An Agent-Based Modeling Approach to Spatial Accessibility

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***Abstract*— Place-based spatial accessibility represents the ability of populations within geographic units to access goods and services, and thus is an important indicator for sustainable development. Existing spatial accessibility models treat population as simply demand, calculating statistics or optimizing average cost for the population within each geographic unit, rather than modeling individual decisions. This paper proposes AgentAccess, a general-purpose Agent-Based Model (ABM) for spatial accessibility analysis. An ABM framework brings us closer to reality by simulating individual and imperfect decision-making. We introduce the model and compare its results against existing spatial accessibility models using a case study of hospital beds in Cook County, IL, USA.**

Keywords—Spatial accessibility, Agent-Based Models, cyberGIS

I. INTRODUCTION

Place-based spatial accessibility quantifies access to vital resources like healthcare [1; 2; 3], jobs [4; 5], and electric vehicle charging stations [6] by calculating metrics—e.g. ratios of supply-to-demand—for each geographic unit in a study area. While this approach provides key information about spatial patterns of access, it ignores individual decision-making and assumes a homogeneous population. Individual accessibility has been proposed to help alleviate these issues [7], but in many cases it is illegal or unethical to share individual-level data [8].

Agent-Based Models (ABMs) have the potential to be a powerful tool for exploring spatial accessibility at the individual level. ABMs allow us to simulate a heterogeneous population of agents each making their own decision about locations to patronize. Not only is this a better representation of the real world, the ABM literature has shown that unexpected results can emerge from the collective impact of individual level decisions [9] which may not be captured by other modeling paradigms. ABMs also allow us to simulate heterogeneous populations, for example some agents with access to a vehicle and some without, which can drastically change the results of an accessibility analysis [10]. While there is previous research utilizing ABMs to address for exploring accessibility in the same way that place-based spatial accessibility have generalized models.

In this paper, we introduce AgentAccess, a generalized model for spatial accessibility analysis. The model is designed to utilize the same logic behind current place-based spatial accessibility measures, but with decisions made at the individual level rather than at the level of each geographic unit. With this new model, this paper seeks to answer: how do the results of an ABM with individual decision-making compare against traditional place-based accessibility measures? The remainder of the paper is organized as follows: Section 2 details the AgentAccess model, Section 3 lays out our data and experiments, Section 4 provides our results, and we conclude with Section 5.

II. AGENTACCESS MODEL

AgentAccess is a generalized spatial ABM for spatial accessibility. Our goal is to create an ABM that uses the same intuition and data inputs as traditional place-based spatial accessibility models, is applicable to a variety of applications, and simulates individual level decision-making. Satisfying these requirements means that our model can be used in all of the same contexts and applications as existing models. AgentAccess simulates individual-level decisions, but to compare our results against traditional spatial accessibility models we will aggregate individual costs to spatial units. This will allow us to calculate correlations and identify how similar modeling results are.

AgentAccess simulates individual agents making decisions about which locations they will utilize to receive the resource or good of interest. It was designed to create agents proportional to the population within each spatial unit at various scales using the popPerAgent parameter. This allows us to explore how the granularity of our agents, for example an agent for every person versus an agent for every thousand people, affects our results. Each agent has a single geographic unit (a census tract in Cook County, Illinois for our experiments) that is static throughout each experiment. Agents make decisions about which location to visit every time step and we run the model for timeSteps steps to allow the population to settle into an equilibrium.

During each time step, every agent chooses a supply location to patronize. This is done by first calculating some cost function for the agent to obtain goods at each supply location. For our experiments, we used a cost function based on the Gravity model, but we used the inverse to transform the value from potential to cost, yielding $t^2 * u$ where t is the travel-time to the supply location and u is the utilization ratio measured by demand divided by supply. In the first step we use the global demandto-supply ratio for the utilization of supply locations, but in subsequent steps use the average utilization for the location across previous time steps. Given the costs for each supply location, each agent chooses from the k least costly options randomly, with probability inversely proportional to their costs and k being a model parameter. This injects some randomness

