IS SOCIOECONOMIC OR RELIGIOUS SIMILARITY MORE DOMINANT IN RESIDENTIAL SEGREGATION IN JAKARTA? A SPATIAL AGENT-BASED MODELING AND SIMULATION APPROACH

THESIS

In partial fulfillment of the requirements

for the Degree of Master of Science in Management

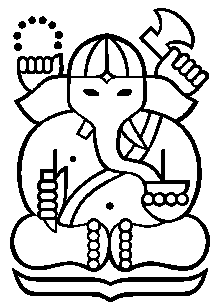
from Institut Teknologi Bandung

By

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Student ID: 29020038

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**INSTITUT TEKNOLOGI BANDUNG**

**December 2022**

# ABSTRACT

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This study analyses whether religion or socioeconomic status similarity is more dominant in shaping segregation patterns. As a case study, we analyze the segregation patterns of Jakarta – Indonesia, one of the largest global metropolitans. To do so, we use agent-based modeling and extend Schelling's segregation model by incorporating the random utility discrete approach to simulate the inhabitants' relocation decisions. Using actual census data from 2010-2013 and the Jakarta GIS map, we simulate the relocation movements of inhabitants at the sub-district level. We set the inhabitants’ socioeconomic and religious similarities as the independent variables and the housing constraint as the moderating variable. As the dependent variables, we simulate and analyze the segregation indicators (i.e., dissimilarity and Simpson indexes) and spatial indicators (i.e., Moran index and segregation pattern maps). This study concludes that religious similarity is a more dominant determinant compared to the socioeconomic similarity in driving inhabitants’ relocation decisions which leads to segregation patterns. Understanding the collective reasons behind residential segregation is valuable for policymakers in developing a socially sustainable city.

Keywords: Residential segregation, Schelling Model, Socioeconomic status, Ethnicities, Religion, GIS, Netlogo, Agent-based modeling, Simulation, Social Sustainability

# *ABSTRAK*

*APAKAH PREFERENSI SOSIO-EKONOMI ATAU AGAMA YANG LEBIH DOMINAN DALAM SEGREGASI PERUMAHAN DI JAKARTA? PENDEKATAN PEMODELAN DAN SIMULASI BERBASIS AGEN SPASIAL*

*Oleh*

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*(Program Studi Magister Sains Manajemen)*

*Studi ini menganalisis apakah kesamaan agama atau status sosial ekonomi yang lebih dominan dalam membentuk pola segregasi. Sebagai studi kasus, kami menganalisis pola segregasi Jakarta – Indonesia, salah satu metropolitan global terbesar. Untuk melakukannya, kami menggunakan pemodelan berbasis agen dan memperluas model segregasi Schelling dengan menggabungkan pendekatan diskrit utilitas acak untuk mensimulasikan keputusan relokasi penduduk. Dengan menggunakan data sensus aktual 2010-2013 dan peta GIS Jakarta, kami menyimulasikan pergerakan relokasi penduduk di tingkat kelurahan. Kami menetapkan kesamaan sosial ekonomi dan agama penduduk sebagai variabel independen dan kendala perumahan sebagai variabel moderasi. Sebagai variabel dependen, kami menyimulasikan dan menganalisis indikator segregasi (Index Disimilaritas dan Indeks Simpson) dan indikator spasial (Indeks Moran dan peta pola segregasi). Studi ini menyimpulkan bahwa kesamaan agama merupakan determinan yang lebih dominan dibandingkan dengan kesamaan sosial ekonomi dalam mendorong keputusan relokasi penduduk yang mengarah pada pola segregasi. Memahami alasan kolektif di balik segregasi perumahan sangat berguna bagi pembuat kebijakan dalam mengembangkan kota yang berkelanjutan secara sosial.*

*Kata kunci: Segregasi perumahan, Model Schelling, Status Sosioekonomi, Etnis, Agama, GIS, Netlogo, Model berbasis agen, Simulasi, Keberlanjutan Sosial*

# VALIDATION PAGE

IS SOCIOECONOMIC OR RELIGIOUS SIMILARITY MORE DOMINANT IN RESIDENTIAL SEGREGATION IN JAKARTA? A SPATIAL AGENT-BASED MODELING AND SIMULATION APPROACH

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# DEDICATION PAGE

*This thesis is dedicated to my wife (Ina), my sons (Rashafni, Dimitri, Nevad, and Bocan), my parents, and and my beloved family who always support me.*

# STATEMENT OF AUTHORSHIP

I hereby declare that I am the sole author of this thesis and to the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made. I further declare that this thesis has not been previously submitted to obtain a degree at this or any other higher education institution.

Signature:



Bandung, 9 December 2022

Hendra Kusumah

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# LIST OF ABBREVIATIONS AND SYMBOLS

|  |  |  |
| --- | --- | --- |
| **ABREVIATIONS** | **Name** | **Page of initial usage** |
| ABM | Agent-based Modeling | 2 |
| SSOT | Single source of truth | 4 |
| EGJ | Ethnic groups from Java Island | 17 |
| EGS | Ethnic groups from Sumatra Island | 17 |
| SES | Socioeconomic Status | 12 |

| **SYMBOLS** | **Name** | **Page of initial usage** |
| --- | --- | --- |
|  | Dissimilarity Index | 16 |
|  | Moran’s Index | 17 |
|  | The minority proportion of the whole city | 16 |
|  | The fraction of the population with the same ethnicity of location | 14 |
|  | The fraction of the population with the same SES or the same religion of location | 14 |
|  | The total number of groups | 16 |
|  | The total population |  |
|  | Utility function as interaction of (ethnicity), (SES or religion), and (agent’s threshold) | 14 |
|  | The sum of spatial weights | 17 |
|  | Mean value of an attribute | 17 |
|  | The number of areas ()  The number of objects in space () | 16 |
|  | The minority proportion of area ()  The fraction of the population of the th type in the dataset () | 16 |
|  | The total population of area | 16 |
|  | Utility value of agent as the sum of utility value (first location) and (new location) | 14 |
|  | The spatial weight for a pair of objects | 17 |
|  | Values of an attribute for objects | 17 |
|  | Values of an attribute for objects | 17 |
|  | Weight of ethnic similarity | 14 |
|  | Weight of religious similarity | 13 |
|  | Weight of sosioeconomic status similarity | 13 |
|  | The unobservable utility of the agent | 14 |
|  | Random error as the unobservable properties of agent (first location) and (new location) | 14 |
|  | Simpson Index | 16 |
|  | All weighted observable properties of agent (first location) and (new location) | 14 |

# Introduction

## I.1 Background

The segregation phenomenon has attracted the attention of social researchers, considering that social and spatial segregation is a fundamental characteristic of modern cities (Yao et al., 2019). Timberlake (2015) defines residential segregation as the spatial separation of several social groups within a particular geographic area. Typically, more heterogeneous groups of people inhabit cities compared to rural areas, which, though not always, are inhabited by more homogenous people. This heterogeneity is associated with an uneven population distribution in urban spaces, leading to a certain segregation pattern (Lloyd et al., 2015). Furthermore, this residential segregation influences many aspects of life (Johnston et al., 2014), such as access to transportation (Nilsson & Delmelle, 2020), education (Silver et al., 2021), job opportunities (Tomasiello et al., 2020), and health services (Caldwell et al., 2017).

Several factors contribute to population heterogeneity, e.g., race/ethnicity, gender, religion, socioeconomic status, language, etc. These factors can motivate an individual in deciding her place of residence (Benenson et al., 2009; Caldwell et al., 2017; Merino, 2011; Tajima et al., 2018; Zuccotti, 2021). This fact is understandable, given the definition of segregation which also connotes inequality (Browne, 2020). As a source of urban problems, segregation, in the form of income inequality, has become a central theme for researchers in understanding the relationship between socioeconomic segregation and spatial patterns in settlements (Prener, 2021; van Ham et al., 2021; Zhang et al., 2021) In many cases, the interplay between socioeconomic characteristics and basic property of inhabitant (e.g., race, ethnicity, and religion) manifests in a clear segregation pattern (Zuccotti et al., 2020).

