ARC PECAS Model System

Atlanta Regional Commission (ARC) PECAS MODEL

FINAL REPORT

HBA Specto Incorporated

Alberta, Canada

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"… There is no logic that can be superimposed on the city; people make it, and it is to them, not buildings, that we must fit our plans"

Jane Jacobs, 1916 – 2006

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1. Introduction

This report summarizes and describes the development and form of the ARC Land Use Modeling framework developed for the Atlanta Regional Commission (ARC). The intended purpose of this report is to explain in plain language the elements developed to build this model, the model's evolution, its current design, and its application in exploring scenarios and developing forecasts for the Atlanta Region.

This document is organized into six sections. Section 1 is this introduction. Section 2 explains the two primary applications for which the ARC uses the Production, Exchange, Consumption Allocation System (PECAS) modelling framework. It also briefly describes the theory and the background of PECAS, and summarizes the elements required to develop its two modules: Activity Allocation (AA) and Space Development (SD). Section 3 presents the evolution of the ARC PECAS model through six cycles of time and effort. Section 4 describes the current design of the model. Section 5 discusses the model application used to produce the ARC Series 16 (S16) Conformity Forecast to support the update to The Atlanta Region's Plan. It also presents the approach of this forecast and a scenario analysis of a policy for the City of Atlanta. Section 6 outlines possible areas of enhancement for the current version of the model.

2. Overview of the ARC PECAS Model

2.1. Dual Role: Forecasting and Regional Growth Scenarios

ARC is responsible for developing and updating the Atlanta Region's Plan, a long-range blueprint that details the investments needed to ensure metro Atlanta's future success and improve the region's quality of life. Regional and small-area forecasts are foundational elements of the Region's Plan.

The Research and Analytics Group (RAG) has been working with HBA Specto Incorporated (HBA) since the year 2008 in developing, calibrating, and enhancing the Atlanta Region PECAS land use model (ARC PECAS). This model is used for two main applications:

For the first of these, forecasting, the primary objective is to develop socioeconomic forecasts by Traffic Analysis Zones (TAZ) by integrating with ARC Activity Based Model (ABM) transportation model. This integration allows assessment of the level of usage for different future transportation infrastructure and services by different types of users, so that infrastructure can be constructed of appropriate size and design to perform well given expected future travel volumes.

The second application involves development of land use scenarios to model policy alternatives. The primary objective here is to understand the social and economic impact of applying different policies (e.g. building a project, changing zoning in specific places, etc.) to the Atlanta Region's growth patterns by providing information that can be visualized and compared by zone, so better decisions can be made and public funds directed to optimal projects and services.

For forecasting, RAG uses ARC PECAS holistically to combine data from different sources and at different geography levels. It uses growth rates provided by REMI (Regional

Economic Model Inc.) and local zoning information to provide a simulation of the future spatial allocation of the population and employment considering the transport interactions provided by the ABM down to the TAZ level.

The current version of ARC PECAS dynamically balances regional control totals of population, household and employment data at the region level to smaller geographies, including 20 counties, the Land Use Zone (LUZ) level (currently 1,031 zones aligning with census tracts) and finally down to the TAZ level (around 6,000 zones).

Population, households and employment baseline data are updated every few years, with the last update taking place in 2018. In 2019, the model was calibrated using a) trip length data region-wide, b) proportions of households by type choosing housing types to live in and generating labor occupations region-wide, as well as c) rent data by space type at a zonal level. In addition, the space development (SD) module was also updated, including zoning data and the data used for calibration of the parcel simulation.

Local jurisdictions were informed about and involved with the forecasting process, providing information concerning major buildingabout future development projects as well as local policy goals which are inputs to assess using the ARC PECAS model. The localities are as such quite aware of the instrumental roles of the model in scenario work and forecast development.

2.2. Theory and Background

The ARC PECAS model is a spatially disaggregate input-output economic model that has two main components: the Activity Allocation (AA) module, which simulates the location of different kinds of households and businesses and the spatial interaction between them; and the Space Development module (SD), which simulates the development of land with newly built or expanded buildings within which to locate activities as simulated by AA. ARC PECAS runs through time from 2015 to 2050.

2.2.1. Activity Allocation

The AA module simulates the economic 'activities' in the Atlanta Region. There are eighty-one (81) activities in the ARC PECAS model, representing types of households, kinds of business, government activities, and classes of importers and exporters. Households are split into size and income categories, while businesses and government activities are segmented into industries, such as agriculture and forestry, health, or retail.

These activities produce and consume inputs and outputs that quantify their interactions. These are referred as 'puts' (or commodities). Households produce labor and consume goods and services. Businesses consume labor, goods and services while each produces a specific type of good or service based on their industrial classification, along with some by-products. A special kind of 'put' is space; each activity consumes some appropriate floor space; a household can choose to live in different types of housing, while businesses have a single appropriate type of space, like office or industrial space.

Each activity allocates the buying and selling of their 'puts' to different locations within the Atlanta Region. There are 1,031 land use zones (LUZs) representing subareas of the region. The activity is located in the LUZ where it consumes space, but it draws inputs from, and supplies outputs to, zones all over the region, as well as from import/export locations. However, the travel costs (provided by the ABM) are included in this buying and selling, so a cheaper price is not always the most attractive if it comes from a more distant location.

Consider a restaurant, which has a single output – restaurant meals – but requires many inputs. Restaurants hire accountants, use electricity, buy furniture and so on, but the three most important (highest cost) inputs are labor, various kinds of food products, and appropriate floor space. People are not willing to travel far for restaurant meals, so in the model they have a high travel cost. This means that a restaurant will tend to locate near its clients; which are primarily households. A restaurant will be willing to pay extra in rent to locate somewhere that is convenient to a customer base.

A food processor, on the other hand, might supply restaurants and supermarkets with food, but it is somewhat cheaper to ship processed food than to drive a family to a restaurant. A processing location might require production labor and industrial floor space but will not be as sensitive to location.

AA thus simulates this entire process simultaneously across all activities, puts and LUZ. If the demand for a commodity (or 'put') in an area is high, the price will go up; the users in that area might get supply from further away and more suppliers might locate in that area. Some puts are elastic; households can choose to produce different kinds and amounts of labor to match that market need, for instance. Space consumption is elastic, allowing more activity in high demand areas even before the SD module can respond by building more space. AA iterates until all supply/demand curves are at equilibrium for all locations and for all commodities.

2.2.2. Space Development

The SD module is a microsimulation of the process of land development. It considers all parcels of land in the Atlanta Region individually.

As SD considers each parcel, it considers several possible events that could take place. The most likely event, by far, is that nothing happens on the parcel during a given modeled period. If the parcel is undeveloped, it remains as undeveloped land, or if there is a building of a given use on the parcel, the building and its use remain as is. The building on the parcel can be renovated, added to, or demolished. If the parcel is empty, a new building can be created.

These development 'decisions' are guided by two main factors: the zoning for the parcel and the rent (price) of the space. Zoning is a policy input to the model that determines what types of floor space can be built, and at what intensities (measured in Floor Area Ratio). In addition to zoning, greenfield sites can have phasing specified, so that the plans for the order of development are followed.

The higher the potential rent for a development compared to what exists now, the greater the probability that it will be built. The PECAS framework uses the concept of 'economic rent' to measure the price of floor space; this does not necessarily mean that a rent payment is literally being made for the space, but represents that floor space's value. Even a homeowner who has no mortgage still has the choice to sell their house or rent it out – by living in it instead, they are using up that value—in effect they are paying rent to themselves.

The base rent for each space is established by the AA module at the LUZ level. However, within LUZs, some parcels are more appealing for development (or redevelopment) than others. A series of 'local effects' adjusts the rent for each individual parcel; they represent the effect of the distance from the parcel to major roads, to the expressway exits, to the MARTA stations, to parks and greenspace, and to schools. The age of the building is considered in the same way; as buildings age, they are worth less in rent.

This combination of zonal rent and local effects goes into the parcel-by-parcel microsimulation. The decision to leave a parcel as is or to develop new space is affected by the potential value of the new space. If there is an old building of low value, or if the parcel is vacant and zoned for a higher use, is near local amenities (or far from noxious local effects), and/or if rents in the LUZ are high, development is more likely to occur there.

The SD module runs in each year of the simulation, calculating these probabilities and possibilities. As a result, the model predicts the changing quantity of space, in a way that is responsive to zoning, demand, travel system performance, and other things impacting market conditions. Before moving to the next year of the simulation, the total predicted quantity of development in each LUZ is assigned to the best individual parcels, which makes SD deterministic (if it's run again with the same inputs it will produce exactly the same results). This assignment makes the detailed spatial patterns easier to understand and visualize.

2.2.3. Model Interactions – AA, SD and the ABM

The ARC PECAS model simulates the future year-by-year from 2015 to 2050. In each year the AA module establishes prices, including rents. In each year SD will run, generating a year's worth of development. This increased floor space goes back to AA, affecting the rents and prices in the subsequent AA year. As the ARC PECAS model runs through time, the two principal modules "communicate" back and forth. For every year, an updated set of population and employment numbers are generated by the model. Every 10 years, the ABM takes this new land use forecast, simulates the travel demand and the delay caused by the demand and determines the resulting travel cost. These costs then update the ARC PECAS's understanding of how accessible all the parts of the region are, and the iterative process continues.

For example, consider a project that expands a congested highway in a given part of the Atlanta Region. With this higher-capacity project, the ABM will model less congestion in that geographic area, and less travel times to and from that area. ARC PECAS will take the reduced commuting times into account, and more people and businesses will locate there, increasing housing prices and rents. As there is now an increase in economic activity in the area, a developer might build more houses on nearby vacant land zoned for residential construction. After a few years when the ABM is rerun, there are now more residents within that area and some of the local roads might show congestion.

2.3. Elements of the PECAS model by module

2.3.1. Elements required by the Activity Allocation Module

Thirteen model elements are usually required to develop a PECAS Activity Allocation Module. These elements' complexity depends on the scope of the simulation. A brief description of the elements is presented in Table 1.

