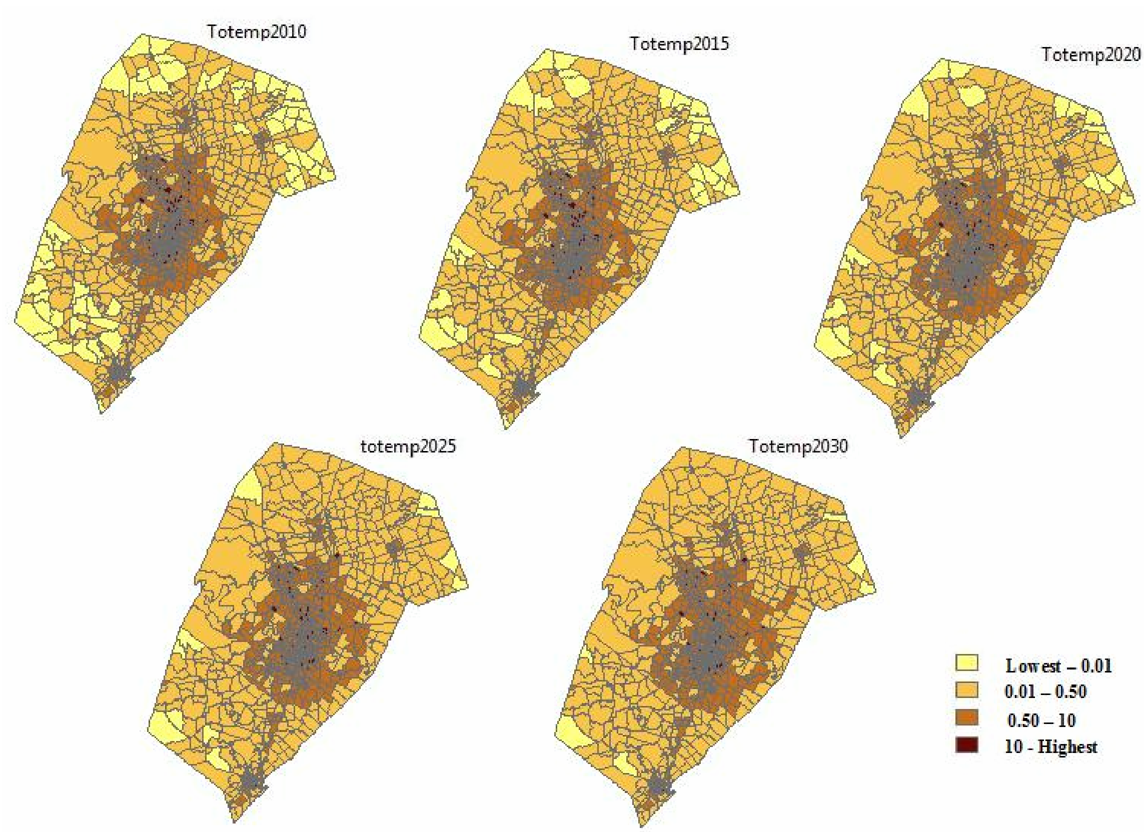


Figure 35: G-LUM forecast by TAZ for density of total employment for the three-county Austin region

G-LUM predicts that in 2030 the TAZs with high density of total employment will be located in the center of Travis County while the majority of the remaining TAZs would have similar employment density. The employment density has increased during the forecast in most of the zones in Hays and Williamson counties that had low employment in the base year.

Total Households

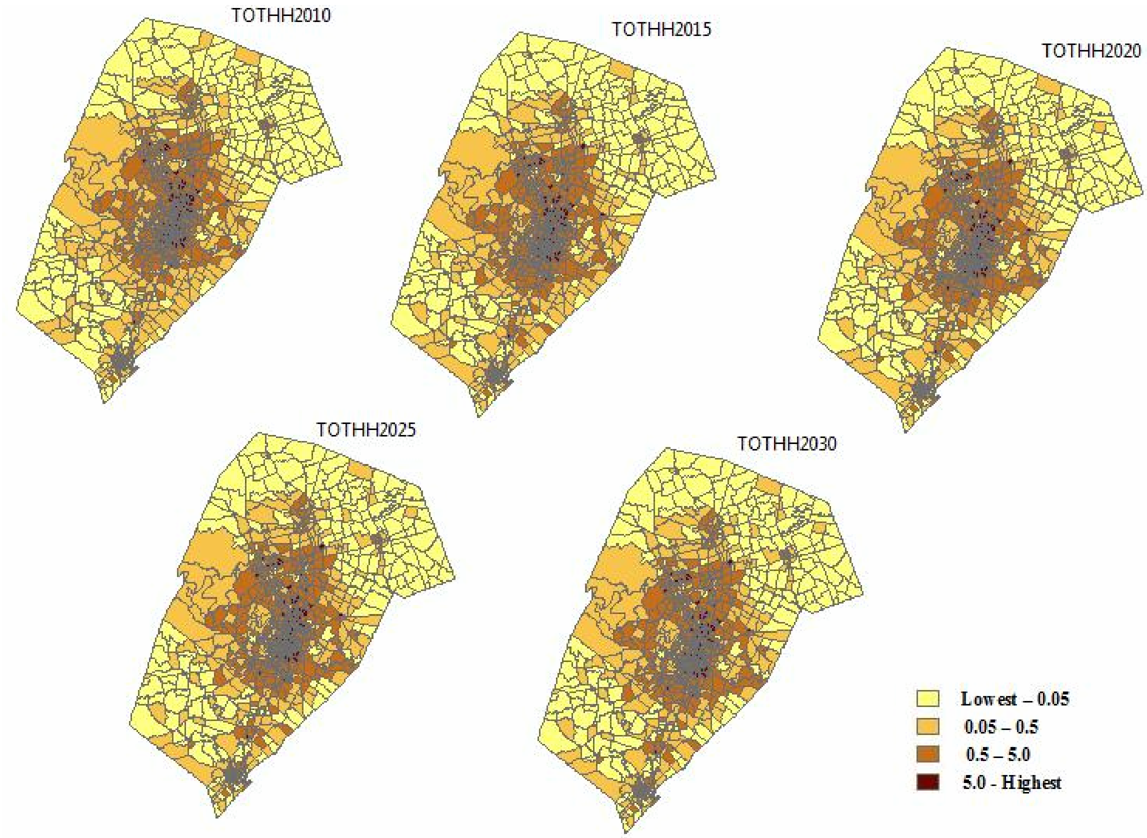


Figure 36: G-LUM forecast by TAZ for density of total household for the three-county Austin region

The high density zones of total households are predicted in the G-LUM forecast by TAZ to be located in the center of Travis County in 2030. Most of the zones in Williamson and Hays counties are predicted to have low household density. The G-LUM forecast by TAZ does not predict any major change in the spatial distribution of density of total household during the forecast years.

4.3.2.4 Summary

The spatial distributions of total employment, basic employment, low income households and total households in the City of Austin generated using G-LUM by district and by TAZ are considerably different. So the size of a zone has a big influence on the predictions using G-LUM equations. The TELUM user manual recommends that the ITLUP equations work best when the size of the zone is such that the average population per zone lies between 3,000 and 10,000. However, the TELUM user manual does not cite any reference on research conducted examining the influence of size of the zone on the prediction generated by ITLUP. So it is not clear how these limits on the zone size were derived.

5. Waco Metropolitan Region Implementation

The forecast of the spatial distributions of employment and household of the Waco region, generated by TELUM and G-LUM is discussed in this section. G-LUM was also used to generate the forecast of the Waco region by TAZ to gauge the influence of zone size on the predictions. The base year of implementation is 2005, and 2000 was chosen as the lag year since TELUM generates forecast in five year increments. The inter-zonal travel time in the year 2005 was used by both TELUM and G-LUM. The travel time was assumed to remain constant throughout the forecast years.

Employment in the Waco region is categorized into the following types:

i) Basic
ii) Retail
iii) Services
iv) Other types

Households in the Waco region are classified into:

i) Low income
ii) Below average income
iii) Above average income
iv) High income

The data for the Waco region were obtained from Wilbur Smith Associates.

The division of the Waco region into districts and TAZs is shown below. The red line shows the district boundary while the blue line shows the boundary of TAZs. Please also note the direction of orientation of the map indicated in top right corner of the figure.

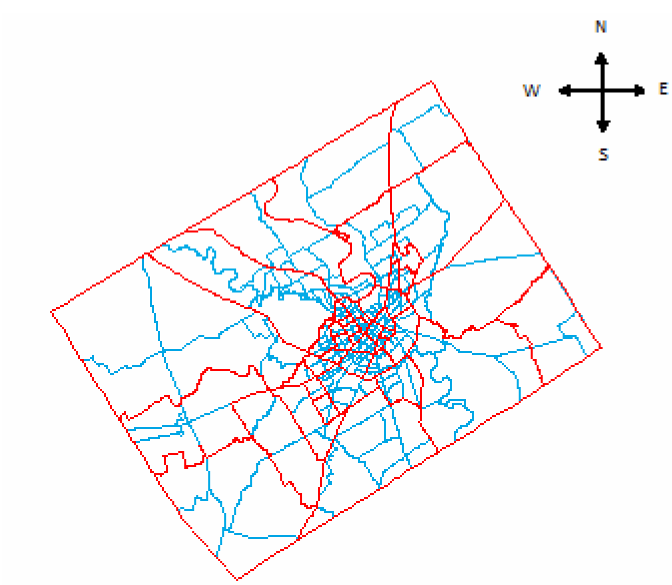


Figure 37: Waco metropolitan region

5.1 Base Year and Lag Year Data

The spatial distribution of the employment and households by type for the base year (2005) and lagged year (2000) is presented here.

5.1.1 Basic Employment

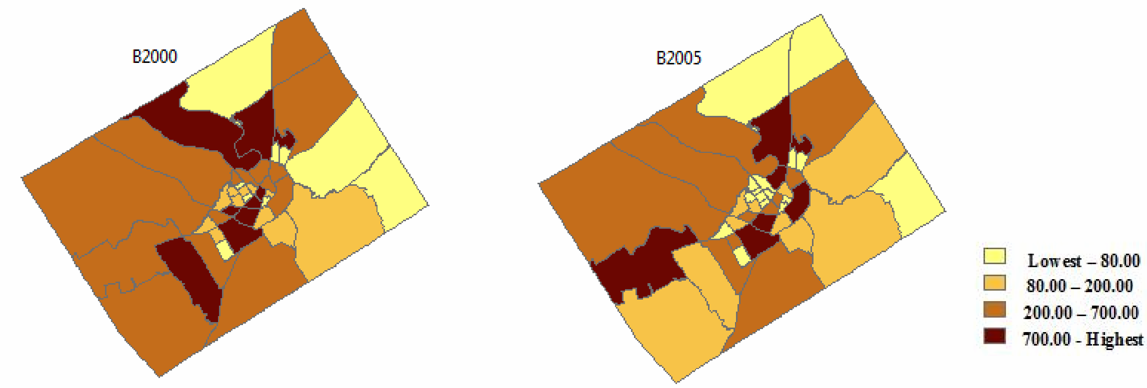


Figure 38: Spatial distribution of basic employment in base and lag years for the Waco region

Most of the zones with dense basic employment are located towards the west of the Waco region in the base year. There are also a few zones with high basic employment in the center of the region. There was a reduction in basic employment from 2000 to 2005 in a couple of zones in south of the region.

5.1.2 Retail Employment

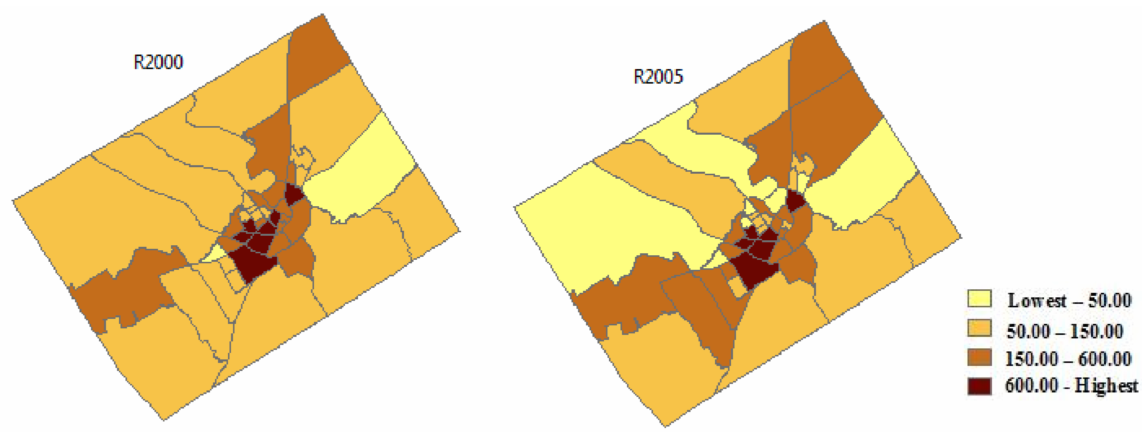


Figure 39: Spatial distribution of retail employment in base and lag years for the Waco region

The retail employment is situated mostly in the southern and eastern parts of the Waco region in the year 2005. There are a couple of zones in the north of the region with high retail employment. Some of the zones on the east side of the Waco region experienced a reduction in retail employment while an increase in retail employment was observed in a few zones in the northern and southern parts of the region in between 2000 to 2005.

5.1.3 Service Employment

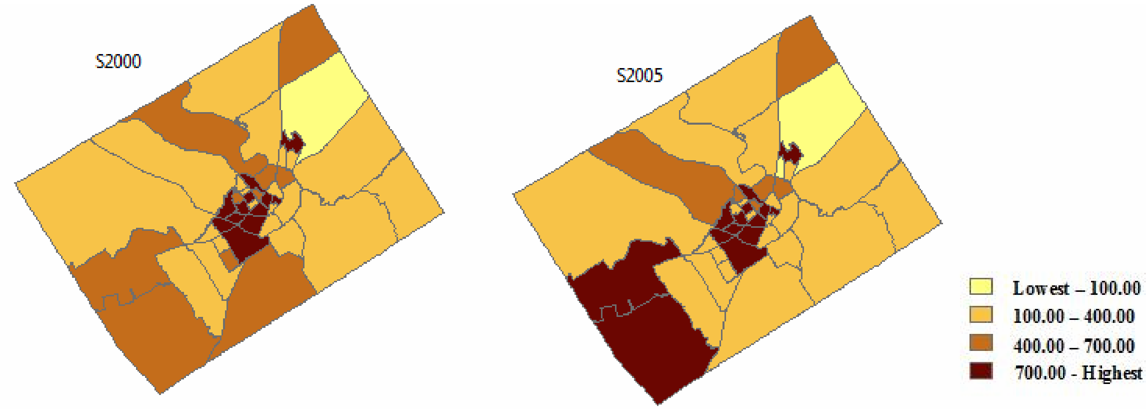


Figure 40: Spatial distribution of service employment in base and lag years for the Waco region

The zones with high levels of service employment are located in the southern and central parts of the Waco region. There is an almost uniform distribution of services employment for the rest of the zones in the base year. The major change in spatial distribution from lagged year to base year is the increase in services employment in a couple of districts in the south and also a decrease in services in a few zones in the east.

5.1.4 Total Employment

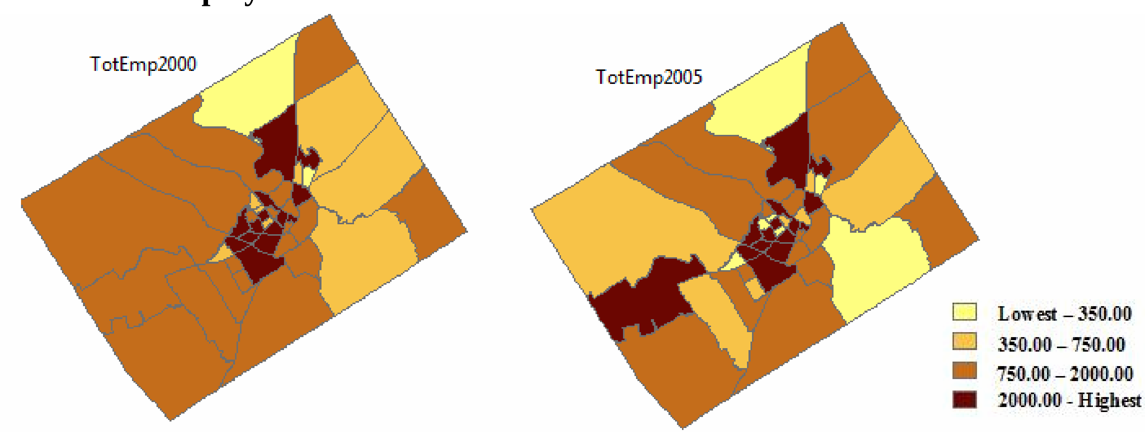


Figure 41: Spatial distribution of total employment in base and lag years for the Waco region

In the base year the zones with large number of total employment were located in the center of the Waco region and also in a couple of zones in the south. The total employment reduces as we move away from the center of the region. In comparison, in the lagged year 2000, the total employment seems to be uniformly distributed in the south and east parts of Waco with a few zones of high employment in the center. In between 2000 and 2005, a reduction in total employment was observed in a few zones situated to the east and west of the region.

5.1.5 Low Income Households

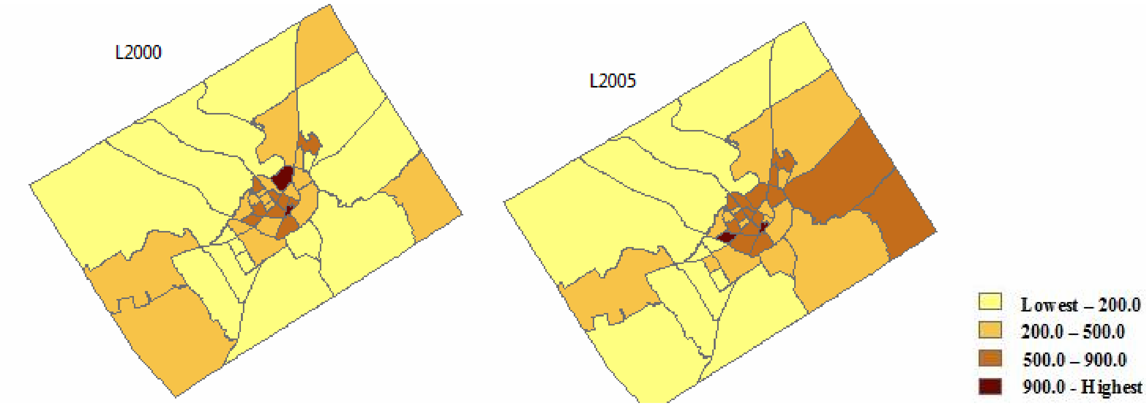


Figure 42: Spatial distribution of low income households in base and lag years for the Waco region

The low income households are located mainly in the east and central zones of Waco region in the base year. The low income households have increased in the central and eastern region of Waco between the base year and lag year. The rest of the zones have witnessed either a decrease in the low income households or minor changes.

5.1.6 Below Average Income Households

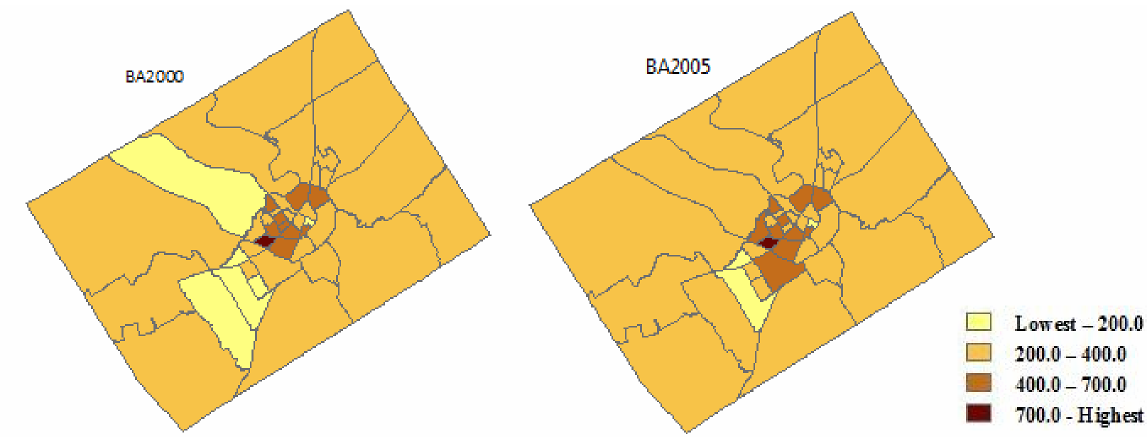


Figure 43: Spatial distribution of below average income households in base and lag years for the Waco region

The zones with high number of below average income households are located in the center of the Waco region in the base year. It is distributed almost uniformly throughout the rest of the Waco region. The significant change in the spatial distribution between 2000 and 2005 is the increase in below average households in zones in the central Waco region and its outskirts.