Studies on segregation mostly use descriptive approaches in clarifying the clustering phenomenon in the people's choice of residency (Florida & Mellander, 2020; Johnston et al., 2021; Nilsson & Delmelle, 2020; Prener, 2021; Rademakers & van Hoorn, 2021; Rukmana & Ramadhani, 2021; van Ham et al., 2021; Xu et al., 2021; Zhang et al., 2021). However, studies exploring inhabitants' internal motivation and reasons for choosing their residency remain few. It is challenging for a study to ask individuals why they choose to live in a specific place, especially if the reasons relate to sensitive matters such as race, religion, etc. Research method, such as surveys and in-depth interviews, have their limitations. To overcome this, we need an alternative research approach to analyze the driver of residential segregation and verify the findings with the actual empirical demographic data.

Agent-based modeling (ABM) is a computer simulation that enables the modeling of the operational dynamics of a system at an individual agent level (Malanson & Walsh, 2015). The agents in ABM act autonomously based on a set of behavioral rules, producing emergent collective behaviors (Singh & Gupta, 2009). One of the earliest studies analyzing segregation using ABM is Schelling's "Dynamic Models of Segregation" (Schelling, 1971). In the original Schelling model, agents decide to move or stay based on the percentage of dissimilarity they can tolerate in their neighborhood, represented by the agent's *threshold* value (Schelling, 1971). We extend this simple mechanism by applying a random utility discrete choice approach as the basis for each agent's decision (Hegselmann, 2017).

As a case study, we focus on analyzing segregation in Jakarta province, a metropolitan area of Indonesia associated with multidimensional complexity. Jakarta has an area of ​​664.01 square kilometers and is inhabited by 10,562,088 people. Jakarta administratively consists of five municipalities (Central Jakarta, West Jakarta, South Jakarta, East Jakarta, and North Jakarta) and one regency (Thousand Islands). Regarding segregation topic, Jakarta is one of the most heterogeneous provinces in Indonesia that is inhabited by several ethnic groups such as Javanese (36.17%), Betawi (28.29%), Sundanese (14.61%), Chinese (6.62%), Batak (3.42%), Minangkabau (2.85%), Malay (0.96%), and others (7.08%) (Ananta et al., 2018).

Previous studies on residential segregation in Jakarta has concluded that socioeconomic factor is the primary driver of population segregation (Firman, 2004; Rukmana & Ramadhani, 2021; Tajima et al., 2018). This study challenges previous research findings by incorporating the religious aspect of the analysis. Specifically, this study aims to figure out whether inhabitants’ religion or socioeconomic similarity is more dominant in shaping spatial segregation patterns.

## I.2 Research Questions

According to what has been explained in the earlier section, the research questions of this study are as follows:

1. How does socioeconomic preference affect residential segregation in Jakarta?
2. How does religious preference affect residential segregation in Jakarta?
3. Is socioeconomic or religious similarity more dominant in residential segregation in Jakarta?

## I.3 Research Objectives

The objectives of this study can be stated as:

1. to simulate and analyze the role of socioeconomic preference in shaping residential segregation patterns.
2. to simulate and analyze the role of religious preference in shaping residential segregation patterns.
3. to find whether inhabitants’ religion or socioeconomic similarity is more dominant in shaping spatial segregation patterns.

## I.4 Research Approach and Methods

The place of this study within the context of research onions (Saunders et al., 2009) is depicted in Figure I.1 and is denoted by the red boxes. The study's philosophical stance is pragmatism, which accepts abductive reasoning as a method of inquiry. Given that we are looking for the best explanation of the phenomena of segregation, this abduction technique is consistent with the use of ABM in case studies of segregation analysis.

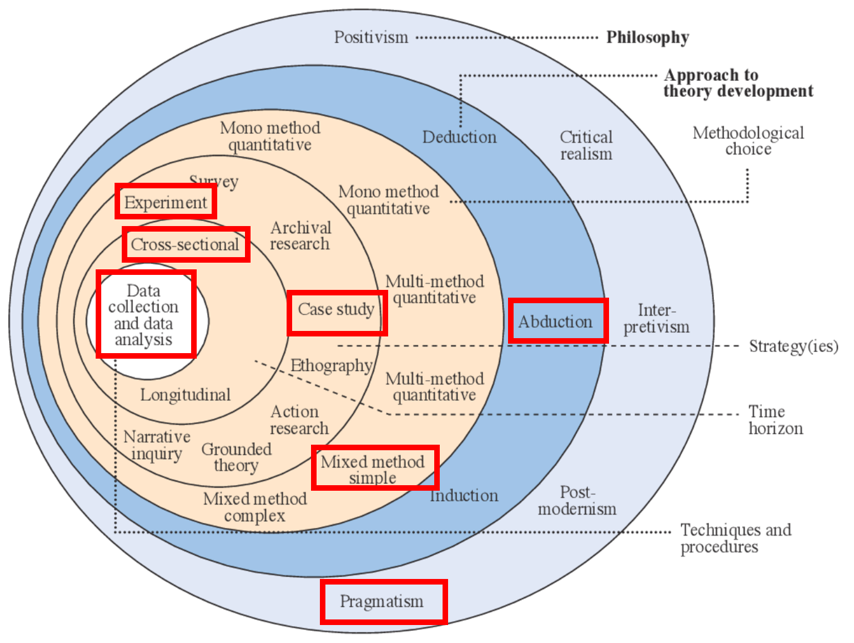


Figure I.1 The research position.

This study's methodological choice was a straightforward mixed approach, in which only one research phase required a qualitative evaluation (the spatial map pattern), and the other phases were assessed using quantitative techniques. Additionally, the case study (Jakarta) and experiment research methods have been selected (ABM Simulation). The census data used for the simulation, which is cross-sectional in the context of the temporal horizon, comes from the years 2010 through 2013. We gather data from a variety of government agencies that adhere to the single source of truth (SSOT) philosophy. Finally, the data is analyzed in this manner utilizing the methods and resources covered in further detail in the study methodology chapter.

## I.5 Key Assumptions and Research Limitations

The case study of Jakarta Province is the main premise of this study. The information used comes from the 2010 and 2013 censuses, which also provide statistics on the population's level of education and religious affiliation. The sub-district (*kelurahan*) level aggregate values are what we model. We overlay those aggregate data at the same level on the Jakarta GIS map, which serves as the study's unit of analysis.

This study's first drawback relates to the population's ethnic composition. To get this information, we extrapolate the population's religious makeup using percentages from research done by Ananta et al. (2018).

The second drawback is the use of socioeconomic status as a measure of educational attainment. Income data would ideally be used to determine a person's socioeconomic level, but as far as we are aware, such data are not accessible. However, information regarding the nature of Jakartans' occupations does not adequately depict the segmentation.

## I.6 Writing Structure

The five chapters that make up this thesis each include the following data: The primary topics covered in Chapter I are the issue that inspired this study, its goal, and its research questions. The discussion of prior research on segregation studies, including the various methodologies selected, preferences, and study locations, is covered later in Chapter II. The methodology employed in this study, including the data explanation and research techniques, is described in Chapter III. The simulation results and analyses are presented in Chapter IV. The research is summarized and concluded in the final chapter, Chapter V.

# Literature Review

## II.1 Introduction

﻿Schelling (1971) concludes that segregation can arise through mild preferences of agents in choosing their demographic or socioeconomic groups. Previous studies have identified the influence of demographic elements such as race (Stepinski & Dmowska, 2019), ethnicity (Johnston & Poulsen, 2013), sex (Poston et al., 2017), or age group (Sabater & Catney, 2019) on individual residential preferences in shaping residential segregation patterns. Some studies have also explored cultural characteristics, such as language (Johnston et al., 2021) and religion (Fong & Chan, 2011). Recently, studies investigating the socioeconomic aspect as the driver of segregation have become more popular. These studies aim to find the root of socioeconomic problems by analyzing the inhabitants’ spatial footprint (Roy & Lees, 2020; van Ham et al., 2021; Zhang et al., 2021).

