WINNING THE FUTURE

SHARPENING OUR FOCUS

SHRP2 Element C08 (Volume 3)

Scenario Testing Procedures and Results

ARC
ATLANTA REGIONAL COMMISSION

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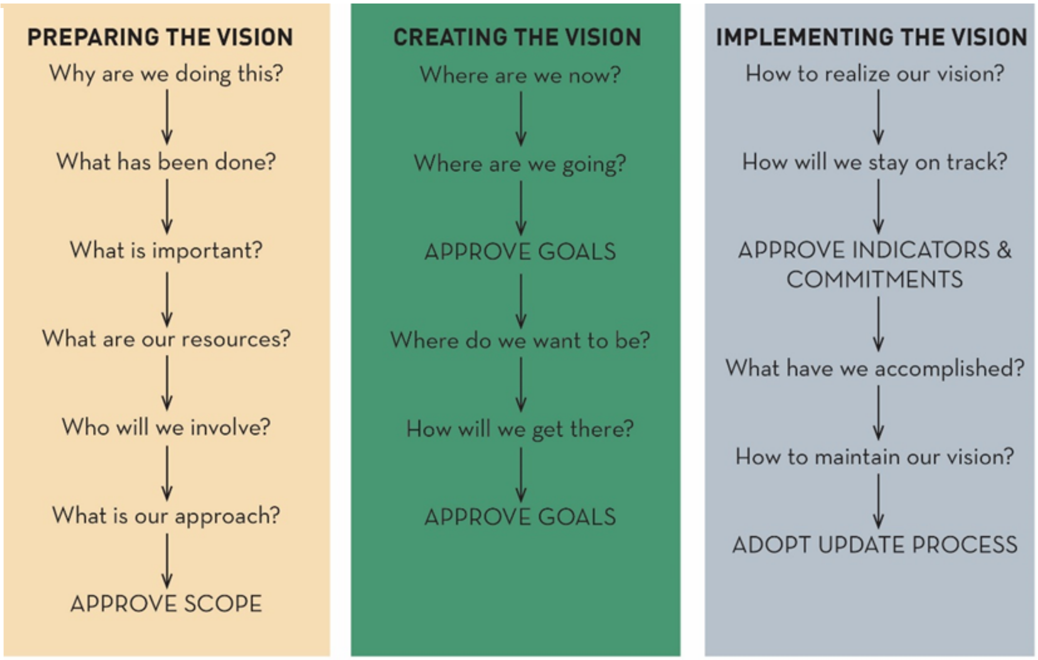
Background

ARC, as a Lead Adopter in the SHRP2 Implementation Assistance Program Round 5, executed an 18 month work plan that created a vision for the Atlanta Region following the SHRP2 C08 Report “Linking Community Visioning and Highway Capacity Planning” and associated interactive Vision Guide website PlanWorks. During this vision development process, two other SHRP2 bundle products were integrated into the process by (1) incorporating performance measures at key decision points in the planning process (C02- Performance Measurement for Highway Capacity Decision Making) and (2) involving freight stakeholders in the process as identified by the report “Integrating Freight Considerations into the Highway Capacity Planning Process: Practitioner’s Guide” (C15). The outcome was a regional vision and strategies developed through a transparent and replicable planning process.



FHWA PlanWorks Vision Guide

The SHRP2 (Strategic Highway Research Program) was created to find strategic solutions to three transportation challenges the nation is facing: improving highway safety, reducing congestion, and improving methods for renewing roads and bridges. Research has been focused in four areas: safety, renewal, reliability, and capacity. This effort will follow planning process bundles under the Capacity research area. The tools integrate environmental, economic, and community requirements into the analysis, planning, and design for new highway capacity.

This visioning effort built upon a policy foundation laid out in the 2016 iteration of *The Atlanta Region's Plan*. The long-range plan, adopted in February 2016, constructed an interdisciplinary policy framework for "winning the future". The 2016 Policy Framework allows ARC, working with other key organizations in the Atlanta Region, to advance policy objectives and work together to meet the region's tough challenges. *The Atlanta Region's Plan* also meets federal regulations for MPO long-range transportation planning and state mandates for regional commissions and comprehensive plans.

The purpose of the visioning effort was to implement the Round 5 bundle of SHRP2 products and meet the following agency-specific objectives:

- Identify a model approach for generating consensus about long-range goals and accompanying transportation investments through the use of the SHRP2 suite of visioning tools and other FHWA products;
- Promote fuller integration of freight considerations into the next iteration of *The Atlanta Region's Plan* through direct outreach to new stakeholders, including those in the Piedmont Megaregion; and
- Use enhanced performance measures to track progress, measure impact, and promote actions that yield desired results.

In terms of planning processes, this implementation assistance grant was used as a way to sharpen our focus and create more consensus for a shared vision of what "winning the future" looks like in the Atlanta Region. By starting the process of visioning now, we added front-end resources to the next long range plan update. By the time we adopt the 2020 long-range plan update, we will have a sharper focus on the key drivers that could potentially impact our ability to win the future. Similarly, we will be well-positioned to further enhance our ability to construct a long-range plan that reflects the region's stated policies and matches clear investment priorities with measurable progress toward our larger goals.

How the specific SHRP2 planning process bundle process bundles were used is shown below, along with the key deliverables produced by ARC under each. All contractual task obligations have been fulfilled and documented, although the titles and contents of certain deliverables have changed since *C08 Volume 1: Vision, Approach & Stakeholder Plan* was prepared in February 2016 (the chronologically first of the nine documents listed).

SHRP2 Bundle	Description and Deliverables
C02 **Performance Measures for Highway Capacity Decision-Making**	ARC used this product to expand the list of performance factors used in transportation decision-making during long-range planning. Performance measures were tailored to help the regional policymakers and others better understand the potential outcomes of planning decisions. By focusing on the practical application of performance metrics, ARC can better articulate the linkages between transportation, communities, and the economy. **C02 Volume 1: Best Practices in Performance Measurement for Transportation Decision Making** **C02 Volume 2: Incorporating Performance Measurement into the Planning Process** **TIP Project Evaluation Framework** *(supplemental related material; not a core deliverable)*
C08 **Transportation Visioning for Communities**	ARC worked with key partners and member governments to develop a vision for the Atlanta region. ARC integrated new approaches to scenario planning into *The Atlanta Region's Plan*. Innovative stakeholder engagement techniques were applied, including regional surveys. Scenario planning used the region's vision as a starting point for solutions and measuring performance. **C08 Volume 1: Vision, Approach & Stakeholder Engagement Plan** **C08 Volume 2: Scenario Development Process** **C08 Volume 3: Scenario Testing Procedures and Results** **C08 Volume 4: Addressing Uncertainty and Change in the Planning Process**
C15 **Integrating Freight Considerations into Highway Capacity Planning Process**	ARC concurrently finalized an update to *The Atlanta Region Freight Mobility Plan*. This planning endeavor ran in parallel to the long-range planning effort. Use of the C15 product brought freight stakeholders more fully into *The Atlanta's Region's Plan* development process. Collaboration with freight stakeholders was widened to incorporate adjacent MPOs, Georgia DOT, and key stakeholders in the Piedmont Megaregion. **C15 Volume 1: Improving the Integration of Freight into the Planning Process** **Regional Models of Cooperation Peer Exchange Summary Report: Freight Planning and Regional Cooperation in the Piedmont Atlantic Megaregion** *(supplemental related material; not a core deliverable)*

Impacts 2050

OVERVIEW OF TOOL

What is it?

Impacts 2050 is a strategic model for scenario planning built to explore alternate futures in a regional context. The model integrates socio-demographic, travel behavior, employment, land use, and transport supply variables. Impacts 2050 treats the metropolitan area as one geographic area with three distinct land use categories: urban, suburban, or rural. Residential and commercial land markets are also modeled in aggregate.

What is it generally used for?

While Impacts 2050 does not provide spatial forecasts, it is useful as a long-range sketch planning tool across a variety of areas. By working to understand the relationships between the input and output variables, Impacts 2050 is useful for quick analysis across a wide swath of questions. Impacts 2050 was a part of Transportation Research Board's (TRB) National Cooperative Highway Research Program (NCHRP) Report 750, Volume 6, which explores the effects of socio-demographics on future travel demand at the regional level through the year 2050. Part of the report is the Impacts 2050, in which Atlanta was used as one of the test cases. With that in mind and its niche ability to look at transportation and associated sociodemographics, ARC decided to use Impacts 2050 for the region's scenario planning needs.

How was it used for SHRP2?

Initially, ARC planned to use Impacts 2050 as the primary model for the SHRP 2 scenario planning process. While modifications are possible, Impacts 2050 has four pre-specified scenarios built into the model: Momentum, Tech Triumphs, Gentle Footprint, and Global Chaos. These four scenarios served as a useful way to structure Atlanta's own scenarios. For specific information on the four scenarios outlined in Impacts 2050 (Transportation Research Board 2014, p. 14-18).

Using the NCHRP 750 scenarios and ARC's 2015 data as a starting point, ARC staff tailored the model for the SHRP 2 project. The development of the coefficients through a process of identifying potentially influential factors is outlined in *C08 Volume 1: Scenario Development Process*.