5.1.7 Above Average Income Households

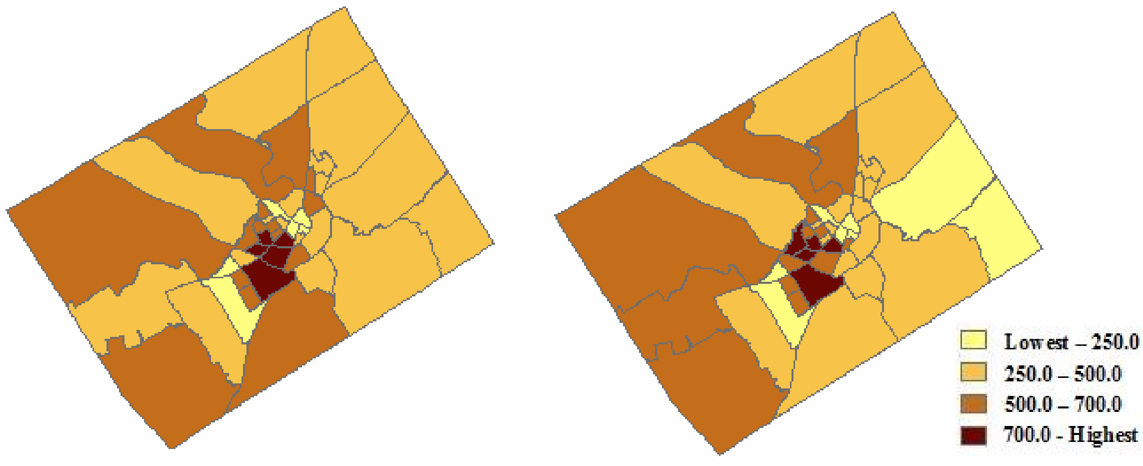


Figure 44: Spatial distribution of above average income households in base and lag years for the Waco region

In the base year, above average income households are concentrated mainly in the triangular region with its vertices at the center, east and south of the region. In between 2000 and 2005, the number of above average income households have increased in this triangular domain while at the same time above average income households have reduced in some zones situated to the east.

5.1.8 High Income Households

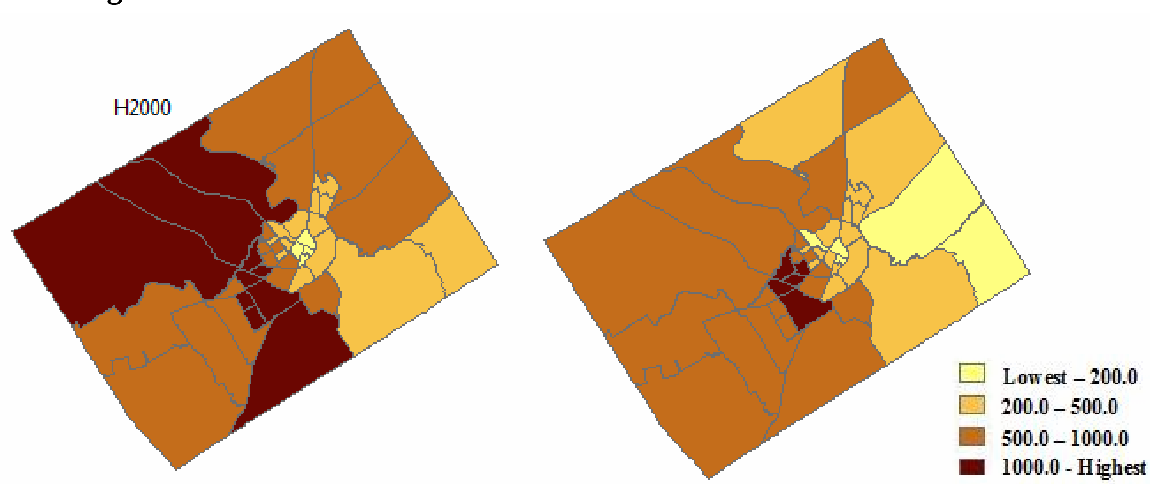


Figure 45: Spatial distribution of high income households in base and lag years for the Waco region

The high income households are distributed mainly in the southern and eastern zones of Waco. There are a couple of zones with large number of these households in the center of the region. There has been a significant reduction in number of high income households in almost all the zones except those located center and south of the Waco region in between the 2000 and 2005.

5.2 District Level Implementation

Waco has a total of 44 districts. The employment and household location district data for the base year and lag year was obtained by aggregating the data available at TAZ level. TELUM and G-LUM were used to generate forecast by districts from 2010 to 2030 in five year increments. The calibration results and the mapped output of the forecast generated by TELUM and G-LUM codes are discussed in the following sections.

5.2.1 Calibration Results

The parameters of ITLUP equation computed by TELUM and G-LUM for the Waco region by calibration are displayed in this section. The entropy value, which is a measure of goodness of fit, is computed for each set of parameters.

TELUM Calibration Results

Table 22: DRAM® parameters – calibrated using TELUM for Waco districts

Parameters	Low-HH	BAvg-HH	AAvg-HH	High-HH
η	0.604	0.218	0.023	0.286
α	0.584	0.864	1.013	0.784
β	-0.114	-0.326	0.092	-0.059
q	-0.108	-0.109	-0.071	-0.198
r	0.479	0.439	0.501	0.499
s	0.075	0.027	0.813	0.258
B (HHtype,Low)	5.413	-0.516	-4.064	-3.377
B (HHtype, BAvg)	4.229	8.593	1.674	0.302
B (HHtype,Aavg)	-0.911	0.516	8.223	3.356
B (HHtype,High)	-2.2717	-3.804	-0.37	5.12
Entropy	105840	106330	1.23E+05	1.66E+05

Table 23: EMPAL® parameters – calibrated using TELUM for Waco districts

Parameters	Basic	Retail	Serv	Other
λ	0.1677	0.1754	0.2408	0.3413
α	2.8193	2.8108	2.8184	2.7947
β	-0.0223	-0.0098	-0.0395	-0.0055
a	0.9788	0.7053	1.0178	1.649
b	0.1149	-0.0072	-0.2123	0.0007
Entropy	1.41E+05	9.25E+04	2.96E+05	102010

Table 24: LANCON parameters – calibrated using TELUM for Waco districts

Parameters	Residential	Industry	Commercial
Constant	0.059309	0.025122	0.137656
PerDev	-2.046	-0.236	1.1
PerBas	-0.579	0.967	0.973
PerComm	0.065	-0.892	-1.4
PerLI	-0.263	0.784	0.947
PerHI	-0.317	0.372	-0.333
Developable	0.787		
Entropy	1.26E+06	2.09E+06	3.10E+05

G-LUM code parameters

Table 25: RESLOC parameters – calibrated using G-LUM for Waco districts

Parameters	Low-HH	BAvg-HH	AAvg-HH	High-HH
η	0.0287	0.0599	0.0192	0.1231
α	0.5556	0.2068	4.712	3.0031
β	-0.0099	-0.0004	-0.0193	-0.01
q	-0.556	0.1767	0.1878	-0.0819
r	-9.571	5.2581	-0.6027	2.1755
s	0.8513	-0.1348	-0.4744	0.0716
B (HHtype,Low)	20.7034	-1.0138	11.2348	0.4038
B (HHtype, BAvg)	4.6583	33.7005	-3.687	0.8373
B (HHtype,Aavg)	1.0941	-0.7295	31.9376	10.6711
B (HHtype,High)	-33.6038	0.4439	6.4714	35.5861
Entropy	1.13E+05	1.09E+05	1.24E+05	1.69E+05

Table 26: EMPLOC parameters – calibrated using G-LUM for Waco districts

Parameters	Basic	Retail	Serv	Other
Λ	0.0373	0.0336	0.0083	0.0336
A	0.5893	1.2636	2.8372	1.2748
B	0.0031	-0.00049	-0.0558	-0.006
A	4.6397	1.1029	1.2792	1.8191
B	-0.4408	-0.08663	-0.263	0.0012
Entropy	1.44E+05	9.31E+04	2.98E+05	1.03E+05

Table 27: LUDENSITY parameters – calibrated using Matlab for Waco districts

Parameters	Residential	Industry	Commercial
Constant	0.0394	45.9755	3.81E+03
PerDev	1.4831	12.3301	-4.7166
PerBas	0.065522	-1.0057	-0.08
PerComm	2.0083	0.0086	-2.2052
PerLI	2.4696	0.4968	3.6589
PerHI	1.4216	0.4975	4.175
Developable	1.1351		
Entropy	1458200	2751300	365270

The entropy value of parameters computed by G-LUM is more than TELUM in all the cases. The difference may be because the solution algorithm of TELUM got stuck at a local optimum.

5.2.2 Comparison of TELUM and G-LUM Forecasts

The following section contains the mapped output of the predictions produced by TELUM and G-LUM for Waco region by districts. This section also contains a discussion on these forecasts and how the TELUM forecasts differ from the G-LUM forecasts.

5.2.2.1 R^2 and weighted R^2 values

The $\mathbf{R^2}$ and weighted $\mathbf{R^2}$ is an indicator of change in the spatial distribution of employment and households in the forecast year from that of the base year.

Table 28: EMPAL® parameter R^2 values using TELUM for Waco Districts

Forecast Years	Basic	Retail	Services	Other
2010	0.988	0.958	0.895	0.983
2015	0.974	0.893	0.762	0.959
2020	0.962	0.831	0.701	0.944
2025	0.945	0.795	0.673	0.933
2030	0.925	0.775	0.675	0.921

Table 29: DRAM® parameter R^2 values using TELUM for Waco Districts

Forecast Years	Low Inc	BAvg Inc	AAvg Inc	High Inc
2010	0.994	0.995	0.999	0.997
2015	0.887	0.979	0.973	0.889
2020	0.812	0.882	0.867	0.652
2025	0.78	0.255	0.677	0.436
2030	0.764	0.634	0.522	0.295

Table 30: Weighted EMPAL® parameter R^2 values using TELUM for Waco Districts

Forecast Years	Basic	Retail	Services	Other
2010	0.987	0.95	0.871	0.986
2015	0.97	0.876	0.707	0.966
2020	0.957	0.804	0.63	0.96
2025	0.939	0.767	0.594	0.957
2030	0.917	0.746	0.596	0.951

Table 31: Weighted DRAM® parameter R^2 values using TELUM for Waco Districts

Forecast Years	Low Inc	BAvg Inc	AAvg Inc	High Inc
2010	0.992	0.993	0.998	0.995
2015	0.872	0.955	0.943	0.839
2020	0.786	0.785	0.725	0.531
2025	0.751	0.197	0.453	0.287
2030	0.725	0.501	0.295	0.153

Table 32: EMPLOC parameter R^2 values using G-LUM for Waco Districts

Forecast Years	Basic	Retail	Services	Other
2010	0.988	0.958	0.895	0.983
2015	0.974	0.893	0.762	0.959
2020	0.962	0.831	0.701	0.944
2025	0.945	0.795	0.673	0.933
2030	0.925	0.775	0.675	0.921

Table 33: RESLOC parameter R^2 values using G-LUM for Waco Districts

Forecast Years	Low Inc	BAvg Inc	AAvg Inc	High Inc
2010	0.827	0.314	0.753	0.008
2015	0.636	0.069	0.673	0.001
2020	0.351	0.04	0.555	0.01
2025	0.233	0.181	0.568	0.001
2030	0.138	0.031	0.56	0.016

Table 34: Weighted EMPAL® parameter R^2 values using TELUM for Waco Districts

Forecast Years	Basic	Retail	Services	Other
2010	0.987	0.95	0.871	0.986
2015	0.97	0.876	0.707	0.966
2020	0.957	0.804	0.63	0.96
2025	0.939	0.767	0.594	0.957
2030	0.917	0.746	0.596	0.951

Table 35: Weighted DRAM® parameter R^2 values using TELUM for Waco Districts

Forecast Years	Low Inc	BAvg Inc	AAvg Inc	High Inc
2010	0.801	0.18	0.556	0.004
2015	0.62	0.049	0.448	0.022
2020	0.346	0.025	0.332	0.001
2025	0.261	0.153	0.349	0.006
2030	0.151	0.022	0.329	0.026

4.2.2.2 Forecast from 2010 to 2030

The forecast generated by TELUM and G-LUM by districts for the Waco region in five year increments is given in this section. The districts have been divided into four classes based on the number of employment and household type present in the district. Each of these classes has been assigned different colors.

Basic Employment

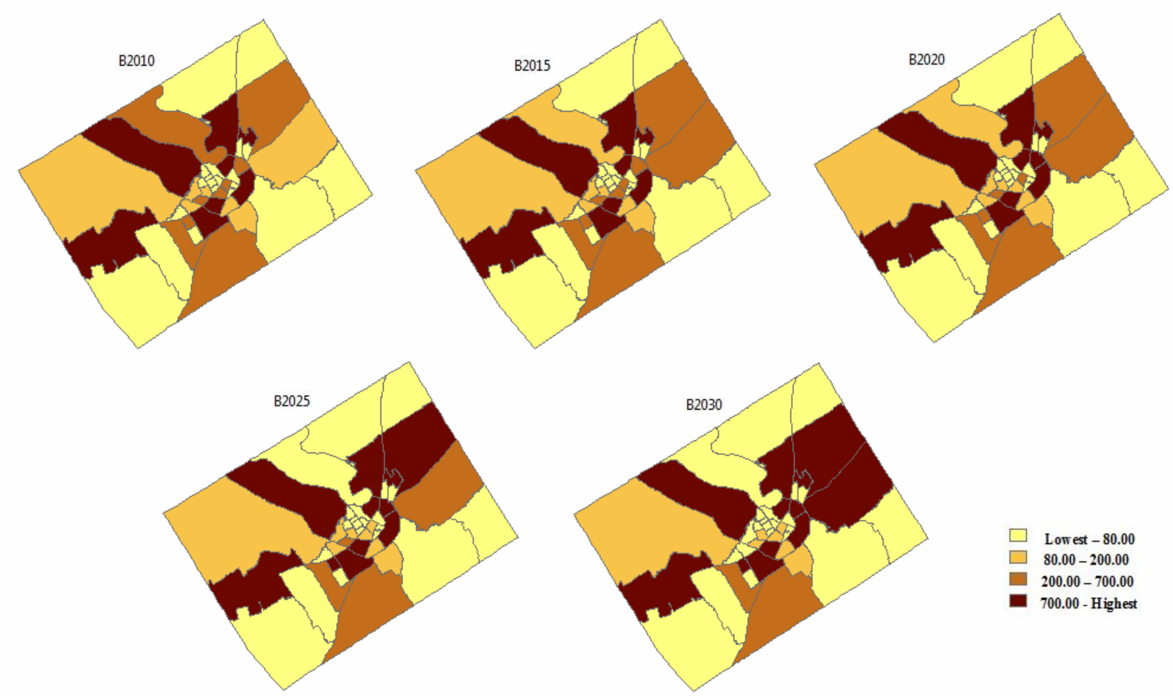


Figure 46: TELUM forecast by district for basic employment for the Waco region

TELUM's prediction for the basic employment distribution for 2030 is that the zones with high basic employment would be located in the center and would radiate out in the north-east, north-west and south-west directions. The significant change predicted between 2010 and 2030 is the reduction in basic employment in a couple of zones in eastern and southern parts of the region.

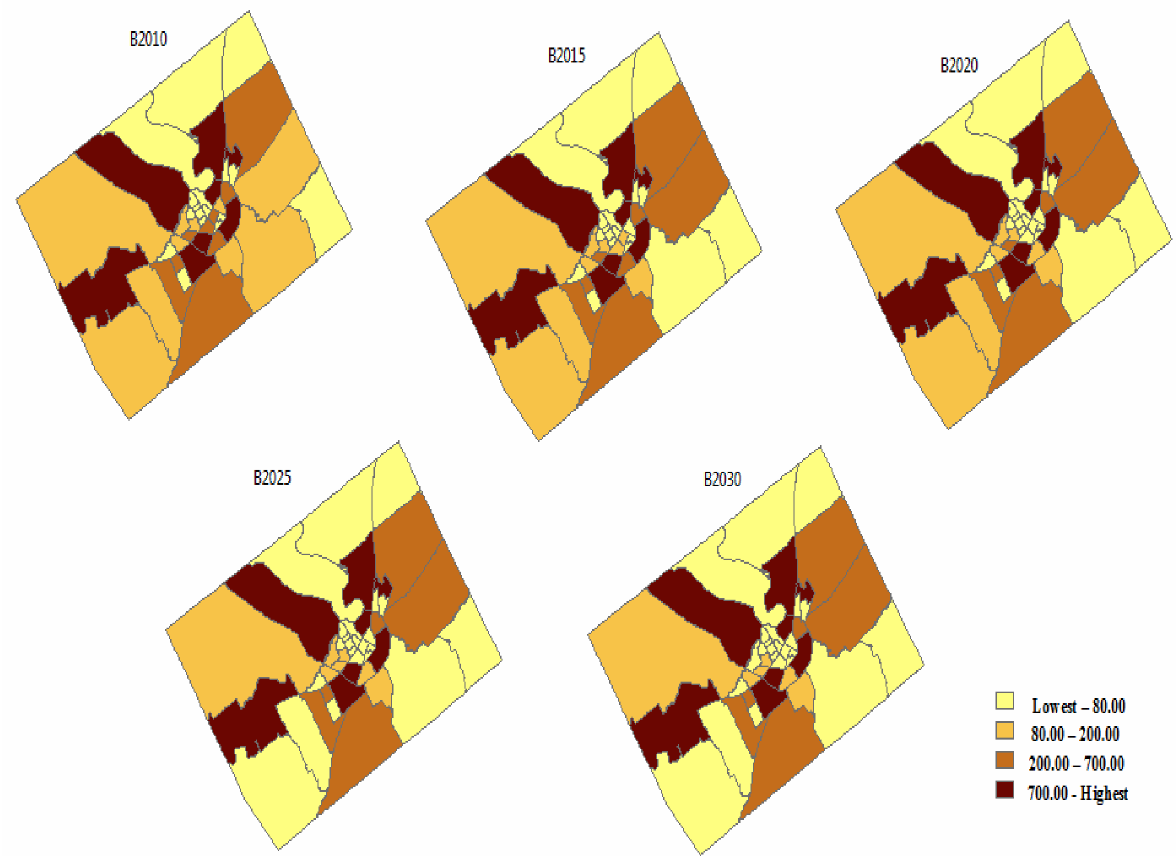


Figure 47: G-LUM forecast by district for basic employment for the Waco region

G-LUM forecast for basic employment is very similar to TELUM's. The difference between the two forecasts is that the basic employment of a couple of zones in the south-west direction in TELUM's prediction is more than that of G-LUM's predictions.

Retail Employment

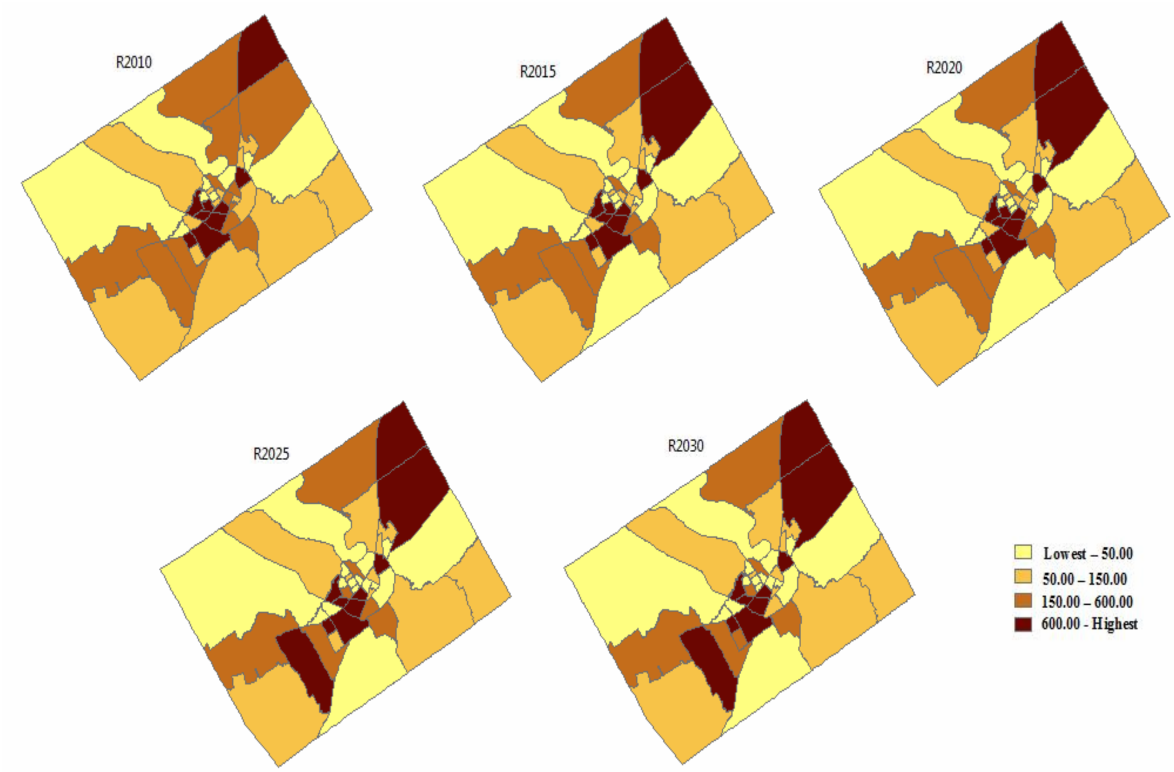


Figure 48: TELUM forecast by district for retail employment for the Waco region

The zones with large retail employment are predicted to be located in the central and northern region of Waco and also in a few zones in the south in the TELUM forecast. No major changes are predicted in the spatial distribution of retail employment during the forecast years.