## II.2 Past Studies on Segregation

### II.2.1 Ethnicity Preference

Ethnicity has also been identified as a dominant driver of segregation (Caldwell et al., 2017; Johnston & Poulsen, 2013; Sabater & Catney, 2019; Zuccotti, 2021; Zwiers et al., 2018). Ethnic identity is an attribute attached to individuals through inheritance. Although -in some instances- ethnic switching occurs due to marriage (Rademakers & van Hoorn, 2021). Earlier studies have found that ethnic segregation can occur in schools (Stroub & Richards, 2013), workplaces (Hu et al., 2020), or neighborhoods (Catney, 2018) Specific ethnic compositions that result in the presence of minority groups contribute to the emergence of segregation. With computational approaches, researchers have succeeded in visualizing this ethnic composition into observable patterns (Loughran et al., 2020; Mahdavi Ardestani et al., 2018; Prener, 2021; Sage & Flache, 2021).

### II.2.2 Religious Preference

To our knowledge, religious preferences have received less attention in the literature. Merino (2011) reported that although scholars believe religion contributes significantly to segregation in the United States, no one has provided solid evidence. Meanwhile, Fong & Chan (2011) conducted a statistical analysis to examine residential patterns among religious groups in Canada. They concluded that religious institutional behaviors, such as the institutional orientation of religious community services, subcultural identity, religious identity, and discrimination influence segregation patterns (Fong & Chan, 2011).

### II.2.3 Sosioeconomic Preference

The socioeconomic aspect has received the highest attention in segregation literature (Rukmana & Ramadhani, 2021; van Ham et al., 2021; Zuccotti et al., 2020). The segregation process will always have implications for the social and economic conditions of a region. Segregation studies are essential in unraveling classic social issues in the urban area such as poverty and economic growth (Rukmana & Ramadhani, 2021). Policymakers can take advantage of the recommendations of segregation research in improving decision-making related to urban planning. The act of physically destroying slum areas to reduce segregation, for example, does not solve the root cause of the problem; instead, it will only redistribute poverty throughout the city (van Ham et al., 2021).

## II.3 Schelling Model

Schelling's two-dimensional segregation model served as the foundation for the study's model. We give an example of a linear distribution model to illustrate the movement of the agents. In 70 columns, 35 stars and 35 zeros are distributed at random (Figure II.1). Everybody wants at least four of their eight closest neighbors (whether they are stars or zeros) to be similar. If there is a dot above zero, it means that the agent wants to leave because he dislikes his neighbors. The degree to which the agent's nearest neighbors are equal to him determines how happy the agent is. The 26 agents are dissatisfied. For instance, the zero wants the same thing as the star, which desires at least four identical neighbors on both its right and left. When you add him up, each agent wants to be in a five to nine ratio majority atmosphere. The following guidelines apply to each agent's transfer:

1. Any agent who is unsatisfied moves to the nearest column where he is content. As a result, some agents who were previously content report declining levels of happiness as a result of new neighbors who fall short of their expectations. Several other agents rejoiced at the same time because his undesirable neighbors had fled the area.
2. Agents who become dissatisfied upon the entrance of new neighbors are forced to wait their turn until all 26 dissatisfied agents have completed the relocation (Figure II.2 top).
3. Each agent's movements are unexpected by the other agents.
4. Up until a state of equilibrium is attained with no more dissatisfied agents, this movement is repetitive (Figure II.2 bottom).

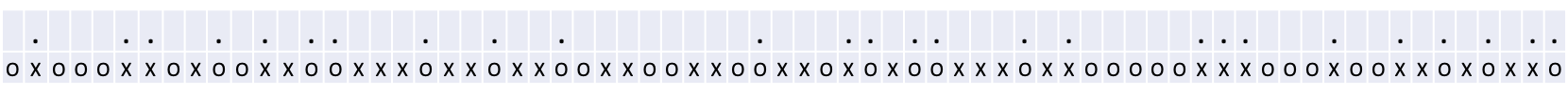


Figure II.1 Initial agents on linear distribution.

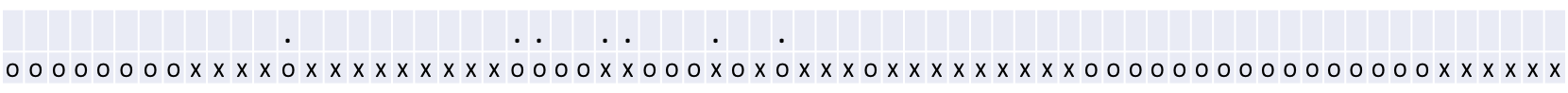
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Figure II.2 The final movement (linear distribution).

Six new clusters made up of 8, 15, 10, 15, 16, and 6 individuals each, on average, were created as a result of the movement of these agents. If the calculations show that there are 440 out of 540 neighbors of the same kind (81.5%), then every 70 agents have eight neighbors, both of the same and different types.

The agent in the area distribution model moves in a two-dimensional space, but the mechanism is the same as it is in the linear distribution.

## II.4 Proposed Research

Table II.1 depicts an overview of previous studies related to segregation driver’s investigation. In general, many previous studies focused on a singular aspect of segregation, namely ethnic/race, religion, or socioeconomic status only. Those studies applied either statistical, spatial, or agent-based modeling in analyzing segregations in different regions like America, Australia, Brazil, the UK, etc (Florida & Mellander, 2020; Rukmana & Ramadhani, 2021; Ta et al., 2021). This study complements previous studies by analyzing two segregation determinants altogether namely, religion and socioeconomic dissimilarity aspects using agent-based modeling and simulation.

## II.5 Chapter Summary

In this chapter, recent research on residential segregation based on three preferences—ethnic, religious, and socioeconomic—as well as earlier work on the creation of agent-based modeling, particularly the Schelling model, are described. I discovered the research gap mentioned in section II.4 Research Proposal from the literature review mentioned above.

Table II.1 State of the Art

| **No.** | **Study** | **Method(s)** | | | **Preference(s)** | | | **Location(s)** | **Finding** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Statistical analysis** | **Spatial analysis** | **ABM** | **Ethnic/race** | **Religion** | **Socio-economic status** |
| 1 | Florida & Mellander (2020) | √ |  |  |  |  | √ | The U.S. *(country level)* | Technology and talent are typically associated with higher levels of economic segregation but not with increased economic segregation growth over time. |
| 2 | Johnston et al. (2021) | √ |  |  | √ |  |  | Sydney, Australia *(city level)* | There is consistent evidence of a significant degree of segregation among those speaking 17 languages ​​at the neighborhood level but a lack of difference between the other aspect. |
| 3 | Loughran et al. (2020) |  |  | √ | √ |  |  | The U.K. *(country level)* | An increase in immigration rates causes a small but significant increase in voter turnout among the nonimmigrant population. Higher levels of civil obligation among immigrants lead to higher turnout rates among nonimmigrants over time. |
| 4 | Nilsson & Delmelle (2020) | √ | √ |  |  |  | √ | The U.S. *(country level)* | ﻿There is no statistical evidence that rail transport investment spurred changes in neighborhood income diversity when compared to similar neighborhoods elsewhere in the city. Similarly, no significant impact of new or expanded rail transit lines on metropolitan-wide income segregation. |
| 5 | Prener (2021) | √ | √ |  | √ |  |  | ﻿St. Louis, Missouri (U.S.) *(city level)* | ﻿St. Louis's peripheral areas expanded over the twentieth century, first in the city and then in the county, creating dual zones of exploitation where poverty, segregation, and income inequality remain persistently higher. |
| 6 | Rademakers & van Hoorn (2021) | √ |  |  | √ |  |  | Indonesia, the U.S., India *(country level)* | Ethnic switching is accurate and highly relevant for studying ethnic diversity and segregation. |
| 7 | Rukmana & Ramadhani (2021) | √ | √ |  |  |  | √ | Jakarta Metropolitan Area *(inter-provincial level)* | ﻿The correlation among income inequality, socioeconomic segregation, and other institutional and contextual factors caused residential Segregation in Jakarta Metropolitan Area. |
| 8 | Tomasiello et al. (2020) |  |  | √ |  |  | √ | Sao Paulo, Brazil *(city level)* | ﻿The ACCESS allowed the residential location of different social status groups to be depicted with a high correlation to the observed situation. |
| 9 | van Ham et al. (2021) | √ | √ |  |  |  | √ | Metropolitan regions across Europe *(city level)* | ﻿Socioeconomic segregation is the outcome of a combination of inequality and poverty and the spatial organization of urban housing markets. |
| 10 | Xu et al. (2021) | √ | √ |  |  |  | √ | ﻿2,055 communities in City ZG, a megacity along the southern coast of China *(sub-district level)* | ﻿The study shows that different occupational groups have different social characteristics and socioeconomic status, and so do their different impacts on various criminal activities. |
| 11 | Zhang et al. (2021) | √ | √ |  |  |  | √ | ﻿Shenzhen, China *(city level)* | ﻿The more segregated communities, which are composed of the poorest and richest groups, are mostly in the peripheral regions of the city, while the inner city has lower levels of segregation due to differentials in transit accessibility. |
| 12 | This study | √ | √ | √ | √ | √ | √ | Jakarta *(provincial level)* | Religious similarity has a stronger influence on an inhabitant to choose a housing location than socioeconomic status. |