Table 1. Elements of a PECAS Activity Allocation Module

Model Element	Description
01: zone system	Locations in the AA Module are represented using a mutually exclusive and collectively exhaustive system of land use zones, or "LUZ". Each LUZ contains a given number of Traffic Analysis Zones, or "TAZs", that provide a finer level of spatial resolution used in the transportation model.
02: activity category definitions	Activities are of six basic types: households, firms, government, non-profits, importers and exporters. Accounts for funding allocations, investment spending and factors of production can also be included as activities. Households are categorized by size and income, and firms are categorized based on outputs, technology, and associated input requirements. Firms are often placed into industrial classifications.
03: 'Puts' category definitions	'Puts' are the inputs used and outputs made by activities and include physical items, services, labor, money or credit, and (floor) space in buildings, other factors of production, and waste. 'Puts' have widely varying characteristics regarding form, durability, divisibility, units, values, transportability and transportation costs and requirements. Per-unit market-clearing prices or rents are determined by the AA Module for each put in each LUZ as an exchange location. Physical items include types of raw materials, intermediate products, and manufactured goods. Services include education, health, professional and technical services, wholesale, retail, management, financial, insurance, policing, information, food and accommodation and broker services. Labor includes categories of occupation, such as managers, administrators, analysts, instructors, drivers, laborers, technicians, etc. Space includes types of residential dwellings, and non-residential buildings and other categories of fixed infrastructure and improvements. The categorization of 'puts' depends on the scope and objectives of the modelling work and may be influenced by data availability.
04: technology options representation and the design diagram	The "PECAS design diagram" uses a standard layout and set of symbol definitions to present the design of a specific model, as per the 'puts' included in technologies and whether one or multiple technology options and associated sets of technical coefficients are available to an activity. For typical land use transport interaction modelling, households and firms have (a) one technology option for the make and use of goods and services (making these rates constant), and (b) multiple technology options for the make and use of labor and the use of space (making these rates elastic).
05: aggregate economic flows	The model-wide total flows of puts produced and consumed by activities are set out in the "PECAS aggregate economic flows table", which uses a standard layout consistent with the "PECAS design diagram". This table is used to establish that the flows are balanced, where, for each put, the total flow into the model and the total amount made by all activities matches the total amount used by all activities and the total flow out of the model area.

Model Element	Description
	This table shows the production and consumption of each put by each activity, including labor productivity at firms and consumption by households. It also shows government spending on health and education.
06: space by zone (built form)	Space (or "floor space") is a special category of put: It is a fixed capital asset that is a required input for many activities. It is 'non-transportable' in that it must be exchanged and consumed where it was previously constructed (or produced) and remains located. It provides much of the fixedness and inertia in the locations of activities over time. Its production is simulated in the SD Module and provided as an input to the AA Module. A representation of the quantities of space by type and LUZ for one or more years is developed as an input to the AA Module. The primary direct measurement is often from the legal ownership records or property tax assessments. However, remote sensing data (imagery, terrain elevation, LIDAR, etc.), population information, vacancy rates, employment summaries, market summaries including rental rates, and other sources are usually used to supplement assessor files.
07: spatial distribution of activities	The spatial distribution of activities is represented as quantities in the LUZs. One of the objectives of model calibration is to match the model values to the target values for these quantities for one or more years. Direct observations of these quantities are not available generally, and thus must be synthesized from proxy variables and less than complete observations. The work on their development can be extensive.
08: puts flows	The flows of puts from production activity and location, through exchange location, and on to consumption activity and location are synthesized in the AA Module as flows among the LUZs. Quantification of the corresponding flows in the real world are used as targets in model calibration. In principle, these flows could be full origin-destination matrices developed by observations or synthesis. More typically, corresponding flow length distributions or even related trip length distributions are used as representations.
09: imports and exports	Imports and exports of puts flow across model boundaries to one or more external zones (both domestic and international) that contain put-specific importer and exporter activities. These exporter activities have demand curves, and importer activities have supply curves. The links to the external zones have associated transport costs. These curves and costs establish (a) export markets with price-elastic demand that help drive the model economy and encourage more efficient production and (b) import markets with price- elastic supply that meet requirements and help moderate prices.
10: transport utilities	The transport utility of transporting a unit of a given put among LUZs is calculated using some form of sum of weighted travel times, money costs and mode utilities, provided by the ABM. The mode utilities are generally composite utilities for the full set of available modes connecting the LUZs. The precise form of the sum and the values for the weights vary depending on the nature of the 'put' to be transported. There are four general categories: (1) "physical items" carried once to consumption locations in shipments typically involving flows of vehicles, with drivers providing transport services and possibly involving logistics considerations — transport utilities are calculated using driving times and money costs for vehicle operation and tolls. (2) "labor" requiring the presence of the worker each day; transport utilities are calculated using composite utilities for the available modes for person travel for the trip from home to work and the trip from work to home each workday.

Model Element	Description
	(3) "producer delivered services" brought by producers visiting the consumption location; transport utilities include both the arrival trip to the visit and the departure trip from the visit; when the worker uses a specialized vehicle — transport utilities are calculated using driving times and money costs for the vehicle operation and tolls; otherwise transport utilities are calculated using composite utilities for the available modes for person travel. (4) "consumer obtained services" acquired by consumers visiting the production location; transport utilities are calculated using composite utilities for the available modes for person travel for both the arrival trip to the visit and the departure trip from the visit. The measures of travel conditions used and the values for their weights are established for each put. These weights reflect the different values of time and relative sensitivities involved. They also transform the units from those of the measures output from the transportation model to the "utils per unit put" of the inputs to the AA Module.
11: observed space rent	One of the objectives of model calibration is to match the model-simulated rents for puts in LUZs to corresponding observed values. Direct observations are possible, and data may be available for many types of puts in many locations. Processing of the observations may be required to separate space rents into components represented in the AA Module and into components represented in the SD Module. Uniform pricing approaches and widespread agreements (such as union wage contracts) may remove spatial effects from observed values, leading to a need for further processing.
12: space short-run supply functions	Each space put has a short-run supply function that indicates the landlord's willingness to accept lower rents for space as demand decreases and to lease higher proportions of the total space (approaching 0% vacancy rate) at higher rents as demand increases. These functions must extrapolate beyond normal and structural vacancy rates so that the model software can both (a) accommodate extreme situations (approaching 0% or even 100% vacancy rates in LUZs) during the search for market-clearing prices and also (b) provide results for extreme policy scenarios. Usually, these supply functions are developed using observations of local-level rents and occupancy rates. Both residential and non-residential space types are often collected in a census or provided by the real estate industry. Typically, the determination of the central part of the function is informed by observed data, whereas the treatments at the extreme ends (very high rents, very high vacancy rates) are based on expert judgment and extrapolation.
13: observations of technology choice	Elasticities in the rates of production and consumption are incorporated into the AA Module by applying alternative technology options. Typically, in land use transport interaction modelling, households and firms have multiple alternative technology options for the make and use of labor and for the use of space. In some cases, the alternative technology options have been developed using clustering techniques to classify a dataset of many individual observations into a handful of representative clusters. In other cases, standard "more" and "less" alternatives are generated above and below observed rate levels. One of the objectives of model calibration is to match the distributions of make and use rates determined by the model across the LUZ to corresponding observed distributions.

2.3.2. Elements required by the Space Development Module

Thirteen model elements are usually required to develop a PECAS Space Development Module. These elements' complexity depends on the scope of the simulation. A brief description of the elements is presented in Table 2.

Table 2. Elements of a PECAS Space Development Module

Model Element	Description
01: parcel layer	The parcel layer is a spatial layer containing the shapes of the land parcels in the region, ideally based on land ownership. Each parcel should have some basic attributes defined, including its area, which Traffic Analysis Zone (TAZ) it falls in, and the level of utilities servicing currently available on it. The parcels should never overlap, but do not need to cover the entire region, since it is rarely worth including roads, rivers, cliffs, and other unsuitable building sites.
02: space category definitions	The usable floor space and productive land in the region must be divided into categories. These are usually distinguished by: whether the space is residential, commercial, industrial, or agricultural; finer distinctions of purpose, such as office versus retail; and building height, quality, or location. An additional type represents unimproved land.
03: inherent transition limits	This is the set of rules defining what kinds of changes between space types are physically possible. Each space type should have a minimum and maximum possible intensity, measured as a floor area ratio (FAR), or the ratio of floor area to parcel area. There should also be a list of the allowed change types: new construction, expansion of buildings, renovation, demolition, abandonment, repurposing, etc. In addition, any restrictions on these transitions because of type should be listed; e.g. specifying that high-density residential cannot be demolished to build low-density residential.
04: conversions from SD space categories to AA put categories	SD needs to know how to interpret space rents generated by AA, and how to produce floor space amounts that AA can understand. The categories may be different because each model cares about different things: AA cares about the purposes the space can be used for, while SD cares about the type of structure. In such cases, a conversion between SD and AA space categories must be established. It is easiest if the relationship is many-to-one, i.e. multiple SD types can map to the same AA type, but each SD type only maps to one AA type. Many-to-many relationships require weights indicating how relatively common each AA type is in the given SD type(s).
05: base year space inventory	The space inventory is the complete listing of the kinds and quantities of space currently built on each parcel, as well as when that space was built. SD normally only allows one type of space per parcel, so large parcels with a mixture of space types should be divided into smaller parcels.
06: zoning policies	Zoning policies are imposed by municipal governments to restrict the kinds and densities of space that can be built in different parts of the municipality. These policies need to be reflected as accurately as possible, specifying the SD space types and range of FARs allowed on each parcel. Each parcel must have a zoning policy in the base year; anticipated future changes in zoning should be included as well.

Model Element	Description
07: urban fringe release patterns and schedule	If the region includes cities and towns that are sprawling onto the surrounding land, areas that are expected to develop should be given small parcels to develop on – otherwise large rural parcels will try to develop all at once, producing large jumps in available space. These parcels should ideally be arranged according to approved neighborhood plans. The expected sequence in which growth areas will develop should also be determined.
08: construction costs	The cost to a developer of physically constructing each type of space should be established. This can include site preparation costs, which scale with land area rather than with the built area within the building. Construction costs can vary from location to location within the region.
09: development fees	The fee imposed by the municipality for building each type of space should be established. Like construction costs, fees can vary from location to location, usually at least changing at municipality boundaries.
10: local effects and observed prices for estimation	Local effects are the mechanisms, beyond the characteristics of the building itself, via which features of the area around a building may affect the rent its owners can charge. These features can include distances to high-quality transportation options, distances to parks, noise levels, etc. The age of the building is also considered a local effect despite being a property of the building, because age of the building increases every year and usually reduces the value of the building. Local effects consist of two parts – parameters and distances. The parameters that control the strength of the local effect have to be estimated using the observed sale or rental prices for a sample of buildings of different types. The distances require information about the locations of the local effect features.
11: intensity effects	The core of SD's profit model for developers implies a linear relationship between the size of the building and expected profit. But this is often not realistic; larger buildings are often more efficient up to a point, but eventually the costs of stronger materials or additional elevators start to outweigh the benefits of the additional space. SD implements a *density shaping function* to address this. Creating the density shaping function requires deciding on a form for the function – how many times does the relationship between space and profit change as the intensity increases, and at which intensities does it change. A preliminary function can be estimated if a sample of observed buildings with known FAR values is available.
12: observed construction	Calibrating the SD module relies on good observations of past construction in the region. At minimum this should include construction events for each space type, along with the sizes of the buildings produced, over about five years. Better results can be achieved if there is also information on renovations and other types of transitions, as well as information about where each construction event took place.
13: known future construction projects	Any large buildings, such as hospitals, stadiums, or large apartment complexes, that are under construction or approved for construction, should be coded directly into the model as *site specific developments*, which force SD to build in the exact locations indicated. This helps SD produce better short-term forecasts.