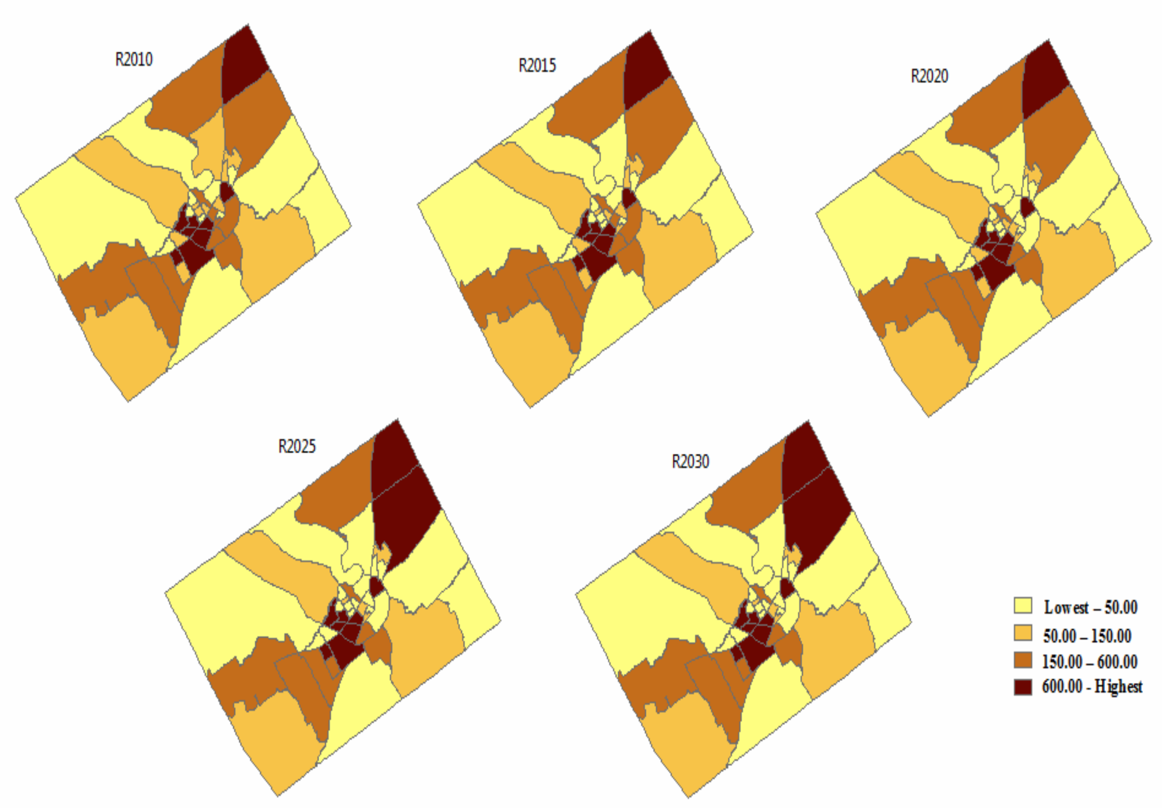


Figure 49: G-LUM forecast by district for retail employment for the Waco region

The G-LUM forecast for retail employment matches the TELUM forecast in almost all the districts. There is no significant difference between the two forecasts.

Service Employment

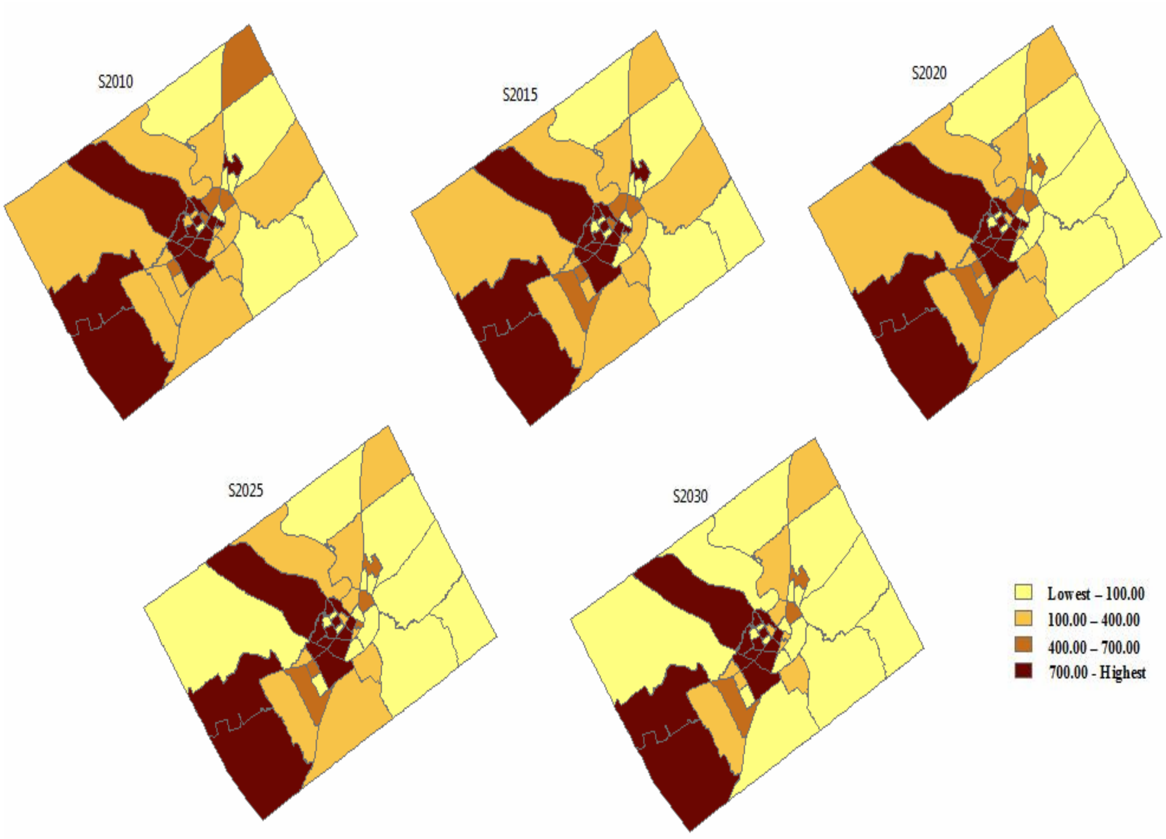


Figure 50: TELUM forecast by district for service employment for the Waco region

The service employment is predicted to be concentrated in center and south Waco in 2030 by TELUM. The significant change during the forecast years is the reduction in the services employment in some of the zones located to the east and south-east part of the region.

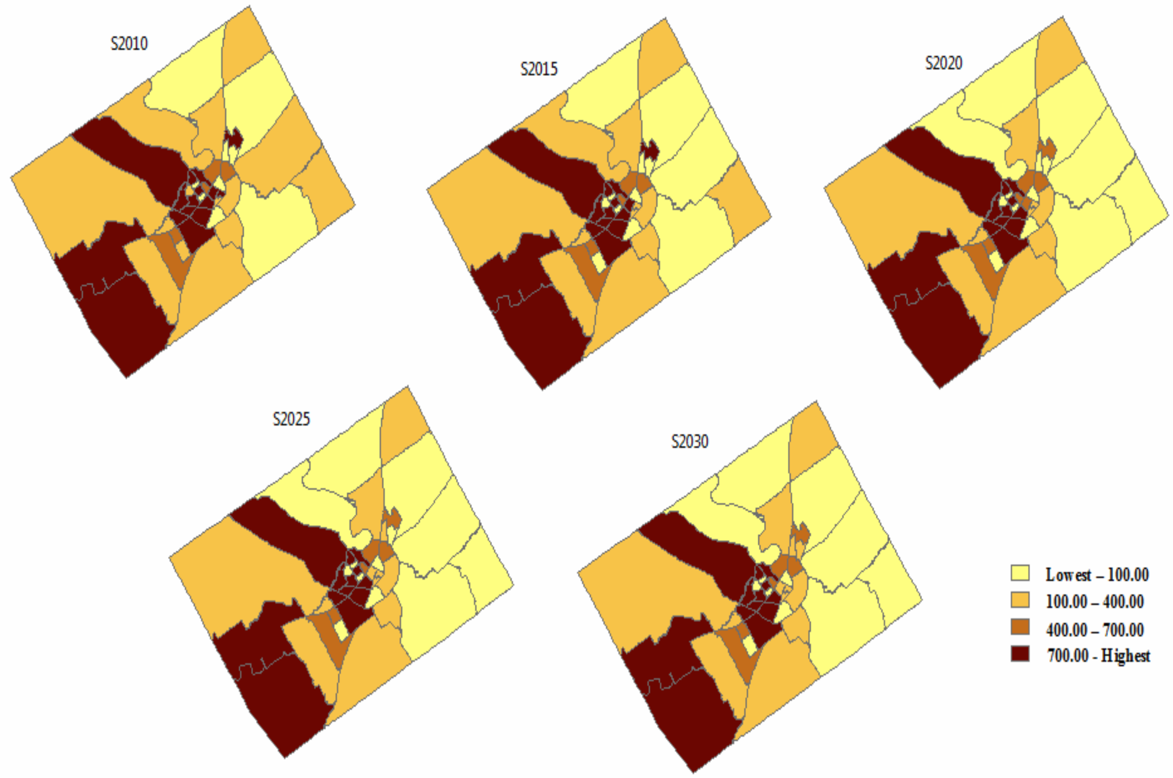


Figure 51: G-LUM forecast by district for services employment for the Waco region

The G-LUM forecast also predicts that the zones with high number of service employment would be located in center and south of Waco. However, unlike TELUM, G-LUM does not forecast the decrease in service employment in zones located to the west and south-east of Waco.

Total Employment

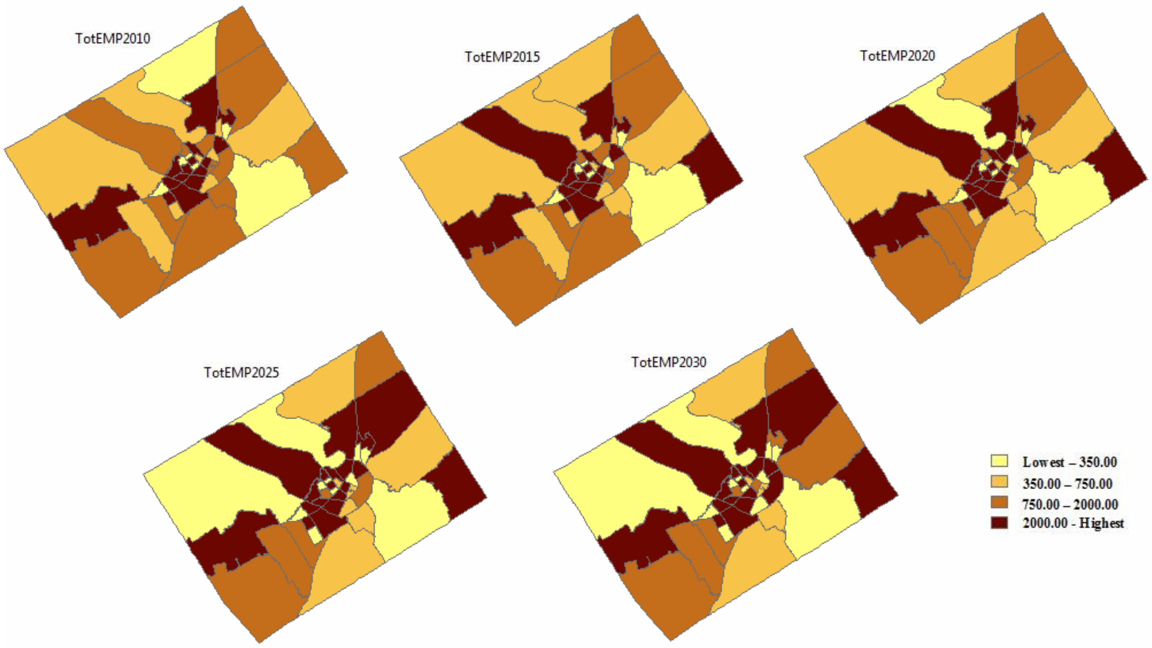


Figure 52: TELUM forecast by district for total employment for the Waco region

TELUM forecasts that, by 2030, the zones with high total employment would be in the center and radiating in the south and north-west regions of Waco. A couple of zones in north-west region also have high number of total employment in 2030. The increase in total employment in most of the regions located in the north-west region of Waco and decrease in total employment in a few zones in east of Waco were significant changes during the forecast years.

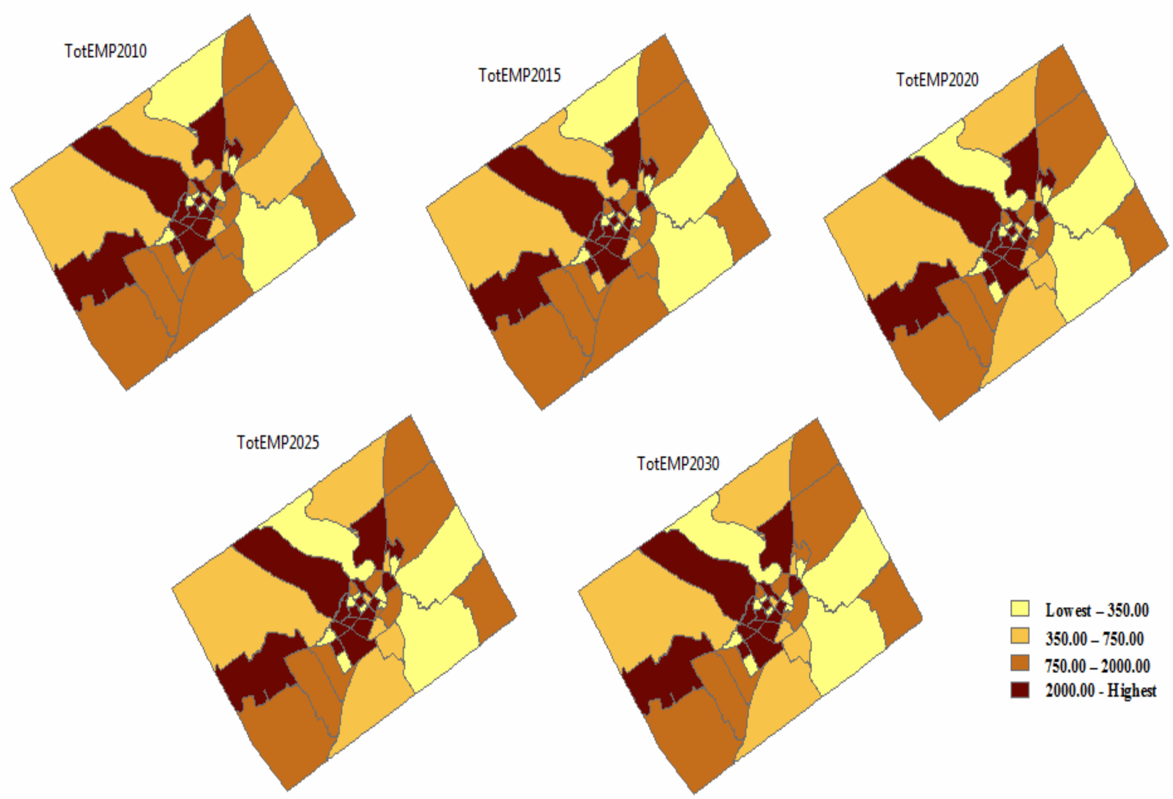


Figure 53: G-LUM forecast by district for total employment for the Waco region

G-LUM predicts the zones with high employment would be in the center and radiating in the south and north of Waco in 2030. The main difference between the TELUM and G-LUM forecast is that G-LUM does not forecast an increase in total employment north-eastern districts of Waco but TELUM does.

Low Income Households

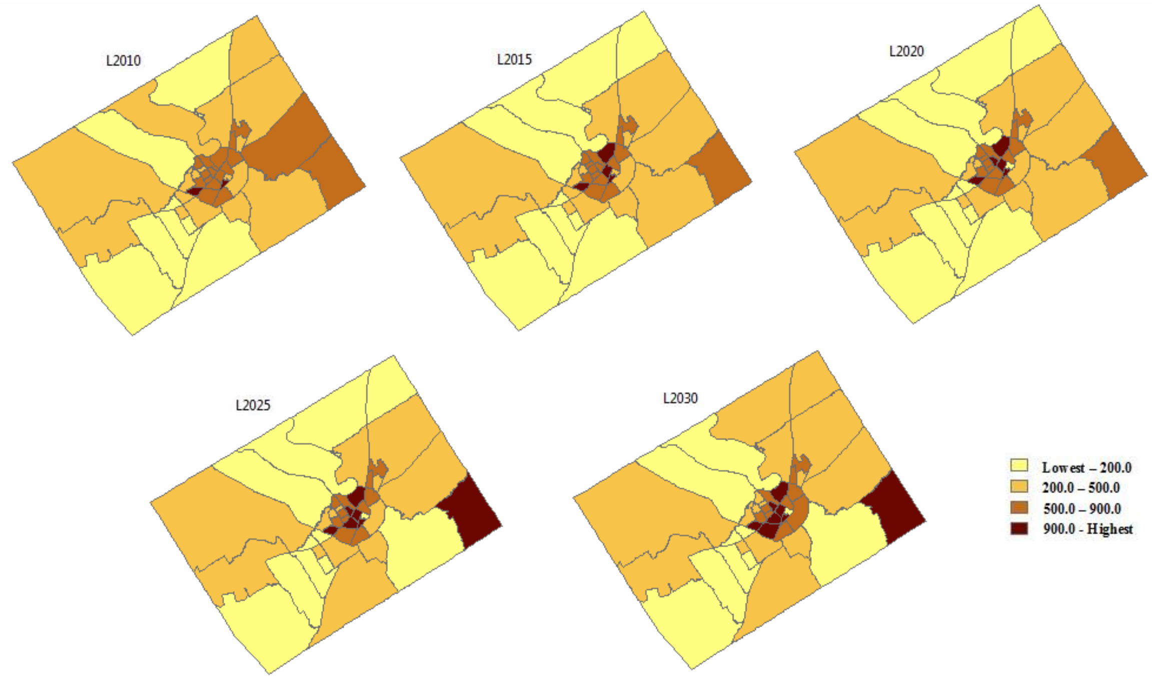


Figure 54: TELUM forecast by district for low income households for the **Waco region**

The low income households are predicted to be located mainly in the central, western and north-eastern zones of Waco by TELUM in 2030. TELUM predicts that during the forecast years the low income households located in central and northern regions of Waco would increase.