Before the coefficients could be applied, the model had to be calibrated to match the population numbers from ARC's Activity-Based Model (ABM) (see detailed explanation of calibration below). Once the model was calibrated to the population estimates, the coefficients were applied. Once the coefficients had been modified and model was calibrated, the four scenarios became Atlanta's own versions of the Impact 2050 scenarios. The new scenarios, which used the model of Impacts 2050 but tailored them for Atlanta's future, were: Full Steam Ahead (Momentum), Tech Reigns (Technology Triumphs), Green Growth (Gentle Footprint), and Fierce Headwinds (Global Chaos). Ultimately, outputs from the calibrated Impacts 2050 model—as indicated by the Momentum scenario—were significantly different from the ABM's trend line. Unable to identify the problem, the use of Impacts 2050 was reduced to two components: providing a four scenario framework and setting the population for other models.

ARC carried forward the region's tailored versions of the four scenarios, planning to use the segmented alternate futures in different sketch models moving forward. This four scenario format, along with the generalized direction and content of the scenarios, framed the Atlanta region specific scenarios. While the scenarios were edited to reflect Atlanta's drivers of change, the four-scenario concept—which ARC carried to other models as well— originated in Impacts 2050.
Second, the calibrated 2050 population based on ARC's 2015 data served as the baseline in future modeling efforts (RSPM and REMI). In this way, Impacts 2050 laid the groundwork for the scenario planning approach throughout SHRP2.

ARC'S APPLICATION AND ANALYSIS

Calibration

For each region modeled, Impacts 2050 under NCHRP 750 set a baseline for socio-demographics, travel behavior, employment, land-use, and transport supply. This was coupled with external indices reaching beyond the region (i.e. job demand/supply rate, external space demand, external road capacity etc.). Impacts 2050 also allows for a "custom" region, making it adaptable for use throughout the country. This baseline, which used 2010 Census data, served as the "Momentum" scenario—which represented business as usual. From that baseline, coefficients were applied to each of the aforementioned sectors to represent the other three alternate scenarios (Tech Triumphs, Gentle Footprint, and Global Chaos). Based on the baseline and corresponding coefficients, the model runs for each scenario provide socio-demographic, travel behavior, employment, land use, and transport supply outputs. The initial coefficients for the model can be found in the Final Impacts 2050 User Guide, which is linked on a GitHub site. See *Appendix A* for more information.

While Atlanta was one of the five initial regions with data already entered into Impacts 2050, it needed to be brought up to date with more recent data. Before beginning the calibration process, ARC looked to its activity-based model (ABM); if Impacts 2050 was calibrated appropriately, the "Momentum" scenario's outputs for 2040 should match those from the ABM. With the goal of matching the year 2040 in Impacts 2050 to the ABM outputs, staff worked to calibrate the model.

To calibrate Impacts 2050, ARC staff input a new baseline for "Momentum" from 2015 ARC data. For more details on the calibration process, see the GitHub page and explanation in *Appendix A*. The updated data (denoted as red in the spreadsheet) fell into the following categories:

- Demographic (age; marital and family status; race; household income; employment status; and area type) – tab: Demographic Initial Values
- Employment (by area and type; commute patterns; creation/loss/move delay) – tab: Employment Initial Values
- Land Use (non-residential, residential, developable, and protected space by area) – tab: Land Use Initial Values
- Transportation Supply (freeways, arterials, other, rail, and non-rail miles by area; supply delays for road and

transit capacity addition and retirement) – tab: Transp. Supply Initial Values

-

On those four spreadsheets, all data not listed in red remained unchanged from the initial Impacts 2050 model.

The model also requires demographic transition rates and travel behavior rates. ARC staff calibrated to find the appropriate rates in those two categories that would render a result comparable to the ABM (tabs: Demographic Transition Rates and Travel Behavior Models). The Demographic Seed Matrix remained unchanged.

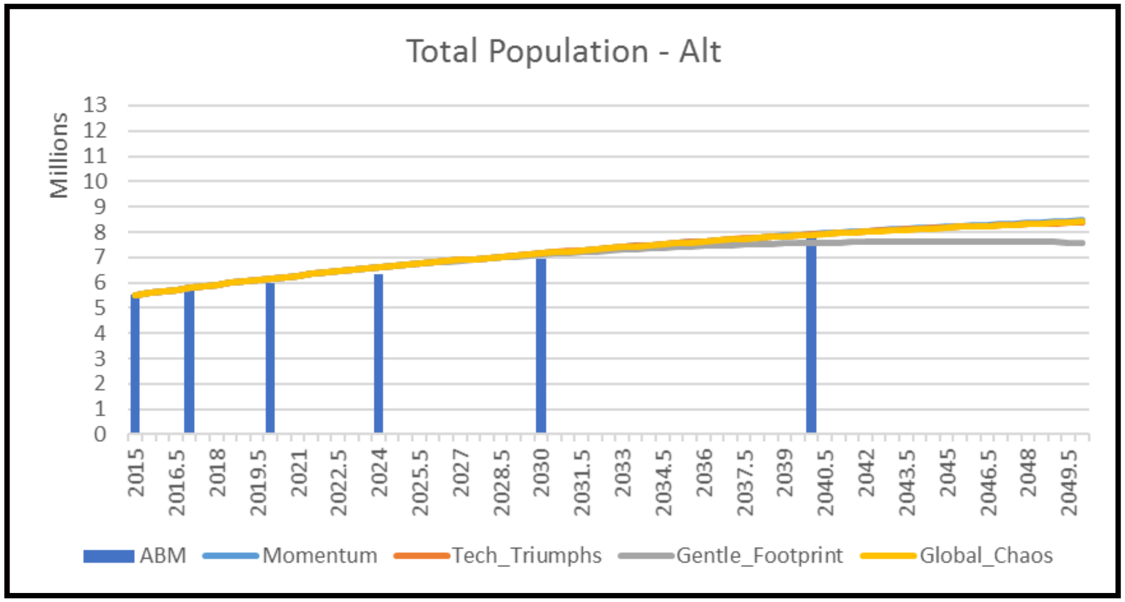
Once the Momentum scenario was adjusted, the population, workforce, trip, and VMT for 2040 in Impacts 2050 was within a 0.2-1% margin of error of the ABM.

Inputs

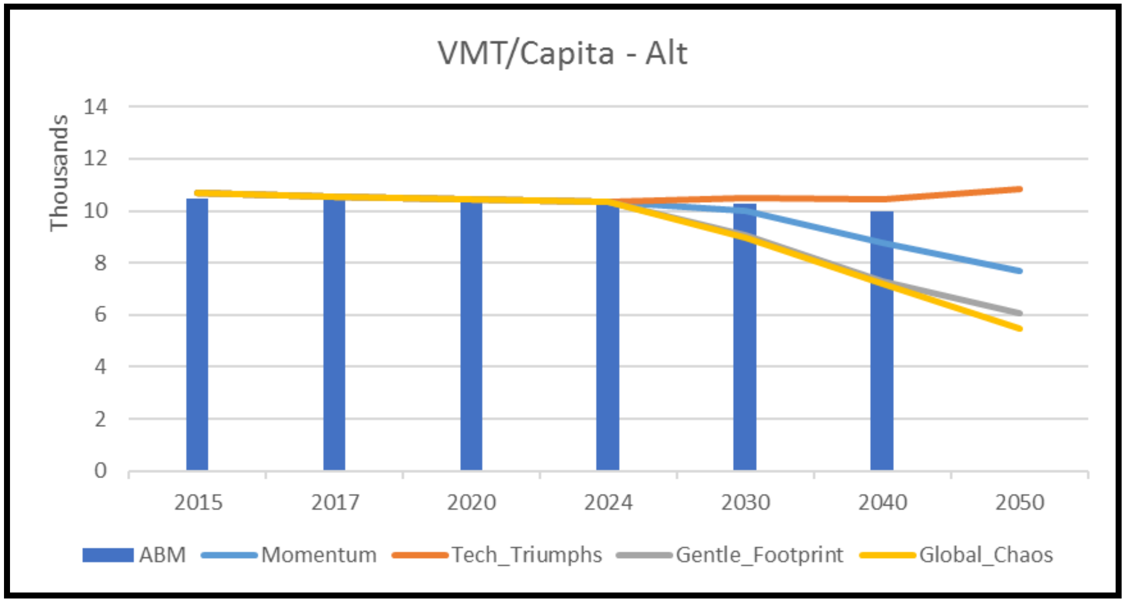
After calibrating Momentum using 2015 ARC data, staff applied coefficients to each of the sectors for the three other scenarios. The chosen coefficients for use in Impacts 2050 were based on a STEEP factor analysis and narrative scenario development as part of the overall SHRP2 process. For more information on STEEP and scenario creation, see *C08 Volume 1: Scenario Development Process*. The coefficients for each of the four scenarios are found on the first four tabs of the spreadsheet in *Appendix A*. The scenarios are Full Steam Ahead (Momentum), Tech Reigns (Technology Triumphs), Green Growth (Gentle Footprint), and Fierce Headwinds (Global Chaos). For all four scenarios, the changed coefficients are bolded. A summary column on each scenario tab explains the rationale behind the changes.

