Multi-Scenario Multi-City Simulations with Stakeholder-Driven Levers to Assess Mobility, Cost, and Energy Impacts

Joshua Auld, Pedro Camargo, Jamie Cook, Taner Cokyasar, Felipe De Souza, Krishna Murthy Gurumurthy, Yantao Huang, Abdelrahman Ismael, Navjyoth Jayashankar, Nazmul Arefin Khan, Gopindra S Nair, Aymeric Rousseau, Olcay Sahin, Hui Shen, Hyunseop Uhm, Omer Verbas, Griffin White, Jan Zill, Natalia Zuniga, Michel Alhajjar
Transportation and Power Systems Division, Argonne National Laboratory, Lemont IL USA

Submitted for presentation at the MATSim User Meeting 2025 to be held in Munich, Germany from June 12-13, 2025

EXTENDED ABSTRACT

Large-scale agent-based model simulations provide high-fidelity results that are beneficial in understanding the impact of various policies, technologies, and network design considerations in with sufficient heterogeneity across demographics, spatial features, and times of day. While agent-based models boast the ability to capture complexity, there is a computational and data cost associated with using agent-based models. Runtimes of several hours for a 24-hour simulation day and output data in the orders of gigabytes adds time and effort in understanding the interactions between the inputs and outputs and how they vary across multiple regions.

POLARIS [1] is one available agent-based model for travel demand simulation. Recent advances in the federated toolset around POLARIS now allows modelers to setup detailed scenarios – including input generation before a simulation is launched as well as extracting key performance indicators (KPIs) from the outputs. The ability to synthesize and simulate detailed travel demand for 25% or more of the population within reasonable runtimes allows modelers to scale analysis through full-factorial study of any levers chosen, and across a variety of land-uses and behavioral contexts. One such undertaking by the authors in close collaboration with a variety of stakeholders is presented here.

Case Study & Lever Identification

A questionnaire was designed to obtain key focus areas for metropolitan planning organizations (MPOs) in the U.S. for travel demand modeling and analysis. Key topics included demand, land use, multimodal transit, ride-hailing and pooling, traffic control, vehicle technology, intelligent transportation systems, electrification, and freight, and respondents were asked to provide priority ratings for sub-topics (such as telecommuting under demand, or road pricing under ITS) that each MPO is currently engaged in addressing. Responses from 17 staff across 7 MPOs were obtained. Subsequent analysis of the responses and current capability of POLARIS were considered together to determine studying the following key levers across a full-factorial study: Role of telecommuting rates & hybrid work across industry types; Transit-oriented development and potential vehicle disposal arising as a result; Freeway-use pricing by charging entry fees on ramps; Electric vehicle adoption, charger availability, and energy dominance from adoption; Transit expansion through service frequency upgrades and strategic provision of bus rapid transit lines; Freight modal shifts from highway to rail and off-hours drayage.

Additional considerations from the survey included the number of cities MPO staff think reasonable to compare and contrast lever efficacy. A total of three models were included in this study design – Atlanta, Chicago, and Dallas Ft. Worth.

Lever Design

Models for the year 2050 were created with demographic data and planned network expansion being provided by MPO partners for the regions chosen. Lever-specific design and lever-specific analysis was conducted to identify the best set of input parameters to consider. Only a couple of examples are provided here for brevity.

On-Ramp Tolling for the Freeway Network

Other studies have shown the benefit of tolling. Toll-setting, however, needs to be carefully planned to maximize traveler benefit. The price to levy at on-ramps is a function of speed benefits and the number of travelers experiencing lower travel times. Simulations for Chicago were conducted to understand the price that maximizes revenue without leaving the freeway system unused.

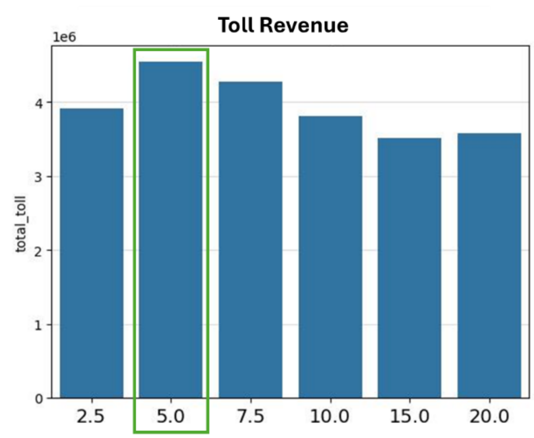

Figure 1: Toll Revenue as a Function of Toll Price

Transit-Oriented Development (TOD)