# Research Methodology

## III.1 Introduction

As a case study, this study focuses on analyzing the segregation phenomenon in Jakarta, the capital of Indonesia. Jakarta consists of six administrative regencies: North Jakarta, East Jakarta, South Jakarta, West Jakarta, Central Jakarta, and Kepulauan Seribu. This study excludes the Kepulauan Seribu regency since it is located on other islands and not located on the mainland thus, relocation of inhabitants across the sea is less likely. Five analyzed administrative regencies consist of 261 sub-districts (*kelurahan*) (see Figure III.1). A *kelurahan,* the smallest geographical region in our simulation model, has an average area of 2.5 square kilometers with ﻿15,907 inhabitants per square km. North Jakarta consists of 30 *kelurahan*; East Jakarta consists of 65 *kelurahan*, South Jakarta 65 kelurahan, Central Jakarta with 44 *kelurahan*, and west Jakarta with 56 *kelurahan*. In our study, relocation happens when the inhabitant moves residency between different *kelurahan*.

Map

Description automatically generated

Figure III.1 The population distribution in Jakarta.

More than 10.56 million people inhabits jakarta (Badan Pusat Statistik, 2021). Figure III.1 portrays the population density of Jakarta. As shown, the population is higher in the peripheral areas farther from the city center. Areas with low population density (Central Jakarta, parts of South Jakarta, and parts of West Jakarta) are dominated by office buildings and malls where people do commercial activities but do not consider the region as their residence. The black region in the circle highlights the two most populated *kelurahan*.

## III.2 The Religion Spatial Pattern

Figure III.2portrays the spatial pattern of the dominating religion for each kelurahan. The green area is where the Muslim population is the highest in that kelurahan. The population concentration of Protestants and Catholics is high in the blue areas. While the red area is an area of ​​concentration of Buddhists, Confucians, Hindus, and Others. We can see the red-colored kelurahan are located close to each other. The green-colored regions also tend to be close to one another. The spatial pattern indicates an early symptom of residential segregation driven by religion.

Map

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Figure III.2 Spatial pattern of Jakarta's population based on religion.

To reduce the computational load of the agent-based simulation, we group the actual seven categories of religions into three clusters, namely Muslims, Christians, and others based. We conduct the clustering based on two considerations: (1) the magnitude of the religions' followers and (2) the correlation analysis among followers of different religions (see Table III.1). The first group is Muslim, where the number in Jakarta is the majority (83.4%). For the second group, the Protestant and Catholic populations have a high correlation value (0.799), and we group them as Christians. The rest we classify as "others" groups.

Table III.1 The religion correlation matrix of Jakarta inhabitants.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Attributes | Islam | Protestant | Catholic | Hindu | Buddha | Confucian | Others |
| Islam | 1 | 0.502 | 0.226 | 0.197 | 0.106 | 0.203 | 0.013 |
| Protestant | 0.502 | 1 | 0.799 | 0.347 | 0.616 | 0.481 | -0.071 |
| Catholic | 0.226 | 0.799 | 1 | 0.371 | 0.549 | 0.502 | -0.141 |
| Hindu | 0.197 | 0.347 | 0.371 | 1 | 0.091 | 0.189 | 0.143 |
| Buddha | 0.106 | 0.616 | 0.549 | 0.091 | 1 | 0.489 | -0.080 |
| Confucian | 0.203 | 0.481 | 0.502 | 0.189 | 0.489 | 1 | -0.133 |
| Others | 0.013 | -0.071 | -0.141 | 0.143 | -0.080 | -0.133 | 1 |
|  |  |  |  |  |  |  |  |

## III.3 The Socioeconomic Spatial Pattern

Previous studies have used inhabitants’ occupation information as a reference for socioeconomic status (Rukmana & Ramadhani, 2021; Zhang et al., 2021). However, the Jakarta census data classify the occupation of its inhabitants into eighty-eight types of professions. This high number of occupation variants leads to a computational challenge in simulating and comprehensively interpreting the segregation pattern. Thus, we adopt educational attainment as a proxy for an individual's socioeconomic status (Association of American Psychological, 2015). For the simulation, we then codified the educational attainment as follows: not completing elementary school (LOW), graduating from elementary and junior high school (MIDDLE), and graduating from high school (HIGH).

Map

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Figure III.3 Spatial pattern of Jakarta's population based on socioeconomic status.

In contrast to the Ethnicity and Religion concentration maps, the spatial pattern of Jakarta's population based on SES shows a more diverged pattern (Figure III.3). Low SES dominates the green area. The blue area is the population concentration with middle SES. While the red area is a population concentration with high SES. The spatial pattern shows that the distribution of the population with high SES is along the central region from south to north. Also, from Figure III.3 we can see that the middle SES group inhabits the northern part, while the low SES group is distributed evenly in each region.

The Religion and Ethnicity map (Figure III.2) indicates clear zones among population clusters. This is in line with previous research that indicates a strong relationship between an inhabitant's Ethnicity and Religion property (Ananta et al., 2018). The spatial pattern maps based on SES show more moderate clusters' boundaries. This visual indication leads to the conjecture that socioeconomic status does not contribute to segregation. Nevertheless, further investigation is required to clarify the conjecture.

## III.4 Research Conceptual Model

Figure III.4 presents this research’s conceptual model. We apply ABM to determine whether people's socioeconomic or religious similarity is more influential on segregation in Jakarta. In the simulation, we use socioeconomic status similarity ( and religious similarity ( indexes as independent variables. We treat the *housing constraint* as moderating variable. As a dependent variable, we assess the level of segregation using the dissimilarity index, spatial correlation, and spatial pattern map. The level of segregation is assessed using qualitative and quantitative criteria. Qualitatively we use a spatial pattern map. We assess which ABM simulation results of the two scenarios produce a more coherent spatial patterns map between the actual empiric situation and the simulation results. Quantitatively, we asses which ABM simulation scenario produces the least difference in dissimilarity index and spatial correlations between the actual empiric data and the simulation results.

Diagram

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Figure III.4 The research conceptual model.

## III.5 Independent Variable

### III.5.1 Weight of Similarity

In our model, each agent (i.e., an inhabitant) can decide to move to its neighboring kelurahan for each time step. The decision consists of two phases: searching and moving. In the searching phase, the agent evaluates the utility value of its current residence. If the utility value is positive, the agent will stay and ignore the second phase. Suppose the utility value turns out to be negative. The agent will execute the second phase. In the second phase, the agent will compare its current utility value with the proposed utility value of a random prospective neighboring area. If the utility value of the neighboring area is better than its current utility value, the agent will relocate to the new area. Else, the agent will stay at its current residence.