3. Evolution of the ARC PECAS Model

Consistent with the philosophy of the Agile approach the ARC PECAS Model has been evolving in cycles through time. Six cycles can be identified as shown in Figure 1 and in the description of the cycles.

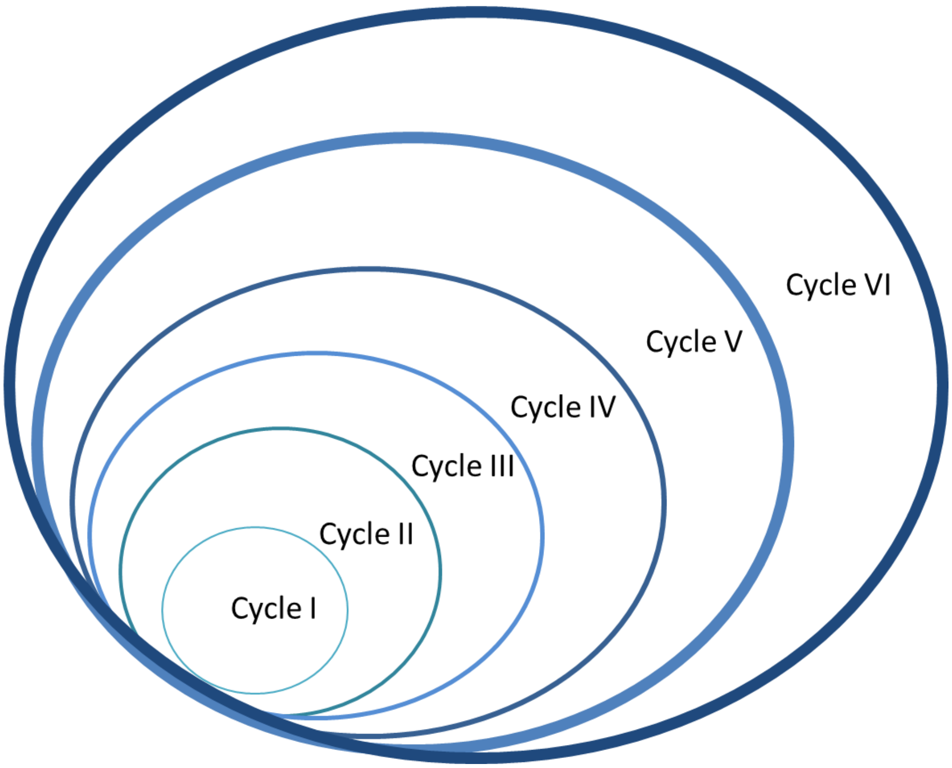


Figure 1. Cycles of Development and Improvements of the ARC PECAS Model

3.1. Cycle I – Model Development (2008 – 2010)

The ARC PECAS Model began development in 2008 and included the two PECAS modules; Activity Allocation (AA) and Space Development (SD). The base year used was 2005 and the model ran through time to 2040. This model was originally developed with 79 land use zones (LUZs), aligned to the Atlanta Region's superdistricts and one external zone, and 2,024 Traffic Analysis Zones (TAZ). The aggregate economic flow (AEF) table was developed to define the production and consumption interactions among 36 Activities and 35 Commodities. Data from the US Census PUMS (Public Use Microdata Sample) for household and labor were used. Samples of households using housing types and households generating labor occupations were developed from this data as well. A population synthesis was generated as a representation of the disaggregate population of the Atlanta Region, using a synthesizer program developed by HBA Specto.

An employment allocation process was performed to identify labor working in office space versus non-office (industry) space (using ARC LandPro land use/ land cover data). A separate rent estimation procedure was created to calculate rents per space type, one for residential space and one for non-residential space. Transport utility functions were calculated using data and skims generated by the 4-step transport model, the TDM of the Atlanta Region at that time. The AA module was calibrated to match average length of commodity flows, choices of residential units by type and observed rents by LUZ.

The parcel database for the Atlanta Region, required by the SD module, was developed using a GIS layer and zoning information provided by each of the twenty counties in the region. The SD module was calibrated to simulate development at the parcel level.

3.2. Cycle II – Model improvements and visualization (2010 – 2014)

During this period, efforts focused on updating the model to use 2010 as the base year instead of 2005. Input files were updated accordingly, including the constraint amounts by TAZ. 2010 Census data were employed for this process. Secondly, a greater consistency between the space (building) data and the employment data was achieved by using a floor space synthesizer. The purpose was to generate a synthetic representation of the built form to assign estimated TAZ-level floor space quantities to parcels, to best match observed parcel conditions. Data from Clayton County was used as a pilot to generate a process that the agency staff applied later to the other 19 counties included in the model area. In addition, new transport skims were obtained which worked better for simulation of the primary school trips. After all these data updates, the model was recalibrated using region-wide trip length, choice of housing types by households, choice of labor generation by households, and simulation of floor space.

The other primary event of this cycle was the creation and installation of MapIt application on the ARC PECAS server. MapIt is a visualization tool that allows PECAS's users to visualize the model results spatially, as well as export results in several standard formats of any GIS program, including ArcGIS, QGIS and other programs.

3.3. Cycle III –Forecast, planned projects, SD calibration and setting up the interactions with the ABM (2015)

During 2015, the ARC PECAS model was improved in several ways. The Traffic Analysis Zone system was upgraded from the original 2024 zones to the new 5873 zones for the 20-county area. With the development of the new activity-based transport model (ABM), new transport utility functions were developed by updating the transport cost coefficients and using the transport skims being generated by the ABM. These skims are used to calculate transport utilities for economic relationships (e.g. labor market commuting) that affects the final allocation of businesses, households, and other institutions in the Atlanta Region. The enhancements included in the ARC PECAS model can be organized in two types: model development and functional improvement.

Enhanced model development included (1) updating growth rates for the model-wide activity amounts (households and industries) through time, using data from an updated regional economic forecast, (2) previously observed or forecast activity amounts (households and jobs) were processed (at the TAZ level) as “constraints” to align to the most recent observations (2005 to 2015), and to facilitate updates of previous forecasts and comparisons to previous work (2016 to 2050), (3) the Activity Allocation model was recalibrated according to the transportation model updates in the new 5873 zone system; this included calibrations to region-wide trip lengths, households by types’ choice of housing by class and space, and rents/prices, and (4) the Space Development module was recalibrated to match updated targets and to provide more consistent statistical distributions.

Added model functionality included (1) TAZ level constraints on development in the SD module to incorporate local knowledge beyond what was available in the parcel database (thereby mitigating the effect of inevitable remaining errors in detailed parcel data), (2) indications of programmed development (future planned projects) by the local jurisdictions , and (3) better integration with ARC ABM to produce what the transportation model needed, (but still using different categories).

3.4. Cycle IV –Initial Exploring of Atlanta City Design scenarios (2016)

In 2016 the ARC started using the PECAS model to explore possible population scenarios under which the population in the city of Atlanta could reach 1.3 million in the future. These scenarios were defined in the following way:

- Scenario A: no constraints on the amount of construction through time;
- Scenario B: making the City of Atlanta more attractive than the rest of the region, so more jobs and people move to the city;
- Scenario C: releasing growth constraints in the City of Atlanta, but keeping the model constraints elsewhere;
- Scenario D: making the City of Atlanta more attractive than the rest of the region and increasing jobs in future-year constraints.

These analyses were done using PECAS model alone without integrating with ARC ABM in this project. Module upgrades were required before embarking on this type of integrated analyses in the future. These population scenario analyses will be revisited next year with upgraded models.

3.5. Cycle V -Model improvements, calibration, deterministic SD, Technology Scaling, and Atlanta City Design Scenario (2017-2018)

In 2017 and 2018, inputs of the AA module were updated using 2015 Census and economic data. Furthermore, the LUZ system was updated to 1,031 zones using census tract boundaries in the model area. In this version of ARC PECAS, new categories of the activities, commodities were defined, including more detail in the categorization for households. Moreover, model design was modified to produce outputs in number of jobs and households in categories needed by the ABM. After updating the model inputs, model parameters were also calibrated using 2015 targets (i.e. trip lengths, household distribution, residential and non-residential rents, imports and exports).

In 2018, another important change was the updating of zoning regulations in the SD module to better align with ARC regional landuse policies, Unified Growth Policy Map (UGPM). The UGPM provides direction for future growth based on the ‘areas’ and ‘places’ within the region, representing local plans as well as The Region’s Plan policies and goals.

During this period, the City of Atlanta’s “City Design” scenario was run with ARC PECAS, to assess the impact of both densifying the core and corridors of the City of Atlanta and allowing these areas to grow more quickly. The analysis explored new opportunities of development and resulting changes in the patterns of development from 2015 to 2050. The scenario results show the broad impact to the region when the City accommodate the projected population of 1.3 million.

During this cycle two important features were added to the model: Deterministic Space Development Module and the technology scaling feature for the Activity Allocation Module. A brief summary of them are described below:

- The SD Module of PECAS has traditionally been a monte-carlo *microsimulation* model, simulating small behavioral parcels of land with outcomes chosen randomly for each unit with probabilities determined by the relative desirability of each possible outcome. However, the random choice of outcomes leads to different results from different runs, even if no inputs have changed. Investigating the marginal effect of individual policies is problematic with this type of model, because the random variation between two runs can be greater than, and hence mask, the policy impact. The new “deterministic” version avoids this issue of having different results in different runs by accumulating possibilities over each parcel in each LUZ, but then assigning the resulting total development to the best parcels in each LUZ. This allows direct parcel-by-parcel comparisons between a policy scenario and the reference scenario, showing the exact impacts of the policy itself.
- The technology scaling feature has purpose of keeping the economy balanced in future years of the run. In the base year the economic data is balanced, meaning that demand and the supply are in equilibrium. But, different growth rates for different industry or population groups can cause the base-year relationships to be inconsistent in the future. With technology scaling, if an industry (e.g health care) grows more quickly, the relationship that leads to the use of that industry’s output will be scaled up (e.g. higher household use of health care) in future years, and exports and imports will also be adjusted (e.g. more people from outside of the region coming to Atlanta for health services). If jobs grow faster than working-age population, labor force participation will increase. Each consumption relationship is scaled based on the production amounts of the different puts

implicit in the growth forecast. This allows the model to proceed given almost any forecast.