Transit-oriented development, or strategic investments in economic and housing development at or near transit provides mobility benefits from shifting mode shares away from auto to more transit and multimodal options. Chicago already boasts high transit use compared to the U.S. baseline. Average vehicle ownership for households in TOD zones was used to set the standard for possible TOD expansions in Dallas Ft. Worth and Atlanta. Since POLARIS synthesizes households, persons, and subsequently person-agents' travel demand, a change to the input used to discern how households are spatially oriented needed to be done at the zone level. Population densities in Figure

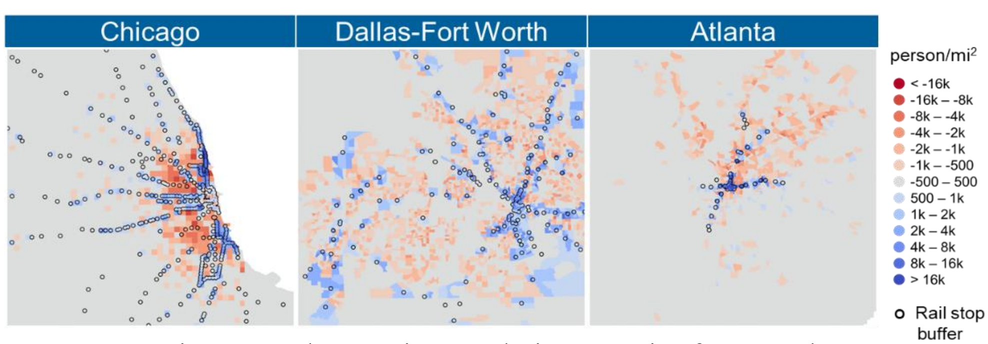

Figure 2: Changes in Population Density for TOD lever

2 show where households and persons are situated in lever on scenarios and where population density drops.

Regression Results That Isolate Lever & Synergistic Benefits

A total of 192 scenarios were simulated while consideration network and demand stability. This included 15 iterations for each scenario. A simple regression was run for each city on KPIs like vehicle hours traveled (VHT), overall cost (from energy of operation and tolls), and energy. Last 5 iterations were chosen after confirming gaps and removing outliers. Independent variables in the regression included base levers and interaction effects, and iterative selection based on p-values allowed the final model to reflect all base levers and significant interaction effects. Table 1 highlights the regression on overall cost, and similar regressions are available for other KPIs, in addition to a detailed analysis from the raw outputs.

	Chicago	**DFW**	**Atlanta**
Base ($/household)	$8.29	$11.04	$8.14
Congestion Pricing	5%	25%	15%
Transit	**-8%**	0%	**-9%**
TOD	3%	-2%	1%
Freight	0%	1%	-1%
Telecommute	**-4%**	**-6%**	**-4%**
EV Penetration	**-9%**	**-14%**	**-12%**
Better Vehicle Technology Model for Energy Use (VT)	**-5%**	**-7%**	**-7%**
Interaction Effects			
Pricing : EV Penetration		1%	
Pricing : Telecommute	-2%	-5%	-3%
Pricing : Transit			7%
EV Penetration : VT High	3%	4%	4%
Freight : EV Penetration		-2%	
Telecommute : EV Penetration			2%
Transit : EV Penetration			2%

As energy use is a key determinant of operating costs, EV adoption proved to be the most effective at reducing transportation costs. For Chicago and Atlanta, which have an acceptable level of transit use, improving transit services had the next highest impact (a combination of interaction and base lever effect). Dallas Ft. Worth, however, remains an auto-centric city and realizing better vehicle technology provides the next biggest reduction in cost. EV adoption is more important than better vehicle technology, as the benefit scales better. As expected, telecommuting – or reducing demand for car travel and making more shorter trips when working from home – reduces cost and has a synergistic benefit with pricing the roads.

ACKNOWLEDGEMENTS

This manuscript and the work described were sponsored by the U.S. Department of Energy (DOE) Vehicle Technologies Office (VTO) under the Pathways to Net-Zero Regional Mobility, an initiative of the Energy Efficient Mobility Systems (EEMS) Program. The U.S. Government retains for itself, and others acting on its behalf, a paid-up nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government. The authors acknowledge the Texas Advanced Computing Center (TACC) at The University of Texas at Austin for providing HPC and database resources that have contributed to the research results reported within the study.

REFERENCES

[1] J. Auld, M. Hope, H. Ley, V. Sokolov, B. Xu, and K. Zhang, "POLARIS: Agent-based modeling framework development and implementation for integrated travel demand and network and operations simulations," *Transp. Res. Part C Emerg. Technol.*, vol. 64, pp. 101–116, Mar. 2016, doi: 10.1016/j.trc.2015.07.017.