Adopting the discrete choice model (Bruch & Mare, 2009), we formalize the agent’s utility value as follows:

|  |  |
| --- | --- |
|  | (III.1) |
|  |  |

where is all (weighted) observable characteristics of neighborhood , interacting with the attributes of agent , and as the term for random error. We refine equation (1) into two new equations to model the expected interactions in the predefined two scenarios. In the first scenario, we incorporate the interaction between Ethnicity and SES in the utility function. The utility function is formalized as follows:

|  |  |
| --- | --- |
|  | (III.2) |

In the second scenario, we incorporate the interaction between ethnicity and religion in the utility function. The utility function is formalized as follows:

|  |  |
| --- | --- |
|  | (III.3) |
|  |  |

where denotes ethnicity; denotes socioeconomic status/religion; is an agent's threshold value which quantifies the minimum fraction of neighbors having similar properties that must be satisfied for an agent to stay at its current location; denotes the fraction of the population with the same ethnicity; denotes the fraction of the population with the same socioeconomic status (i.e., equation 2) or the same religion (i.e., equation 3). The , , and , represent the weights for similarity in ethnicity, socioeconomic status, and religion. The notation stands for the unobservable utility of the agent (Bruch & Mare, 2009; Manski, 1977).

An agent moves to *kelurahan* j when leaves an open place in the origin area (k*elurahan* i). Utility increases linearly in both and so that high similarity on socioeconomic or religion can compensate for low ethnic similarity and vice versa. The unobservable utility factor of denotes all unknown factors that affect an agent's preference.

Diagram

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Figure III.5 The main logic of an inhabitant agent.

The model will automatically add a random value from the standard Gumbel distribution[[1]](#footnote-1) to the total utility value. The effect of this random value will be greater if the value of , , or is low.

### III.5.2 Housing constraints

As shown in Figure III.5, the agent decides to search for a new location when . In each time step, the agent selects potential *kelurahan* , based on a random probability proportional to the number of vacant residences. If the *housing constraints* parameter is activated (i.e., on), the model will track all agents’ trajectory locations based on SES or Religion of the region. For example, a HIGH SES agent will only relocate to a region with similar socioeconomic status to the agent’s previous residency i.e., HIGH SES; the same goes for religion.

## III.6 Dependent Variables

### III.6.1 Segregation Indicators

#### III.6.1.1 Dissimilarity Index

The index of dissimilarity () measures the evenness with which two groups are distributed across the component geographic areas that make up a larger area. This parameter refers to the ratio of population proportion between the minority and the majority group across geographic areas (Massey & Denton, 1988). The dissimilarity index is formalized as follows:

|  |  |
| --- | --- |
|  | (III.4) |
|  |  |

where is the total population of area , is the minority proportion of areal , is the total population, is the minority proportion of the whole city, and is the number of areas (census tracts) in the study area, in this study refers to the number of *kelurahan* in Jakarta.

#### III.6.1.2 Simpson Index

The Simpson Index () is a measure of ethnic diversity. It can be viewed as an index of concentration to formalize the probability that two agents selected by random chance have a similar property (i.e., ethnic, religious, or socioeconomic property) (Kelly, 2019). The Simpson Index () is formalized as follows:

|  |  |
| --- | --- |
|  | (III.5) |
|  |  |

where is the fraction of the population of the th type in the dataset and denoted the total number of groups (i.e., ethnic, religion, or socioeconomic property).

### III.6.2 Spatial Indicators

#### III.6.2.1 Moran Index

Moran Index (Moran’s I) refers to the spatial autocorrelation across regions*.* It indicates whether the concentration of agents having similar properties exists. The index value ranges from -1 to 1, whereas -1 is the perfect clustering of distinct values (dispersed), 0 is no autocorrelation (perfect randomness), and 1 is the perfect clustering of similar values (clustered) (Glen, 2016). The Moran index is formalized as follows (Ukrainski, 2018):

|  |  |
| --- | --- |
|  | (III.6) |
|  |  |

where is the number of objects in space; is a mean value of an attribute; , are values of an attribute for objects and ; is a spatial weight for a pair of objects, and is the sum of spatial weights.

#### III.6.2.2 Segregation Pattern Map

Figure III.6 shows all segregation pattern maps for each ethnicity, namely Javanese (EGJ), Sumatrans (EGS), Chinese, and other ethnicities. Note that we use the actual empirical data to produce the plots and the complementary information such as Moran I and dissimilarity indexes. Note that for each index, we display two values, the first one complies with the ethnicities-SES scenario and the second one (i.e., the value inside the parentheses) complies with the ethnicities-religion scenario. As shown inhabitants with Sumatrans ethnicities (EGS) contribute to 7.2% of the total population with Moran-I index value of 0.163 (0.277) and ethnic dissimilarity index value of 0.036 (0.034). Inhabitants with Javanese ethnicities (EGJ) inhabit 78.5% of the total population with Moran-I index value of 0.578 (0.569) and ethnic dissimilarity index value of 0.24 (0.241). Inhabitants with Chinese ethnicities inhabit 7% of the total population with Moran-I index value of 0.679 (0.674) and ethnic dissimilarity index value of 0.418 (0.421).

Map

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Figure III.6 Distribution of ethnic groups in Jakarta.

Figure III.6 shows that inhabitants with Sumatran ethnicities EGS have the lowest value of dissimilarity (0.036(0.034)) and Moran I index (0.163(0.277)). The values indicate that the population of Sumatran ethnicities have the highest population dispersion in the region and the lowest level of preference for residing in a place with similar ethnic background. In contrast, inhabitants with Chinese ethnicities have the highest value of dissimilarity (0.679(0.674)) and Moran I index (0.418(0.421)). The values indicate that the population of Chinese ethnicities has the highest population concentration in the region and the highest level of preference for residing in a place with similar ethnic background compared to other population ethnicities. In addition, the concentration of the population of Chinese ethnicities in the northwestern part of Jakarta can be well observed in the segregation pattern plot (see Figure III.6C).

Figure III.7 shows the distribution of the Excess Simpson Index value for each Kelurahan in Jakarta. The excess Simpson index is the difference between the Simpson index value of that specific kelurahan and the Simpson index value of the whole Jakarta region. On average the average Simpson index value of all kelurahan is 0.645(0.646) and the Simpson index value of Jakarta region is 0.627(0.628). Figure III.7 shows a clear blue zone cluster at the north-western part of Jakarta. The visualization is inline with the visualization of inhabitants of Chinese ethnicities and Javanese ethnicities as shown in Figure III.6A and Figure III.6B.

Map

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Figure III.7 Distribution of Excess Local Simpson Index Value in Jakarta.

## III.7 Agent-based Model and Simulation

To develop the simulation, we use NetLogo 6.3.0 (Wilensky, 1999), an open-source agent-based modeling environment. We adopt the segregation model from Jan Lorenz (<https://github.com/janlorenz/Schelling_on_GIS>) and do further modifications to accommodate this study's purpose. Our model can be accessed at the following URL <http://github.com/hendro93/Segregation>. We develop two separate simulation files, one file to investigate the impact of socioeconomic similarities and the other one to investigate the impact of religious similarities. We upgrade the housing constraints' global parameter settings so that the experiment can be run flexibly. Moreover, we added six new monitoring panels using the BehaviorSpace feature of Netlogo, namely excess average Simpson index, dissimilarity indexes for each ethnicity (e.g., EGJ, Chinese, EGS, dan Other), dan Moran-I.

Figure III.8 depicts the simulation environment's graphical user interface (GUI). The GUI consists of seven panels, i.e., Load GIS Data, Explore Local Data, Simulation Setup, Run Simulation, Visualization, Empirical Validation, and Further Parameters. The *Load GIS Data* panel is used to retrieve a town’s GIS alongside the population quantity scaling which will scale down the actual population quantity to a reasonable quantity of inhabitant agents. The *Explore Local Data* panel consists of several features including whether the map visualization is updated dynamically or only visualizes the final map when the simulation analysis ends. Setup Simulation and Run Simulation panels enable users to set and monitor the agent’s utility function (see Equation 1, i.e., threshold-mean, slider threshold-sd), housing-constraints option, shuffle-population button, Gumbel-distribution plot, dan a text box indicating the number of inhabitant agents in the simulation.