3.6. Cycle VI – Generating S16 Conformity Forecast for the Atlanta Region’s Plan (2019)

In 2019, since in the previous cycle the model had gone through data updates, calibration and scenario growth assessment, ARC PECAS development was complete. Consequently, ARC PECAS model, integrated with the REMI model and the ABM, was applied to develop the S16 Conformity Forecast supporting the Atlanta Region’s Plan.

PECAS small area forecasts (population, households and employment) were sent to the ABM, then ARC PECAS was provided with the information on future travel conditions (“skims”) from the ABM. The skims were used to calculate transport utility functions representing the economic relationships (e.g. labor market commuting) that affect exchange location choices and location and technology choices for businesses, households, and other institutions in the Atlanta Region. The integration of the model runs between ARC PECAS and the ABM were for five forecasting years, 2015, 2020, 2030, 2040 and 2050. Section 5.1 of this report describes in more detail the data flow process for generating the forecast, while section 5.2 presents the forecasts of population, employment and households by county for 2020, 2030, 2040, and 2050.

4. Current Model Design

In the AA module, all model inputs are based on updated estimates of population and employment. The current ARC PECAS model has been upgraded with a zone system involving 1,031 LUZs.

The following are the main improvements made to ARC PECAS model in 2018:

- There are new categories for activities, including more detail in the categorization for households—the current version has 24 categories of households.
- Model constraints for industry are handled in jobs instead of in monetary amounts.
- New categories were established for commodities (goods, labor and space)
- Calibration data was updated including household use of residential space, household provision of labor by type, as well as rent/price data for residential and non-residential space.
- Zoning regulations were updated, using the Unified Growth Policy Map (UGPM)

4.1 Activities and Commodities

Monetary flows (including production and consumption) among the 46 activities and the 31 commodities defined for the ARC PECAS model were calculated using 2015 data from REMI (Regional Economic Models, Inc.). The categorizations of the activities and commodities defined for the ARC PECAS model are shown in Tables 3 and 4 respectively.

Table 3. Activity categories defined in the ARC PECAS Model

No	Activity Name	Description
Industries		
1	AI11AgFor	Agriculture and forestry
2	AI21Mining	Mining
3	AI22Util	Utilities
4	AI23Constr	Construction
5	AI313233Manu	Manufacturing
6	AI42Whlsale	Wholesale services
7	AI4445Retail	Retail and food services
8	AI4849Trans	Transportation services
9	AI51Info	Information services
10	AI52Finance	Finance and insurance services
11	AI53RealEst	Real estate services
12	AI54ProfTech	Professional and technical services
13	AI55Manag	Management services
14	AI56Admin	Administrative and business services
15	AI61EduServ	Education services
16	AI62Health	Health services
17	AI71Arts	Arts and cultural services
18	AI72Accom	Accommodation services
19	AI81Other	Other services
20	AI92Gov	Federal, state, and local government services

No	Activity Name	Description
21	AI125GovDemand	Representation of government spending (in dollars)
22	AI126InvDemand	Representation of capital investment (in dollars)
Households		
23	I1H1	Households with annual income < $20,000; 1 person
24	I1H2	Households with annual income < $20,000; 2 persons
25	I1H3	Households with annual income < $20,000; 3 persons
26	I1H4	Households with annual income < $20,000; 4 persons
27	I1H5	Households with annual income < $20,000; 5 persons
28	I1H6	Households with annual income < $20,000; 6 persons+
29	I2H1	Households with annual income $20 to 50,000; 1 person
30	I2H2	Households with annual income $20 to 50,000; 2 persons
31	I2H3	Households with annual income $20 to 50,000; 3 persons
32	I2H4	Households with annual income $20 to 50,000;4 persons
33	I2H5	Households with annual income $20 to 50,000; 5 persons
34	I2H6	Households with annual income $20 to 50,000; 6 persons+
35	I3H1	Households with annual income $50 to 100,000; 1 person
36	I3H2	Households with annual income $50 to 100,000; 2 persons
37	I3H3	Households with annual income $50 to 100,000; 3 persons
38	I3H4	Households with annual income $50 to 100,000; 4 persons
39	I3H5	Households with annual income $50 to 100,000; 5 persons
40	I3H6	Households with annual income $50 to100,000; 6 persons+
41	I4H1	Households with annual income > $100,000; 1 person
42	I4H2	Households with annual income > $100,000; 2 persons
43	I4H3	Households with annual income > $100,000; 3 persons
44	I4H4	Households with annual income > $100,000; 4 persons
45	I4H5	Households with annual income > $100,000; 5 persons
46	I4H6	Households with annual income > $100,000; 6 persons+

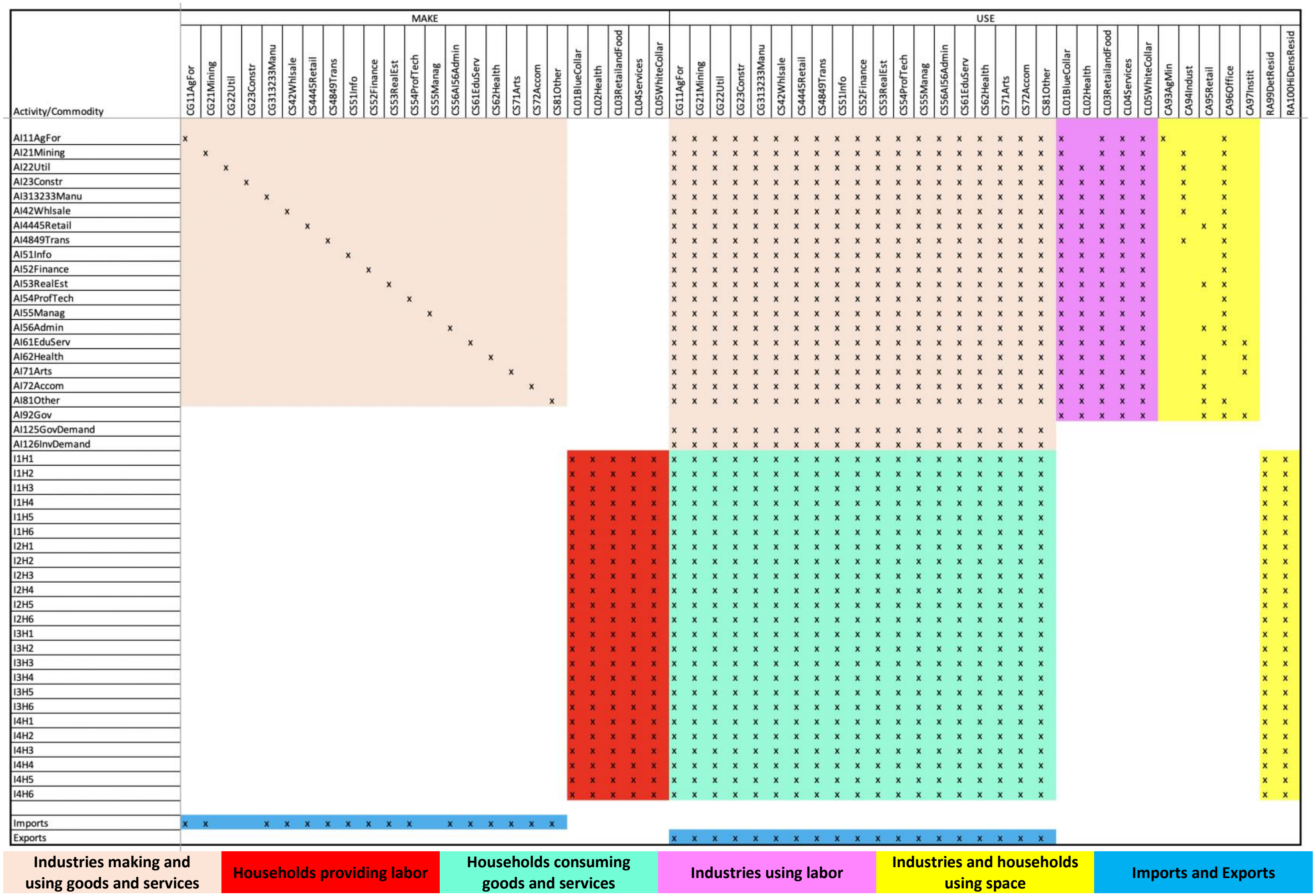
Table 4. Commodity categories (inputs and outputs, or 'puts') defined in the ARC PECAS Model

No	Commodity Name	Description
Goods		
1	CG11AgFor	Agriculture and forestry
2	CG21Mining	Mining
3	CG22Util	Utilities
4	CG23Constr	Construction
5	CG313233Manu	Manufacturing
6	CS42Whlsale	Wholesale services
7	CS4445Retail	Retail and food services
8	CS4849Trans	Transportation services
9	CS51Info	Information services
10	CS52Finance	Finance and insurance services
11	CS53RealEst	Real estate services
12	CS54ProfTech	Professional and technical services
13	CS55Manag	Management services
14	CS56AI56Admin	Administrative and business services
15	CS61EduServ	Education services
16	CS62Health	Health services
17	CS71Arts	Arts and cultural services
18	CS72Accom	Accommodation services
19	CS81Other	Other services

No	Commodity Name	Description
Labor		
20	CL01BlueCollar	Blue collar (SOC:45,47,49,51,53)
21	CL02Health	Health (SOC:29,31)
22	CL03RetailandFood	Retail and food (SOC:35,41)
23	CL04Services	Services (SOC: 27,33,37,39)
24	CL05WhiteCollar	White collar (SOC:11-23, 25, 43)
Space		
25	CA93AgMin	Agricultural and mining space
26	CA94Indust	Industrial space
27	CA95Retail	Retail space
28	CA96Office	Office space
29	CA97Instit	Institutional space
30	RA99DetResid	Detached residential space
31	RA100HiDensResid	Higher density residential space

An overview of the Aggregate Economic Flow Table (AEFT) developed for ARC PECAS is shown in Figure 2. The left half of the Table shows the “make” or production of commodities by the activities, while the right half shows the “use” or consumption of commodities by the activities. Color codes indicate particular interactions between certain activities and commodities in the model (Figure 2).