Outputs

Total population modeled in Impacts 2050 compared to the ABM



Total VMT modeled in Impacts 2050 compared to the ABM



The outputs from the model are all located in the "Outputs" tab on the Impacts 2050 spreadsheet in GitHub. There, the scenarios are each compared to each other and to the ABM across all output metrics. The same information is displayed in charts in the "Output Charts" tab.

Unfortunately, even when the 2040 Momentum population from Impacts 2050 resembled that of the ABM, some of the other data outputs—which was calibrated with existing 2015 data—did not match the ABM's trend line. For example, the top figure to the left shows the total population; the Momentum line almost perfectly aligns with the 2040 ABM population. However, when you look at the next figure showing VMT per capita, the Impacts 2050 modeling results are far off from the well-established ABM results.

As Impacts 2050 is not open source and the calibration yielded inexplicable results, the runs were rendered unusable. However, ARC retained some of the structure provided by the Impacts 2050 model, as detailed above.

RECOMMENDATIONS FOR FUTURE APPLICATIONS

While endless mutations of the four scenarios can be made, Impacts 2050 will not ultimately be usable as a sketch planning model until the documentation of model becomes more transparent. The difficulties ARC encountered while calibrating the model to match the ABM hindered progress on using Impacts 2050 as a sketch modeling too. No future application recommendations can be made until the foundation of the model and the relationships between the variables is clarified.

RSPM

OVERVIEW OF TOOL

What is it?

The Regional Strategic Planning Model (RSPM) is a sketch long range transportation and land use planning tool. RSPM is unique in its incorporation of greenhouse has (GHG) emissions into the model outputs. The model divides the metropolitan areas (based on traffic analysis zones (TAZs) into districts; every district has a unique population density, housing type, and proportion that is classified as urban-mixed use. However, RSPM does not have a physical network zone; it relies on generalized regional knowledge to sketch model travel behavior. RSPM does not model employment or commercial space. Additionally, RSPM has a significant number of potential policy inputs, shows sensitivity to pricing, and can model congestion and delay at an aggregate level.

What is it generally used for?

RSPM can be used to strategically assess current plans or to evaluate alternate futures through scenario planning. RSPM is built on the creation of households, the estimation of daily VMT as a function of travel costs, and an analysis of vehicles and greenhouse gas emissions. It ultimately provides diverse outputs including mobility, lane use, economy, equity, and environmental metrics.

The strategic assessment functionality allows MPOs to examine the impacts of current transportation policies today and into 2050. Through the strategic assessment function, MPOs can develop long-range visions and discuss policy implications based on a number of benchmarked metrics.

The second functionality—scenario planning—allows planners and policy makers to investigate alternate futures outside the realm of traditional planning. By incorporating a range of potential future scenarios, MPOs can foster conversations around a diversity of policy options.

While RSPM was originally developed to measure Oregon DOT's progress in achieving the state's 2035 GHG reduction targets, its use can be extrapolated to other regions.

Additionally, RSPM is uniquely visual and can be interactive. Oregon DOT implemented an online visualization allowing the policy makers and the general public to assess the model runs, a valuable tool for conversation facilitation.

How was it used for SHRP2?

ARC relied on the scenario planning functionality during SHRP2. Using the region's four scenarios from the Impacts 2050 process, ARC used RSPM to model the alternate futures. The outputs from the four scenarios formed the basis for an online scenario visualization tool, developed by ARC and its consultants, and they will continue to inform the policy conversations shaping the next regional plan update.

In addition, ARC's four scenarios called for changes to two inputs not previously available in RSPM: autonomous vehicle adoption rate and car sharing availability rate. During the SHRP2 process, ARC contracted with Brian Gregor, the developer of RSPM, to add those two variables to the model. ARC used the variables in the scenarios, and they are now open-source on GitHub along with the rest of the model. Documentation for the incorporation of the autonomous vehicles is available in *Appendix B: Design for Incorporating Autonomous Vehicles into RSPM*.

Similar to Oregon DOT's visualization, ARC aimed to present its modeling results as an interactive tool. Ultimately, ARC rebuilt the visualization interface and tied the tool into the scenario planning process, utilizing RSPM outputs as the foundation for in-depth policy discussions.

A complete description of the online scenario visualization tool, including how RSPM results are presented within it, is contained in *C08 Volume 4: Addressing Uncertainty and Change in the Planning Process.*

ARC'S APPLICATION AND ANALYSIS

Calibration

ARC contracted with Brian Gregor to prepare the model for use. After Mr. Gregor altered some coding to adapt the model to the Atlanta region, RSPM did not have to be calibrated for ARC's use—ARC then input the regional data to serve as the baseline. RSPM is developed as an off-the-shelf model, so no calibration is required; rather, MPOs and DOTs using the model just input their regional data. The model can be adapted for use throughout the country without calibration.

The model as used by ARC is available on GitHub.

Inputs

In order to use RSPM, which was initially built for the Oregon Department of Transportation, basic model estimation data for the Atlanta region was required.

As a baseline, all four scenarios required a population total by age range, an output from Impacts 2050. In addition, each scenario had to be rooted in 2015 data. The necessary model estimation data was extensive. The model estimation data is available on GitHub. See *Appendix A: Guide to the ARC SHRP2 GitHub Site* for more information.

The key inputs and the source of the data used to set the 2015 baseline are listed below:

- Population Total by Age Range (pop_targets) - Impacts 2050 Scenarios
- Land Area and Housing Types by TAZ (district_groups and du_forecast)- 2015 ABM
- Income (Hhincttl), Lane Miles (lane_miles), Parking Costs (parking)- 2015 ABM
- Transit Revenue Miles (transit_revenue_miles)- 2015 National Transit Database
- TDM Parameters for the region (tdm_parameters)- 2015 Estimates, Mobility Services documentation

Once the necessary model estimation data, which was used to set the region's parameters, was entered, the inputs for the four scenarios were manipulated for the future year 2050. A full list of inputs adapted by ARC can be found on GitHub. See *Appendix A* for more information.

As with Impacts 2050, ARC staff matched the narratives and drivers from the scenario planning process to the model's potential inputs, using proxies when necessary. Ultimately, 40 of the input variables were matched to key drivers of change (shown below). The relevant variables for each key driver of change are shown below. Note: Input variables may apply for multiple driver of change. Definitions of input variables can be found on the GitHub site, unless otherwise noted.

Once paired, ARC staff applied appropriate coefficients to each of the input variables, rendering four distinct scenarios. For the specific factor applied for each scenario, see the GitHub site and associated explanation in *Appendix A*.

Beyond the four distinct scenarios, ARC staff ran additional permutations—using the four scenarios as a baseline— to reflect potential changes in policy inputs. For each of the four independent variables listed below, there was a "low," "medium," and "high" setting:

Arterial Lane Mile Growth

- Low: Planned growth from the Regional Plan (3%) – Full Steam Ahead; Fierce Headwinds; Technology Reigns; Green Growth
- Medium: Double the planned growth (6%)
- High: Triple the planned growth (9%)

Transit Service Growth

- Low: Planned growth from the Regional Plan (70%) – Full Steam Ahead; Fierce Headwinds
- Medium: Double planned growth (140%) – Technology Reigns
- High: Triple planned growth (210%) – Green Growth

Key Drivers Matched with RSPM Inputs

Key Driver of Change	Relevant Policy/Planning Lever	Input Variable(s)
Aging of the Population	Regional Population by Age	pop_by_age_2050; age_adj
Autonomous Vehicles	Vehicle adoption; Regional operations, regional lane miles, regional TDM strategies, car share by TAZ, regional parking availability and cost.	group_auto_ownership; car_svc_avail(1); car_svc_cost_parm(2); hh_veh_own_cost_parm(3); lane_mile_growth; ops_deployment; optimize; other_ops; parking; commute_options; fwy_art_growth
Intelligent Infrastructure	Regional commute options, regional operations, car share by TAZ	Carshare; cong_efficiency; congestion_charges; ops_deployment; optimize; other_ops; commute_options
Spatial, Racial, and Economic Equity	Regional household income, car share by TAZ, dwelling unit type by TAZ	group_auto_ownership; group_hh_income; du_2050; transit_growth; transit_rev_mi_calcs; transit_revenue_miles
Transportation Finance Infrastructure		
Ride hailing/Carsharing	Car share by TAZ, Regional TDM strategies	group_auto_ownership; group_hh_income; carshare; parking; commute_options
Climate Change Regulations	Regional fuel variables, regional parking, vehicle age, transit infrastructure, electric vehicles, active transportation use; congestion charges	du_2050; land_supply; auto_lighttruck_fuel; auto_lighttruck_mpg; bus_fuels; comm_service_fuel; comm_service_lttruck_prop; comm_service_pt_prop; costs; congestion_charges; eco_tire; ev_characteristics; fuel_co2_ heavy_truck_fuel; hev_characteristics; hvy_veh_mpg_mpk; imp_prop_goal; light_vehicles; lttruck_prop; phev_characteristics; power_co2; prop_wrk_eco; speed_smooth_ecodrive
Water Supply	Land supply and housing types	land_supply
Port Traffic	Proportion of truck VMT	Heavy_truck_prop

(1) Car_svc_avail – availability of car services, by district
(2) Car_svc_cost_parm – cost of car sharing services, universal
(3) Hh_veh_own_cost_parm –household vehicle ownership cost parameters, universal (includes autonomous vehicles)

Autonomous Vehicles/Carsharing

- Low: No autonomous vehicles or carsharing available – Full Steam Ahead; Fierce Headwinds
- Medium: Limited autonomous vehicles and carsharing available – Green Growth
- High: Full deployment of autonomous vehicles and carsharing – Technology Reigns

Congestion Charges

- Low: No congestion charges – Full Steam Ahead; Fierce Headwinds; Technology Reigns
- Medium: Limited congestion charges on limited access highways – Green Growth
- High: Extensive congestion charges on limited access highways, and less, but significant on arterial highways

The low settings are based on the growth planned in *The Atlanta Region's Plan*.