The Visualization panel is used to adjust the map visualization’s parameters. The *Empirical Validation* panel enables users to evaluate whether the values of simulation output parameters (i.e., Simpson and dissimilarity indexes) are close to the actual values of the existing segregation condition. The *Further Parameters*panel is used to set numerous settings, i.e., the fraction of free space area within a region (i.e., free space), an agent’s incentive to relocate to another region (i.e., turnover), etc.

|  |
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Figure III.8 The graphical user interface of the agent-based simulation.

At the beginning of the simulation, we generate the inhabitant agents. For computational performance reasons, we scaled down the number of agents by a fraction of 100 of total Jakarta's population. The actual total number of 4.2 million working inhabitants is scaled down to 42,000 agents. each agent is assigned to one of the 260 *kelurahan* locations. On average, 162 agents inhabit each *kelurahan*. The number of agents we model stays proportional to the ethnic composition in Jakarta.

Each agent in the model has the following properties: *ethnicity* (EGJ, CHINESE, EGS, or OTHER), *socioeconomic status* (LOW, MID, or HIGH), and *religion* (MUSLIM, CHRISTIAN, or OTHER). For each property, an agent has a threshold value that quantifies the minimal fraction of neighboring agents having similar properties for an agent to be satisfied with its current location.

In line with the conceptual model, we execute two simulation scenarios to determine whether socioeconomic or religion is the most influential determinant of segregation. As shown in Table III.2, in the first scenario, we vary the value of socioeconomic similarity incrementally (i.e., 0, 4, 8, 12, 16, 20, 24, 28). Likewise, in the second scenario (ethnicities-religion), we vary the value of religious similarity incrementally (i.e., 0, 4, 8, 12, 16, 20, 24, 28). We set each scenario's "housing *constraints*" parameter to different values (i.e., on and off). We execute ten simulation runs for each simulation setting using the BehaviorSpace feature of NetLogo. For each simulation setup, we recorded the value of six output parameters: the Simpson Index, the dissimilarity Index for each of the four ethnic groups, and the Moran-I (spatial correlation) index.

Table III.2 The design of the simulation experiments.

| **Simulation parameter** | **Values** |
| --- | --- |
| Simulation replications | 10 |
| Simulation length | 1000 ticks |
| GIS Map (town) | Jakarta |
| Population scaling | 1:100 (i.e., 4,200,000 inhabitants are projected to be 42,000 agents) |
| Free-space fraction | 0.05 |
| Ethnicity focus | CHINESE |
| Housing constraint | [false, true] |
| Weight of ethnic similarity () | 8 |
| Weight of socio-economic similarity () | [0, 4, 8, 12, 16, 20, 24, 28] |
| Weight of religious similarity () | [0, 4, 8, 12, 16, 20, 24, 28] |
| Other parameters | The simulation detail is listed in the supplementary material (Appendix C). |

## III.8 Chapter Summary

The conceptual model, independent and dependent variables, a spatial pattern map, and the main features of agent-based modeling are all covered in this chapter's discussion of the research's methodology. The data collection, processing, and simulation results for each scenario are covered in great detail in this chapter.

# Results and Analysis

## IV.1 Introduction

The findings and analysis of the research are covered in detail in this chapter. The results and analysis of the agent-based simulation are discussed in the part that follows the chapter's introduction. The results will be coherently discussed in the following chapter. There will be a chapter summary at the end.

## IV.2 Socioeconomic Similarity and Segregation Pattern

Figure IV.1 portrays several plots indicating the impact of different levels of socioeconomic status and housing constraints on the segregation pattern map. Note that indicates the strength of the inhabitant agent’s preference for having neighbors with similar properties to the agent. The higher the the less tolerance an agent has for accepting a neighbor having different socio-economic status.

Looking at the simulated plots where inhabitants have no housing constraint preference, the clustering of people concentration is increasing as the value increases from zero to four. However, as the is increased, the concentrations of people with similar properties are decreasing. Similar behavior also emerges in simulation with active housing constraint preferences. we can see the clustering of people's concentration is increasing as the value increases from zero to eight. However, as the is increased to a larger number, and concentrations of people with similar properties are decreasing. Analyzing all the plots produced by varying the socio-economic similarity values we see that there is no single segregation pattern map that has a similar pattern to the segregation pattern map of the actual segregation map reference (see Figure III.6). Moreover, for a unique simulation setting, each simulation run produces a different segregation pattern. Thus, the segregation pattern is not stable if we use the socio-economic pattern variable as the dependent variable.

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Figure IV.1 The impact of socio-economic similarity and housing constraints on the segregation pattern.

Figure IV.2 shows the simulated spatial autocorrelation index (i.e., Moran’s I) for each set of socioeconomic level in both no housing constraints and with housing constraints contexts. Coherent with the inference of Figure IV.1, in no housing constraint simulation conditions (i.e., red line), the value of Moran’s Index increases along with the increase of from the value of 0 to 4. However, the Moran’s Index decreases drastically as is further increased from 8 to 28. For simulation scenarios with housing constraint conditions (i.e., blue line), we see that the Moran’s Index value reaches its peak (Moran’s Index of 0.8) when the value ofuntil the value of 12. The Moran’s Index decreases drastically as is further increased from 12 to 28. In general, simulation runs, where agents have housing constraints, have higher Moran’s Index values than the ones with no housing constraints.

## IV.3 Religious Similarity and Segregation Pattern

Figure IV.3 portrays several plots indicating the impact of different levels of religious status and housing constraints on the segregation pattern. Note that indicates the strength of the inhabitant agent’s preference for having a neighbor with similar property to the agent. The higher the the less tolerance an agent has for accepting a neighbor having a different religion.

Looking at the plots where inhabitants have no housing constraint preference, we can see the location of people concentration clusters is constantly changing as the value increases. In contrast, in plots from simulation scenarios where inhabitants have housing constraint preferences, the spatial pattern is more stable. As displayed, the location of people concentration cluster is located in the north-western part of Jakarta. The simulated plots are consistent with the actual empirical condition (see Figure III.6) of people with Chinese ethnicity that are concentrated in the north-western part of Jakarta also.

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Figure IV.2 The influence of socio-economic similarity (*βSES*) on Moran’s Index.

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Figure IV.3 The impact of religious similarity and housing constraints on the segregation pattern.

Figure IV.4 shows that for simulation runs where agents have no housing constraints (i.e., red line), the value of Moran’s Index increases along with the increase from the value of 0 to 12. However, the Moran’s Index decreases drastically as is further increased from 16 to 28. For simulation scenarios with housing constraint conditions (i.e., blue line), we see that the Moran’s Index value reaches its peak (Moran’s Index of 0.8) when we increase the value ofuntil the value of 8. The Moran’s Index decreases as is further increased to 12. Furthermore, the Moran’s Index value becomes constant as the more constant as value is increased from 12 to 28. The consistent and coherent spatial pattern between the maps from simulation results and the actual empiric segregation pattern indicates that the impact of the religious aspect is more prominent than the socio-economic aspect in shaping the segregation pattern.

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Figure IV.4 The influence of religious similarity (βrel) on Moran’s Index.

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Figure IV.5 The relationship between *βrel* and Chinese dissimilarity index (with housing constraints).

Figure IV.5 shows the relationship between religious preference on Dissimilarity Index of inhabitants with Chinese ethnicity. The blue line indicates the actual empirical value reference of 0.421. For simulation runs with agents having housing constraints, we observe that the Dissimilarity Index gets more stable as the religious similarity goes beyond the value of 12. The finding is consistent with the behavior of the spatial autocorrelation index (Moran’s I) indicating the segregation clustering becomes more stable as the value of the religious similarity is higher than 12.