Figure 2. Overview of the AEFT for the ARC PECAS Model



The total number of households and the split by category were provided by ARC. These amounts are presented in Table 5.

Table 5. Total Number of Households by Household Type 2015

Household type	Number of households
I1H1	172,465
I1H2	69,544
I1H3	35,303
I1H4	20,779
I1H5	10,380
I1H6	8,825
I2H1	240,069
I2H2	199,733
I2H3	108,479
I2H4	78,161
I2H5	35,021
I2H6	25,678
I3H1	110,141
I3H2	241,315
I3H3	159,452
I3H4	135,158
I3H5	56,251
I3H6	36,438
I4H1	33,506
I4H2	127,065
I4H3	81,769
I4H4	80,644
I4H5	31,545
I4H6	17,226
Total	2,114,947

The total number of jobs was also provided by ARC. The split by industry is presented in Table 6.

Table 6. Total Number of Jobs by Activity

Activity	Number of jobs
AI11AgFor	2,015
AI21Mining	1,147
AI22Util	12,109
AI23Constr	120,226
AI313233Manu	200,466
AI42Whlsale	167,146
AI4445Retail	329,845
AI4849Trans	175,450
AI51Info	97,955
AI52Finance	128,237
AI53RealEst	50,964
AI54ProfTech	219,905
AI55Manag	63,472
AI56Admin	233,542
AI61EduServ	248,195
AI62Health	328,403
AI71Arts	32,580
AI72Accom	276,787
AI81Other	87,874
AI92Gov	147,638
Total	2,923,956

The amount of Imports and Exports for the Atlanta Region are shown in Table 7.These amounts were used as the targets for the Imports and Exports calibration of the ARC PECAS model.

Table 7. Total Imports and Exports by Commodity (Goods and Services)

Commodity	Total Imports	Total Exports
CG11AgFor	686,226,111	47,684,496
CG21Mining	9,324,843,987	122,401,415
CG22Util		1,277,605,505
CG23Constr		898,603,817
CG313233Manu	76,010,003,186	41,608,009,218
CS42Whlsale	5,267,640,561	24,141,761,793
CS4445Retail	81,451,704	1,618,968,740
CS4849Trans	6,814,066,111	24,241,629,486
CS51Info	5,258,358,024	32,661,966,365

Commodity	Total Imports	Total Exports
CS52Finance	9,640,186,875	19,065,584,534
CS53RealEst	11,499,728,707	29,630,687,842
CS54ProfTech	3,201,489,519	12,577,559,921
CS55Manag		3,791,883,143
CS56AI56Admin	1,660,925,157	6,567,854,702
CS61EduServ	1,692,406,352	4,487,651,088
CS62Health	9,422,078,834	10,508,381,617
CS71Arts	2,712,958,266	2,854,654,349
CS72Accom	1,312,649,975	3,037,371,584
CS81Other	2,957,018,312	2,635,904,869

4.2. Updated Land Use Zone System

The Land Use Zone (LUZ) system was updated to 1,031 LUZ system. Figure 3 shows the current LUZ and TAZ system.

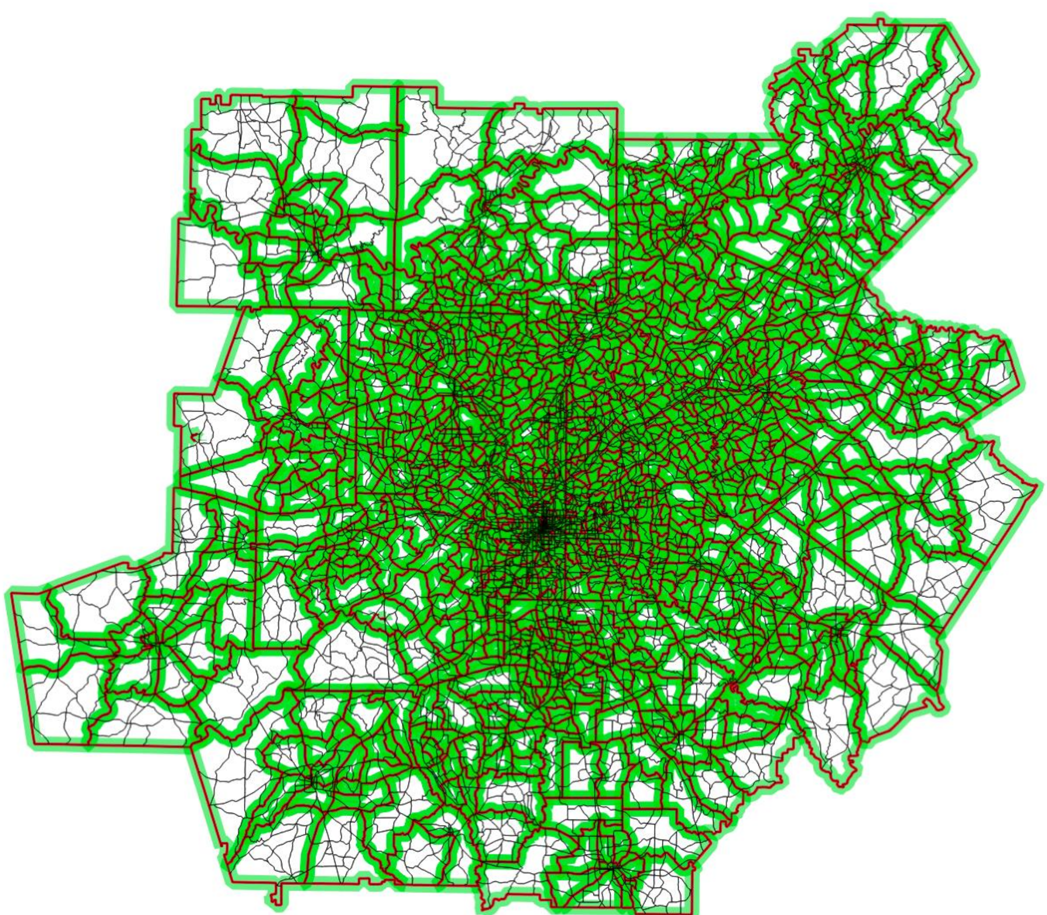


Figure 3. New Traffic Analysis Zone System

4.3. Updated zoning rules in the space development (SD) module

In the previous ARC PECAS model, zoning restrictions for the parcels were defined by 2005 data. In 2018, the SD module was updated to respect the Unified Growth Policy Map (UGPM). The UGPM provides direction for future growth based on ‘areas’ and ‘places’ within the region. The UGPM represents local plans,as well as The Region’s Plan policies and goals. Figure 4 shows centers and regions as defined in the UGPM.

