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An Agent-Based Modelling Approach

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Publication date

2025

Document Version

Final published version

Published in

AAMAS '25

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Citation for published version (APA):

Michailidis, D., Tasnim, M., Ghebreab, S., & Santos, F. P. (2025). A summary of: Tackling School Segregation with Transportation Network Interventions: An Agent-Based Modelling Approach. In Y. Vorobeychik, S. Das, & A. Nowe (Eds.), *AAMAS '25: Proceedings of the 24th International Conference on Autonomous Agents and Multiagent Systems : May 19-23, 2025, Detroit, Michigan, USA* (pp. 3074-3076). International Foundation for Autonomous Agents and Multiagent Systems. <https://www.ifaamas.org/Proceedings/aamas2025/pdfs/p3074.pdf>

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A summary of: Tackling School Segregation with Transportation Network Interventions – An Agent-Based Modelling Approach

JAAMAS Track

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ABSTRACT

We address school segregation in the context of free school choice systems, where families consider both proximity and demographic composition in their decisions, potentially reinforcing residential segregation. We explore whether transportation network interventions can enhance school accessibility and reduce segregation. Using a novel agent-based model, we simulate populations in synthetic and real-world networks, including Amsterdam. Our findings reveal that improving the centrality of key neighborhood nodes within transportation networks can reduce school segregation by up to 35% under certain conditions. This framework highlights the interplay between citizens' preferences, school capacity, and public transportation in shaping urban segregation.

KEYWORDS

Transportation Networks; School Admission; Segregation; Agent-based Modelling; Dynamic Preferences

ACM Reference Format:

Dimitris Michailidis, Mayesha Tasnim, Sennay Ghebreab, and Fernando P. Santos. 2025. A summary of: Tackling School Segregation with Transportation Network Interventions – An Agent-Based Modelling Approach: JAAMAS Track. In *Proc. of the 24th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2025), Detroit, Michigan, USA, May 19 – 23, 2025*, IFAAMAS, 3 pages.

1 INTRODUCTION

Urban segregation reverberates across various socioeconomic contexts, influencing everyday social interactions, workplaces, entertainment venues, school selection for children, and education [3, 7, 10, 11, 13, 15, 18, 19]. This phenomenon extends beyond residential choices, often creating a self-reinforcing cycle. Urban segregation can become deeply entrenched in society, and challenging to address [7, 15].

In education, urban segregation manifests in school admissions, even under free-choice systems [2, 5, 12]. Distance and travel time are critical in school choice, but socio-economic homophily can be equally influential [7, 15, 16]. Many parents opt for schools outside their neighborhoods, especially when their local area lacks socio-economic or ethnic alignment. Data show that local school choices could significantly reduce segregation levels [6, 16].

To address segregation in school choice, centralized admission mechanisms such as *Deferred Acceptance* and *Random Serial Dictatorship* are widely adopted [1, 4, 8]. These systems allow parents to list preferences while a central authority allocates spots based on accessibility, popularity, and school composition. However, most households, especially low-income ones, are limited by location and rarely move to optimize school choice [2]. Enhancing public transportation networks may enable broader school access, raising the question: *Can transportation interventions effectively reduce school segregation?*

In this extended abstract, we summarize our paper in which we use agent-based modeling (ABM) to address this question [9]. Prior studies have explored school segregation and preference models but have not examined the strategic impact of transportation accessibility [7, 15, 17, 20]. While graph-based interventions have improved accessibility [14], their potential to tackle school segregation and its long-term effects remains unexplored. To bridge this gap, we develop an agent-based model to study school segregation using network structures, with publicly available code and datasets. We examine the conditions under which segregation naturally decreases over time and evaluate the effectiveness of graph-based transportation interventions in reducing disparities in group composition within schools under centralized admission systems. Additionally, we test intervention strategies based on both classic and novel group-based centrality measures. Finally, we conduct experiments in synthetic settings and real-world scenarios in Amsterdam, demonstrating that targeted interventions can significantly reduce segregation over time.

2 METHODS

We model a city as an undirected graph $\mathbb{G} = (V, E)$, where V represents nodes (census tracts) and E represents unweighted edges indicating transportation connections. The graph is connected,



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Proc. of the 24th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2025), Y. Vorobeychik, S. Das, A. Nowé (eds.), May 19 – 23, 2025, Detroit, Michigan, USA. © 2025 International Foundation for Autonomous Agents and Multiagent Systems (www.ifaamas.org).

with shortest paths calculated using Dijkstra’s algorithm. Agents $A = a_1, \dots, a_N$ reside on nodes $v_a \in V$ and belong to predefined socio-economic groups $g \in G$. Each agent has a homophily attribute $h_i \in [0, 1]$, representing their preference for attending schools with an optimal fraction of similar group members. Schools $F = f_1, \dots, f_m$ are located on nodes $v_f \in V$, with capacities s_f and group compositions $c_{g,f}$.