In addition to the analysis of the dissimilarity index for inhabitants of Chinese ethnicity, we also analyze the similarity index for inhabitants of Javanese (i.e., EGJ) and Sumatrans (i.e., EGS) ethnicities. As portrayed in Figure IV.6, the dissimilarity index for Javanese and Sumatrans ethnicities reaches its minimum value at equals to 8 and the dissimilarity index for Javanese and Sumatranese ethnicities stabilizes at reaches the value of 12 and beyond. Note that, the dissimilarity index outputs produced by the simulation runs for Javanese and Sumatrans ethnicities are closer to the empirical values than the dissimilarity indexes of the Chinese ethnicities (Figure IV.5). Moreover, the actual and empirical dissimilarity index for both Javanese () and Sumatrans is lower than the dissimilarity index for inhabitants of Chinese ethnicity ().

|  |  |
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Figure IV.6 The relationship between *βrel* and Javanese and Sumatran Dissimilarity Indexes (with housing constraints).

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Figure IV.7 Excess Average Simpson Index on *βrel* with housing constraints (ethnicity and religion interaction).

Figure IV.7 shows the relationship between people's concentration value (i.e., the Simpson Diversity index) and the inhabitants’ religious similarity . In line with our previous findings, the value of the excess Simpson Diversity index also reaches the minimum value when the religious similarity equals to 8 and stabilizes when the religious similarity is set to the value of equals to 12 and beyond.

## IV.4 Verification and Validation

For an ABM model to be reliable, verification and validation are crucial. According to Ormerod & Rosewell (2009), the following are the distinctions between the two procedures:

**Verification**

* Confirming that the model has been faithfully represented by the computational software implementation as anticipated.
* Verify that the model's mathematical equations have been successfully solved.

Table IV.1 The values of ethnic segregation measurement.

|  |  |  |  |
| --- | --- | --- | --- |
| Segregation measures | | Value (SES/Religion) | Value range |
| Average Local Simpson Index | | 0.646 | 0 to 1 |
| Town Simpson Index | | 0.628 | 0 to 1 |
| Dissimilarity Index | |  |  |
|  | EGJ | 0.24 (0.241) | 0 to 1 |
|  | CHINESE | 0.418 (0.421) |
|  | EGS | 0.036 (0.034) |
|  | OTHER | 0.204 |

**Validation**

* It evaluates a computer model's degree of resemblance to reality in light of the applications for which it is intended.
* Check to see if the equations we are using are correct.

By making sure that the simulation model on NetLogo can properly implement Schelling's extended model, we carry out the verification procedure. We reduced the number of agents in the simulation model in order to maintain performance (according to the computational memory constraint). We divided the population of Jakarta by 100 and decreased it. Therefore, each simulation used 42,083 agents, or 162 agents per kelurahan, on average. The number of agents in our model remains constant with Jakarta's ethnic distribution. All the equations in the simulation model, as shown in Table IV.1, have values that fall within the range of values for each metric[[2]](#footnote-2).

The validation procedure that follows should ensure that the simulation's results accurately represent the current situation (external validation). Theoretical verification, external validation, and cross-model validation are three methods of validation, according to Singh & Gupta (2009). Our simulation model simultaneously presents the results of the simulation and actual data. We can compare them quantitatively (Moran's I autocorrelation and measurement values of segregation) and qualitatively (spatial picture). Since much research on segregation and the census authority (Iceland et al., 2002) has used these two measures, we utilize the Dissimilarity Index and the Simpson Index.

We also use the simulation findings from the Bradford, UK model, which served as the study's reference, to complete the verification and validation procedure for our model (Zuccotti et al., 2020). Various simulation results demonstrate that the written code delivers various results for various input data (see Appendix B).

## IV.5 The Emergent Behavior

The distinguishing feature of agent-based modeling is the emergence of complex aggregate-level behavior as a result of interactions between agents that are governed by straightforward rules (Stonedahl, 2011). In two situations with housing restrictions, the disimilarity index for each ethnicity is compared, as shown in Figure IV.8.

|  |  |
| --- | --- |
|  |  |
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Figure IV.8 Dissimilarity Index Comparison (Scenario 1 and 2 with housing constraints).

|  |  |
| --- | --- |
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Figure IV.9 Moran’s Index and Excess Average Simpson Index Comparison (Scenario 1 and 2).

If we carefully examine Figure IV.8, we will notice that the curves for Scenario 1 (the SES chart), which is colored gray, and Scenario 2 (religion), which is colored red, differ in terms of their shapes. In scenario 2, with housing constraints, the Gumbel distribution has a non-linear impact on the utility function, which is then projected onto the Disimilarity Index value. When particular parameter settings are used, this nonlinearity shows an emergent pattern as a result of agent interaction (in this case, religious preferences with housing constraints).

The Moran's Index and the Excess Average Simpson Index are compared in Figure IV.9, which improves our understanding of how complex patterns of agent interaction emerge.

## IV.6 Chapter Summary

The research's entire body of findings is explained in this chapter. After the findings and analysis of each study were presented, there was a discussion that included the results and analysis of the two scenarios. The results of the spatial agent-based modeling and simulation approach have enriched the segregation study's conclusions.

# Summary and Conclusion

## V.1 Conclusion

The goal of this study is to examine the pattern of residential segregation that exists in Jakarta and identify the main factor that contributes to it. The study as designed must respond to three research questions. To do so, we use agent-based modeling and extend Schelling's segregation model. Using actual census data from 2010-2013 and the Jakarta GIS map, we simulate the relocation movements of inhabitants at the sub-district level. We set the inhabitants’ socioeconomic and religious similarities as the independent variables and the housing constraint as the moderating variable. As the dependent variables, we simulate and analyze the segregation indicators (i.e., dissimilarity and Simpson indexes) and spatial indicators (i.e., Moran index and segregation pattern maps).

***RQ1:*** *“How does socioeconomic preference affect residential segregation in Jakarta?”*

In the various parameter settings, the simulation results that incorporate ethnic similarity weights and SES do not reveal a consistent spatial pattern. When the housing constraints toggle is turned on, the same outcomes are displayed (see Figure IV.1).

The resulting dissimilarity index value also has a bias that deviates significantly from the situation in the real world. In light of this, it can be said that socioeconomic preferences are not the primary factor motivating a person to choose their place of residence.

***RQ2:*** *“How does religious preference affect residential segregation in Jakarta?”*

When the moderating variable housing constraints is not enabled, the findings of the second scenario simulation, in which we couple ethnic and religious components, are also not different from the results of the first scenario simulation. However, when housing constraints are added to the simulation, we discover consistent spatial pattern maps for any combination of the parameter settings (see Figure IV.3). These results support the notion that a person's choice of location is mostly influenced by his or her religious preferences.

**RQ3:** “Is socioeconomic or religious similarity more dominant in residential segregation in Jakarta?”

This study concludes that inhabitants’ religious similarity has a more dominant role than socioeconomic status. Compared to segregation pattern maps from the socioeconomic similarity simulation runs (Figure IV.1), the result of the simulation shows that the segregation pattern maps from the religious similarity simulation runs (Figure IV.2) are more coherent with the actual segregation (Figure III.6 and Figure III.7) pattern map.

## V.2 Practical Implications

Understanding the phenomenon of residential segregation in a region and its determinant is extremely useful for formulating the region's development. From this study, we gain a clear perspective that religion as an inherent property of inhabitants plays a larger role than socioeconomic status in shaping the segregation pattern. Thus, incorporating a cultural approach in planning and executing regional development programs is of high importance in a society where religious properties are dominant. Abandoning the religious aspect and applying a pure ratio-economic approach may not bring the maximum impact in terms of the socio-economic development contexts.

## V.3 Limitations and Future Research Reccomendations

Studies on segregation mostly use descriptive approaches in clarifying the clustering phenomenon in the people's choice of residency. However, studies exploring inhabitants' internal motivation and reasons for choosing their residency remain few. It is challenging for a study to ask individuals why they choose to live in a specific place, especially if the reasons relate to sensitive matters such as race, religion, etc. This study has proved the usefulness of agent-based modeling and simulation to analyze an individual’s drive for residential segregation and verify the findings with the actual empirical demographic data.