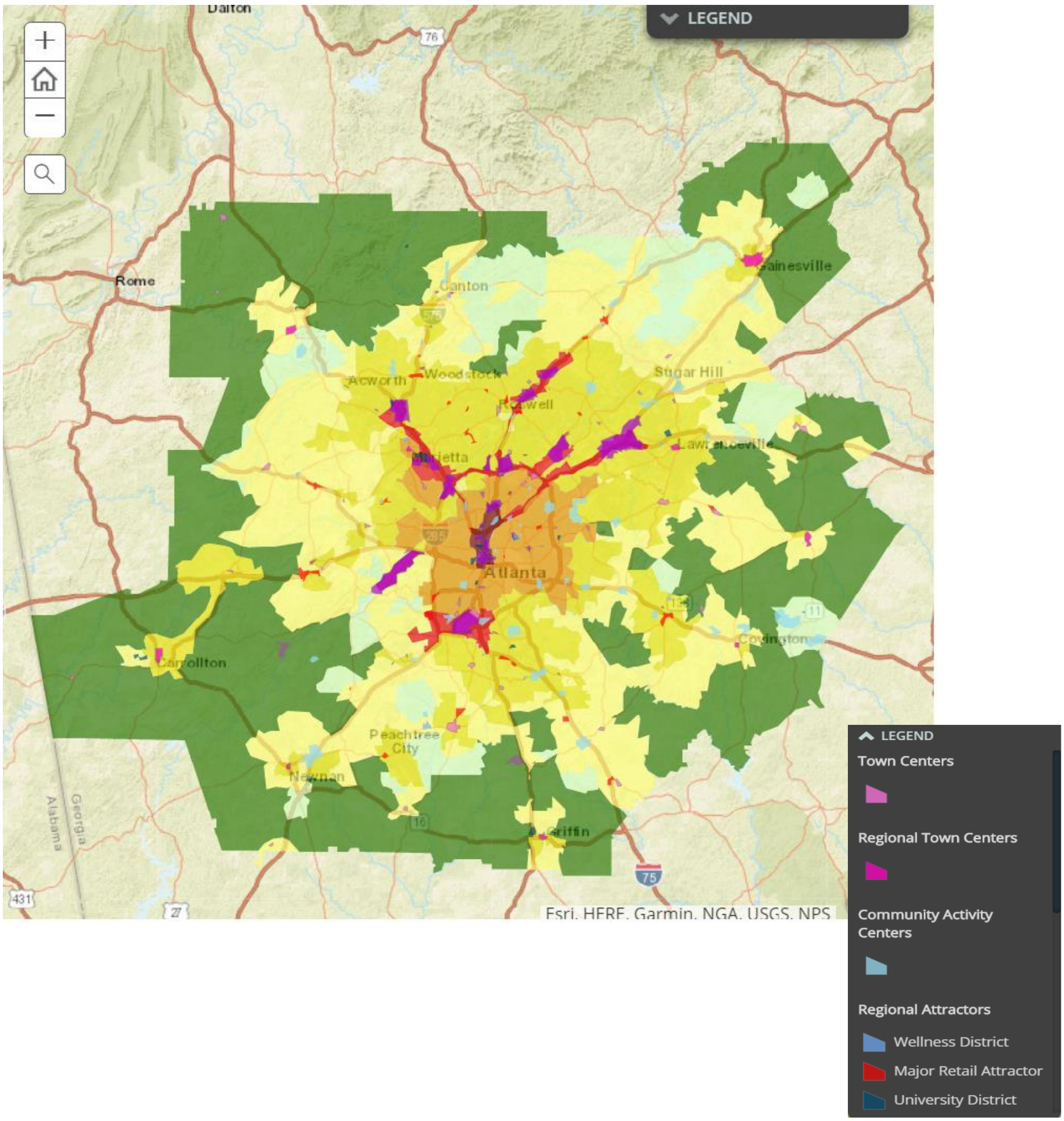


Figure 4. Unified Growth Policy Map for the Atlanta Region

5. ARC Series16 Conformity Forecast to support Atlanta Region's Plan

5.1. Forecasting approach

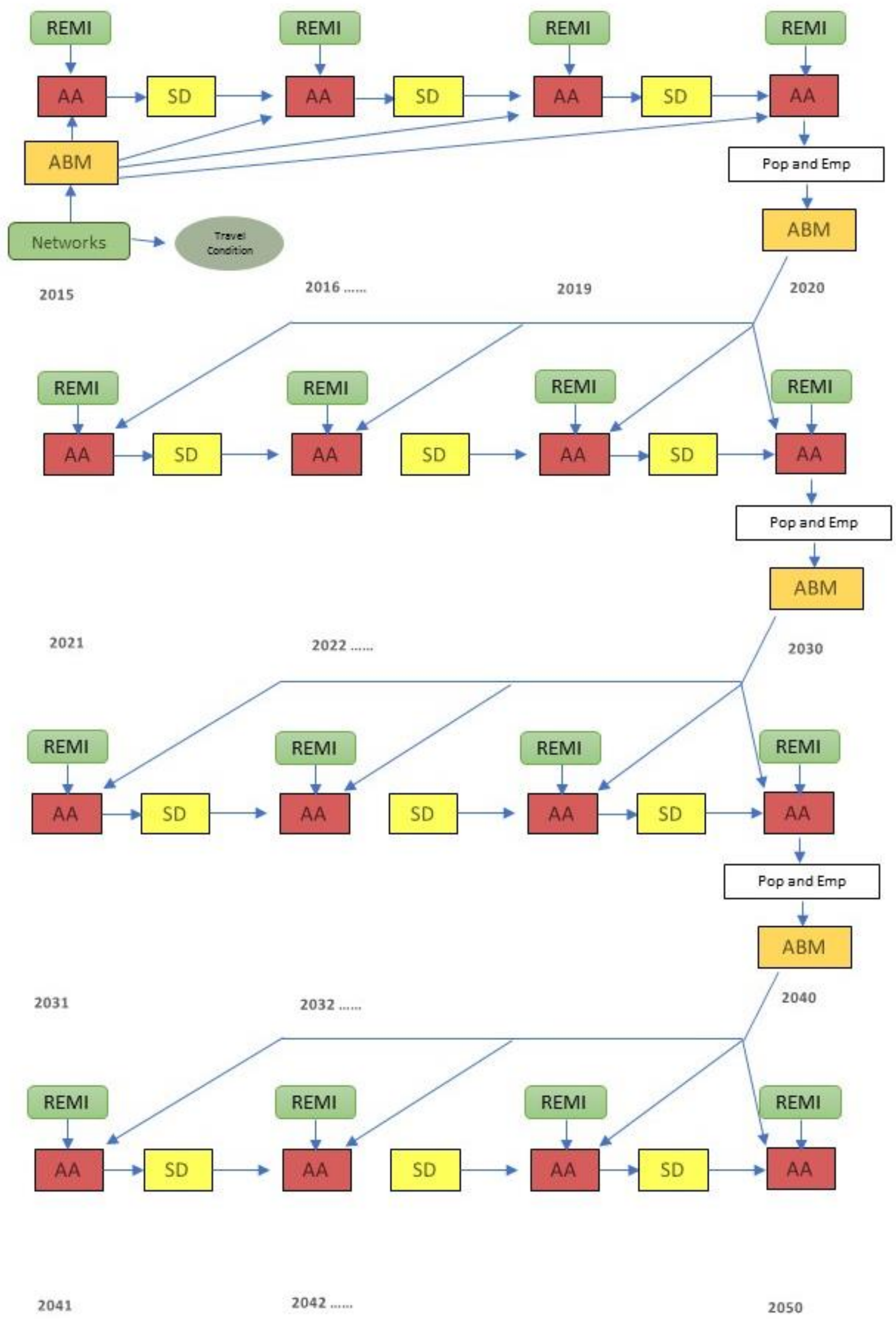
The ARC PECAS model currently interacts with the REMI (Regional Economic Model Inc.) model and the ABM to develop the conformity forecasts that supports the Atlanta Region's Plan. The official forecast includes households, population and employees by type and by location for the simulation period (2015 – 2050).

The ARC PECAS model is calibrated to its base year, which is 2015, and then simulates the future year-by-year from 2016 to 2050. Each year, the AA module establishes prices (including prices for the goods, services, labor and floor space), and then the SD module runs, generating a year's worth of development to balance the system. This increase in floor space feeds the next year of AA, affecting rents and prices in that subsequent year. As the ARC PECAS model runs through time, the two modules interact every year in this manner.

Activities in the AA module were constrained from the year 2015 to 2020 based on the ABM input data that had been developed for 2020, as well as Census observations. This provides consistency in terms of the data being used for the whole process in both models, while still allowing ARC PECAS to begin its simulation in 2015.

After preparing the model inputs the ARC PECAS model was run up to 2030, and the forecast of employment and households by TAZ for the year 2030 were produced. These numbers were introduced in the ABM to produce the skims (matrices of travel time, distance and cost) for the year 2030. Then, the model was run from 2030 to 2040 using 2030 skims to produce the 2040 forecast. This process was repeated for the period of 2040 to 2050. Figure 5 shows the model run system and its interactions to generate the official forecast.

In summary, every ten-year period, an updated set of population and job data was generated by ARC PECAS. This new forecast fed the ABM. The ABM simulated the resultant travel demand, the delay caused by this demand, and then determined travel disutilities. These transport impedances were then inputs to the next run of ARC PECAS, and provided indications of zone transportation accessibility and affordability.



ED = Economic Forecast; AA = Activity Allocation Model; SD = Space Development Model

Figure 5. Data flow and model system interactions between REMI, ARC PECAS and the ABM

5.2. Forecasting results

A summary of the forecasts developed to support the Atlanta Region's Plan are presented below. Figure 6 shows the total number of households, employment and population in the Atlanta Region from 2015 to 2050.

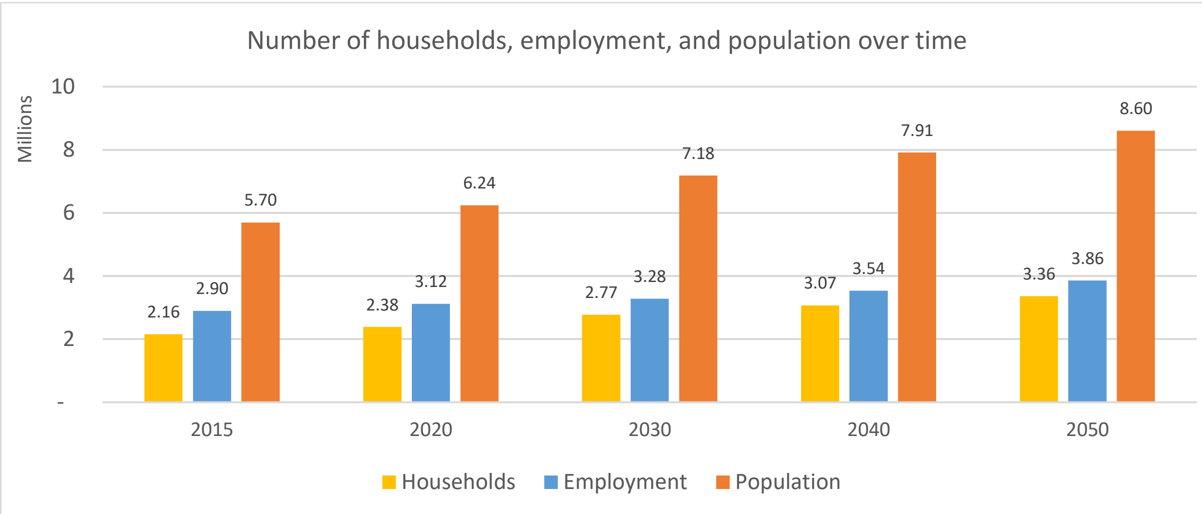


Figure 6. Number of households, employment, and population over time

Figures 7 to 9 show the totals for households, population, and employment over time, disaggregated to county level. The charts below show increase in the total number of households and total population for each county.

It is interesting to note that Fulton County and Gwinnet County maintain almost identical population totals, but there are fewer forecast total households in Gwinnet, suggesting a larger average household size. This aligns with the total job forecasts, where Fulton County comes in higher than Gwinnett County. This result mirrors the differing land use patterns in the two areas.: Fulton County is a metropolitan center with a greater job base and smaller households. Gwinnett County is a suburban center with a larger household size and a smaller job base. Gwinnett County has less population in 2015 than does Fulton County, but Gwinnett surpasses Fulton by 2050.

Total employment shows a slightly different trajectory than households and population, in which the employment totals do not correspond proportionally to future increases in population. Instead, Fulton County is seen as the dominant employment hub with the counties Cobb, DeKalb, and Gwinnett as secondary hubs surrounding Fulton. These results seem reasonable as these counties are adjacent to the metropolitan core and are relatively accessible to the employment of the core county. The charts below illustrate this relationship.