Agents generate preference lists P_i over schools based on a Cobb-Douglas utility function: $U_{i,f} = c_{g,f}^\alpha t_{i,f}^{(1-\alpha)}$, where $t_{i,f}$ is the travel time and $\alpha \in [0, 1]$ balances preferences between group composition and travel time. Travel time $t_{i,f}$ is normalized, while group composition utility peaks when the fraction of similar agents matches h_i . The Random Serial Dictatorship (RSD) mechanism assigns schools based on these preferences, ensuring capacity constraints are met. Allocation outcomes are evaluated using the Dissimilarity Index (DI), a standard measure of segregation.

$$DI = \frac{1}{2} \sum_{f=1}^{|F|} \left| \frac{g_{1,f}}{G_1} - \frac{g_{2,f}}{G_2} \right|, \quad DI \in [0, 1], \quad (1)$$

where $g_{1,f}$ and $g_{2,f}$ are the sizes of group 1 and 2, respectively, in school f . G_1 and G_2 denote the total sizes of groups 1 and 2 in the entire population. The Diversity Index (DI) value ranges from 0 (minimal segregation) to 1 (maximal segregation).

Transport network interventions aim to reduce travel times $t_{i,f}$ to improve access to segregated schools. These interventions modify the graph by adding edges E' under a budget B , simulating new transportation links. We use a greedy algorithm to optimize school accessibility, using classic centrality measures (*closeness* and *betweenness*) and group-based extensions to ensure equitable access between demographic groups.

Group-based Closeness Centrality. Group-based closeness \mathbb{C}_C^g of a node $v \in V$ is defined as the sum of the reciprocal of travel times from all other nodes u , weighted by the fraction of agents of group g in u , defined as $p(g|u)$ (also called harmonic centrality).

$$\mathbb{C}_C^g(v) = \sum_u \frac{1}{t(u,v) p(g|u)} \quad (2)$$

Where $t(u,v)$ is the travel time between nodes u and v . This metric expands upon the conventional definition of overall closeness for a node by introducing $|G|$ centrality measures. Each centrality measure represents the closeness of the node with respect to a specific group $g \in G$.

Group-based Betweenness Centrality. Group-based betweenness \mathbb{C}_B^g of a node $v \in V$ is defined as the number of shortest paths σ from all nodes $o \in V$ to all nodes $d \in V, o \neq d$, that pass through v , weighted by the fraction of agents of group g in d . $p(g|d)$.

$$\mathbb{C}_B^g(v) = \sum_{o \neq v \neq d} \frac{\sigma_{t_{o,d}(v)}}{\sigma_{t_{o,d}}} p(g|d) \quad (3)$$

Our framework supports experiments in real-world (e.g., Amsterdam) and synthetic environments (grid and stochastic block models) to analyze the impact of network interventions on segregation dynamics, and the code is available online ¹.

¹Github: <https://github.com/sias-uva/transport-network-school-choice>

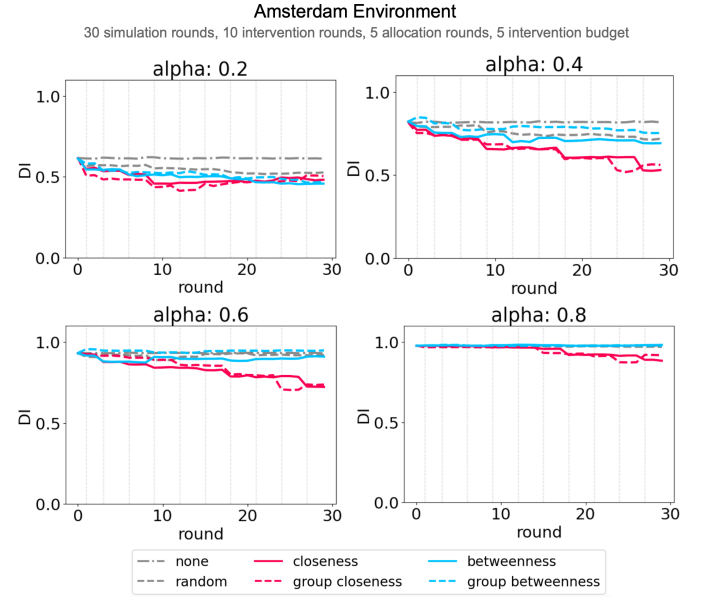


Figure 1: In Amsterdam, targeted interventions in the network can decrease segregation over time, particularly for values of alpha in the range of $0.2 \leq \alpha \leq 0.6$. Strategies based on closeness perform best over other centrality measures.

3 RESULTS

We analyzed the impact of transport network interventions on school segregation in Amsterdam across 30 simulation rounds, varying the importance of group composition (α). Results are shown in Figure 1. The simulations incorporated real-world data on residential segregation and school capacities, with preference generation and school allocation consistent with prior experiments.

For $\alpha = 0$ (preferences depend solely on distance), baseline segregation was low, and interventions showed minimal impact, aligning with empirical findings that distance-based school choice fosters mixed schools ($DI_{\text{residential}} = 0.40$, $DI_{\text{school}} = 0.25$).

For $0.2 \leq \alpha \leq 0.6$, segregation was notably reduced using interventions based on closeness centrality, contrasting with synthetic environments where betweenness performed better. Group-based centrality strategies offered no significant advantages over classic measures in Amsterdam, suggesting structural differences in real-world graphs influence intervention efficacy.

When $\alpha > 0.6$, where school composition strongly influences preferences, interventions had limited impact on reducing segregation. However, Amsterdam exhibited greater resilience to high- α agents compared to synthetic environments, showing segregation reductions even when homophily outweighed travel time preferences. This supports findings that moderate tolerance levels ($0.2 \leq \alpha \leq 0.6$) most effectively reduce segregation while highlighting transportation interventions’ limitations under high homophily preferences.

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