These inputs were also imbedded in the four scenarios, but ARC allowed additional manipulation of these four variables in order to facilitate policy conversations. See the GitHub site for the details of each scenario and the association permutations.

Outputs

While RSPM provides a large variety of outputs, ARC chose to focus analysis on the following model results:

- CO2 annual & per capita
- Transit ridership per capita
- Walk and bicycle trips per capita
- Annual hours of delay per capita
- VMT per capita
- Average vehicle operating cost per capita
- Social cost per household

Staff chose these modeling outputs because they can be easily communicated to policy makers and the general public. Many of them are also similar to or the same as other metrics analyzed by ARC. Thus, ARC already has a baseline for comparison and for checking the model outputs.

However, all outputs are available on GitHub and referenced in *Appendix A*.

The table below shows the key outputs for each scenario compared to 2015.

	Full Steam Ahead	**Fierce Headwinds**	**Technology Reigns**	**Green Growth**
Walk/bike trips per capita	221.9	253.8	232.7	430.16
Total CO_2 (metric tons)	14,455,416	12,621,268	11,721,298	9,603,818
CO_2 per capita (metric tons)	1.53	1.78	1.45	1.21
Transit trips per capita	21.5	31.6	22.6	102.26
VMT per capita (miles)	32.5	31.4	34.6	29.24
VHD per capita (hours)	75.3	67.9	52.5	45.17
Social cost per household	$945	$944	$912	$749.78
Vehicle operating cost per capita	$3,766	$5,295	$3,738	$4,511.96

The Green Growth scenario is the most dramatically different from the Full Steam Ahead scenario. These results are due to ambitious transit service availability growth, limited autonomous vehicle and carsharing adoption, and medium level congestion charges. In addition to the higher levels of the variables mentioned above, the Green Growth scenario had the most aggressive land use changes, with densities much higher than other scenarios. These factors, including cleaner vehicle technology, among others, pushes down the CO2 emissions, and increases transit ridership, walking/bike trips, and decreases social costs, as well as vehicle trips (because of the increase in operating costs).

The second most aggressive scenario, and most related to Green Growth, was Technology Reigns. While there is a medium increase in transit availability in this scenario, there is also a full deployment of autonomous vehicles and carsharing. Unlike the Green Growth scenario, there are no major land use changes; however, household incomes do increase, decreasing transit and walk/bike trips. Similar to the Green Growth scenario, vehicle technology is greatly improved, lowering CO2 emissions. However, the lack of congestion charges in this scenario keep costs lower and emissions higher.

The Fierce Headwinds has an overall decrease in household income, thus increasing transit and walk/bike trips, despite minimal transit service growth in the region. Also, due to a stall in vehicle technology improvements, CO2 emissions per capita are higher than in Full Steam Ahead (although still lower than baseline 2015 numbers). In Fierce Headwinds, high fuel costs due to global instability increase vehicle operating costs, which also increases transit and walk/bike trips.

Full Steam Ahead is essentially the 2050 baseline model run, with the available variables resembling the unofficial 2050 Activity Base Model where possible. The overall CO2 emissions are higher than in Fierce Headwinds because population is also higher, but the per capita emissions are lower due to sustained vehicle technology improvements. Household income and gas prices remain steady while autonomous vehicle adoption is held at bay. Thus, no major changes are seen in transit and walk/bike trips.

Overall, the RSPM provided results that were consistent with what ARC staff expected.

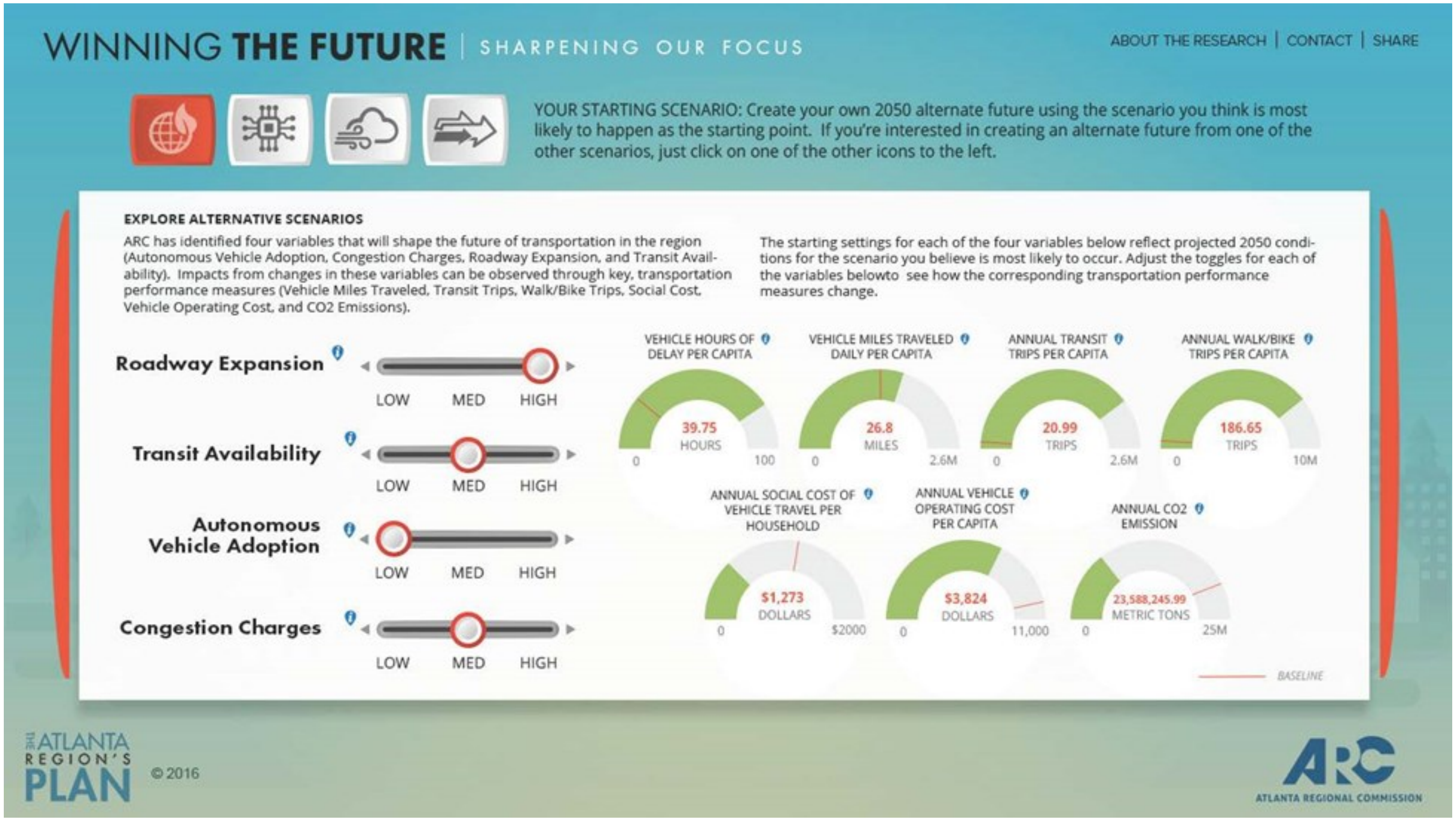
Additional Applications

Part of the rationale for using RSPM was the potential functionality of visually displaying the model outputs. After looking at Oregon's extensive RSPM website, ARC decided to create a similar visual display with a pared down interface and a more limited selection of potential scenarios. To do this, ARC build an online scenario visualization tool.

In ARC's tool, the user first runs through the process of choosing drivers of change and finding the scenario that most closely resembles the future they predict (see *C08 Volume 1: Scenario Development Process* for more information on the tool). Then, the user is led to a page with the scenario that most closely aligns with their beliefs and corresponding outputs displayed. From there, the user is able to see a visualization of their outputs and is able to manipulate four potential variables (congestion charges, transit expansion, roadway expansion and autonomous vehicle adoption) that may change their scenario's outcome. As the outputs change, the user can see the visualization move along the 2015 benchmark.

Once a user is done exploring their scenario, they are able to do the same exploration exercise with the other three scenarios. Ultimately, this process allows the user explore a total of 324 RSPM runs visually. In the coming months, this tool will be invaluable as it helps to facilitate conversations with the public and policy makers as ARC kicks off of the next Regional Transportation Plan (RTP). The tool is also scalable; if additional RSPM runs are desired to continue to flush out the scenario planning, they can be added to the visualization tool. A screenshot from the visualization tool is shown below.