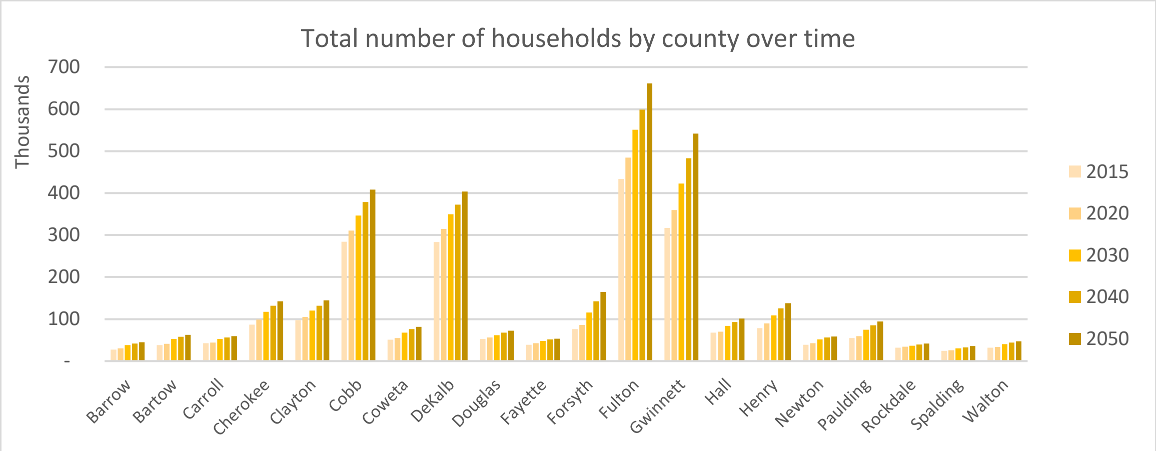


Figure 7. Total number of households by county over time, Series 16

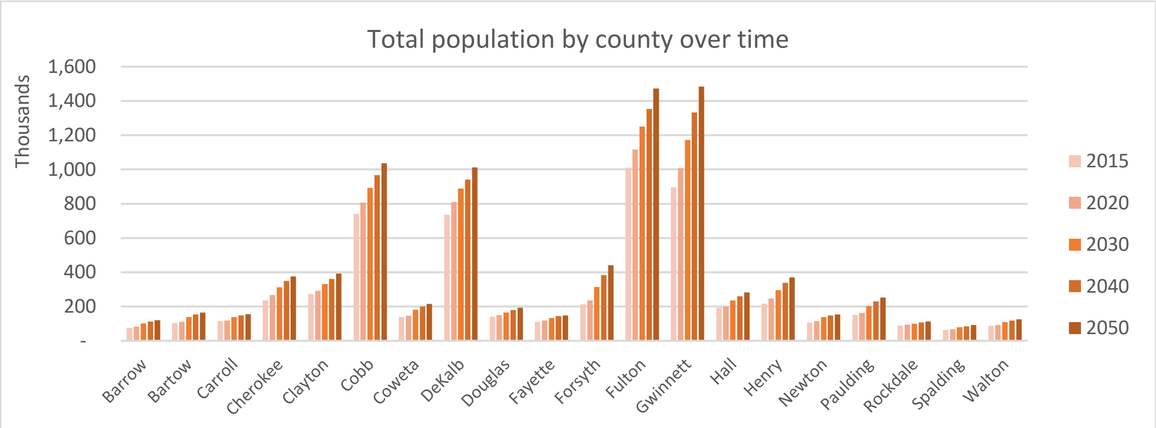


Figure 8. Total population by county over time, Series 16

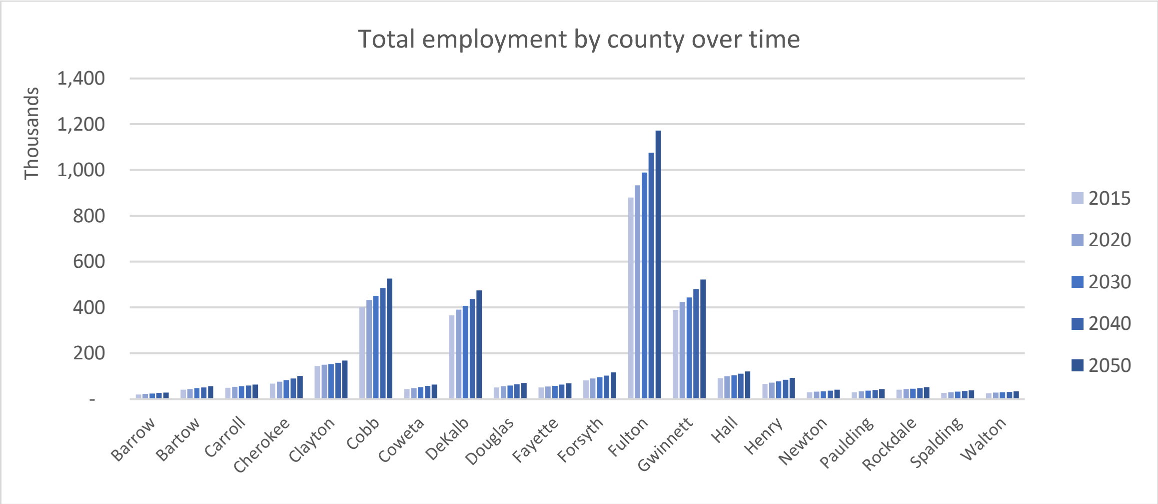


Figure 9. Total employment by county over time, Series 16

The maps in Figures 10 to 12 indicate the spatial distribution of households, population, and employment by county. Figures 10 and 11 show that though Fulton County has more households than Gwinnett, these two counties have similar population totals. For population, Gwinnett exceeds Fulton by 11,442 persons in 2050. In terms of jobs (Figure 12), Fulton is a clear frontrunner, with Cobb, Gwinnett, and DeKalb as a secondary surrounding tier of employment.

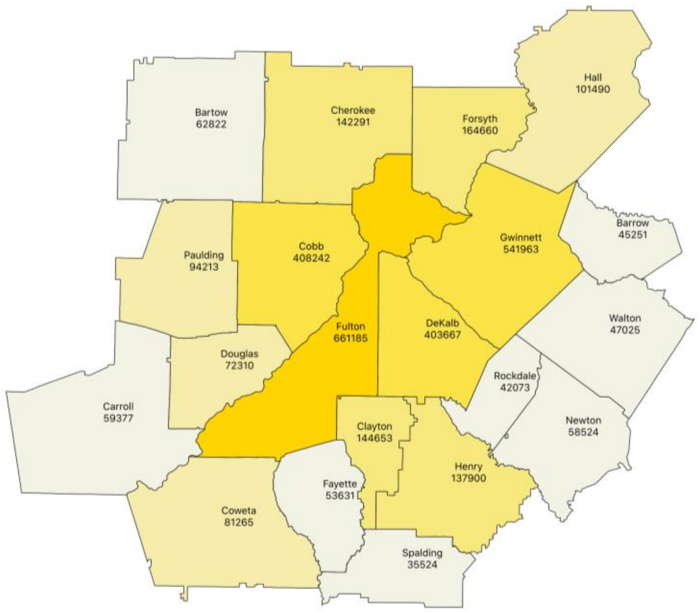


Figure 10. Map of households by county in the Atlanta Region in 2050

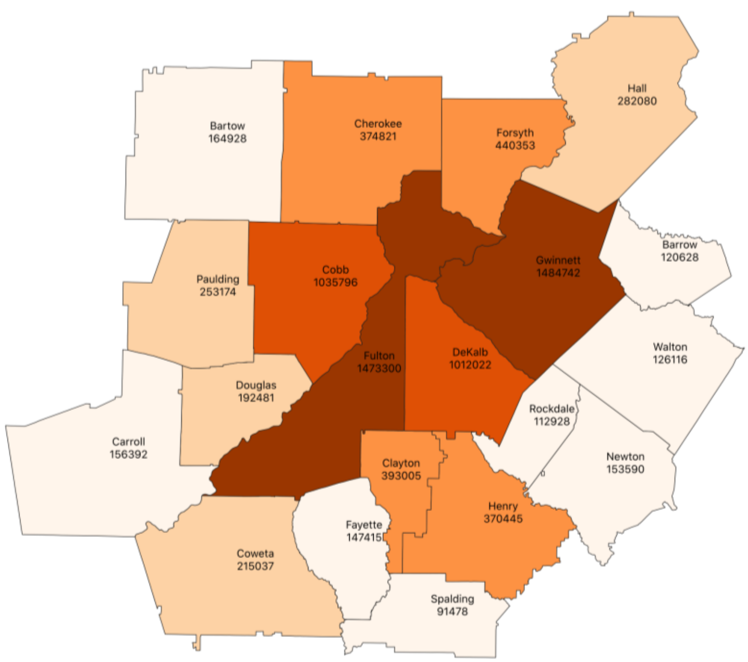


Figure 11. Map of population by county in the Atlanta Region in 2050

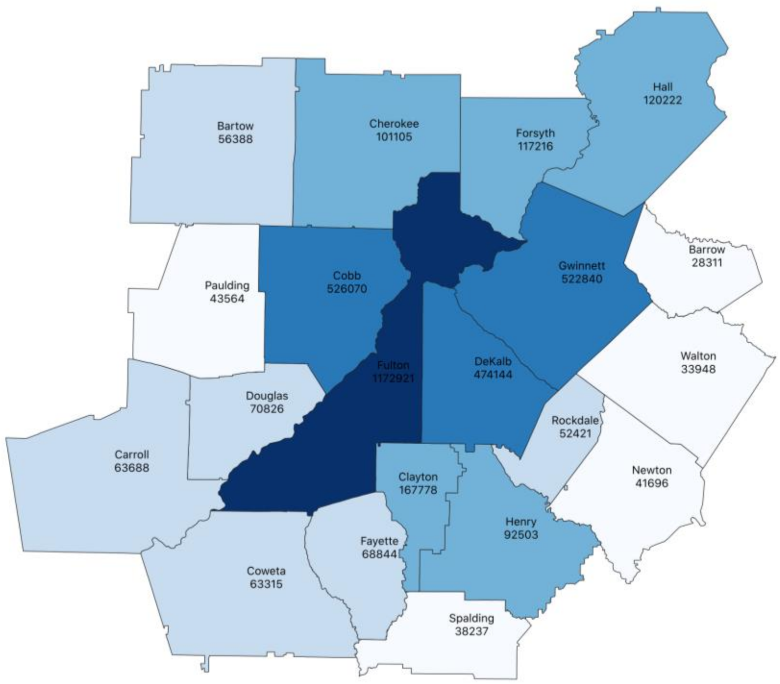


Figure 12. Map of employment by county in the Atlanta Region in 2050

Figure 13 depicts the ratio of jobs to population for each county from 2015 to 2050. It is apparent that there is an overall decline in some counties, while others show a u-shaped trend where the job to population ratio decreases but then increases. As one example, Fulton County experiences a decline in this ratio compared Cobb, suggesting a broader distribution of employment outside the core county over time. This consequently would create a redistribution of transportation demand and an overall shift of congestion to other corridors or centers outside that core county.