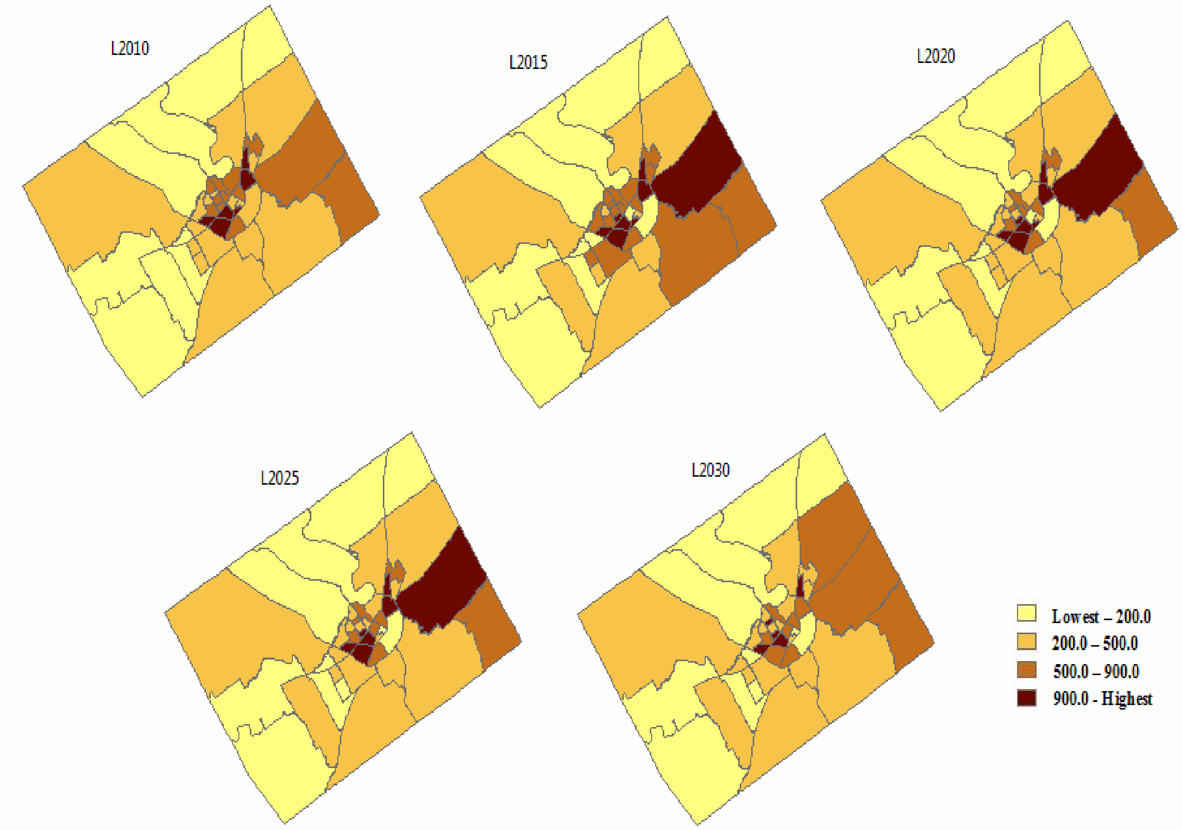


Figure 55: G-LUM forecast by district for low income households for the Waco region

The G-LUM forecast for low income households are different from that of TELUM's. G-LUM predicts low income households to be located mainly in eastern and central zones of Waco by 2030. The reduction of low income households in the central Waco and their increase north-western parts of region is the major predicted change over the forecast years.

Below Average income households

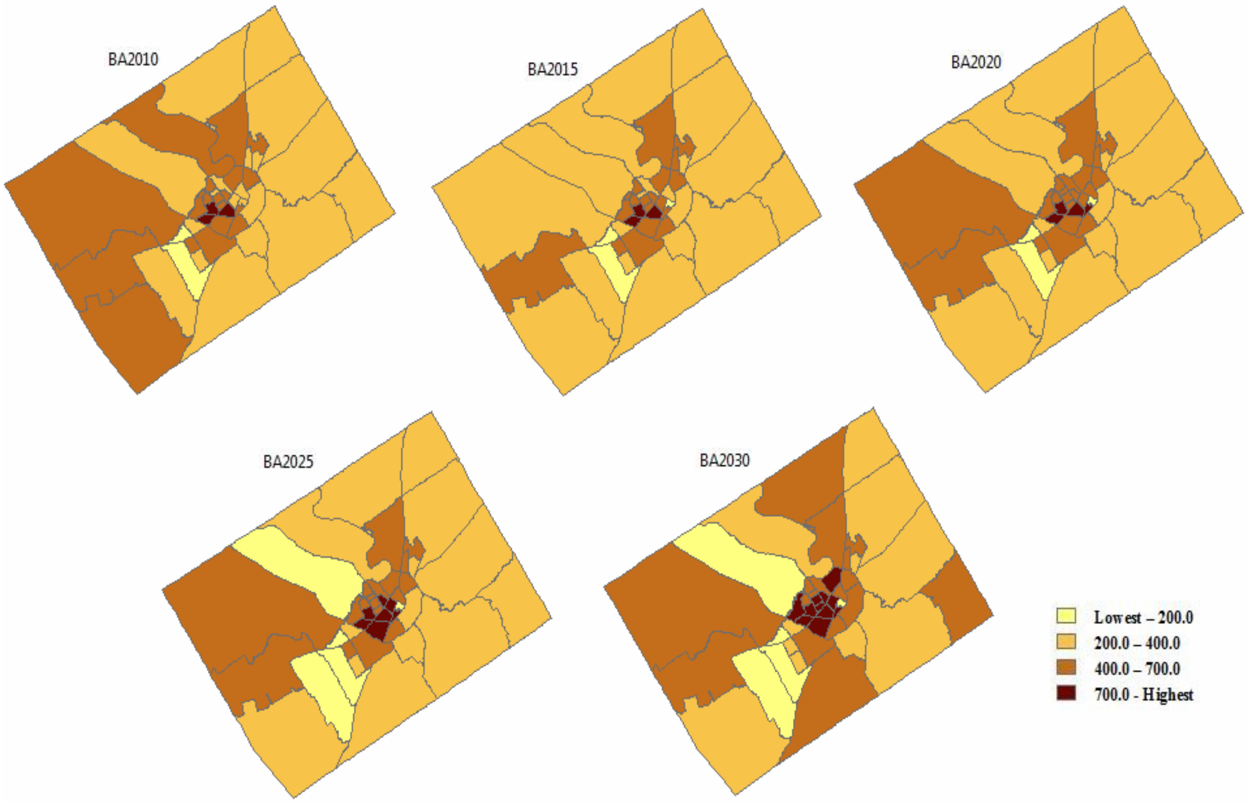


Figure 56: TELUM forecast by district for below average income households for the Waco region

The zones with large number of below average income households are forecasted by TELUM to be located in center and is radiating out towards all the four corners of the Waco region in 2030. There has been a reduction in the below average households in a few zones located in the south and north-west parts of the region during the forecast years. Zones in north and eastern parts of the region are predicted to experience an increase in the below average households.

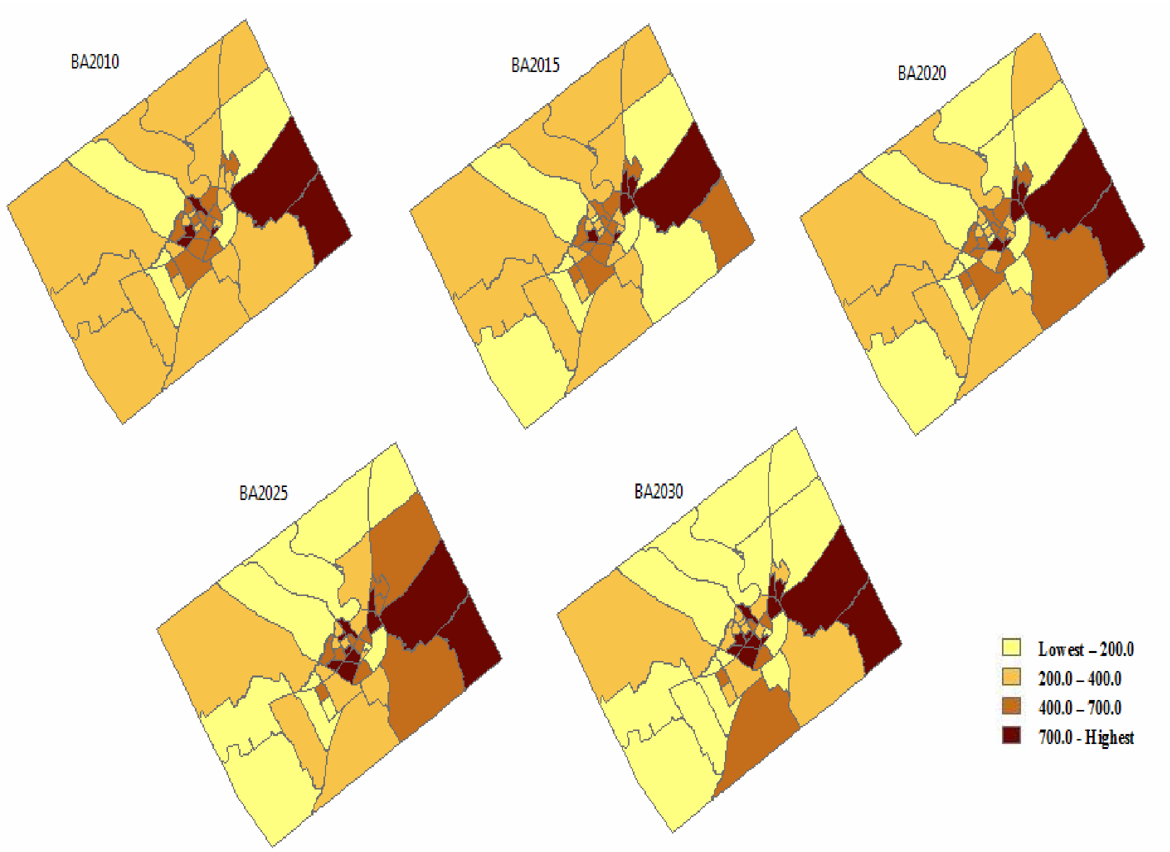


Figure 57: G-LUM forecast by district for below average income households for the Waco region

The predictions of G-LUM are considerably different from those produced by TELUM. The below average income households are predicted by G-LUM to be located mainly in the center and eastern regions of Waco by 2030. Contrary to TELUM predictions, the below average households have reduced in all zones except those located in the eastern parts of the region.

Above Average income households

Figure 58: TELUM forecast by district for above average income households for the Waco region

TELUM forecasts significant changes in the spatial distribution of the above average income households across the forecast years. The zones with high number of above average income households are predicted to be located in the western and central regions of Waco. During the forecast years, the zones located in the center and west are predicted to experience an increase while zones in the south of the region are predicted to witness a decrease in number of above average income households.

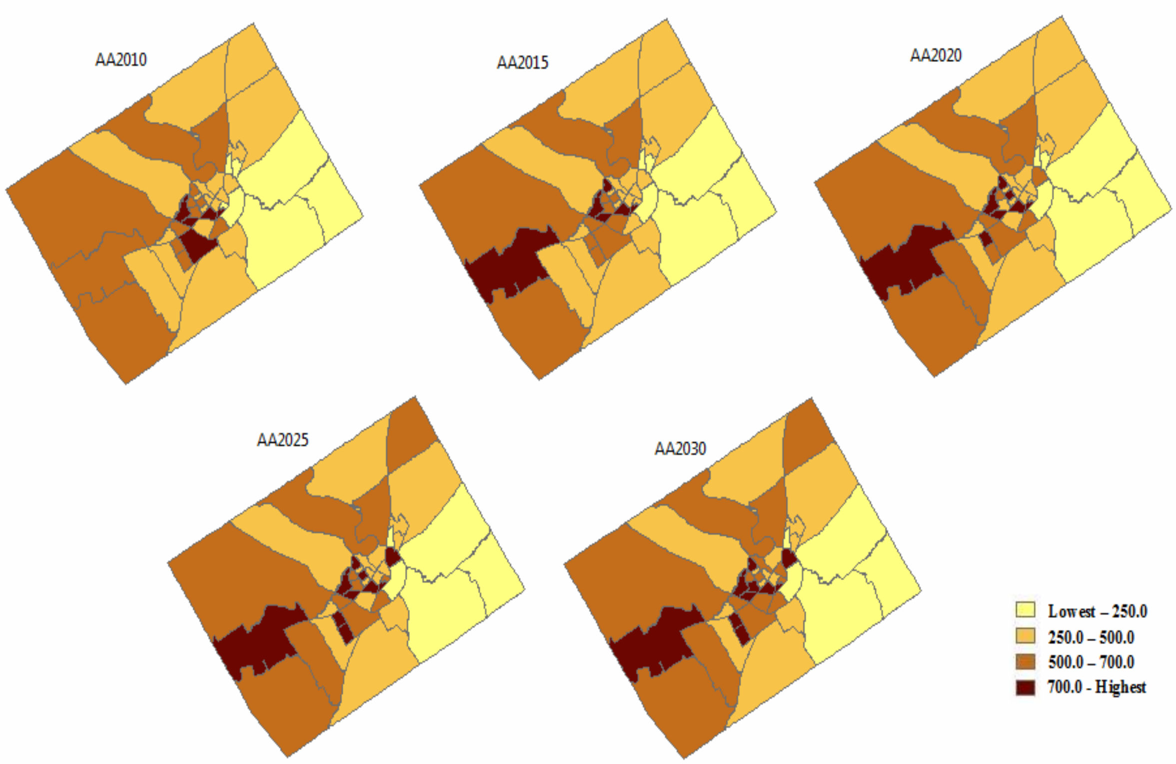


Figure 59: G-LUM forecast by district for above average income households for the Waco region

In 2030, G-LUM too predicts a large number of above average households in the center and west of Waco. However contrary to TELUM predictions, G-LUM predicts that zone located to the south will witness an increase in the above average income households. Many of the above average income households are also predicted to be in northern zones of Waco by 2030 in the G-LUM predictions.

High income households

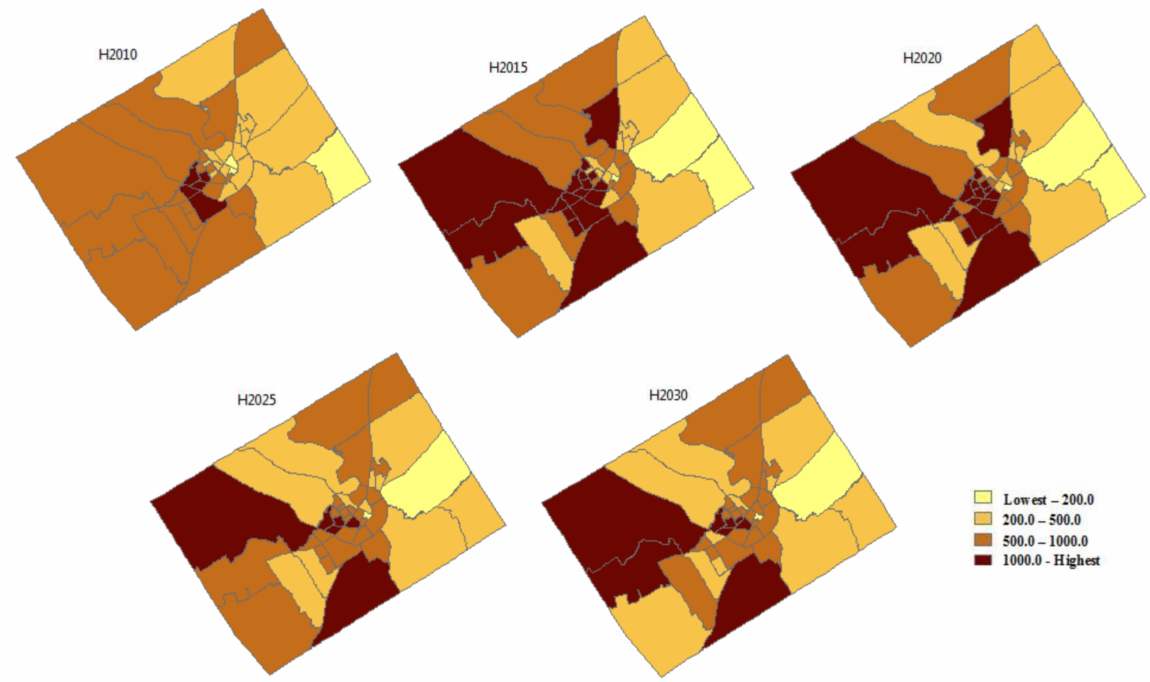


Figure 60: TELUM forecast by district for high income households for the Waco region

TELUM forecast a large number of high income households in western part of Waco and also in a couple of zone in the center and south-east of Waco. A few zones located in the south and north-east parts of the region are predicted to witness decreases in the number of high income households. The zones that are forecasted to experience an increase in high income households are situated mainly in the north and west of Waco.

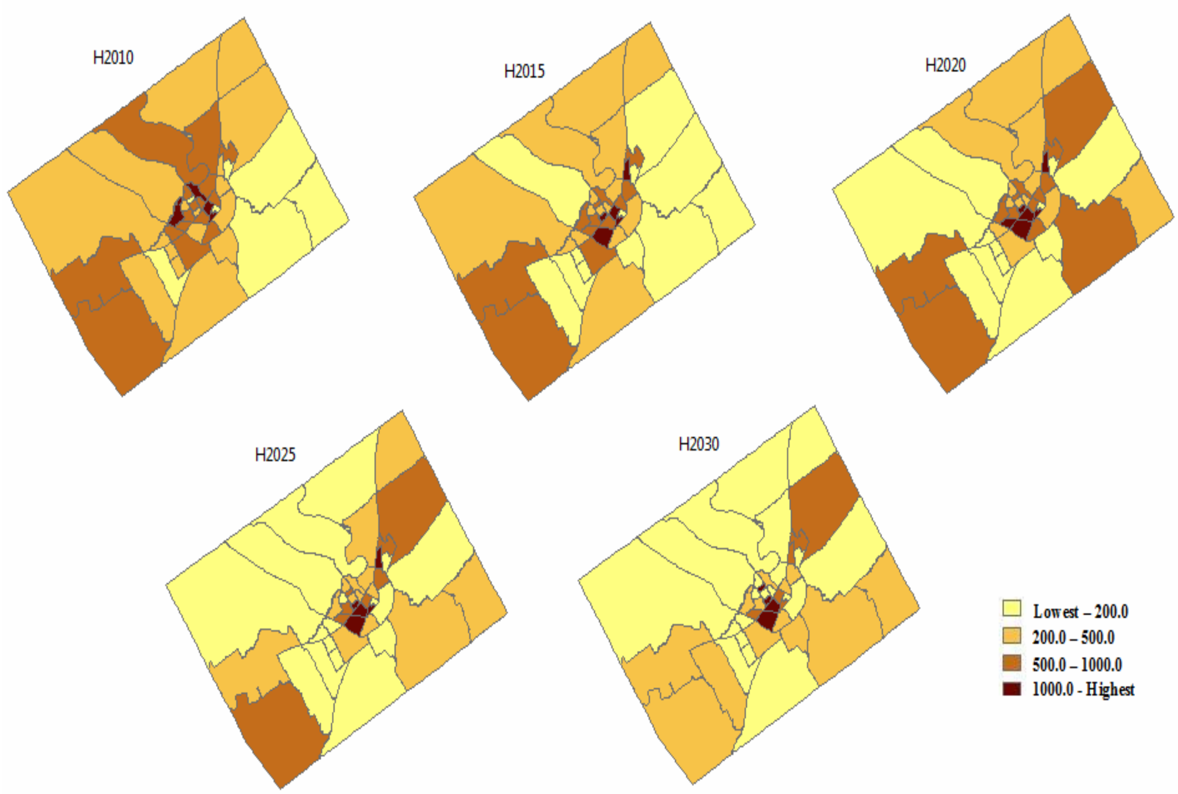


Figure 61: G-LUM forecast by district for high income households for the Waco region

The G-LUM forecast for high income households is completely different from the TELUM forecast. In the G-LUM forecast, the high income households are predicted to be located mainly in the center of the Waco region and also in a couple of zones in the southern and eastern parts of Waco by 2030. The zones located to the west of Waco are predicted to have a very low number of high income households, which is the exact opposite of TELUM's prediction. The high income households have reduced in all zones except those located in the eastern part of Waco during the forecast years.

4.2.2.3 Density Variation in Forecast Years

This section presents a comparison of TELUM and G-LUM forecasts of the density of total employment and total households in the Waco region by district. The zones are classified into four classes based on the magnitude of density.

Total Employment

Figure 62: TELUM forecast by district for density of total employment for the Waco region

TELUM forecast that the districts with high densities of total employment are located in the centre of Waco and radiating in the north-east, north-west and south-west direction in 2030. The remaining districts are predicted to have low density of total employment. The total employment density has increase in a couple districts situated in the northern parts of the region during the forecast years.

Figure 63: G-LUM forecast by district for density of total employment for the Waco region

The spatial distribution of the density of total employment predicted by G-LUM matches the TELUM forecast.

Total household

Figure 64: TELUM forecast by district for density of total household for the Waco region

Districts with high density of total households are located in the center and radiating from center towards the east and western parts of the Waco. The household density has increased in a few districts in eastern parts of Waco while there has been small variation of density in the remaining zones.