Online scenario visualization tool



YOUR STARTING SCENARIO: Create your own 2050 alternate future using the scenario you think is most likely to happen as the starting point. If you're interested in creating an alternate future from one of the other scenarios, just click on one of the other icons to the left.

EXPLORE ALTERNATIVE SCENARIOS

ARC has identified four variables that will shape the future of transportation in the region (Autonomous Vehicle Adoption, Congestion Charges, Roadway Expansion, and Transit Availability). Impacts from changes in these variables can be observed through key, transportation performance measures (Vehicle Miles Traveled, Transit Trips, Walk/Bike Trips, Social Cost, Vehicle Operating Cost, and CO2 Emissions).

The starting settings for each of the four variables below reflect projected 2050 conditions for the scenario you believe is most likely to occur. Adjust the toggles for each of the variables belowto see how the corresponding transportation performance measures change.

RECOMMENDATIONS FOR FUTURE APPLICATIONS

There are a number of recommendations for future applications, two of which are already being tested in the Atlanta region. First, RSPM was built for use on the regional or statewide scale; however, its outputs would also be useful for smaller jurisdictions. A county-level RSPM model would enable communities to run their own, more specific models without the interference of the rest of the region. ARC is currently working on scaling down the model for use in Gwinnett County. Similarly, scaling the model up—as it was originally intended in Oregon—to the statewide level would be helpful for interregional planning. ARC is also actively working to scale the model up by incorporating the Georgia statewide model.

As one of the drivers of change suggests, the Atlanta region continues to struggle with water supply. The availability of water in the region has the potential to significantly impact the region's economy and, consequently, the transportation network. Adding inputs that could help to refine the water use model for the Atlanta region would be helpful for modeling the links between water and transportation.

Refining the geography for the model for a variety of the inputs would also be a helpful addition to the model. If roadway and transit service could be specified to the district level, more accurate results would follow. In a large region like Atlanta, the ability to create more specific spatial distinctions is very important.

Lastly, as autonomous vehicles become increasingly prevalent, the model that includes a diversity of inputs just for self-driving cars and trucks is important. Enhancing the ability to change the assumptions regarding autonomous vehicle efficiencies could yield more nuanced futures.

Much of this work is already underway through the development of VisionEval, an open source tool that will be useful for performance-based scenario planning. The common tool platform will host a number of swappable components and enable modelers and developers to build and share their own components. ODOT, FHWA-RPAT, and FHWA-EERPAT are partnering in the development of the VisionEval framework, which should be finished in 2017.

REMI

OVERVIEW OF TOOL

What is it?

The Regional Economic Model, Inc. (REMI) was founded in 1980 on a transformative idea: government decision-making should test the economic effects of their policies before they are implemented. REMI is committed to providing better understanding of the economy and improving public policy through developing and supporting the use of economic models that inform policymakers.

The REMI model is a dynamic forecasting and policy analysis tool that can be variously referred to as an econometric model, and input-output model, or even a computable general equilibrium model. REMI integrates several modeling approaches, incorporating the strengths of each methodology while overcoming its limitations. The result is a comprehensive model that answer "what if…?" questions about an area's economy.

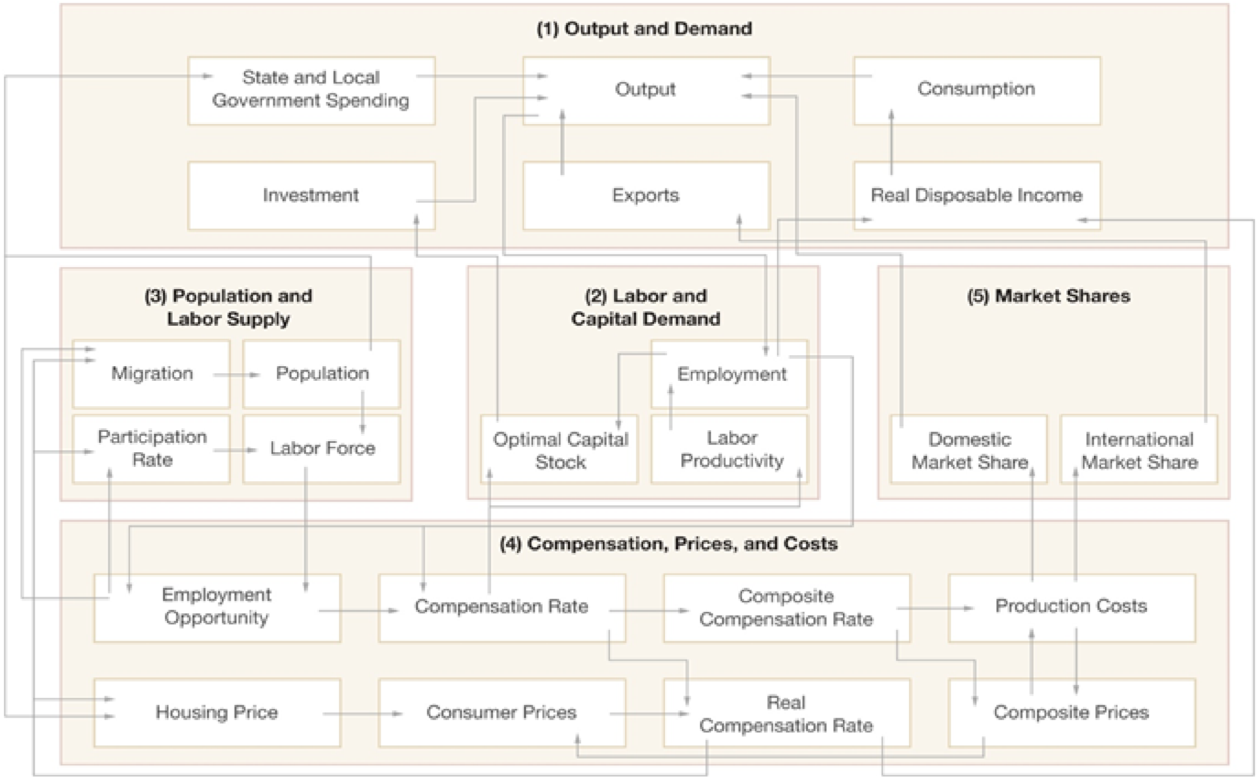
REMI Policy Insight is a structural economic forecasting and policy analysis model. It integrates input-output, computable general equilibrium, econometric, and economic geography methodologies. The model is dynamic, with forecasts and simulations generated on an annual basis and behavioral responses to wage, price and other economic factors.

REMI TranSight is a transportation module built on top of the Policy Insight model to evaluate the total economic effects of changes to transportation systems. TranSight provides an integrated system for comprehensive evaluation of transportation networks and assesses the impact of transportation investments and long-term planning decisions. This approach allows analysts to thoroughly describe the far-reaching economic and operational effects of transportation projects.

Integrating economics with travel demand modeling, TranSight dynamically demonstrates how transportation makes economies competitive. Users can test alternative transportation changes and observe the short and long-term impact on jobs, income, population, and other economic variables. TranSight is a modeling tool that integrates travel demand models with the REMI model and constructed with extensive data on emissions, safety valuation factors, and other data.