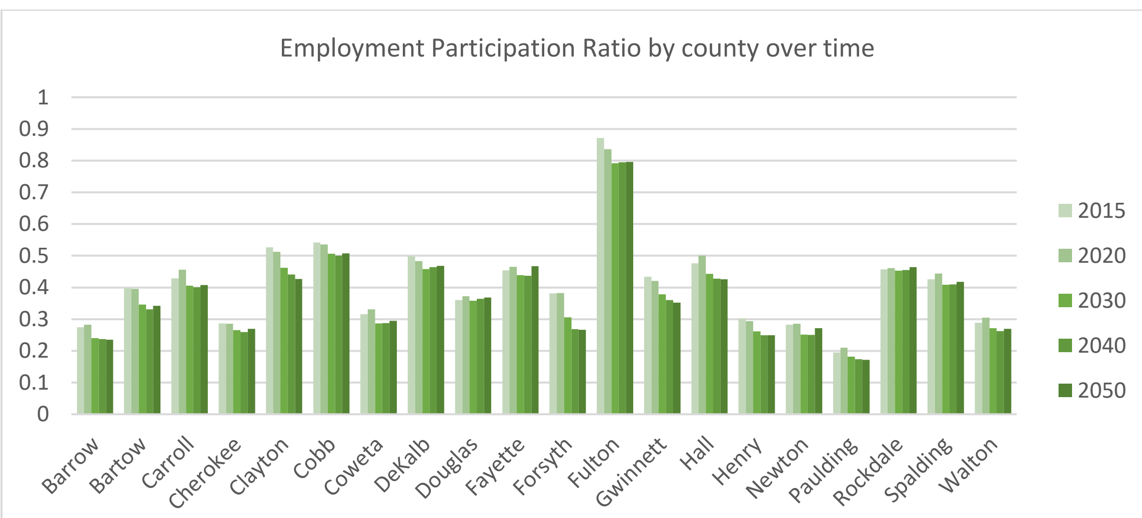


Figure 13. Employment Participation Ratio by county over time

5.3. Regional growth scenarios and policy

One of key uses of ARC PECAS is to explore when the City of Atlanta or the Atlanta Region might attain a specific population or employment target due to a new policy, and to assess the social and economic impacts of that policy. This analysis was performed in 2018 with the ARC PECAS model, for a scenario called the "City Design Scenario".

The purpose of the investigation was to assess the impact of densifying the core and corridors of the City of Atlanta. The analysis explored new opportunities of development and resulting changes in the patterns of development from 2015 to 2050. It also investigated reallocation of households and firms and the gains and losses of benefits (consumer surplus) due to changes in transport, size and price utilities associated with this reallocation.

The PECAS model for the Region of Atlanta was used to simulate variations on a growth scenario for the City of Atlanta. The city's planning staff identified the "Core" and various "Corridors" as intended densification areas (Figure 14). The policy inputs to the model were twofold: 1) assumed that the city was generically more attractive for both businesses and households, and 2) modified zoning to allow slightly higher densities in the Core and Corridors.

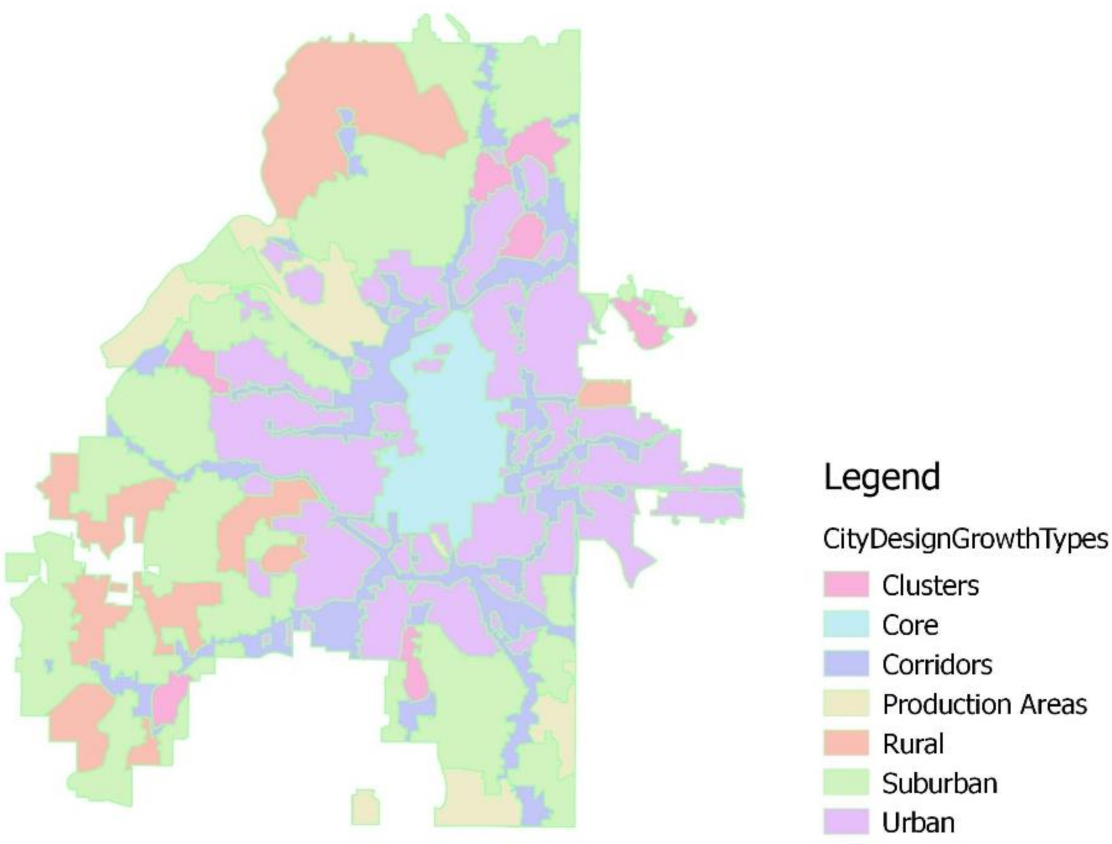


Figure 14. City Design Scenario

Planners at the Atlanta Regional Commission and the City were interested in seeing the simulated patterns of land use and development for the Region, in particular which parcels are predicted to experience new development, the types of development that might occur (e.g. office buildings, residential towers, etc.), the intensity (that is, floor area ratio) of simulated development, and the resulting allocation of different types of industry, jobs and households to the developed space(s). In addition, planners were interested in the transport and accessibility impacts of these reallocations, in terms of job markets and access to goods and services for households and for business. Further, there was interest in seeing whether the pattern of modeled development would continue to locate in certain higher-income but congested areas, or if growth might spread out and benefit more socioeconomically disadvantaged but less congested areas.

Baseline scenario results indicated that the City could reach 1.3 million population in 35 years, as compared to a previous forecast of almost 900,000. Initial scenario results were shown to planners, and then the scenario was adjusted based on their input. For instance, the model identified large development opportunities on parcels with zoning that allowed high-rise development. Some of these opportunities were not realistic since the parcel database did not include: a) the most recent data on parcels that had been developed at a much lower intensity than the zoning maximum, b) implicit (intangible) restrictions such as community opposition, c) physical constraints on parcels, such as difficult-to-demolish previous uses.

Variations were run on the baseline scenario, including a) no increase in density, and b) greater growth for the region as a whole. Output for these alternatives provided a richer understanding of potential impacts.

The baseline simulation modeled 77% of new space development in the targeted core and corridors. The total amount of new space through to 2050 was around 45 million square feet, with the core containing much of the new office space but also significant amounts of retail and multifamily residential space. Within the corridors, the dominant space is multifamily residential. In both the core and corridors, new office, retail and residential buildings often replaced industrial buildings, which relocated to less central areas of the Region.

Discussion of modeled development on a few specific sites was important for creating a give and take dialogue between the planners and the model. Examples included two golf courses (one abandoned and operating as a movie studio), an art center operating in a warehouse, parking lots around the former professional baseball stadium (Turner Field), and a wealthy residential neighborhood. Planners were able to react in a useful and thoughtful way to these particular simulated developments. In cases where they were skeptical of the simulated development intensity, they were willing to help refine model representation of very high-density development to focus it in more likely locations.

There were implications of the households and firm’s relocation, in terms of increased and decreased benefits. The following impacts in the entire Region stood out:

1) Firms received a surplus, from having more white-collar labor choices available for their employees. The households as providers of labor also gained access to jobs but some of these faced the added costs of lost transport utilities;
2) Households accessing education and health services showed gains in consumer surplus, while households accessing financial, real estate, insurance and other services showed losses in benefits;

3) Managers of manufacturing, transportation or utility industries travelling for business purposes lost relative accessibility to the production sites, due to an increase in commuting times.

With all the new construction of office towers in the core and the corridors of the city, the consumer surplus for the renters of office space went down in 2050, indicating that prices for office space increased. The opposite effect is observed for both residential space types: detached and multifamily. Renters of residential space will benefit from a global decrease in rents in the Atlanta Region, with more space made available. Nevertheless, it would be necessary to look at the rent effect by zone, and by year, which can go up or down depending upon the space type and the location.

It should be noted that after this 2018 assessment, the model has had major updates including implementation of a new version of the Activity Allocation model with more zones, and more direct representation of job and household categories used in the ABM.

From an institutional point of view, the Atlanta Regional Commission recognizes the advantages of having ARC PECAS for the Region of Atlanta, and looks to leverage the model's versatility for a variety of purposes.

6. Potential Future Model Enhancements

ARC Research and Analytics Group wants to continue using the ARC PECAS model to generate forecasts and assess policy scenarios in support of the planning and decision making of the Atlanta Regional Commission. Possible areas of improvement have been identified to keep strengthening ARC PECAS model capabilities during the next cycle of the model development and application. These include:

- Expanding the study area of the simulating model from 20 counties to 22, including in the future the Dawson county and Pike County.
- Activate the PECAS Population Synthesis procedure, which creates a full synthetic population for each future year. This can be used as an input to the ABM and/or for various other economic/demographic analysis.
- Making the model easier to use and understand by the staff of ARC and other government jurisdictions in the study area (counties, City of Atlanta, Georgia Department of Transportation - GDOT).
    - This could be accomplished by development of an enhanced user interface in combination with delivering training on how to use and analyze model results with the current knowledge and programs (MapIt, QGIS plugin, MRS GUI, etc.).
- Improving consistency between space data (parcel data) and population and employment data by TAZ.

- This investigation could help to measure the size of the work needed for upgrading and updating the parcel geometries and the parcel attributes (type and quantity of space, age of buildings, tax assessments, etc.) in the study area.
- Improving the parcel attributes may involve finding and incorporating data sets about specific kinds of space, such as lists of schools or skyscrapers, and updated zoning and/or zoning alternatives.

1) Generating a more formal detailed inventory of future projects and projected associated phasing (e.g. public and private communities, shopping malls, industrial parks, facilities, etc.)
2) Producing an inventory of targeted vacant sites
3) Recalibrating the SD module using updated construction costs, development fees, observed rents by space types and observed construction as calibration targets.
4) Recalibrating the space quantities and prices in the AA module, using existing price targets, to realign the module with the updates in the space data.
5) Improving the visualization of outputs -- for example, by developing CityPhi videos showing the iterative development of space throughout the simulation period.