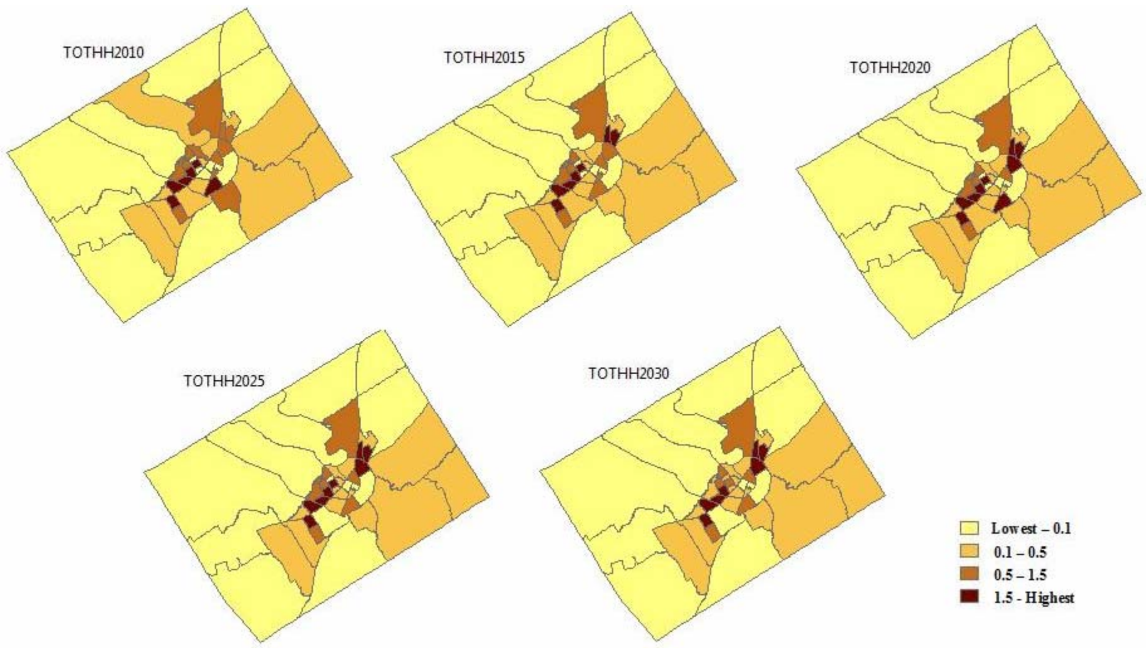


Figure 65: G-LUM forecast by district for density of total household for the Waco region

G-LUM forecast for density of total household differ from the TELUM forecast mainly in the eastern parts of Waco. TELUM predicts the density of total households in eastern districts of Waco to be more than G-LUM forecasts. The household density predicted for the remaining zones are similar in both forecasts.

Summary

The TELUM prediction for the spatial distribution of three main employment types of Waco - namely basic, retail and services employment - is very similar to G-LUM forecasts. However, the TELUM forecasts for all household types are completely different from that of the G-LUM forecast. TELUM predicts large increases in the number of household for many zones while G-LUM does not. So the numbers of zones with high number of households in TELUM forecast are much more than that of the G-LUM predictions.

5.3 TAZ Level Implementation

G-LUM was used to implement ITLUP equations by TAZs for the Waco region. This was done to investigate the effect of zone size on the predictions generated by ITLUP equations for the Waco region. Waco has 283 TAZs and total population of 213,517. So the average population per TAZ is 755 persons. The average population per TAZ of Waco region falls below the recommended range for the average population per zone by TELUM.

5.3.1 Calibration Results

The parameters obtained by calibrating G-LUM equations using the lag year and base year data of Waco by TAZ is presented in this section. The entropy corresponding to the parameters chosen for prediction is also displayed.

Table 36: RESLOC parameters – calibrated using G-LUM for Waco TAZs

Parameters	Low-HH	BAvg-HH	AAvg-HH	High-HH
H	0.0452	0.031	0.0337	0.06
A	-1.9067	3.8548	6.2622	1.2759
B	0.0012	-0.0133	-0.0038	-0.0053
Q	0.0305	-0.0004	0.0411	0.0355
r	0.5067	2.9815	4.3716	4.8126
s	0.0554	0.0902	0.2555	0.1049
B (HHtype,Low)	2.705	1.7648	2.8402	2.6254
B (HHtype, BAvg)	1.3504	16.5731	-2.0653	-10.5456
B (HHtype,Aavg)	-7.0137	-1.0398	9.3155	-0.2937
B (HHtype,High)	-24.3505	-4.2318	3.1853	20.6163
Entropy	8.39E+04	8.06E+04	9.27E+04	1.29E+05

Table 37: EMPLOC parameters – calibrated using G-LUM for Waco TAZs

Parameters	Basic	Retail	Serv	Other
λ	0.02	0.0272	0.0397	0.03
α	1.486	0.5628	-0.7431	1.23
β	-0.0061	-0.0087	-0.0016	-0.002
a	-0.1068	-0.0964	0.0031	0.05
b	-0.2729	-0.2154	0.1519	0.05
Entropy	1.10E+05	6.79E+04	2.41E+05	75838

Table 38: LUDENSITY parameters – calibrated using G-LUM for Waco TAZs

Parameters	Residential	Industry	Commercial
Constant	0.1172	5.3489	0.2402
PerDev	-1.8645	5.0805	-1.3936
PerBas	-0.0186	-1.0107	-0.0124
PerComm	0.0085	-0.1866	-0.9396
PerLI	1.9055	0.0107	0.0579
PerHI	2.0559	0.0823	-0.4632
Developable	1.0322		
Entropy	1.16E+06	1.98E+06	3.71E+05

5.3.2 G-LUM Forecasts by TAZs

The mapped output of the G-LUM forecast for two employment and household types by TAZs for the Waco region is displayed here. The TAZ level forecast generated by G-LUM was aggregated to the district level to facilitate a direct comparison with district level forecast generated by TELUM. The R^2 and weighted R^2 values were also calculated for all the household and employment types.

5.3.2.1 R^2 and weighted R^2 values

Table 39: EMPLOC parameter R^2 values using G-LUM for Waco TAZs

Forecast Years	Basic	Retail	Services	Other
2010	0.939	0.937	0.855	0.951
2015	0.854	0.886	0.753	0.886
2020	0.796	0.856	0.722	0.84
2025	0.765	0.837	0.691	0.82
2030	0.765	0.841	0.694	0.822

Table 40: RESLOC parameter R^2 values using G-LUM for Waco TAZs

Forecast Years	Low Inc	BAvg Inc	AAvg Inc	High Inc
2010	0.516	0.846	0.819	0.756
2015	0.557	0.707	0.641	0.592
2020	0.476	0.47	0.411	0.224
2025	0.307	0.213	0.315	0.065

2030	0.278	0.254	0.192	0.045

Table 41: Weighted EMPLOC parameter R^2 values using G-LUM for Waco TAZs

Forecast Years	Basic	Retail	Services	Other
2010	0.943	0.909	0.927	0.983
2015	0.863	0.818	0.822	0.963
2020	0.809	0.761	0.778	0.952
2025	0.783	0.729	0.757	0.946
2030	0.784	0.744	0.76	0.944

Table 42: Weighted RESLOC parameter R^2 values using G-LUM for Waco TAZs

Forecast Years	Low Inc	BAvg Inc	AAvg Inc	High Inc
2010	0.927	0.943	0.957	0.916
2015	0.747	0.817	0.83	0.612
2020	0.74	0.403	0.306	0.225
2025	0.456	0.336	0.257	0.23
2030	0.426	0.364	0.194	0.205

5.3.2.2 Forecasts from 2005 to 2030

Basic Employment

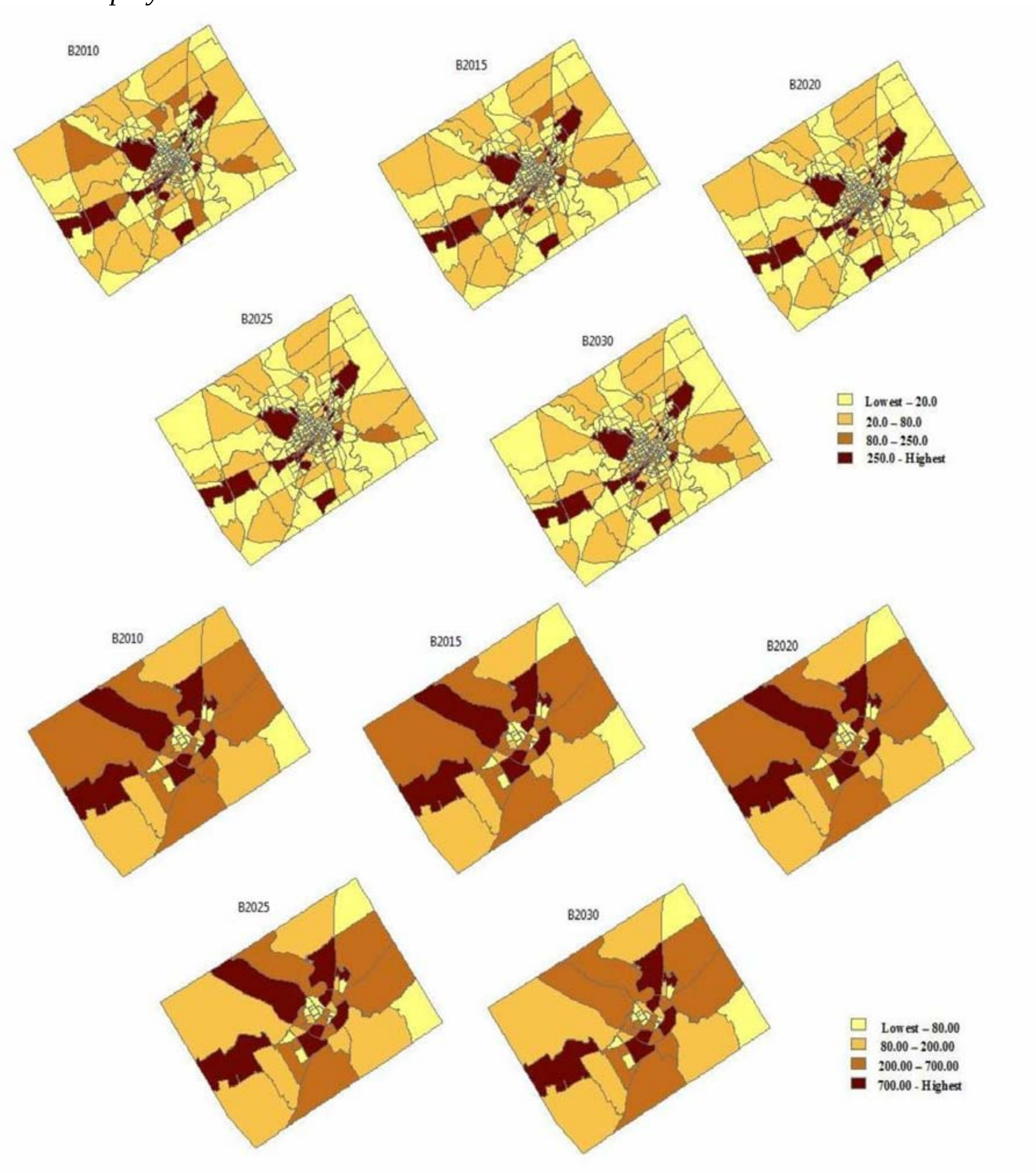


Figure 66: G-LUM code forecast by TAZ for basic employment in Waco region

During the forecast years 2010 to 2030, the basic employment increases in zones located in the centre of Waco region while in the remaining zones, the basic employment either reduces or has only marginal changes. In comparison, the forecast generated by G-LUM for the G-LUM Waco region, by district, predicts that in addition to the zones wit high basic employment in the center, there would be some additional high basic employment in the west and south-west regions of

Waco by 2030. The number of low basic employment zones predicted in the forecast by district, in the south, north and eastern parts of the region in 2030 is more than those in the forecast by TAZs.

Total Employment

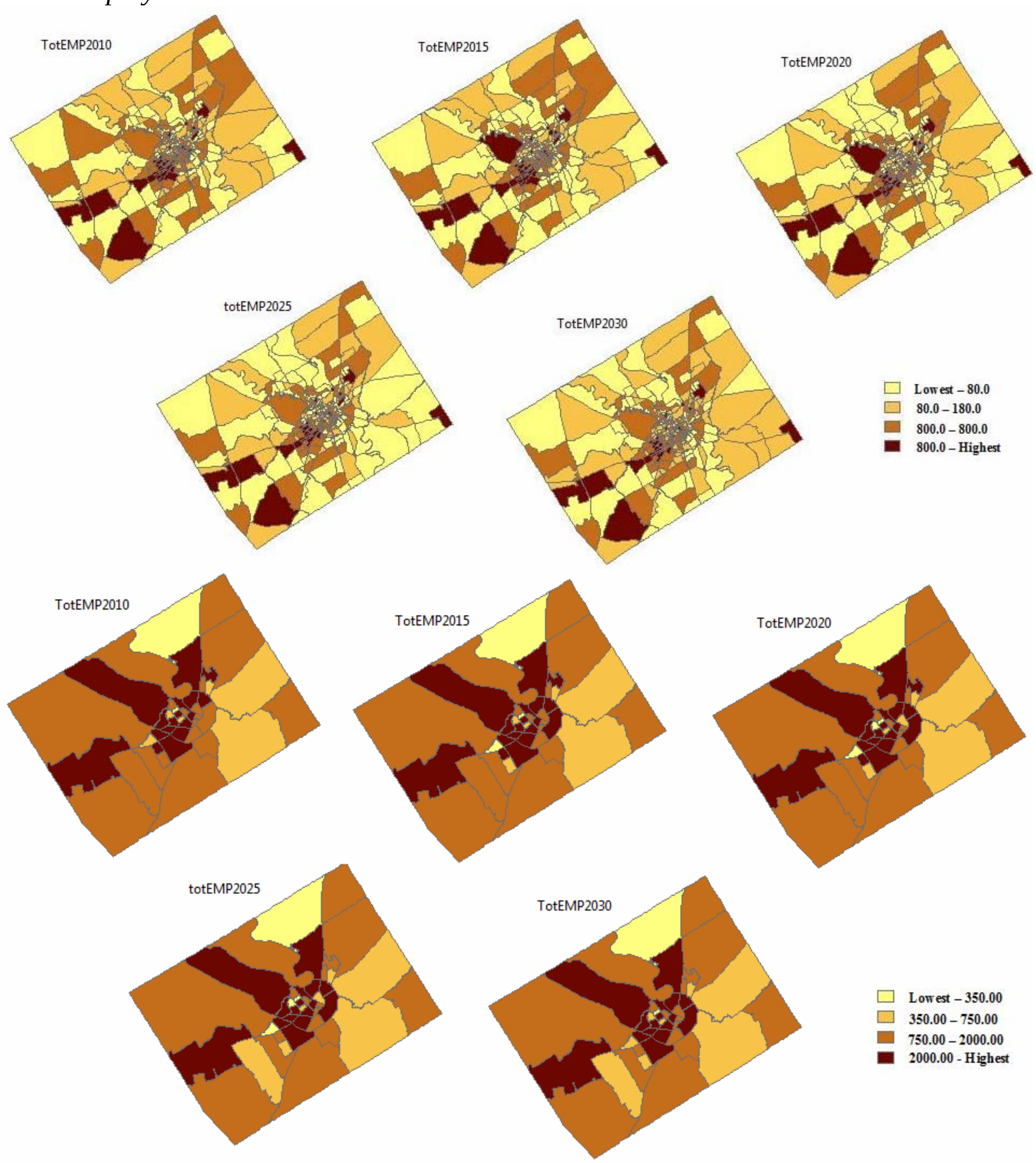


Figure 67: G-LUM forecast by TAZ for total employment in Waco region

In the forecast by TAZs, the zones with large total employment are predicted to be located in center of Waco region and in a couple of zones in the outskirts in 2030. In the forecast by district, these zones are also located in the same area. The spatial distribution of the two forecasts is similar except for the fact that in the forecast by districts there are more zones with low basic employment than in the forecast by TAZs.

Low income households

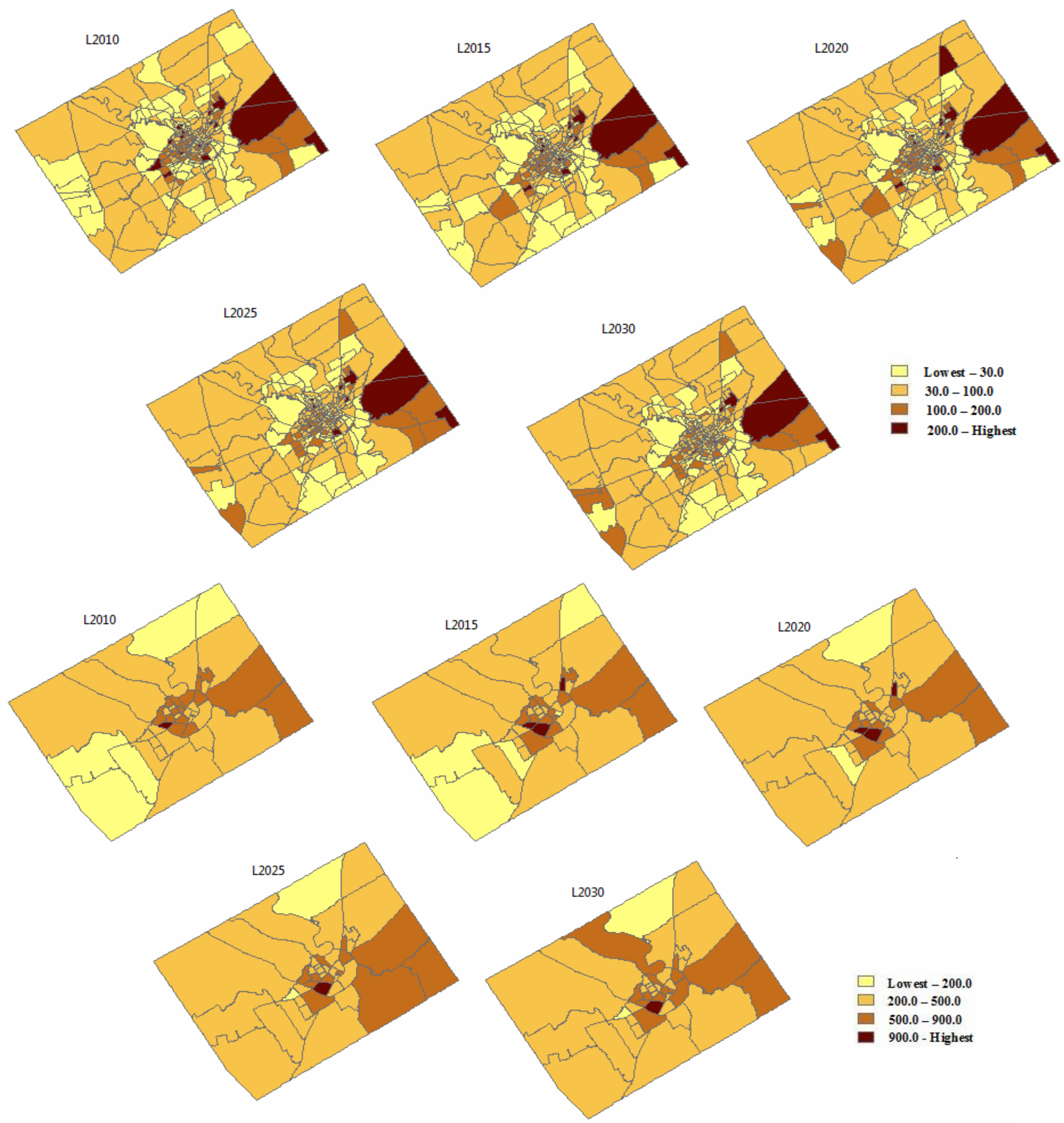


Figure 68: G-LUM forecast by TAZ for low income households in Waco region

The forecast by TAZ predicts that by 2030, the zones with a high number of low income households will be centrally situated and radiating in the east and north-west direction from the center. They are predicted to be distributed almost uniformly in the remaining zones. While in the forecast by districts, zones with high number of low income households in 2030 are in the center and in a couple of zones to the east of the region. A large number of zones with low income households are predicted in the north-west region of Waco in forecast by district, which are absent in the forecast by TAZs.