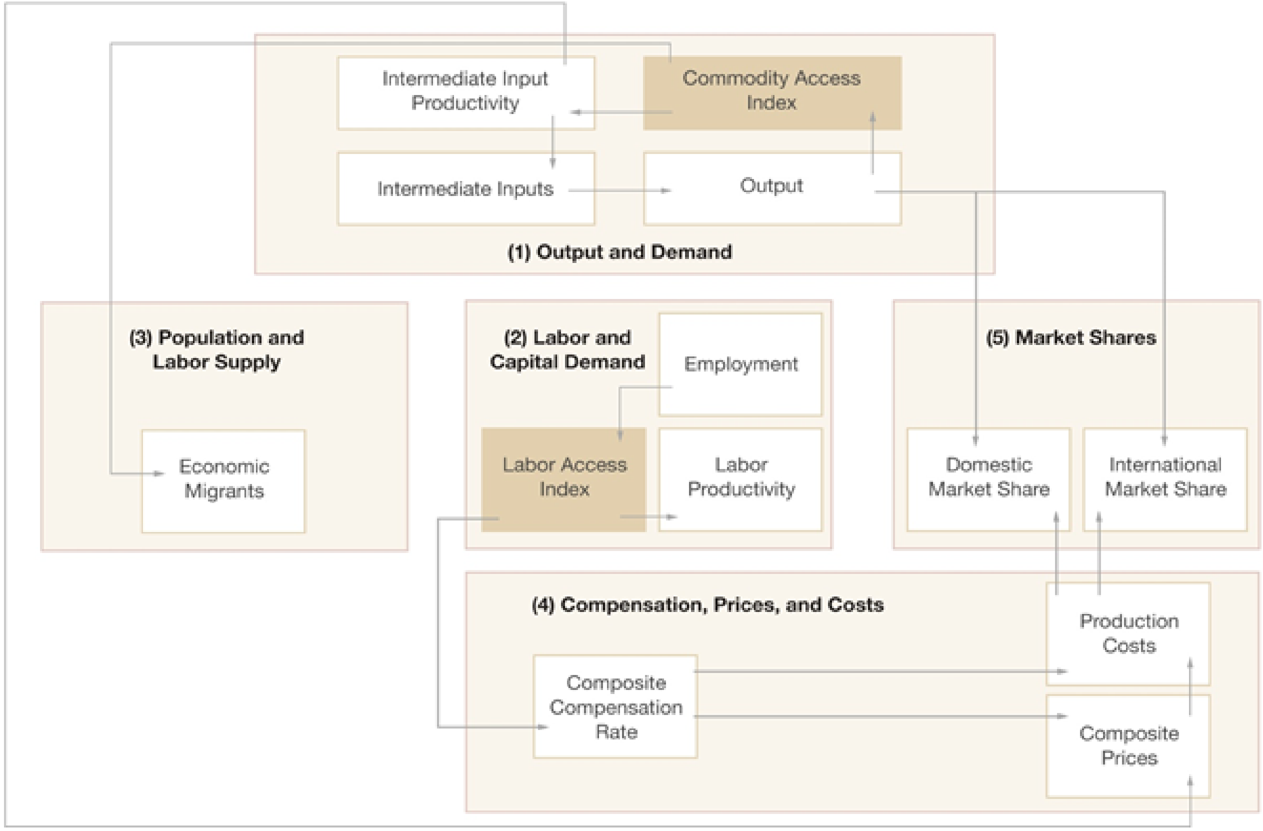
The REMI model consists of thousands of simultaneous equations with a structure that is relatively straightforward. The exact number of equations used varies depending on the extent of industry, demographic, demand, and other detail in the specific model being used. The overall structure of the model can be summarized in five major blocks: (1) Output, (2) Labor and Capital Demand, (3) Populations and Labor Supply, (4) Wages, Prices, and Costs, and (5) Market Shares. The blocks and their key interactions are shown following.

REMI Model Structure and Linkages



The Output block consists of output, demand, consumption, investment, government spending, exports, and imports, as well as feedback from output change due to the change in the productivity as well as demand for labor and capital. Labor force participation rate and migration equations are in the Population and Labor Supply block. The Wages, Prices, and Costs block includes composite prices, determinants of production costs, the consumption price deflator, housing prices, and the wage equations. The proportion of local, inter-regional, and export markets captured by each region is included in the Market Shares block.

Economic Geography Linkages



Models can be built as a single region, multi-region, or multi-region national models. A region is defined broadly as a sub-national area, and could consist of a state, province, county, or city, or any combination of sub-national areas.

Single-region models consist of an individual region called the home region. The rest of the nation is also represented in the model. However, since the home region is only a small part of the total nation, the changes in the region do not have an endogenous effect on the variables in the rest of the nation.

Multi-regional models have interactions among regions, such as trade and commuting flows. These interactions include trade flows from each region to each of the other regions. There are also multi-regional price and wage cost linkages.

The economic component of the REMI model uses a compilation of methodologies [Input-Output, Computable General Equilibrium (CGE), New Economic Geography, and Econometrics] to examine the internal interactions within each of the blocks and linkages between the blocks in order to forecast economic activity for a region. The model inherently contains policy variables in order to build assumptions, simulate changes (or shocks), or input exogenous data as components to guide the simulation process for analyzing effects and economic change. Selection of policy variables depend on the nature of the policy change being evaluated.

What is it generally used for?

ARC uses the REMI (Regional Economic Models, Inc.) model to produce its control forecasts and support the region's scenario development and planning process. The purpose of the REMI model is to develop regional forecasting and policy analysis models to inform and improve the quality of public policy decisions. The ARC obtained the REMI model in 2008 and adapted it for use in Atlanta. Minor improvements have been made to this model, but its basic structure and its theoretical underpinnings are unchanged.

In the REMI model, the ARC's region consists of 20 counties: Fulton, DeKalb, Cobb, Clayton, Gwinnett, Henry, Douglas, Rockdale, Cherokee, Fayette, Barrow, Bartow, Carroll, Coweta, Forsyth, Hall, Newton, Paulding, Spalding, and Walton. The study area for these "regional" scenarios is the 15-county air-quality nonattainment area. As for the economic composition, the model is a 70-sector, 94-occupational county-level build.

How was it used for SHRP 2?

In SHRP2, REMI aimed to expand the analysis offered by Impacts 2050 and RSPM by allowing staff to assess the roles of specific local factors or themes that may have substantial impact on the actual economic impacts of individual projects, assumptions or socioeconomic influences.

During the SHRP 2 process, ARC executed intermediate-level analyses on the four alternate futures using the multi region model. Besides the traditional indicators that were measured in RSPM, REMI allowed ARC explore the broader economic impacts that are often driven by changes in the environment, technology and land use or a combination of these through single region outputs.

The purpose of sketching out these themes in the REMI model was to develop useful, practical, and "aspirational" tools that can actually make a transformation in transportation investment and planning in the future. Providing a set of four alternate futures for socioeconomic and transportation impact assessment that planners can use to assess the dynamic impacts of employment, demographics, land use, travel behavior, and the environment aims to enable measurement of conditions that directly affect broader socioeconomic benefits.

ARC'S APPLICATION AND ANALYSIS

Inputs

As with Impacts 2050 and RSPM, the REMI model application built upon the narratives. Based on prior knowledge, staff proposed changes to the standard regional scenario in the tool to reflect each of the four scenarios. From there, staff developed a crosswalk translating SHRP2 narrative assumptions from each alternate futures, respectively, into policy variables that mirror, behave or represent the narratives in the model.

The full list of input variables can be found on GitHub.

Outputs

Analysis of the REMI results is limited as the socioeconomic modeling results had little correlation with the other outcomes ARC had from other programs within the modeling suite (i.e. RSPM or the ABM). Baseline data were not controlled or simulated using the Region's latest adopted socioeconomic forecasts. Due to the tight timeline of the SHRP2 project, staff was only able to tweak the major assumptions developed for each alternative future, leaving many underlying variables unchanged. Thus, there was a risk of double counting broader transportation impacts in the model.

In addition, the alternative future assumptions were not vetted in conjunction with previous forecast assumptions in order to mitigate or eliminate redundancy. Ultimately, the outputs from REMI suggest that future scenario planning work is feasible; however, this round of SHRP2 did not produce reliable results for analysis.

The full list of outputs can be found on GitHub.

RECOMMENDATIONS FOR FUTURE ANALYSIS

The work accomplished by the REMI model through this sketch planning project has shown: (1) that it is possible to produce or repurpose tools to assess broader transportation effects and their economic worth, and (2) that there is noteworthy need for future work to improve upon both the application and simulation of these alternative futures and other sketch planning endeavors.

Additional measures of transportation and socioeconomic impacts are needed. While there are multiple methods to measure the magnitude of effects, each metric has advantages and disadvantages that vary depending on the intended or interpreted use. In some cases, alternate conditions can produce comparable findings regarding the relative impacts of a proposed future. However, more research is required to further illustrate similarities and differences among these alternative futures and to guide future interpretation of them across a variety of sketch modeling tools.

The economic worth of broader transportation impacts has been shown to vary widely depending on the type of future envisioned for the Atlanta region. The REMI model provided illustration of how simple assumptions can be simulated and derive results for comparison to other tools in the modeling suite. The REMI model can provide a starting point for development of enhanced scenarios; further detail is needed to improve the forecast process.

APPENDIX A

GUIDE TO ARC SHRP2 GITHUB SITE

The spreadsheets reflecting inputs and outputs and the RSPM model used by ARC during the SHRP2 grant are all available on GitHub. In addition, the code for the scenario visualization tool will be available in the same location after ARC releases the tool in Q4 2017. The files and code available on GitHub and this report should help to guide staff at peer agencies through the process of reproducing the modeling work done by ARC. Links to the user guides for the models are also included on GitHub as the overall goal is not to recreate existing content.

