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

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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].

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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, with shortest paths calculated using Dijkstra's algorithm. Agents $A = a_1, \ldots, a_N$ 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 $F = f_1, \ldots, f_m$ 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: $U_{i,f} = c^{\alpha}_{g,f} t^{(1-\alpha)}_{i,f}$, 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.

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

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 $\mathbb{C}^g_C$ 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).

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

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 $\mathbb{C}^g_B$ 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. $p(g|d)$.

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

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].

[1] Github: https://github.com/sias-uva/transport-network-school-choice

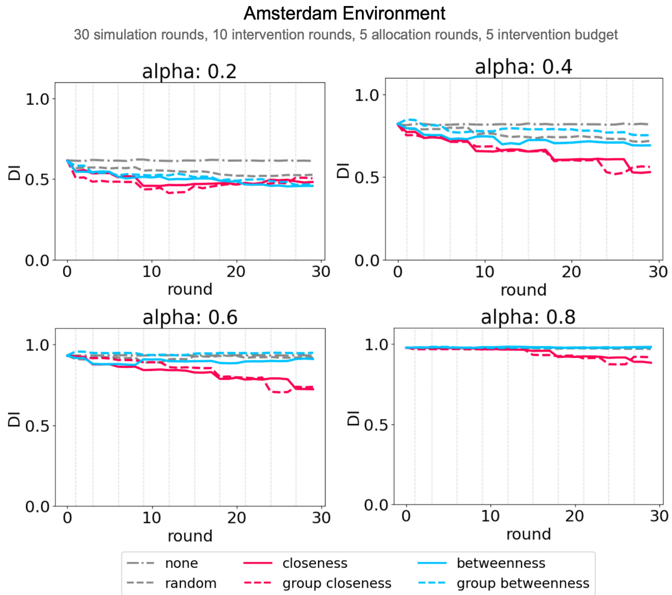

Figure 1: In Amsterdam, targeted interventions in the network can decrease segregation over time, particularly for values of alpha in the range of $0.2 \leq \alpha \leq 0.6$. Strategies based on closeness perform best over other centrality measures.

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.

REFERENCES

[1] Atila Abdulkadiroğlu, Joshua D. Angrist, Yusuke Narita, and Parag A. Pathak. 2017. Research Design Meets Market Design: Using Centralized Assignment for Impact Evaluation. *Econometrica* 85, 5 (Sept. 2017), 1373–1432. https://doi.org/10.3982/ECTA13925 Publisher: John Wiley & Sons, Ltd.

[2] Willem R. Boterman. 2021. Socio-spatial strategies of school selection in a free parental choice context. *Transactions of the Institute of British Geographers* 46, 4 (2021), 882–899. https://doi.org/10.1111/tran.12454

[3] Willem R. Boterman, Sako Musterd, and Dorien Manting. 2021. Multiple dimensions of residential segregation. The case of the metropolitan area of Amsterdam. *Urban Geography* 42, 4 (April 2021), 481–506. https://doi.org/10.1080/02723638.2020.1724439 Publisher: Routledge _eprint: https://doi.org/10.1080/02723638.2020.1724439.

[4] Caterina Calsamiglia and Maia Güell. 2018. Priorities in school choice: The case of the Boston mechanism in Barcelona. *Journal of Public Economics* 163 (July 2018), 20–36. https://doi.org/10.1016/j.jpubeco.2018.04.011

[5] Caterina Calsamiglia, Francisco Martínez-Mora, and Antonio Miralles. 2021. School Choice Design, Risk Aversion and Cardinal Segregation. *The Economic Journal* 131, 635 (April 2021), 1081–1104. https://doi.org/10.1093/ej/ueaa095

[6] Lotje Cohen, Merel van der Wouden, Manilde van der Oord, and Esther Jakobs. 2015. *Segregatie in het Amsterdamse onderwijs*. Onderzoek en Statistiek, Gemeente Amsterdam.