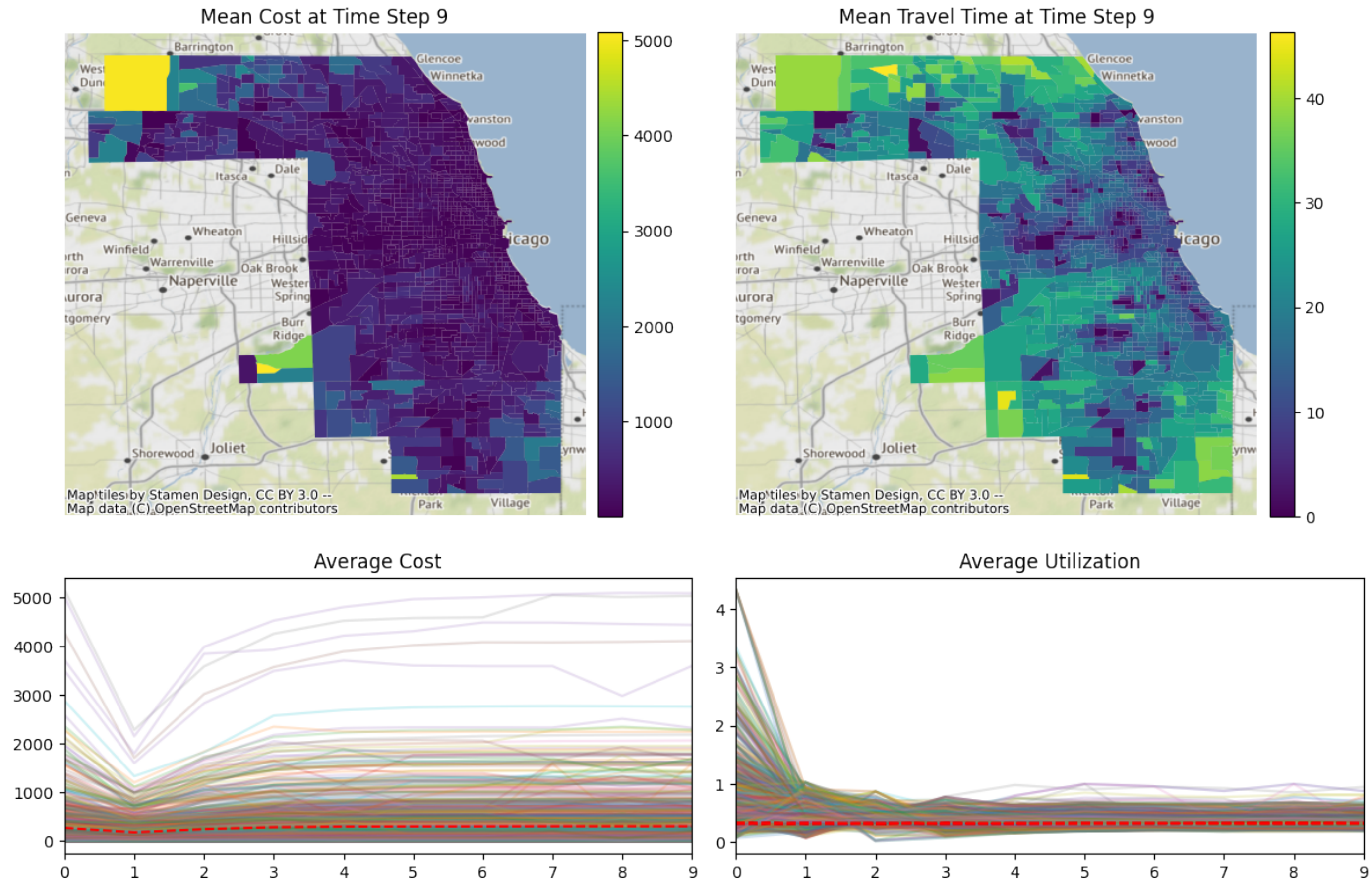

Fig. 1. An example of AgentAccess results and the dashboard the code creates.

to avoid getting stuck in local minima and simulates imperfect information or preferences agents may have. When each agent has chosen a supply location, we record the demand at each supply location and calculate average costs for each spatial unit. An example of the model output can be seen in Figure 1.