High income households

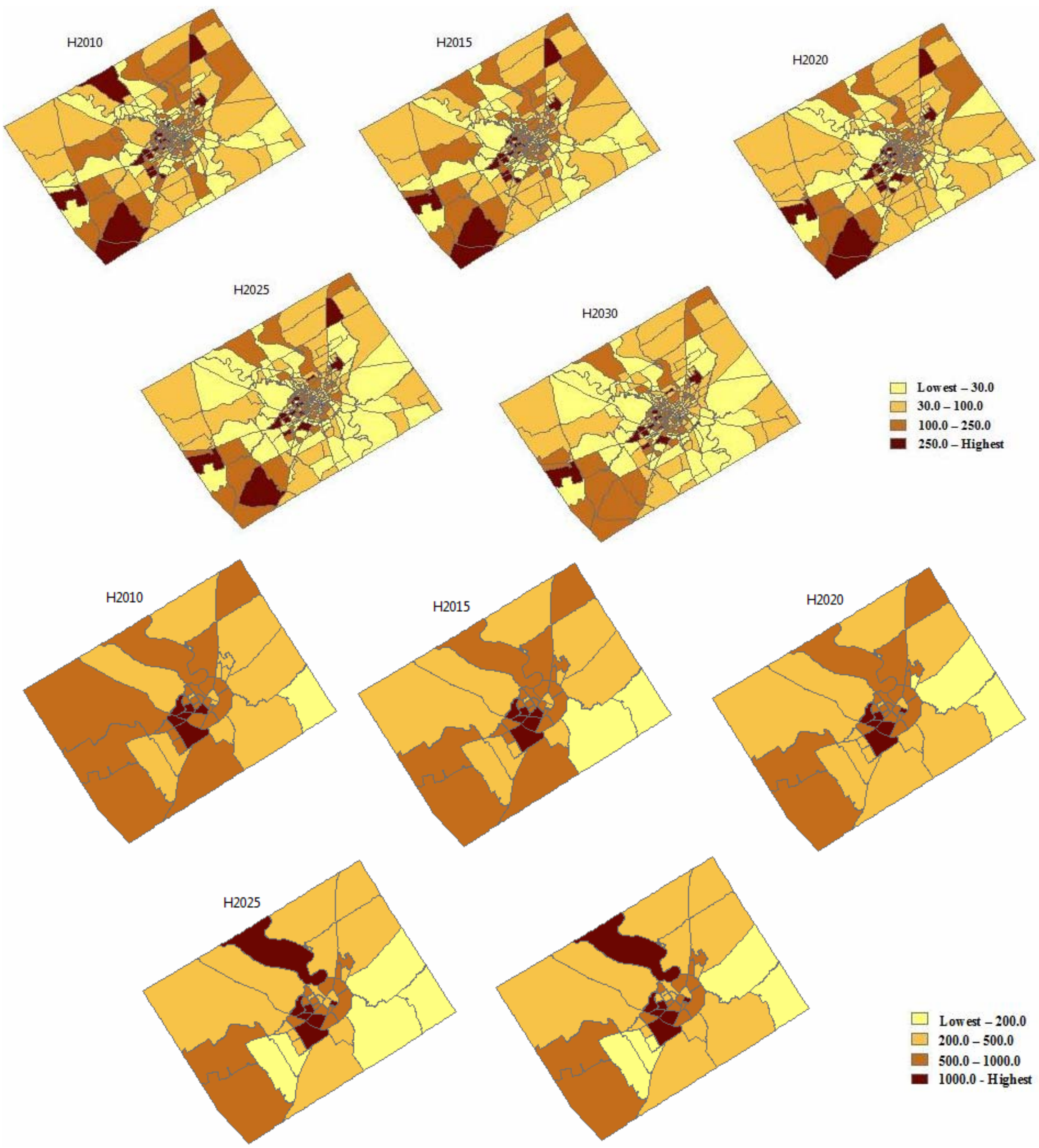


Figure 69: G-LUM forecast by TAZs for high income households in Waco region

The high income households are predicted in 2030 to be situated mainly in the central and eastern parts of Waco region in the forecast by TAZ. A couple of zones in the south of the region are also predicted to have a high number of high income households by 2030. The remaining zones are forecast to have a medium to low number of high income households. In comparison in the forecast by districts, the high income households are predicted to be concentrated mainly in the center and in a couple of zones north of the region. The remaining zones are forecasted to have medium to low number of high income households.

5.3.2.3 Density Variation in Forecast Years

The variation in the density across TAZs in G-LUM predictions of the Waco region is discussed in this section. The TAZs are classified into four classes depending upon the magnitude of density.

Total employment

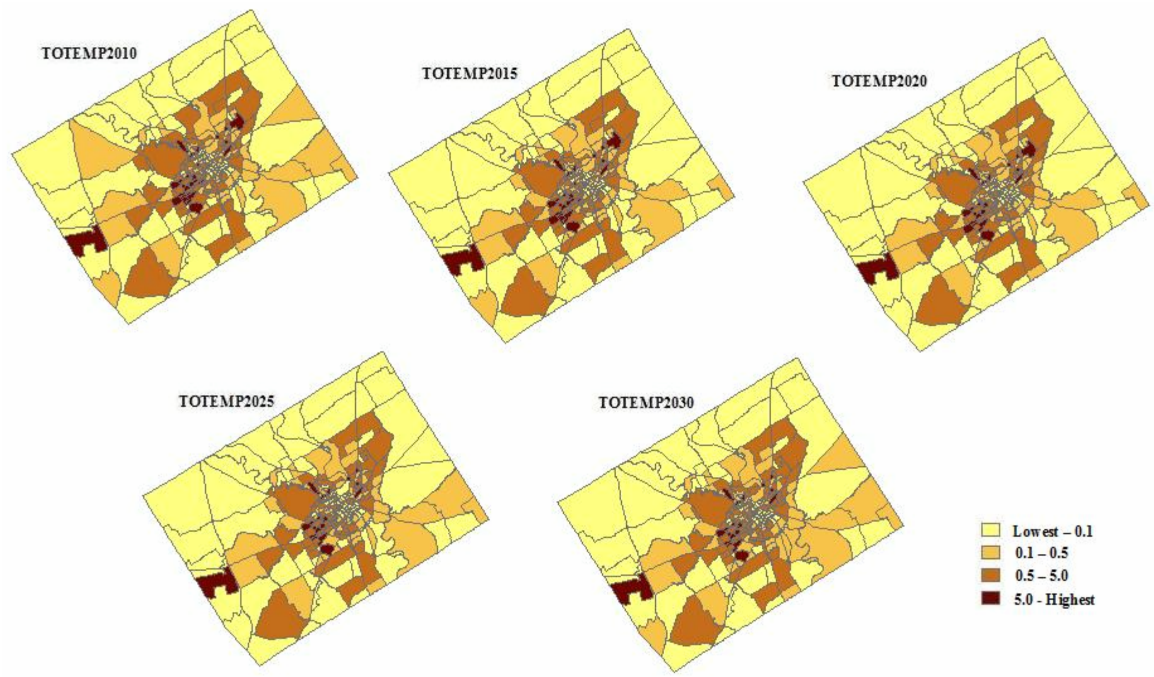


Figure 70: G-LUM forecast by TAZs for density of total employment in Waco region

TAZs with high densities of total employment are predicted in 2030 to be situated in center and fanning out in south and western parts of Waco. The rest of the zones are predicted to have low density of total employment. G-LUM doesn't forecast any major change in total employment during the forecast year other than the reduction of total employment density in a few zones in south and west of Waco.

Total households

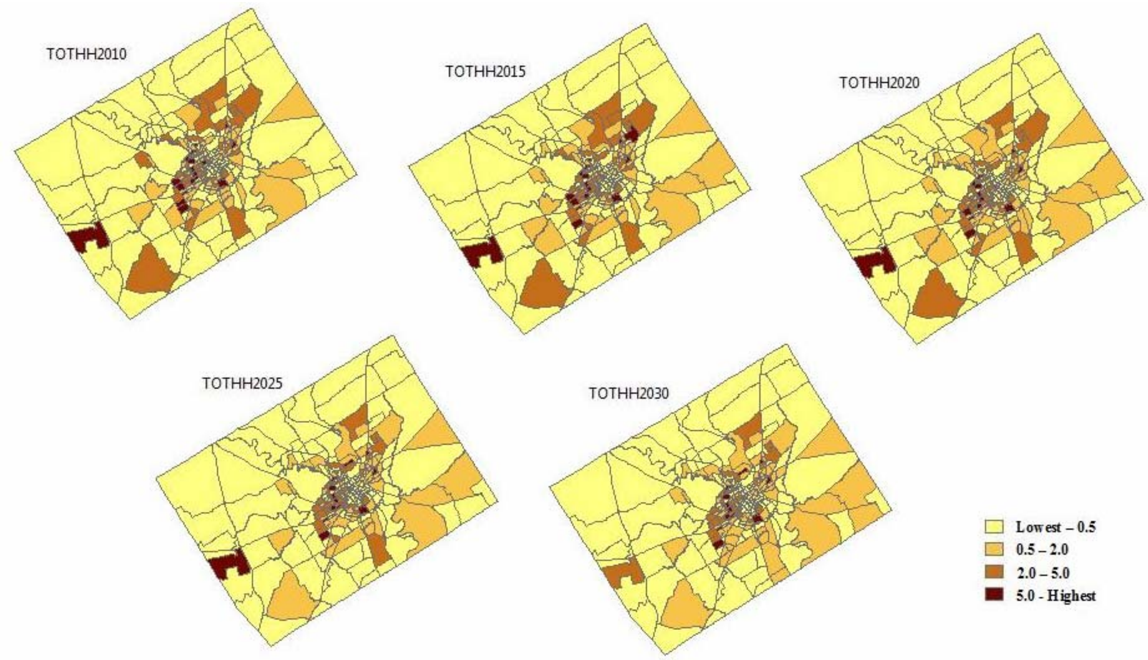


Figure 71: G-LUM forecast by TAZs for density of total households in Waco region

G-LUM forecast zones with high density of total households to be located mainly in central parts of region. Some zones in south and eastern parts of Waco are predicted to have medium density of households. The increase in density of households in a couple of TAZs in the eastern part of Waco is the only noticeable change that occurred during the forecast years.

Summary

The employment and household forecasts made using G-LUM differ depending on whether they are made by district or TAZs. G-LUM forecasts by district predict more total employment in eastern and western parts of Waco than the G-LUM forecast by TAZs. G-LUM predictions for low income households and high income household by district are completely different from forecast TAZs for most of the zones. Thus, the size of zone used for analysis has a significant influence in the spatial distribution forecast generated using the ITLUP equations for the Waco region.

6. Our Experience with TELUM

This section summarizes our TELUM work experiences:

6.1 Advantages of TELUM

1) The data requirements of TELUM are not very demanding so it is ideally suited to generating employment and household forecasts for small MPOs.

2) Calibration is done internally within the software. Hence, users with no knowledge about optimization methods can use TELUM.

3) TELUM has a built in interface with ArcGIS. The forecasts generated by TELUM are uploaded to ArcGIS automatically so the user need not be familiar with ArcGIS to view mapped output of the forecasts.

4) TELUM has a good Graphical User Interface (GUI).

6.2 Drawbacks of TELUM

1) TELUM does not seem to calibrate DRAM® and EMPAL® sub-models to optimality. We believe TELUM does not allow more than 20 steps in calibration which may not always be enough. Our team had developed a module in Matlab that solves DRAM® and EMPAL® models to optimality using a built-in optimization program. The parametric values obtained by calibration using the G-LUM developed by our team are different from those of TELUM's. It is also not clear how TELUM overcomes the problem of local optimality since the ITLUP equations are non-linear in nature. In our code we used sets of starting points to overcome this problem. TELUM does not seem to adopt this approach.

2) The equations used in the land consumption model (LANCON) of TELUM are not clear. The TELUM user manual does not mention the equations used in LANCON. The equations given in Putman (1991) require land use data of base year and lag year data to calibrate, but TELUM requires only base year land use data. Moreover the TELUM names of variables given in the LANCON calibration report of TELUM do not match the equations given in Putman (1991).

3) TELUM does not run on all computers despite satisfying the requirements given in the user manual. In our lab, TELUM was installed in four computers and TELUM generates output only in one system. We had contacted the developers with error message displays in other systems. However, they were not able to locate the reason for the problem and they were unable to reproduce the error in their system.

4) TELUM does not have an effective error detection mechanism. For example if you accidentally assign two employment types by the same name, then the software doesn't detect it

when you enter the name of employment type, but instead it crashes in the final stages without mentioning the cause of error. Also the software gives the same error message for multiple errors which makes it difficult for us to determine the exact cause of the error.

5) Formatting of the input data is bit tedious in TELUM especially in the case of travel impedance data. It is very strict in the number of spaces between the input numbers. It also has a tedious validation of input travel time data.

6) TELUM cannot display multiple maps simultaneously, which makes it difficult to analyze the changes in spatial distribution that have happened over multiple forecast years.

7. Conclusions

In this study, ITLUP equations were used to generate the employment and household location forecast of three-county region of Austin and the Waco region from 2010 to 2030. The ITLUP model was implemented using TELUM and also G-LUM, a code developed by our team. The G-LUM code was developed to overcome some of the restrictions imposed by TELUM and also to validate the results of TELUM.

TELUM forecast for the spatial distribution of three main employment types and the total employment is different from the G-LUM forecasts for Austin region. The major difference generally lies in the spatial distribution in Travis and Williamson counties. In the case of total employment, TELUM predicts an increase in most zones of Travis County while G-LUM predicts an increase only for zones within Austin city boundaries. Many zones of Williamson County were predicted to experience an increase in G-LUM but not by TELUM. In Waco, the forecast of G-LUM and TELUM forecast are similar for the three main employment classes. The spatial distribution of low income households and high income households of Austin predicted by TELUM is completely different from that of G-LUM. The forecasts of TELUM and G-LUM were similar for the other two household classes in Austin. The TELUM forecast for all the household types in Waco are completely different from that of G-LUM forecast. Thus, there is a significant difference in employment and household forecast generated by TELUM and G-LUM. LANCON in TELUM likely contributes to the differences because it is not properly documented.

The primary reason for the difference in forecasts may be due to different parameters estimated by TELUM and G-LUM during calibration. The calibration process of ITLUP involves solving a non-convex, non-linear optimization problem. In such cases the solution algorithm may get trapped at a local optimum. Our code solves the calibration problem with different starting points, and thus reduces the chance of getting trapped at local optima. TELUM does not address this issue. We also believe that TELUM restricts the maximum number of iterations for solving the optimization problem to 20, which may not be sufficient in many cases. The calibration results of our code gave higher entropy values than parameters computed by TELUM. So our code is more likely generate more accurate forecast using ITLUP equations than TELUM.

We also investigated the influence of zone size on the predictions of ITLUP. Forecasts from 2010 to 2030 were generated by district and by TAZ for both the Austin and Waco regions. The basic and total employment forecast for the three county Austin region generated by the G-LUM, by district, was considerably different from G-LUM forecast by TAZs. In the case of Waco, forecasts by district showed more total employment in the eastern and western parts while forecasts by TAZ showed more total employment in southern parts of the region. The spatial distribution of low income households of Austin was completely different for district and TAZ wise forecast. But the forecast by districts and by TAZs were similar for the high income households of Austin. There were no similarities between the G-LUM predictions by districts for low income and high income households of Waco and G-LUM predictions by TAZs for the same household types. Thus, the forecast generated by ITLUP equations is sensitive to the zone size used for generating the forecast. TELUM advocates that ITLUP equations generate accurate forecasts when the zone size is such that average population in a zone lie between 3,000 and

10,000. However it is not clear how the TELUM developers arrived at this conclusion. We believe that more research must be conducted to identify the zone size at which ITLUP equations generate the best forecast.

An employment and household location forecasting model like TELUM which does not have stringent data requirements would be of great help to small MPOs in planning for the future. However, TELUM remains something of a black box for analysts, and the team was unable to duplicate its parameter predictions, long-run jobs and housing predictions, or discern the fractions of residuals it chooses to lose in each time step. Better documentation and more analytical flexibility are needed for its widespread application. Hence, TELUM is not recommended by us for implementation in the current form. We hope TxDOT personnel and others will be comfortable applying our G-LUM code, or can obtain very nearly the same code that runs in a TransCAD environment (but is not yet available for public distribution). In the implementation phase of this project, we plan to convert the G-LUM code to Visual Basic format, for running within Microsoft Excel software.

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Appendix A: Equations in TELUM

i) Employment Allocation Model (EMPAL®):

The following equations were used to allocate the employment in a zone (Putman 2005):

$$E_{j,t}^{k} = \lambda^{k} \sum_{i} P_{i,t-1} A_{i,t-1}^{k} W_{j,t-1}^{k} c_{i,j,t}^{\alpha^{k}} \exp\left(\beta^{k} c_{i,j,t}\right) + \left(1-\lambda^{k}\right) E_{j,t-1}^{k} \tag{1}$$

where

$$A_{i,t-1}^{k} = \left[\sum_{l} \left(E_{l,t-1}^{k}\right)^{a^{k}} \left(L_{l}\right)^{b^{k}} c_{i,l,t}^{\alpha^{k}} \exp(\beta^{k} c_{i,l,t}) \right]^{-1} \tag{2}$$

$$W_{j,t-1}^{k} = \left(E_{j,t-1}^{k}\right)^{a^{k}} \left(L_{j}\right)^{b^{k}} \tag{3}$$

$E_{j,t}^{k}$ = Employment (place-of-work) of type *k* in zone *i* at time *t*
$P_{i,t}$ = Total number of households in zone *i* at time *t*
$c_{i,j,t}$ = Impedance (travel time or cost) between zones *i* and *j* at time *t*
L_{j} = Total area of zone *i*

λ^{k}, α^{k}, β^{k}, a^{k}, b^{k} are empirically derived parameters

ii) Disaggregate Residential Allocation Model (DRAM®):

The allocation of households in a zone was based on the following equations (Putman S.H, 2005):
-

$$N_{i}^{n} = \eta^{n} \sum_{j} Q_{j}^{n} B_{j}^{n} W_{i}^{n} c_{i,j}^{a^{n}} \exp\left(\beta^{n} c_{i,j}\right) + (1-\eta^{n}) N_{i,t-1}^{n} \tag{4}$$

$$Q_{j}^{n} = \sum_{k} a_{k,n} E_{j}^{k} \tag{5}$$

$$B_{j}^{n} = \left[\sum_{i} W_{i}^{n} c_{i,j}^{a^{n}} \exp\left(\beta^{n} c_{i,j}\right) \right]^{-1} \tag{6}$$

$$W_{i}^{n} = \left(L_{i}^{v}\right)^{q^{n}} \left(x_{i}\right)^{r^{n}} \left(L_{i}^{r}\right)^{s^{n}} \prod_{n'} \left[\left(1 + \frac{N_{i}^{n'}}{\sum_{n} N_{i}^{n}} \right)^{b_{n'}^{n}} \right] \tag{7}$$

N_{i}^{n} = Households of type *n* residing in zone *i*
$c_{i,j}$ = Impedance (travel time or cost) between zones *i* and *j*

$a_{k,n}$ = (Regional) number of type *n* households per type *k* employee
E_j^k = Employment of type *k* (place-of-work) in zone *j*
L_i^v = Vacant developable land in zone *i*
x_i = 1.0 plus the proportion of developable land already developed in zone *i*
L_i^r = Residential land in zone *i*

α^n, q^n, r^n, s^n, $b_{n'}^n$ are empirically derived parameters

iii) Land Consumption Model (LANCON):

The land consumption for different purposes in zone at a time period is computed by the following equations. TELUM user manual does not mention the LANCON equation used in it. The LANCON equation given in (Putman S.H, 1991) requires the land use data of both lead and lag year for calibration. The LANCON equations given below were constructed by us based on the calibration report of TELUM.