The site address is:
https://github.com/atlregional/shrp2

Impacts 2050

- User guide
- Calibrated Model (tab 1: main menu) – file name: Impacts2050_ARC
    - Inputs
        - Scenarios
            - Tab 2: Full Steam Ahead
            - Tab 3: Tech Reigns
            - Tab 4: Green Growth
            - Tab 5: Fierce Headwinds
        - Baseline Data
            - Demographic (Tab 6: Demographic Initial Values)
            - Employment (Tab 7: Employment Initial Values)
            - Land Use (Tab 8: Land Use Initial Values)
            - Transportation Supply (Tab 9: Transportation Supply Initial Values)
            - Demographic Transition Rates (Tab 10: Demographic Transition Rates)
            - Demographic Seed Matrix (Tab 11: Demographic Seed Matrix)
            - Travel Behavior Models (Tab 12: Travel Behavior Models)
    - Outputs
        - Tab 13: Outputs
        - Tab 14: Outputs Charts

RSPM

- User Guide and Model (version 3.6)
    - Explanation for Additional Model Inputs: Design for Incorporating Autonomous Vehicles in the Regional Strategic Planning Model (RSPM)
- Model Inputs and Outputs- file name: RSPM_ARC
    - Inputs
        - Column labeled "scenario". All 364 permutations available in the online visualization tool are included. The codes found in the scenario column refer to:
        - Base Scenarios with altered sociodemographic, land use, and transportation inputs:
            - Full Steam Ahead – L1
            - Fierce Headwinds- L2
            - Tech Reigns- L3
            - Green Growth- L4
        - Arterial Lane Mile Growth
            - Low: Planned growth from the Regional Plan (3%)- R1
            - Medium: Double the planned growth (6%)- R2
            - High: Triple the planned growth (9%)- R3
        - Transit Service Growth
            - Low: Planned growth from the Regional Plan (70%)- T1
            - Medium: Double planned growth (140%) -T2
            - High: Triple planned growth (210%) -T3
        - Autonomous Vehicles/Carsharing
            - Low: No autonomous vehicles or carsharing available -A1
            - Medium: Limited autonomous vehicles and carsharing available –A2
            - High: Full deployment of autonomous vehicles and carsharing – A3
        - Congestion Charges
            - Low: No congestion charges- C1
            - Medium: Limited congestion charges on limited access highways- C2
            - High: Extensive congestion charges on limited access highways, and less, but significant on arterial highways- C3

        - The four scenarios are:
            - L1R1T1A1C1- Full Steam Ahead
            - L2R1T1A1C1- Fierce Headwinds
            - L3R1T2A3C1- Technology Reigns
            - L4R1T3A2C2- Green Growth
            - All other combinations are permutations available within the online scenario visualization tool.
    - Outputs
        - Columns B-T in RSPM_ARC

REMI

- User Guide for Transight Version 3.6.5
- Model Inputs and Outputs- file name: REMI_ARC
    - Inputs
        - Tab: REMI_Simulation inputs
            - Column B lists the specific variable altered.
            - Column B lists the variable type.
            - Column D lists the relevant detail (age, sector etc.).
            - Column E lists the county for which it was altered.
    - Outputs
        - Tab: REMI_Simulation outputs --

APPENDIX B

DESIGN FOR INCORPORATING AUTONOMOUS VEHICLES INTO RSPM

Implications of Autonomous Vehicles for Strategic Modeling

Substantial advancements have been made in the development of self-driving cars in just a few years. About twelve years ago (2004) the farthest that a vehicle drove autonomously in DARPA's Grand Challenge was 7 miles. The following year the 150 mile course was navigated successfully by 5 vehicles. Two years later, in DARPA's Urban Challenge, 6 autonomous vehicles traveled through an urban course, sucessfully following the rules of the road and navigating obstacles and traffic (Fagnant 2015). In 2009, Google started working on their self-driving car project. Six years later (May 2016) Google cars had driven over a million and a half miles in autonomous mode (Google 2016a). Google is by no means the only company working on developing self-driving cars, many others including Tesla, GM, Daimler, Volvo, Ford, Jaguar Land Rover, Audi, and BMW are actively working on automated vehicles(Gibbs 2016). The rapid pace of autonomous vehicle research and development has lead some people to predict that self-driving cars will be on the road within a few years: 2 years according to Eldon Musk, the CEO of Tesla Motors, and by 2020 according to the president of GM and the CEO of Nissan Motor Corporation (Yadron 2016). At that pace, most of vehicles on the road could be self-driving within a few decades. Even skeptical analysts think that a majority of vehicle sales and travel could be of autonomous vehicles by the middle of the century (Litman 2015).

Given that self-driving cars could make up a substantial portion of the vehicle fleet within the next 20 to 30+ years, it is important for transportation planners to consider the implications of autonomous vehicles (AVs) and for strategic planning models to be able to assess the implications. However, the RSPM does not currently include these capabilities because, at the time most of the model's components were being designed and estimated, autonomous vehicle research was still in its infancy. Prospects for autonomous vehicles were highly speculative and quantitative analysis of the implications was very limited. This has changed within the past few years and now there is sufficient information to be able to add simple capabilities for modeling autonomous vehicles to the RSPM.

The effect of AVs on the transportation system will depend on the level of autonomy that is achieved. The National Highway Traffic Safety Administration (NHTSA) identified 5 levels of autonomy in its preliminary policy on autonomous vehicles (NHTSA 2013): * Level 0 (No Automation): The driver is in complete and sole control of the primary vehicle controls – brake, steering, throttle, and motive power – at all times. * Level 1 (Function-specific Automation): Automation at this level involves one or more specific control functions. Examples include electronic stability control or pre-charged brakes, where the vehicle automatically assists with braking to enable the driver to regain control of the vehicle or stop faster than possible by acting alone. * Level 2 (Combined Function Automation): This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. An example of combined functions enabling a Level 2 system is adaptive cruise control in combination with lane centering. * Level 3 (Limited Self-Driving Automation): Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The Google car is an example of limited self-driving automation. * Level 4 (Full Self-Driving Automation): The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles.

At levels 1 and 2, vehicle automation assists the driver with some driving tasks, but the driver must still maintain control of the vehicle at all times. This automation is already being included in vehicles now being sold: blind-spot warning, lane departure warning, forward collision warning and braking, automated parking, lane keep assist, adaptive cruise control. These features are likely to improve traffic safety by reducing crashes due to driver error (Fagnant 2015). Reducing crashes will have a secondary effect on reducing incident-related delay, but is unlikely to have much effect highway capacity. It is also unlikely to have much effect on travel demand because human drivers must still remain in control of their vehicles.

At levels 3 and 4, vehicle automation takes full control of vehicle guidance and operation. The difference being that with level 3, the driver has to be prepared to take over control whereas with level 4 the driver does not. These features, at least at level 4, promise to increase highway capacity as well as highway safety because vehicles will be able to communicate with one-another and with infrastructure to increase traffic density and smooth traffic flow while reducing delay (Fagnant 2015). It is likely that full vehicle automation will also affect vehicle travel demand for several reasons. First if the driving task is made less onerous and if people can use the time traveling for other activities, they will be more likely to "drive" and more likely to "drive" farther. Second, if capacity is increased, then travel speed would be higher than it otherwise would be. This also encourage more dispersion of trip origins and destinations and more VMT. Third, it opens up the possibility of a new travel mode, shared autonomous vehicles (SAV), which provides on-demand taxi-like service at costs that are competitive with private vehicle ownership (Burns 2013). This mode will enable many households to have widespread urban mobility without owning a car. It will also increase the mobility of many people who can't drive because of age, physical disability, or income (Levinson 2015).

As was mentioned, vehicles with levels 1 and 2 automation are already on the roadway. These features are likely to decline in price and be available on a wider selection of vehicles in the next few years, acquainting motorists with vehicle automation and increasing demand for even greater automation. Whether or not level 3 is the next step, or whether manufacturers move directly to level 4 is a matter of debate. Google, which has logged over a million miles of level 3 testing has determined that the technology that is provided for public consumption should be level 4 because of the difficulty of keeping drivers as attentive as they need to be to take control of the vehicle when needed. The company has determined that maintaining driver attentiveness will be more difficult than making a vehicle fully automated so that attentiveness is unnecessary (Crothers 2015). Ford is taking the same approach although some other car companies are trying to develop systems that would enable level 3 vehicles to work safely (Davies 2015).

Whether level 4 vehicle automation is deployed through fleets of SAVs or through personally-owned AVs, is also open to debate. Although the use of car-sharing services (e.g. Car-to-Go, Zipcar) has been growing, as have car driving services (e.g. Uber, Lyft), the proportion of trips served by them is still quite low and auto ownership is popular for a number of reasons. This suggests that the main market for AVs will be households. On the other hand, other economic and use considerations provide compelling arguments that SAVs could be the main market. Level 4 AV technology at present is not cheap. The AV technology in Google cars costs about $150,000 (LIDAR is about half the cost) (Google 2016b). Even a ten-fold decrease in cost would still leave a $15,000 price tag. That is large price boost for all but the highest income households to absorb, especially considering that the average household vehicle is only in use about an hour a day (Burns 2013). On the other hand, level 4 AV technology makes economic sense for automated taxi services because it would eliminate the labor cost for driving the vehicle and the added cost would be amortized over a period of almost continuous use. For example, Fagnant and Kockelman estimated that a SAV system serving about 50 thousand daily person trips in the Austin metropolitan area could realize a 19% annual return on investment with AV cars costing $70,000 ($50,000 for the AV technology) at fares of $1.00 per mile (less than a third of the current taxi fare) (Fagnant 2016). It is telling that Uber has gotten into the business of developing self-driving cars (O'Brien 2016) and that GM is investing $500 million in Lyft (Alba 2016).

Whether self-driving cars are purchased more by households or by SAV companies has substantial consequences for the structure of the light-duty vehicle fleet and the rate at which it turns over, and consequently for the rate of new technology adoption. Although a SAV future scenario has the potential for greatly reducing the total number of light-duty vehicles on the road, VMT may not decrease and neither may the number of vehicles purchased each year. Several SAV modeling studies have estimated that each SAV could replace over 10 vehicles (Burns 2013)(Fagnant 2014)(Fagnant 2016). The number of vehicles replaced would not be as high if the SAVs are electric (SAEV)(Chen 2016a). These studies also show that a smaller vehicle fleet will not necessarily translate into less VMT because unlike household vehicles, the SAVs will be in almost continuous use. In fact, VMT may increase as a consequence of SAV travel between dropping off a customer and picking up the next one. This has substantial implications for vehicle turnover and technology advancement. Currently If each SAV replaces 10 vehicles, and if the total VMT driven is the same, then the lifetime of SAVs would be about a tenth of the lifetime of the household vehicles that they replace. This would greatly increase the rate at which newer, more fuel-efficient, vehicles would get on roadways.