III. Data and Experiments

We ran the model with a variety of parameters to determine accessibility to hospital beds in Cook County, IL, USA. We then compared the AgentAccess results with ten spatial accessibility measures calculated used the Python access package by [15]. Both AgentAccess and the access package used the same model inputs: population data from the 2018 American Community Survey, hospital beds from the Homeland Infrastructure Foundation-Level Data, and census-tract level travel-time data from the access package website1. The spatial accessibility methods used are Gravity [16], Two-Step Floating Catchment Area (2SFCA) [17] with a 30 and 60 minute threshold, Enhanced 2SFCA (E2SFCA) [18] with a 30 and 60 minute threshold using weights of 1, 0.68, and 0.22 for thresholds of 10, 20, 30 and 20, 40, 60 minutes respectively, Three Step Floating Catchment Area [19], Gaussian 2SFCA (G2SFCA) [20] with σ = 10, 20, and the Rational Agent Access Model (RAAM) with τ = 30, 60.

For our experiments, we performed a parameter sweep across the three main parameters: popPerAgent, timeSteps, and k. We used values of 1, 10, 100, and 1000 for popPerAgent to explore how the granularity of decision-making affects the model; 10, 15, 20, 25, and 30 for timeSteps to test how long the model takes to find equilibrium, and 1, 2, 3, 4, and 5 for k to determine how different levels of rationality impact results. This gives us one-hundred model runs to compare across. Each model run had the random number generator seeded with a value of zero and we recorded the average cost at each census tract across the second half of time steps as the model result, this allows the model to settle into an equilibrium and smooths out the randomness.

IV. Results

With the results of AgentAccess across one-hundred parameter settings, we then calculated the correlation between the model output and each of the ten spatial accessibility measures using Kendall's τ . This gives us a one-hundred correlation values for each spatial accessibility method. We negated the values for all methods but RAAM as both RAAM and AgentAccess calculate cost whereas the other methods calculate potential (Saxon and Snow 2020). The distribution of correlations for each method are represented as Kernel Density Estimation (KDE) plots in Figure 2, sorted in ascending order by their mean correlation which is given next to the name of each method.