[7] Eric Dignum, Efi Athieniti, Willem Boterman, Andreas Flache, and Michael Lees. 2022. Mechanisms for increased school segregation relative to residential segregation: a model-based analysis. *Computers, Environment and Urban Systems* 93 (April 2022), 101772. https://doi.org/10.1016/j.compenvurbsys.2022.101772

[8] Macarena Kutscher, Shanjukta Nath, and Sergio Urzúa. 2023. Centralized admission systems and school segregation: Evidence from a national reform. *Journal of Public Economics* 221 (May 2023), 104863. https://doi.org/10.1016/j.jpubeco.2023.104863

[9] Dimitris Michailidis, Mayesha Tasnim, Sennay Ghebreab, and Fernando P. Santos. 2024. Tackling school segregation with transportation network interventions: an agent-based modelling approach. *Autonomous Agents and Multi-Agent Systems* 38, 1 (May 2024), 22. https://doi.org/10.1007/s10458-024-09652-x

[10] Esteban Moro, Dan Calacci, Xiaowen Dong, and Alex Pentland. 2021. Mobility patterns are associated with experienced income segregation in large US cities. *Nature Communications* 12, 1 (July 2021), 4633. https://doi.org/10.1038/s41467-021-24899-8 Bandiera_abtest: a Cc_license_type: cc_by Cg_type: Nature Research Journals Number: 1 Primary_atype: Research Publisher: Nature Publishing Group Subject_term: Computational science;Social sciences Subject_term_id: computational-science;social-sciences.

[11] Jan Nijman and Yehua Dennis Wei. 2020. Urban inequalities in the 21st century economy. *Applied Geography* 117 (April 2020), 102188. https://doi.org/10.1016/j.apgeog.2020.102188

[12] Marco Oberti and Yannick Savina. 2019. Urban and school segregation in Paris: The complexity of contextual effects on school achievement: The case of middle schools in the Paris metropolitan area. *Urban Studies* 56, 15 (Nov. 2019), 3117–3142. https://doi.org/10.1177/0042098018811733 Publisher: SAGE Publications Ltd.

[13] Lincoln Quillian and Hugues Lagrange. 2016. Socioeconomic Segregation in Large Cities in France and the United States. *Demography* 53, 4 (July 2016), 1051–1084. https://doi.org/10.1007/s13524-016-0491-9

[14] Govardana Sachithanandam Ramachandran, Ivan Brugere, Lav R. Varshney, and Caiming Xiong. 2021. GAEA: Graph Augmentation for Equitable Access via Reinforcement Learning. *arXiv:2012.03900 [cs]* (April 2021). arXiv: 2012.03900.

[15] Lucas Sage and Andreas Flache. 2021. Can Ethnic Tolerance Curb Self-Reinforcing School Segregation? A Theoretical Agent Based Model. *Journal of Artificial Societies and Social Simulation* 24, 2 (2021), 2. https://doi.org/10.18564/jasss.4544

[16] Shelby Sissing and Willem R. Boterman. 2023. Maintaining the legitimacy of school choice in the segregated schooling environment of Amsterdam. *Comparative Education* 59, 1 (Jan. 2023), 118–135. https://doi.org/10.1080/03050068.2022.2094580

[17] Victor Ionut Stoica and Andreas Flache. 2014. From Schelling to Schools: A Comparison of a Model of Residential Segregation with a Model of School Segregation. *Journal of Artificial Societies and Social Simulation* 17, 1 (2014), 5.

[18] Tiit Tammaru, Szymon Marcin´czak, Raivo Aunap, Maarten van Ham, and Heleen Janssen. 2020. Relationship between income inequality and residential segregation of socioeconomic groups. *Regional Studies* 54, 4 (April 2020), 450–461. https://doi.org/10.1080/00343404.2018.1540035 Publisher: Routledge _eprint: https://doi.org/10.1080/00343404.2018.1540035.

[19] Gergő Tóth, Johannes Wachs, Riccardo Di Clemente, Ákos Jakobi, Bence Ságvári, János Kertész, and Balázs Lengyel. 2021. Inequality is rising where social network segregation interacts with urban topology. *Nature Communications* 12, 1 (Feb. 2021), 1143. https://doi.org/10.1038/s41467-021-21465-0

[20] Carolina V. Zuccotti, Jan Lorenz, Rocco Paolillo, Alejandra Rodríguez Sánchez, and Selamawit Serka. 2023. Exploring the dynamics of neighbourhood ethnic segregation with agent-based modelling: an empirical application to Bradford, UK. *Journal of Ethnic and Migration Studies* 49, 2 (Jan. 2023), 554–575. https://doi.org/10.1080/1369183X.2022.2100554