Design for Incorporating Autonomous Vehicles into RSPM

The model will be modified to model level 4 automation scenarios. There are several reasons for this. First, level 1 and 2 automation is likely to have relatively small effects on transportation system operation and use aside from reducing vehicle crashes. A significant objective of strategic planning is to investigate possible disruptive changes. It's level 4 automation that's likely to cause those changes. There is a substantial possibility that level 4 automation will greatly affect roadway capacity, vehicle ownership, vehicle characteristics, and rates of vehicle turnover. Level 3 automation is ignored for the same reasons that Google and Ford are not planning to deploy level 3 automated vehicles.

Modeling Congestion Effects

There are two approaches that could be taken to modeling the effects of autonomous vehicles on congestion. The first is to adjust freeway lane-miles account for predicted effects of autonomous vehicles on capacity. Doing so affects the proportions of DVMT at different congestion levels and in turn affects the base levels of recurrent and non-recurrent delay. An alternative approach is to specify delay reductions in the 'other_ops.csv' input file. Of the two, the first is preferred for several reasons: 1. It enables effects on recurring and non-recurring congestion to be separated and easier to model. Estimates of the capacity effects of autonomous vehicles are available as are estimates of the effects on accident rates.

Calculating the joint effects on delay would require more off-model computations to produce the inputs. 2. Adjusting freeway lane-miles also accounts for the effect of improved capacity on the amount of VMT due to increases in auto accessibility. Both the auto ownership model and the household VMT model are sensitive to freeway lane-miles. Furthermore since the new alternative mode trip models (walk, bike, transit) are sensitive to household VMT (negative coefficient) those model result will be sensitive to changes in auto accessibility due to automated vehicles.

Regarding how much to change freeway lane-miles, Fagnant and Kockelman report on the estimates by Shladover et al. that cooperative adaptive cruise control (CACC) deployed at the 10%, 50% and 90% levels would increase freeway lane capacities by 1%, 20%, and 80% respectively (Fagnant 2015). CACC enables automated vehicles to travel in closely spaced platoons and would only be possible with level 4 automation. A simple polynomial model can be fitted to these data to estimate lane-mile increases at different levels of level 4 deployment.

As noted above, autonomous vehicle deployment will also affect non-recurring (i.e. incident-related) congestion. As reported by Fagnant and Kockelman, the FHWA estimates that about half of incident-related congestion is caused by crashes (Fagnant 2015). The effects of reduced crashes due to vehicle automation can be addressed in the RSPM congestion by altering the 'OpsDelayReduce_$Incident' table in the GreenSTEP model object. For automated vehicle scenarios, the model table values for percentage reduction in freeway non-recurring congestion will be overwritten with percentage reductions reflecting the level of crash reduction due to automation. For example, in the unlikely event that all crashes are eliminated, freeway non-recurring congestion delay would be reduced by 50%.

Modeling Automated Vehicle Ownership

It is proposed that automated vehicle ownership be modeled in the same way that other vehicle characteristics are modeled. A new input table will be created which specifies the automated vehicle sales proportions by model year and vehicle type (i.e. auto, light truck). The inputs will be developed to take into account projections of automated vehicle costs and industry/expert opinions about market penetration. Because the existing vehicle age model in RSPM allocated newer vehicles preferentially to higher income households, it will skew automated vehicle ownership towards higher income households as it should. The other characteristics of household-owned automated vehicles will be assumed to be the same as non-automated vehicles of the same model year. In essence, household vehicles will have an additional attribute (automated vs. non-automated). That attribute will affect household travel, as explained in the Modeling the Effects on VMT section below.

Modeling Shared Autonomous Vehicle (SAV) Deployment

SAVs will be modeled by modifying the existing RSPM car-sharing models. It will be assumed that households are or are not regular users of SAV services. There will be no capability for modeling occasional SAV use because of the increased challenge of determining how much use a household would have and because it is likely that only regular users would alter the number of vehicles they own as a result of SAV availability. The first model modification will be to simplify the input that quantifies the degree of car-sharing deployment. Currently, the input is expressed as the number of persons per car-share vehicle. This approach follows that used in the "Moving Cooler" study. This has proven to be confusing for model users. The new approach that will be applied to both car-sharing and SAV participation will be to specify the proportion of households that are subscribers/regular users. A new input will be added for specifying the SAV regular users (percentage of households) by forecast year. The model which determines which households are subscribers will be modified to add another factor, whether a household member has to pay for parking at work. Paying for parking is likely to be a significant consideration for households choosing to commute by SAV rather than a vehicle they own because using an SAV to get to work eliminates the cost of parking which can be fairly sizable relative to the estimated cost of SAV travel.

The existing model will also be changed with regard to how household vehicle equivalents are calculated for households subscribing to car-sharing or SAV services. The current model assigns 1/20th of a vehicle to a household that subscribes to a car-sharing service. This value was chosen because the methodology used in the "Moving Cooler" study assumes that on average 20 households share one car-share vehicle. This may be reasonable at low levels of car-share deployment, but it is likely to substantially underestimate the effect of SAVs on household travel, especially at high deployment levels. Several simulation studies show that SAVs can provide urban service that rivals private vehicle use and so subscribing to a well-deployed service should be viewed as equivalent to owning a vehicle. {To Do: add some examples of findings from simulation studies.} The new approach will be to add an input where the vehicle equivalence ratio will be specified for households that subscribe to car-share services and for households that are regular users of SAV services. The values in this table will be a function of the level of deployment and can be informed by the results of research by Burns, Fagnant, Kockelman, Chen and others.

Modeling the Effects on VMT

Level 4 automated vehicles are likely to affect VMT in several ways including: 1. Improved automobile accessibility due to increased freeway capacity (and speed) is likely to increase automobile use and distance traveled. 2. Eliminating the need to drive will make traveling by car less onerous and relatively more desirable. 3. Self-driving cars will make it possible for people who can't drive because of age, physical disability, or income to be able to travel by car without being chauffeured by another person. 4. A household owning an autonomous vehicle may send it unaccompanied to destinations to avoid paying for parking or for other purposes. 5. SAV vehicles will need to travel additional miles to get between customers. 6. Travel by SAV will have a higher variable cost than traveling by a household-owned vehicle (which has higher sunk cost and lower variable cost) and will as a result be used less.

The first of these effects will be addressed as explained above by increasing the freeway lane-miles to reflect the effect of autonomous vehicle deployment on capacity.

The second, third, and fourth effects will be addressed by an additional input that multiplies the VMT assigned to household -owned autonomous vehicles to account for this additional travel. This input would largely be a judgement call, but some sense of the second effect might be gained by referring to the paper by Chen and Kockelman (Chen 2016b).

The fifth effect will also be addressed by a multiplier input. Household VMT assigned to SAV travel will be multiplied by this factor to calculate total SAV travel. However, unlike the multiplier for household-owned autonomous vehicle travel, the SAV VMT multiplier will not be applied at the household level. It will be applied at the system level. The results of several SAV simulation studies can be used to establish the value of the multiplier.

The sixth effect will be modeled using the existing RSPM household budget model. Household-owned vehicle VMT will be multiplied by the unit cost calculated in the same was as present. The unit cost for SAV VMT will be calculated in the same way except it will include the estimated costs for SAV depreciation, financing, insurance, overhead, and profit. Values for these quantities will be derived from the papers by Burns, Fagnant, Chen et al.

Doing these things requires that each household's VMT is split between autonomous vehicles, non-autonomous vehicles, and SAV use. This will be done in proportion to the number of vehicles in each category, or the number of equivalent vehicles in the case of SAV. This approach will necessitate eliminating a feature of the current model which reshuffles VMT among household vehicles to minimize fuel consumption. This is a feature that has almost never been used and is unlikely to be missed.

Model Effects on Fuel Consumption and Emissions

The deployment of driverless cars is likely to significantly reduce the rates of fuel consumption (gallons per mile) and emissions (grams per mile) for a couple of reasons: 1. CACC will smooth traffic flows, reducing speed variation and accelerations and decelerations that waste fuel;, 2. SAVs will enable vehicle fleets to be smaller, more fuel efficient, and powered largely by electricity; and, 3. The fleet of SAVs will turn over more rapidly, enabling advanced technology to be incorporated more rapidly.

The first of these effects can be modeled using the existing "speed_smooth_ecodrive.csv" file which enables users to specify the proportion of VMT that is affected by speed smoothing.

The second and third effects will be modeled using new input files that specify the assumed characteristics of the SAV fleet by model year. These files would be much like the commercial service vehicle input files. The average vehicle will be calculated based on the total SAV miles, the number of SAVs deployed, and the useful SAV life (in miles).

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