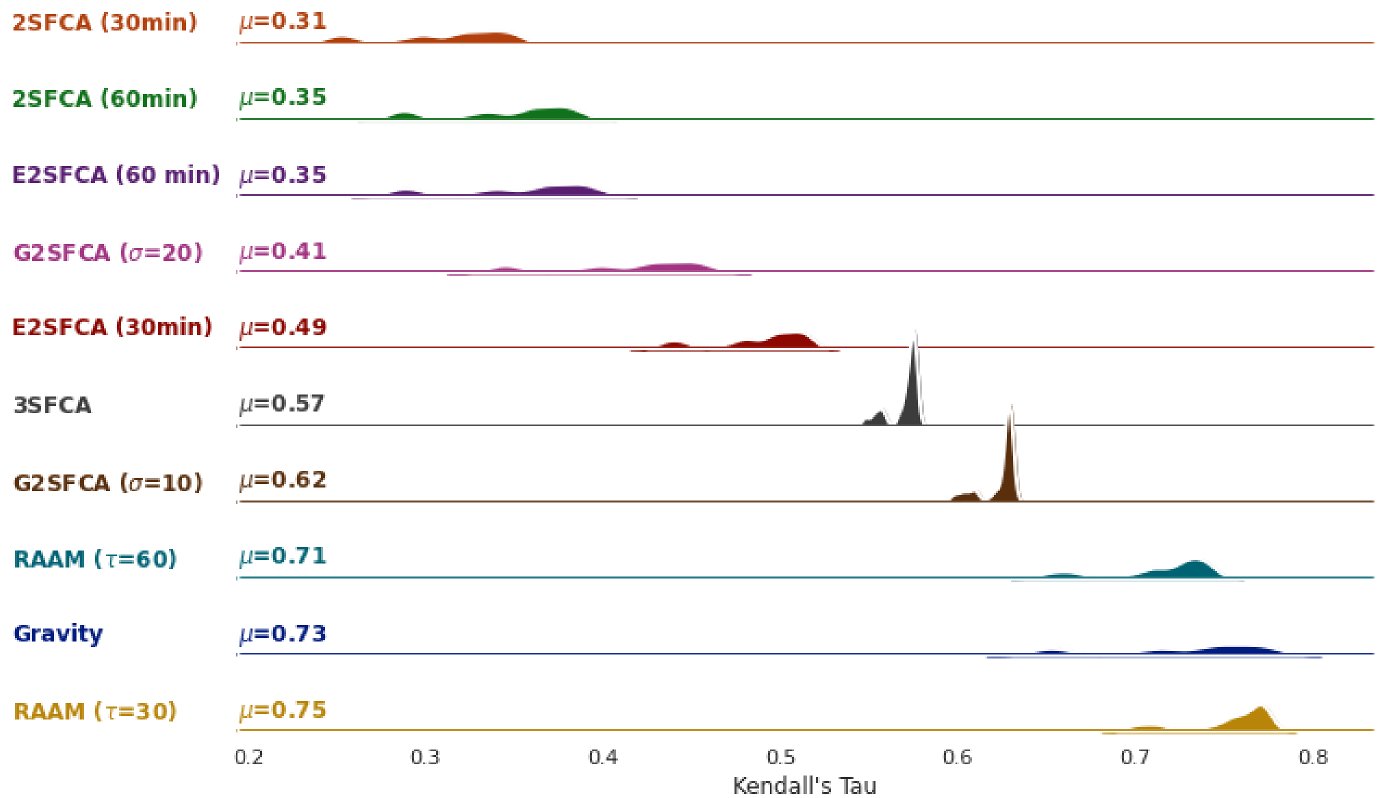

Fig. 2. KDE plots for the Kendall's Tau correlation between various spatial accessibility measures and the AgentAccess model results across a parameter sweep. Note that the values for non-RAAM models have been negated because AgentAccess and RAAM results are cost, thus anti-correlated with traditional models.

These results are unexpected for at least three important reasons. First, we were intrigued that even though the cost function was based on the Gravity model, RAAM with $\tau = 30$ beat Gravity for the highest average correlation. RAAM similarly calculates cost, but optimizes a function that trades off congestion with travel-time to minimize costs for each geographic unit rather than simulating individual decisions [21]. Second, we were surprised by the relatively poor performance of the 2SFCA family of methods given that these models are a special case of the Gravity model. Future work will need to explore why these models, especially 2SFCA with 30 and 60 minute thresholds, have such low correlations with the AgentAccess model, but also if this pattern holds when using different cost functions. Lastly, we expected correlations to be a bit higher across the board. The lack of strong correlations may indicate that modeling individual-level decision making could produce emergent behavior not fully captured by existing models.

V. Concluding Discussion

This paper introduces AgentAccess, a general-purpose Agent-Based Model (ABM) for spatial accessibility analysis. Our model allows for simulating individual agents at various scales and with various levels of rationality. Using a case-study of access to hospital beds in Cook County, IL, USA, we compared the model performance against existing spatial accessibility methods, observing moderate correlations across the board. This result is significant because it indicates that individual-level decision making in the model may produce emergent behavior, which meaningfully differs from the results of existing place-based spatial accessibility models.

While these results are promising, there is much more work to be done. Future research is needed to determine how the model parameters, especially popPerAgent, k, and alternative cost functions, affect the results. Our experiments assumed a homogeneous population, but the model has the potential to simulate a heterogeneous population—e.g. with varying travel cost matrices, degrees of rationality, etc.—which could produce even more realistic modeling and better insights into real-world patterns of access. The model is also very computationally intensive as it can simulate every individual person in a given study area, so cyberGIS [22] will be needed to enable the model to support large-scale (e.g., the contiguous United States) accessibility analysis.

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