The residential land-consumption equation is:

$$\frac{L_{r,i,t}}{N_{T,i,t}} = k_0 L_{D,i,t}^{k_1}\left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{k_2}\left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{k_3}\left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{k_4}\left(\frac{N_{l,i,t}}{N_{T,i,t}}\right)^{k_5}\left(\frac{N_{h,i,t}}{N_{T,i,t}}\right)^{k_6} \tag{8}$$

where

$L_{r,i,t}$ = Amount of residential land use in zone *i* at time *t*
$N_{T,i,t}$ = Total number of households in zone *i* at time *t*
$L_{D,i,t}$ = Amount of developable (developed plus vacant) land use in zone *i* at time *t*
$L_{d,i,t}$ = Amount of "developed" land use in zone *i* at time *t*
$E_{T,i,t}$ = Total employment in zone *i* at time *t*
$E_{b,i,t}$ = Amount of "basic" employment in zone *i* at time *t*
$E_{c,i,t}$ = Amount of "commercial" employment in zone *i* at time *t*
$N_{l,i,t}$ = Number of low-income households in zone *i* at time *t*
$N_{h,i,t}$ = Number of high-income households in zone *i* at time *t*

$k^0 - k^6$ are empirically estimated parameters

The "basic" industry land-consumption equation is:

$$\frac{L_{b,i,t}}{E_{b,i,t}} = g_0\left(\frac{L_{d,i,t}}{L_{D,i,t}}\right)^{g_1}\left(\frac{E_{b,i,t}}{E_{T,i,t}}\right)^{g_3}\left(\frac{E_{c,i,t}}{E_{T,i,t}}\right)^{g_3}\left(\frac{N_{l,i,t}}{N_{T,i,t}}\right)^{g_4}\left(\frac{N_{h,i,t}}{N_{T,i,t}}\right)^{g_5} \tag{9}$$

$g^0 - g^5$ are empirically estimated parameters

The "commercial" industry land-consumption equation is:

$$\frac{L_{c,i,t}}{E_{c,i,t}} = p_0 \left(\frac{L_{d,i,t}}{L_{D,i,t}} \right)^{p_1} \left(\frac{E_{b,i,t}}{E_{T,i,t}} \right)^{p_3} \left(\frac{E_{c,i,t}}{E_{T,i,t}} \right)^{p_3} \left(\frac{N_{l,i,t}}{N_{T,i,t}} \right)^{p_4} \left(\frac{N_{h,i,t}}{N_{T,i,t}} \right)^{p_5} \qquad (10)$$

$p^0 - p^5$ are empirically estimated parameters

Appendix B : G-LUM code

i) RESLOC Calibration

```
clear all;

% Input data
HHactual= load('C:\Calibration\Input\HH2005.txt');
HH_lag = load('C:\Calibration\Input\HH2000.txt');
EMPactual = load('C:\Calibration\Input\EMP2005.txt');
EMP_lag = load('C:\Calibration\Input\EMP2000.txt');

%Dimensions of the HH & EMP matrices
dimZone=size(HHactual,1);
dimHH=size(HHactual,2);
dimEMP=size(EMPactual,2);

unemp=zeros(1,dimEMP); %Assume unemployment rate is zero.

%Fill in 0.0001 when HH or EMP is 0
for i=1:dimZone
   for j=1:dimHH
      if HHactual(i,j) < 0.0001
         HHactual(i,j)=0.0001;
      end;
   end;

   for j=1:dimHH
      if HH_lag(i,j) < 0.0001
         HH_lag(i,j)=0.0001;
      end;
   end;

   for k=1:dimEMP
      if EMPactual(i,k) < 0.0001
         EMPactual(i,k)=0.0001;
      end;
   end;

   for k=1:dimEMP
      if EMP_lag(i,k) < 0.0001
         EMP_lag(i,k)=0.0001;
      end;
   end;

end;

HHactual_1=HHactual(:,1);
HHactual_2=HHactual(:,2);
HHactual_3=HHactual(:,3);
HHactual_4=HHactual(:,4);

HH_lag_1=HH_lag(:,1);
```

```
HH_lag_2=HH_lag(:,2);
HH_lag_3=HH_lag(:,3);
HH_lag_4=HH_lag(:,4);

%Calculate zonal total HH
sumHHzone=sum(HH_lag,2); %1*** by 1

%All necessary land in each zone

landrP_lag = load('C:\Calibration\Input\landr.txt'); %residential
landbP_lag = load('C:\Calibration\Input\landb.txt'); %basic
landeP_lag = load('C:\Calibration\Input\landu.txt'); %unusable land
landuP_lag = load('C:\Calibration\Input\landd.txt'); %undeveloped ..developable
landcP_lag = load('C:\Calibration\Input\landc.txt'); %commerical
landsP_lag = load('C:\Calibration\Input\lands.txt'); %Streets & Highways

for i=1:dimZone
  if(landrP_lag(i) < 0.00001) landrP_lag(i) = 0.00001;end;
  if(landbP_lag(i) < 0.00001) landbP_lag(i) = 0.00001;end;
    if(landeP_lag(i) < 0.00001) landeP_lag(i) = 0.00001;end;
      if(landuP_lag(i) < 0.00001) landuP_lag(i) = 0.00001;end;
        if(landcP_lag(i) < 0.00001) landcP_lag(i) = 0.00001;end;
          if(landsP_lag(i) < 0.00001) landsP_lag(i) = 0.00001;end;
          end;

 % The developable land that has already been developed ...
landdRatio = (landrP_lag + landbP_lag  + landcP_lag + landsP_lag )./( landrP_lag + landbP_lag  + landuP_lag
+ landcP_lag + landsP_lag );
landdRatio = 1 - (landuP_lag./( landrP_lag + landbP_lag  + landuP_lag + landcP_lag + landsP_lag ));
ZoneSize = load('C:\Calibration\Input\ZoneSize.txt');


% landv is the vacant developable land
landv=landuP_lag;
%landr is the residential land
landr=landrP_lag;

% c denotes the travel time of the region.
c = load('C:\Calibration\Input\TT.txt');

%Calculate "a" (ratio of HH to EMP)
sumHHtype=sum(HH_lag,1); %Sum of HH of each type in all zones
sumEMPtype=sum(EMP_lag,1); %Sum of EMP of each type in all zones
a=(ones(1,dimEMP)./sumEMPtype)'*sumHHtype;
a_1=a(:,1);
a_2=a(:,2);
a_3=a(:,3);
a_4=a(:,4);

options = optimset('MaxIter',1000000, 'MaxFunEvals', 1000000,'Tolx', 0.001,'TolFun',0.001);

%Initialization
eta=0.80; alpha= 1.00; beta=-0.05;
```

```
qq=0.01; rr=0.5; ss=0.20;
bnn = [-2.00;4.66;8.2;-0.36];

x0=vertcat(eta,alpha,beta,qq,rr,ss,bnn);

y = @(x)
NLLS_RES_1(x0,HHactual_4,HH_lag_4,EMPactual,sumHHzone,unemp,landv,landdRatio,landr,a_3,c,dimZo
ne,dimHH,dimEMP, HH_lag);

[x,fval,exitflag]= fminsearch(y,x0,options);

 csvwrite('C:\Calibration\Output\RES_4_parameters.dat',x);
csvwrite('C:\Calibration\Output\RES_4_fval.dat',fval);

% RES Function evaluation ....

function ZZ =
NLLS_RES_1(x,HHactual_1,HH_lag_1,EMPactual,sumHHzone,unemp,landv,landdRatio,landr,a_1,c,dimZon
e,dimHH,dimEMP,HH_lag);

%Initialization with the previous iteration values ....
eta=x(1,1); alpha=x(2,1); beta=x(3,1);
qq=x(4,1); rr=x(5,1); ss=x(6,1);
bnn=x(7:6+dimHH,1);

n=1;
dimHH=1;

%Calculate Q
Q=zeros(dimZone,dimHH);
for j=1:dimZone;
        for k=1:dimEMP;
            Q(j,n)=Q(j,n)+(a_1(k,n).*EMPactual(j,k));
        end;
end;

%Calculate W_RES
pipi=ones(dimZone,dimHH);
for i=1:dimZone;
        for nn=1:dimHH;
            pipi(i,n)=pipi(i,n).*((1+HH_lag(i,nn)./sumHHzone(i,1)).^bnn(nn,n));
        end;

        W_RES(i,n)=landv(i,1).^qq(1,n)*(1+landdRatio(i,1)).^rr(1,n)*landr(i,1).^ss(1,n)*pipi(i,n);
end;

%Calculate B
Binv=zeros(dimZone,dimHH);
for j=1:dimZone
        for i=1:dimZone
            Binv(j,n)=Binv(j,n)+(W_RES(i,n).*c(i,j).^alpha(1,n).*exp(beta(1,n)*c(i,j)));
        end
        B(j,n)=1./Binv(j,n);
```

```
end

%Calculate modeled HH
HHsum=zeros(dimZone,dimHH);
HH = zeros(dimZone,dimHH);
for i=1:dimZone;
        for j=1:dimZone;
            HHsum(i,n)=HHsum(i,n)+Q(j,n).*B(j,n).*W_RES(i,n).*c(i,j).^alpha(1,n).*exp(beta(1,n)*c(i,j));
        end;
        HH(i,n)=eta(1,n).*HHsum(i,n)+(1-eta(1,n)).*HH_lag_1(i,n);
        if(HH(i,n) < 0.001) HH(i,n) = 0.001;
        end;
end;


% Scaling the predicted values ..
sum_HHactual = sum(HHactual_1);
sum_HH = sum(HH,1);
HH = HH.*(sum_HHactual/sum_HH);


%Calculate residual
epsilon=zeros(dimZone,dimHH);
for i=1:dimZone;
        epsilon(i)= HHactual_1(i) - HH(i);
end;

csvwrite('C:\Calibration\Output\epsilon_RES.dat',epsilon);

% Likelihood estimation
L = 0;
k = 1;
for i=1:dimZone;
    L = L + (HHactual_1(i).*log(HH(i,k)));
end;

% G-LUM Objective ....
Z = -L;
```

ii) EMPLOC Calibration

```
clear all;

HH_lag = load('C:\Calibration\Input\HH2000.txt');
EMPactual = load('C:\Calibration\Input\EMP2005.txt');
EMP_lag = load('C:\Calibration\Input\EMP2000.txt');

%Dimensions of the HH & EMP matrices
dimZone=size(HH_lag,1);
dimHH=size(HH_lag,2);
dimEMP=size(EMP_lag,2);

%Fill in 0.0001 when HH or EMP is 0
for i=1:dimZone
    for j=1:dimHH
        if HH_lag(i,j) < 0.0001
            HH_lag(i,j)=0.0001;
        end;
    end;

    for k=1:dimEMP
        if EMP_lag(i,k) < 0.0001
            EMP_lag(i,k)=0.0001;
        end;
        if EMPactual(i,k) < 0.0001
            EMPactual(i,k)=0.0001;
        end;
    end;
end;

EMP_lag_1=EMP_lag(:,1);
EMP_lag_2=EMP_lag(:,2);
EMP_lag_3=EMP_lag(:,3);
EMP_lag_4=EMP_lag(:,4);
EMP_lag_5=EMP_lag(:,5);
EMP_lag_6=EMP_lag(:,6);

EMPactual_1=EMPactual(:,1);
EMPactual_2=EMPactual(:,2);
EMPactual_3=EMPactual(:,3);
EMPactual_4=EMPactual(:,4);
EMPactual_5=EMPactual(:,5);
EMPactual_6=EMPactual(:,6);

%Calculate zonal total HH
sumHHzone=sum(HH_lag,2); %1*** by 1

%Zone size
ZoneSize = load('C:\Calibration\Input\ZoneSize.txt');

%Impedance
c = load('C:\Calibration\Input\TT.txt');
```

```
%Initialization
lambda=0.05; omega= 2.00 ; rho=-0.001;
aa=0.5; bb= 0.05;

y0=vertcat(lambda,omega,rho,aa,bb);

z = NLLS_EMP_1(y,EMP_lag_6,EMPactual_6,sumHHzone,ZoneSize,c,dimZone,dimHH,dimEMP);

csvwrite('C:\Calibration\Output\EMP_1_fval.dat',z);

% EMP Function evaluation
function [ZZ]=
NLLS_EMP_1(y,EMP_lag_1,EMPactual_1,sumHHzone,ZoneSize,c,dimZone,dimHH,dimEMP);

%Initialization
lambda=y(1,1); omega=y(2,1); rho=y(3,1);
aa=y(4,1); bb=y(5,1);

k=1;
dimEMP=1;

%Calculate A
Ainv=zeros(dimZone,dimEMP);
for i=1:dimZone;
	for j=1:dimZone;

Ainv(i,k)=Ainv(i,k)+(EMP_lag_1(j,k).^aa(1,k).*ZoneSize(j,1).^bb(1,k).*c(i,j).^omega(1,k).*exp(rho(1,k)*c(i,j
)));
	end;
	if(Ainv(i,k) < 0.001) Ainv(i,k) = 0.001; end;
	A(i,k)=1./Ainv(i,k);
end;

%Calculate W_EMP
for j=1:dimZone;
	W_EMP(j,k)= EMP_lag_1(j,k).^aa(1,k).*ZoneSize(j,1).^bb(1,k);
end;

%Calculate modeled EMP
EMPsum=zeros(dimZone,dimEMP);
EMP = zeros(dimZone,dimEMP);
for j=1:dimZone;
	for i=1:dimZone;

EMPsum(j,k)=EMPsum(j,k)+sumHHzone(i,1).*A(i,k).*W_EMP(j,k).*c(i,j).^omega(1,k).*exp(rho(1,k).*c(i,j))
;
	end;
	EMP(j,k)=(lambda(1,k).*EMPsum(j,k))+((1-lambda(1,k))*EMP_lag_1(j,k));
	if(EMP(j,k) < 0.001)
	   EMP(j,k) = 0.001;
	end;
end;
```

```
% Scaling
sum_EMPactual = sum(EMPactual_1);
sum_EMP = sum(EMP,1);
EMP = EMP.*(sum_EMPactual/sum_EMP);


%Calculate residual
k = 1;
epsilon=zeros(dimZone,1);
for i=1:dimZone;
        epsilon(i,k)=EMPactual_1(i,k) - EMP(i,k);
end;
csvwrite('C:\Calibration\Output\epsilon_emp.dat',epsilon);

% Likelihood functions ......
L = 0;
for i=1:dimZone;
    L = L + (EMPactual_1(i,k)*log(EMP(i,k)));
end;

ZZ = -L;
```

iii) LUDENSITY Calibration

```
clear all;

HHactual = load('C:\Calibration\Input\HH2005.txt');
EMPactual = load('C:\Calibration\Input\EMP2005.txt');


%Dimensions of the HH & EMP matrices
dimZone=size(HHactual,1); %It should be 1***.
dimHH=size(HHactual,2); %It should be 6.
dimEMP=size(EMPactual,2); %It should be 3.

for i=1:dimZone
   for j=1:dimHH
      if HHactual(i,j) < 0.0001
         HHactual(i,j)=0.0001;
      end;
   end;

   for k=1:dimEMP
      if EMPactual(i,k) < 0.0001
         EMPactual(i,k)=0.0001;
      end;
   end;
end;

%Calculate HH by type
HH_1=HHactual(:,1);
HH_2=HHactual(:,2);
HH_3=HHactual(:,3);
HH_4=HHactual(:,4);



%Calculate EMP by BAS & COMM
BASzone=EMPactual(:,1);
COMMzone=EMPactual(:,2)+EMPactual(:,3);

%Calculate zonal total HH
sumHHzone=sum(HHactual,2); %1*** by 1
sumEMPzone=sum(EMPactual,2); %1*** by 1

%All necessary land in each zone
landrP = load('C:\Calibration\Input\landr.txt'); %residential
landbP = load('C:\Calibration\Input\landb.txt'); %basic
landeP = load('C:\Calibration\Input\landu.txt'); %unusable land
landuP = load('C:\Calibration\Input\landd.txt'); %undeveloped ..developable
landcP = load('C:\Calibration\Input\landc.txt'); %commerical
landsP = load('C:\Calibration\Input\lands.txt'); %Streets & Highways

for i=1:dimZone
   if(landrP(i) < 0.0001) landrP(i) = 0.0001;end;
```

```
    if(landbP(i) < 0.0001) landbP(i) = 0.0001;end;
        if(landeP(i) < 0.0001) landeP(i) = 0.0001;end;
            if(landuP(i) < 0.0001) landuP(i) = 0.0001;end;
                if(landcP(i) < 0.0001) landcP(i) = 0.0001;end;
                    if(landsP(i) < 0.0001) landsP(i) = 0.0001;end;
                    end;

ZoneSize = load('C:\Calibration\Input\ZoneSize.txt');

landdable = ZoneSize-landeP; % Developable land
landd = ZoneSize - landuP - landeP; % Amount of developed land
landb = landbP; % Land for basic employment
landc = landcP;% Land for commercial employment
landr = landrP;

NLLS_LUDENSITY_K(landr,landdable,landd,landb,landc,sumHHzone,HH_1,HH_2,HH_3,HH_4,dimZone,s
umEMPzone,BASzone,COMMzone);

%Initialization

kk=0.3*ones(1,9); gg=0.5.*ones(1,6); pp=1.0*ones(1,6);
k0=kk'; g0=gg'; p0=pp';

options = optimset('MaxIter',1000000, 'MaxFunEvals', 1000000,'Tolx', 0.0001,'TolFun',0.0001);

z1 =
NLLS_LUDENSITY_K(k0,landr,landdable,landd,landb,landc,sumHHzone,HH_1,HH_2,HH_3,HH_4,dimZon
e,sumEMPzone,BASzone,COMMzone);

z2 =
NLLS_LUDENSITY_G(g0,landr,landdable,landd,landb,sumEMPzone,BASzone,COMMzone,dimZone,HH_1
,HH_2,HH_3,HH_4,sumHHzone);

z3 =
NLLS_LUDENSITY_P(p0,landr,landdable,landd,landc,sumEMPzone,BASzone,COMMzone,dimZone,HH_1,
HH_2,HH_3,HH_4,sumHHzone);

csvwrite('C:\Calibration\Output\LUDENSITY_k_fval.dat',z1);
csvwrite('C:\Calibration\Output\LUDENSITY_g_fval.dat',z2);
csvwrite('C:\Calibration\Output\LUDENSITY_p_fval.dat',z3);

% Functional Evaluation

function ZK=
NLLS_LUDENSITY_K(k,landr,landdable,landd,landb,landc,sumHHzone,HH_1,HH_2,HH_3,HH_4,dimZone
,sumEMPzone,BASzone,COMMzone);

%Initialization

k0=k(1,1); k1=k(2,1); k2=k(3,1); k3=k(4,1); k4=k(5,1);
k5=k(6,1); k6=k(7,1); % k7=k(8,1); k8=k(9,1);

%Calculate Lr
```

```
for i=1:dimZone
if(landdable(i) < 0.00001) landdable(i) = 0.00001;end;
if(sumHHzone(i) < 0.00001) sumHHzone(i) = 0.00001;end;
if(landb(i) < 0.00001) landb(i) = 0.00001;end;
if(landd(i) < 0.00001) landd(i) = 0.00001;end;
end;

Lr
=(k0.*(landdable.^k1).*((landd./landdable).^k2).*((BASzone./sumEMPzone).^k3).*((COMMzone./sumEMPz
one).^k4).*((HH_1./sumHHzone).^k5).*((HH_4./sumHHzone).^k6).*sumHHzone) ;

% Scaling ...
sum_landr = sum(landr);
sum_Lr = sum(Lr);
if(sum_Lr > sum_landr)
k0_temp = k0.*(sum_landr/sum_Lr)
Lr = Lr.*(sum_landr/sum_Lr);
end;

for i=1:dimZone
    if(Lr(i) < 0.0001)
        Lr(i) = 0.0001;
    end
end

% Residual calculation
epsilon_k = landr -Lr;
csvwrite('C:\Calibration\Output\epsilon_k.dat',epsilon_k);

%Likelihood calculation ...
L = 0;
for i=1:dimZone
    L = L + (landr(i)*log(Lr(i)));

end


Z K = -L;

% Functional evaluation
function
ZG=NLLS_LUDENSITY_G(g,landr,landdable,landd,landb,sumEMPzone,BASzone,COMMzone,dimZone,H
H_1,HH_2,HH_3,HH_4,sumHHzone)

%Initialization
g0=g(1,1); g1=g(2,1); g2=g(3,1); g3=g(4,1); g4=g(5,1); g5=g(6,1);

%Calculate Lb
for i=1:dimZone
if(landdable(i) < 0.001) landdable(i) = 0.001;end;
if(sumEMPzone(i) < 0.001) sumEMPzone(i) = 0.001;end;
if(landd(i) < 0.001) landd(i) = 0.001;end;
end;
```

```
Lb =
g0.*(landd./landdable).^g1.*(BASzone./sumEMPzone).^g2.*((COMMzone./sumEMPzone).^g3).*((HH_1./sumHHzone).^g4).*((HH_4./sumHHzone).^g5).*BASzone;

% Scaling the values.
if(sum(Lb) ~= sum(landb))
    Lb = Lb.*(sum(landb)/sum(Lb));
end;

for i=1:dimZone
    if(Lb(i) < 0.001)
        Lb(i) = 0.001;
    end
end

% Residual calculation ..
epsilon_g = landb - Lb;
csvwrite('C:\Calibration\Output\epsilon_g.dat',epsilon_g);

%Likelihood calculation ...
L = 0;
for i=1:dimZone;
    L = L + (landb(i)*log(Lb(i)));
end;

Z G = -L;

% Function Evaluation
function
ZP=NLLS_LUDENSITY_P(p,landr,landdable,landd,landc,sumEMPzone,BASzone,COMMzone,dimZone,HH_1,HH_2,HH_3,HH_4,sumHHzone)

%Initialization
p0=p(1,1); p1=p(2,1); p2=p(3,1); p3=p(4,1); p4=p(5,1); p5=p(6,1);

%Calculate Lc

for i=1:dimZone
if(landdable(i) < 0.001) landdable(i) = 0.001;end;
if(sumEMPzone(i) < 0.001) sumEMPzone(i) = 0.001;end;
if(landd(i) < 0.001) landd(i) = 0.001;end;
end;

Lc =
p0.*(landd./landdable).^p1.*(BASzone./sumEMPzone).^p2.*((COMMzone./sumEMPzone).^p3).*((HH_1./sumHHzone).^p4).*((HH_4./sumHHzone).^p5).*COMMzone;


% Only for likelihood functions ..
if(sum(Lc) > sum(landc) )
    p_temp = p0.*(sum(landc)/sum(Lc))
     Lc = Lc.*(sum(landc)/sum(Lc));
```

```
end;

for i=1:dimZone
    if(Lc(i) < 0.001)
        Lc(i) = 0.001;
    end
end

% Residual calculation
epsilon_p=landc- Lc;
csvwrite('C:\Calibration\Output\epsilon_p.dat',epsilon_p);

%Likelihood calculation
L = 0;
for i=1:dimZone;
    L = L + (landc(i)*log(Lc(i)));
end;

% G-LUM Objective

Z P= -L;
```

iv) Prediction

```
clear all;

%Input
HHbase_original = load('C:\Predictions\District\Input\HH2005.txt');
EMPbase_original = load('C:\Predictions\District\Input\EMP2005.txt');

%Dimensions of the HH & EMP matrices
dimZone=size(HHbase_original,1);
dimHH=size(HHbase_original,2);
dimEMP=size(EMPbase_original,2);

% Unemployment rate is assumed to be zero
unemp=zeros(1,dimEMP);

%Base year land use data
landrP = load('C:\Predictions\District\Input\landr.txt'); %residential
landbP = load('C:\Predictions\District\Input\landb.txt'); %basic
landeP = load('C:\Predictions\District\Input\landu.txt'); %unusable land
landuP = load('C:\Predictions\District\Input\landd.txt'); %undeveloped ..developable
landcP = load('C:\Predictions\District\Input\landc.txt'); %commerical
landsP = load('C:\Predictions\District\Input\lands.txt'); %Streets & Highways

for i=1:dimZone
    if(landrP(i) < 0.001) landrP(i) = 0.001;end;
    if(landbP(i) < 0.001) landbP(i) = 0.001;end;
        if(landeP(i) < 0.001) landeP(i) = 0.001;end;
            if(landuP(i) < 0.001) landuP(i) = 0.001;end;
                if(landcP(i) < 0.001) landcP(i) = 0.001;end;
                    if(landsP(i) < 0.001) landsP(i) = 0.001;end;
end;

landv = landuP;
landr = landrP;
landdRatio = (landrP + landbP  + landcP + landsP )./( landrP + landbP  + landuP + landcP+ landsP);  %
Proportion of developable land developed
ZoneSize = load('C:\Predictions\District\Input\ZoneSize.txt');

landdable = landrP + landbP  + landuP + landcP+ landsP; % Developable land
landd = landrP + landbP + landcP+ landsP; % Amount of developed land
landb = landbP; % Land for basic employment
landc = landcP;% Land for commercial employment

% Impedance data
c = load('C:\Predictions\District\Input\TT.txt'); % Travel time


% RESLOC parameters
HH_Parameter_temp = [0.0004 0.00021505  0.00023617  0.00010603;
1.2382  0.89818 0.88763 0.89606;
-0.0501 -0.048842   -0.048641   -0.048732;
0.0896  0.011473    0.011458    0.010031;
0.488   0.66018 0.65734 0.65772;
```

```
0.4214  0.20567 0.20496 0.20391;
0.6935  -0.50495    -2.003  -3.1126;
0.6598  8.5297  5.019   0.21482;
0.5699  5.6832  8.8308  3.2166;
0.4857  1.0617  -0.48058    9.3381];

 HH_Parameter = HH_Parameter_temp';

% EMPLOC paramters
EMP_Parameter_temp = [0.5177    0.0905  0.1895  0.2734  0.0283  0.0041;
0.2123  2.5664  4.9848  3.6195  3.8403  1.1559;
-0.0005 -0.0012 -0.0016 -0.0011 -0.0007 -0.0005;
0.8209  0.4449  0.4455  1.0396  0.0046  0.0697;
-0.0701 0.2248  -0.1079 0.1503  -0.033  -0.4992];

% Loading the residuals ...
eps_HH = load('C:\Predictions\District\Input\ResHH.txt'); % residuals of the households
eps_EMP = load('C:\Predictions\District\Input\ResEMP.txt'); % residuals of the employment
eps_LU = load('C:\Predictions\District\Input\ResLU.txt'); % residuals of the land cover

EMP_Parameter = EMP_Parameter_temp';

eta=HH_Parameter(:,1)';
alpha=HH_Parameter(:,2)';
beta=HH_Parameter(:,3)';
qq=HH_Parameter(:,4)';
rr=HH_Parameter(:,5)';
ss=HH_Parameter(:,6)';
bnn=HH_Parameter(:,7:10)';

lambda=EMP_Parameter(:,1)';
omega=EMP_Parameter(:,2)';
rho=EMP_Parameter(:,3)';
aa=EMP_Parameter(:,4)';
bb=EMP_Parameter(:,5)';

% Ludensity parameters ....

k = [1.13E-05;1.2438;0.9725;0.3983;0.0648;-0.3253;-0.3544];

g= [1.0914;0.4303;0.77;1.3301;-0.2558;0.7768];

p = [0.0495;-1.19;0.3021;-0.9004;0.037;0.3942];


%Initialization
k0=k(1,1); k1=k(2,1); k2=k(3,1); k3=k(4,1); k4=k(5,1);
k5=k(6,1); k6=k(7,1); %k7=k(8,1); k8=k(9,1);

g0=g(1,1); g1=g(2,1); g2=g(3,1); g3=g(4,1); g4=g(5,1); g5=g(6,1);

p0=p(1,1); p1=p(2,1); p2=p(3,1); p3=p(4,1); p4=p(5,1); p5=p(6,1);
```

```
%Regional control totals
EMPprojectCT = [262898  158404  392127  3028   28977   26748;
314415  184844  451010  3028   32928   27503;
356697  213915  504380  3028   36013   29528;
404665  247558  564065  3028   39387   31702;
455303  291365  641662  3028   42130   33419];

HHprojectCT = [139619   108709  199437  183629;
162473  126503  232081  213685;
183736  143058  262454  241651;
207781  161781  296802  273276;
242180  188564  345938  318515];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

 % Multi-period predictions ....

for count = 1:5

   temp_count = count


% Seeding
seed=1.0.*ones(dimZone,1);

HHbase=HHbase_original;
EMPbase=EMPbase_original;
HHbase_seed=zeros(dimZone,dimHH);
EMPbase_seed=zeros(dimZone,dimEMP);

for i=1:dimZone;
   for n=1:dimHH;
      if HHbase_original(i,n) < seed(i,1);
        HHbase(i,n)=HHbase(i,n)+seed(i,1);
        HHbase_seed(i,n)=1;
      end;
   end;

   for k=1:dimEMP;
      if EMPbase_original(i,k) < seed(i,1);
        EMPbase(i,k)=EMPbase(i,k)+seed(i,1);
        EMPbase_seed(i,k)=1;
      end;
   end;

end;

%Calculate zonal total HH
sumHHzone=sum(HHbase,2); %1*** by 1


%%%%%%%%%%%%%%%%%%  EMPLOC   %%%%%%%%%%%%%%%%%%
```

```
%Calculation in EMP
%Calculate A
Ainv=zeros(dimZone,dimEMP);
for i=1:dimZone;
   for k=1:dimEMP;
      for j=1:dimZone;

Ainv(i,k)=Ainv(i,k)+EMPbase(j,k).^aa(1,k).*ZoneSize(j,1).^bb(1,k).*c(i,j).^omega(1,k).*exp(rho(1,k)*c(i,j));
      end;
      A(i,k)=1./Ainv(i,k);
   end;
end;

%Calculate W_EMP
for j=1:dimZone;
   for k=1:dimEMP;
      W_EMP(j,k)=EMPbase(j,k).^aa(1,k).*ZoneSize(j,1).^bb(1,k);
   end;
end;

%Calculate modeled EMP
EMPsum=zeros(dimZone,dimEMP);
for j=1:dimZone;
   for k=1:dimEMP;
      for i=1:dimZone;
         EMPsum(j,k)=EMPsum(j,k)+
(sumHHzone(i,1).*A(i,k).*W_EMP(j,k).*c(i,j).^omega(1,k)*exp(rho(1,k).*c(i,j)));
      end;
      EMPproject_withseed(j,k)=(lambda(1,k).*EMPsum(j,k))+((1-lambda(1,k))*EMPbase(j,k));
   end;
end;

%Deduct the seeds
EMPproject_withoutseed = EMPproject_withseed;
for i=1:dimZone;
   for k=1:dimEMP;
      if EMPbase_seed(i,k) == 1;
        EMPproject_withoutseed(i,k)=max(0,EMPproject_withoutseed(i,k)-seed(i,1));
      end;
   end;
end;

%Normalization with projected values ......
EMPproject_withoutseed_total=sum(EMPproject_withoutseed,1);
 for i=1:dimZone;
    for k=1:dimEMP;

EMPproject(i,k)=EMPproject_withoutseed(i,k).*(EMPprojectCT(count,k)./EMPproject_withoutseed_total(1,k
));
    end;
 end;

 % Adding the residuals .....
```

```
 if(count == 1)  temp_EMP = EMPproject + eps_EMP; end;
   if(count == 2) temp_EMP = EMPproject + (0.75*eps_EMP);end;
        if(count == 3) temp_EMP = EMPproject + (0.5*eps_EMP);end;
               if(count == 4) temp_EMP = EMPproject + (0.25*eps_EMP); end;
               if(count == 5) temp_EMP = EMPproject ; end;

  for i=1:dimZone;
    for k=1:dimEMP;
       if(temp_EMP(i,k) > 0) EMPproject(i,k) =  temp_EMP(i,k);end;
       if(EMPproject(i,k) < 0) EMPproject(i,k) = 0; end;
    end;
  end;

%%%%%%%%%%%%%%%%%%  END OF EMPLOC %%%%%%%%%%%%%%%%%%



 %%%%%%%%%%%RESLOC%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Calculation in RESLOC
%Calculate "a" (ratio of HH to EMP)

sumHHtype=sum(HHbase_original,1);
sumEMPtype=sum(EMPbase_original,1);
a=(ones(1,dimEMP)./sumEMPtype)'*sumHHtype;

%Calculate Q
Q=zeros(dimZone,dimHH);
for j=1:dimZone;
   for n=1:dimHH;
      for k=1:dimEMP;
         Q(j,n)=Q(j,n)+((a(k,n).*EMPproject(j,k)./(1-unemp(1,k))));
      end;
   end;
end;

%Calculate W_RES
pipi=ones(dimZone,dimHH); %Initialize the multi-time part
for i=1:dimZone;
   for n=1:dimHH;
      for nn=1:dimHH;
         pipi(i,n)=pipi(i,n).*((1+HHbase(i,1)./sumHHzone(i,1)).^bnn(nn,n));
      end;

      W_RES(i,n)=landv(i,1).^qq(1,n)*(1+landdRatio(i,1)).^rr(1,n)*landr(i,1).^ss(1,n)*pipi(i,n);
   end;
end;

%Calculate B
Binv=zeros(dimZone,dimHH);
for j=1:dimZone;
   for n=1:dimHH;
      for i=1:dimZone;
```

```
            Binv(j,n)=Binv(j,n)+(W_RES(i,n).*c(i,j).^alpha(1,n).*exp(beta(1,n)*c(i,j)));
        end;
        B(j,n)=1./Binv(j,n);
    end;
end;

%Calculate modeled HH
HHsum=zeros(dimZone,dimHH);
for i=1:dimZone;
    for n=1:dimHH;
        for j=1:dimZone;
            HHsum(i,n)=HHsum(i,n)+ (Q(j,n).*B(j,n).*W_RES(i,n).*c(i,j).^alpha(1,n).*exp(beta(1,n)*c(i,j)));
        end;
        HHproject_withseed(i,n)=(eta(1,n).*HHsum(i,n))+((1-eta(1,n)).*HHbase(i,n));
    end;
end;

%Deduct the seeds
HHproject_withoutseed=HHproject_withseed;
for i=1:dimZone;
    for n=1:dimHH;
        if HHbase_seed(i,n) == 1;
           HHproject_withoutseed(i,n)=max(0,HHproject_withoutseed(i,n)-seed(i,1));
        end;
    end;
end;

%Normalization
 HHproject_withoutseed_total=sum(HHproject_withoutseed,1);
 for i=1:dimZone;
     for n=1:dimHH;
         HHproject(i,n)=
HHproject_withoutseed(i,n).*(HHprojectCT(count,n)./HHproject_withoutseed_total(1,n));
     end;
end;

% Adding the residuals .....
if(count == 1) temp_HH = HHproject + eps_HH; end;
 if(count == 2) temp_HH = HHproject + (0.75*eps_HH);end;
        if(count == 3) temp_HH = HHproject + (0.5*eps_HH);end;
                   if(count == 4) temp_HH = HHproject + (0.25*eps_HH);end;
                   if(count == 5) temp_HH = HHproject;end;


for i=1:dimZone;
     for n=1:dimHH;
        if(temp_HH(i,n) > 0 )  HHproject(i,n) = temp_HH(i,n);end;
        if(HHproject(i,n) < 0 ) HHproject(i,n) = 0; end;
     end;
end;


%%%%%%%%%%%%%END OF RESLOC %%%%%%%%%%%%%%%%%%%%%%
```

```
%%%%%%%%%%%%%%%% LUDENSITY %%%%%%%%%%%%%%%%%%%%%%%%

%Calculation in LUDENSITY ....

HHproject_LU = HHproject;
EMPproject_LU = EMPproject;
for i=1:dimZone
   for n=1:dimHH
      if HHproject_LU(i,n) < 0.0001
        HHproject_LU(i,n)=0.0001;
      end;
   end;

   for k=1:dimEMP
      if EMPproject_LU(i,k) < 0.0001
        HHproject_LU(i,k)=0.0001;
      end;
   end;
end;

% HH & EMP in 2010
HH_zone1 = HHproject_LU(1,:);

HH_1=HHproject_LU(:,1);
HH_2=HHproject_LU(:,2);
HH_3=HHproject_LU(:,3);
HH_4=HHproject_LU(:,4);

sumHHzoneproject=sum(HHproject_LU,2);
sumEMPzoneproject=sum(EMPproject_LU,2);
BASzoneproject=EMPproject_LU(:,1);
COMMzoneproject=EMPproject_LU(:,2)+EMPproject_LU(:,3);

for i=1:dimZone
   if(landd(i) < 0.001) landd(i) = 0.001;end;
if(landdable(i) < 0.001) landdable(i) = 0.001;end;
if(sumHHzoneproject(i) < 0.001) sumHHzoneproject(i) = 0.001;end;
if(sumEMPzoneproject(i) < 0.001) sumEMPzoneproject(i) = 0.001;end;
end;
%Calculate Lr

Lr_unrestricted=(k0.*(landdable.^k1).*((landd./landdable).^k2).*((BASzoneproject./sumEMPzoneproject).^k3
).*((COMMzoneproject./sumEMPzoneproject).^k4).*((HH_1./sumHHzoneproject).^k5).*((HH_4./sumHHzon
eproject).^k6).*sumHHzoneproject) ;

%Calculate Lb
Lb_unrestricted=g0.*(landd./landdable).^g1.*(BASzoneproject./sumEMPzoneproject).^g2.*((COMMzoneproj
ect./sumEMPzoneproject).^g3).*((HH_1./sumHHzoneproject).^g4).*((HH_4./sumHHzoneproject).^g5).*BAS
zoneproject;
```

```
%Calculate Lc
Lc_unrestricted=p0.*(landd./landdable).^p1.*(BASzoneproject./sumEMPzoneproject).^p2.*((COMMzoneproject./sumEMPzoneproject).^p3).*((HH_1./sumHHzoneproject).^p4).*((HH_4./sumHHzoneproject).^p5).*COMMzoneproject;



Ldable= Lr_unrestricted+ Lb_unrestricted+ Lc_unrestricted;

%Enforce that Lr+Lb+Lc <= landddable
Lrproject=Lr_unrestricted;
Lbproject=Lb_unrestricted;
Lcproject=Lc_unrestricted;

L_change=zeros(dimZone,1);

for i=1:dimZone;
  if Ldable (i,1) > landdable (i,1);
    Lrproject(i,1)=Lr_unrestricted(i,1).*(landdable(i,1)./Ldable(i,1));
    Lbproject(i,1)=Lb_unrestricted(i,1).*(landdable(i,1)./Ldable(i,1));
    Lcproject(i,1)=Lc_unrestricted(i,1).*(landdable(i,1)./Ldable(i,1));
    L_change(i,1)=1;
  end;
end;

% Adding the residuals ...
if(count == 1)
temp_Lr = Lrproject + eps_LU(:,1);
temp_Lb = Lbproject + eps_LU(:,2);
temp_Lc = Lcproject + eps_LU(:,3);
end;
if(count == 2)
temp_Lr = Lrproject + (0.75*eps_LU(:,1));
temp_Lb = Lbproject + (0.75*eps_LU(:,2));
temp_Lc = Lcproject + (0.75*eps_LU(:,3));
  end;
if(count == 3)
temp_Lr = Lrproject + (0.5*eps_LU(:,1));
temp_Lb = Lbproject + (0.5*eps_LU(:,2));
temp_Lc = Lcproject + (0.5*eps_LU(:,3));
end;
if(count == 4)
temp_Lr = Lrproject + (0.25*eps_LU(:,1));
temp_Lb = Lbproject + (0.25*eps_LU(:,2));
temp_Lc = Lcproject + (0.25*eps_LU(:,3));
end;

if(count == 5)
temp_Lr = Lrproject;
temp_Lb = Lbproject;
temp_Lc = Lcproject;
end;
```

```
for i=1:dimZone;
   if(temp_Lr(i,1) > 0 ) Lrproject(i,1)= temp_Lr(i,1);end;
   if(temp_Lb(i,1) > 0 ) Lbproject(i,1)= temp_Lb(i,1);end;
   if(temp_Lc(i,1) > 0 ) Lcproject(i,1)= temp_Lc(i,1);end;
   if(isnan(Lrproject(i,1)) == 1) Lrproject(i,1) = landr(i);end;
   if(isnan(Lbproject(i,1)) == 1) Lbproject(i,1) = landb(i);end;
   if(isnan(Lcproject(i,1)) == 1) Lcproject(i,1) = landc(i);end;
end;

%}
for i=1:dimZone;
   if(isnan(Lrproject(i,1)) == 1)
      Lrproject(i,1) = Lrproject(i-1,1);end;
   if(isnan(Lbproject(i,1)) == 1)
      Lbproject(i,1) = Lbproject(i-1,1);end;
   if(isnan(Lcproject(i,1)) == 1)
      Lcproject(i,1) = Lcproject(i-1,1);
      %temp_i = i
      %temp_value = Lcproject(i,1)
   end;
end;
%%%%%%%%%%%%%%%%%%%%%%%% END OF LUDENSITY %%%%%%%%%%%%%%%%

%%%%%%%%%%%% PRINTING THE VALUES %%%%%%%%%%%%%%%%%%%%%%%

if(count ==1 )

csvwrite('C:\Predictions\District\Output\EMP2010.dat',EMPproject);
csvwrite('C:\Predictions\District\Output\HH2010.dat',HHproject);
csvwrite('C:\Predictions\District\Output\Lr2010.dat',Lrproject);
csvwrite('C:\Predictions\District\Output\Lb2010.dat',Lbproject);
csvwrite('C:\Predictions\District\Output\Lc2010.dat',Lcproject);

end;


if(count ==2)

csvwrite('C:\Predictions\District\Output\EMP2015.dat',EMPproject);
csvwrite('C:\Predictions\District\Output\HH2015.dat',HHproject);
csvwrite('C:\Predictions\District\Output\Lr2015.dat',Lrproject);
csvwrite('C:\Predictions\District\Output\Lb2015.dat',Lbproject);
csvwrite('C:\Predictions\District\Output\Lc2015.dat',Lcproject);

end;


if(count ==3 )

csvwrite('C:\Predictions\District\Output\EMP2020.dat',EMPproject);
csvwrite('C:\Predictions\District\Output\HH2020.dat',HHproject);
csvwrite('C:\Predictions\District\Output\Lr2020.dat',Lrproject);
csvwrite('C:\Predictions\District\Output\Lb2020.dat',Lbproject);
```

```
csvwrite('C:\Predictions\District\Output\Lc2020.dat',Lcproject);

end;


if(count ==4 )

csvwrite('C:\Predictions\District\Output\EMP2025.dat',EMPproject);
csvwrite('C:\Predictions\District\Output\HH2025.dat',HHproject);
csvwrite('C:\Predictions\District\Output\Lr2025.dat',Lrproject);
csvwrite('C:\Predictions\District\Output\Lb2025.dat',Lbproject);
csvwrite('C:\Predictions\District\Output\Lc2025.dat',Lcproject);

end;


if(count ==5 )

csvwrite('C:\Predictions\District\Output\EMP2030.dat',EMPproject);
csvwrite('C:\Predictions\District\Output\HH2030.dat',HHproject);
csvwrite('C:\Predictions\District\Output\Lr2030.dat',Lrproject);
csvwrite('C:\Predictions\District\Output\Lb2030.dat',Lbproject);
csvwrite('C:\Predictions\District\Output\Lc2030.dat',Lcproject);

end;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%



%%%%%%%%%%%  REINIATIALIZATION   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Assign the predicted values as base year values to continue ...
EMPbase_original = EMPproject;
HHbase_original = HHproject;
landr = Lrproject;
landb = Lbproject;
landc = Lcproject;

landd = landr + landb + landc + landsP; % The streets is assumed to remain the same ..
landdable = ZoneSize - landeP; % Developable land
landv = ZoneSize - landd - landeP;
for i=1:dimZone
if(landr(i) < 0.0001) landr(i) = 0.0001;end;
if(landb(i) < 0.0001) landb(i) = 0.0001;end;
if(landc(i) < 0.0001) landc(i) = 0.0001;end;
if(landv(i) < 0.0001) landv(i) = 0.0001;end;
end;

landdRatio = (landrP + landbP  + landcP + landsP )./( landdable);  % Proportion of developable land developed

for i=1:dimZone;
   for j = 1:dimEMP
```

```
        if(isreal(EMPproject(i,j) ) == 0 )
            temp_EMP = j
        end;
    end;

    for k = 1:dimHH
        if(isreal(HHproject(i,k))==0)
            temp_HHi = i
        end;
    end;
end;

end;
landrPproject = Lrproject;
landbPproject = Lbproject;
landcPproject= Lcproject;
landsPproject = landsP;
landePproject = landeP;
landuPproject = ZoneSize - Lrproject - Lbproject - landsP - landeP;

landall=horzcat(landrPproject,landbPproject,landePproject,landuPproject,landcPproject,landsPproject);
```