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# APPENDICES

**Appendix A: NetLogo Code**

**Code of Scenario 1 (Schelling\_on\_GIS-@SES.nlogo)**

extensions [ matrix rnd gis profiler sound]  
breed [districts district]  
breed [staticempiricals staticempirical]  
  
globals [ townshp admshp jakbarshp jakpusshp jakselshp jaktimshp jakutshp ; shapefiles  
 ethnicities sess ; lists of names  
 town-popdata town-ethnicity-counts town-ses-counts town-totalpop all-thresholds ; lists of constants for statistical purposes  
 decisions-count forced-moves-count searches-count moves-count  
 b  
]  
districts-own [ id popdata ethnicity-counts ses-counts totalpop maxpop ses-maxpop  
 perc-sim-eth perc-sim-ses  
 indivs] ; list of list of length totalpop with each sub list representing one individual in the form [ethn-ind ses-ind thresh]  
staticempiricals-own [ id popdata ethnicity-counts ses-counts totalpop maxpop ses-maxpop indivs]   
  
;; SETUP PROCEDURES  
  
to setup  
 clear-all  
  
 set b 0.9  
 load-gisdataset  
 let vars ["GLO" "GMI" "GHI" "CLO" "CMI" "CHI" "BLO" "BMI" "BHI" "OLO" "OMI" "OHI"]  
; set ethnicities [ "WHITEB" "ASIAN" "BLACK" "OTHER" ]  
 set ethnicities ["EGJ" "CHINESE" "EGS" "OTHER"]  
 set sess [ "LOW" "MID" "HIGH" ]  
 foreach gis:feature-list-of townshp [ x ->  
 let centroid gis:location-of gis:centroid-of x  
 create-districts 1 [  
 setxy item 0 centroid item 1 centroid  
 set id gis:property-value x "NAMOBJ"  
 let pops map [y -> round ((gis:property-value x y) / scale-down-pop)] vars  
 set popdata (list ( sublist pops 0 3) ( sublist pops 3 6) ( sublist pops 6 9) ( sublist pops 9 12))  
 setup-indivs-popdata-subcounts  
 set maxpop round (totalpop / (1 - free-space))  
 set ses-maxpop map [y -> round (y / (1 - free-space))] ses-counts  
 hatch-staticempiricals 1 [ set size 0 ]  
 ]  
 ]  
 ask districts [ create-district-neighbor-links ]  
 ask staticempiricals [ create-district-neighbor-links ]  
 set town-popdata matrix:to-row-list reduce matrix:plus [matrix:from-row-list popdata] of districts  
 set town-ethnicity-counts count-ethnicities town-popdata  
 set town-ses-counts count-sess town-popdata  
 set town-totalpop count-totalpop town-popdata  
 print-town-data  
 visualize  
 reset-ticks  
end  
  
to load-gisdataset  
 set townshp gis:load-dataset (word town "/" town ".shp")  
 gis:set-world-envelope (gis:envelope-union-of (gis:envelope-of townshp))  
end  
  
to create-district-neighbor-links  
 let list-of-neighbors map [x -> one-of turtles with [breed = [breed] of myself and id = gis:property-value x "NAMOBJ"]]  
 (filter [y -> gis:intersects? y gis:find-one-feature townshp "NAMOBJ" id ] gis:feature-list-of townshp)  
 create-links-with other (turtle-set list-of-neighbors)  
end  
  
to shuffle-population  
  
 ifelse housing-constraints [  
 ; The following sets popdata in each district such that ethnicity counts in each ses group are proportional to town-wide ethnicity counts in each ses groups.  
 ; The ses counts in each district remain as original. This makes the ethnic mean local Simpson index minimal (entropy maximal) while keeping ses structure as in reality.  
 let townsesfrac map [x -> normalize-list x] matrix:to-column-list matrix:from-row-list town-popdata  
 ask districts [ set popdata matrix:to-row-list matrix:map round matrix:from-column-list (map [ [x vec] -> map [y -> x \* y] vec] ses-counts townsesfrac) ]  
 ][  
 let towntotalfrac matrix:to-row-list matrix:map [x -> x / sum [totalpop] of districts] matrix:from-row-list town-popdata  
 ask districts [ set popdata matrix:to-row-list matrix:map round (matrix:from-row-list towntotalfrac matrix:\* totalpop) ]  
 ]  
 ask districts [ setup-indivs-popdata-subcounts ]  
 visualize  
 clear-all-plots  
 reset-ticks  
end  
  
to setup-indivs-popdata-subcounts  
 set ethnicity-counts count-ethnicities popdata  
 set ses-counts count-sess popdata  
 set totalpop count-totalpop popdata  
 ; The following produces list of list of length totalpop with each sub list representing one individual in the form [ethn-ind ses-ind thresh]  
 set indivs reduce sentence map [z -> reduce sentence map [y -> n-values item y item z popdata [x -> (list z y random-beta-musigma threshold-mean threshold-sd)]] range length item z popdata] range length popdata  
 set all-thresholds reduce sentence [map [x -> item 2 x] indivs] of districts  
  
end  
  
  
;; GO PROCEDURES  
  
to go  
  
 reset-timer  
 set decisions-count 0 set forced-moves-count 0 set searches-count 0 set moves-count 0  
 ask districts [compute-percentage-similar]  
 repeat town-totalpop [ ask one-of districts [  
 let nummoves totalpop / (town-totalpop / count districts)  
 repeat floor (nummoves) [individual-decides]  
 if random-float 1 < (nummoves - floor (nummoves)) [individual-decides] ; to make the expected number of moves per tick equal to the number of individuals  
 ]]  
 visualize  
 print (word  
 ifelse-value (always-search) [""] [(word decisions-count " decisions, ")]  
 ifelse-value (turnover > 0) [(word forced-moves-count " randomly replaced via turnover (" precision (100 \* forced-moves-count / decisions-count) 1 "%), ")] [""]  
 searches-count " searches (" precision (100 \* searches-count / decisions-count) 1 "%), "  
 moves-count " moves (" precision (100 \* moves-count / decisions-count) 1 "%) in " timer " seconds")  
 tick  
; if ticks = stop-tick or (moves-count / decisions-count < 0.01) [visualize stop]  
 if ticks = stop-tick [  
; sound:play-note-later 1 "TRUMPET" 60 64 2  
 visualize stop  
  
  
 ]  
end  
  
to compute-percentage-similar  
 set perc-sim-eth (list percent-similar-ethnicity-neighborhood 0 percent-similar-ethnicity-neighborhood 1 percent-similar-ethnicity-neighborhood 2 percent-similar-ethnicity-neighborhood 3)  
 set perc-sim-ses (list percent-similar-ses-neighborhood 0 percent-similar-ses-neighborhood 1 percent-similar-ses-neighborhood 2)  
end  
  
to individual-decides ; in a districts select a "virtual" person and let this decide to move  
  
 set decisions-count decisions-count + 1  
 let indiv-ind random length indivs  
 let indiv item indiv-ind indivs  
 let ethn-ind item 0 indiv  
 let ses-ind item 1 indiv  
 ifelse random-float 1 < turnover [  
 set forced-moves-count forced-moves-count + 1  
 let option ifelse-value (housing-constraints) [random-ses-option ethn-ind ses-ind] [random-option ethn-ind ses-ind]  
 individual-moves option ethn-ind ses-ind indiv-ind indiv  
 ] [  
 let thresh item 2 indiv  
 let U\_home utility ethn-ind ses-ind thresh  
 if U\_home < 0 or always-search [  
 set searches-count searches-count + 1  
 let option ifelse-value (housing-constraints) [random-ses-option ethn-ind ses-ind] [random-option ethn-ind ses-ind]  
 let U\_option [utility ethn-ind ses-ind thresh] of option  
; print(U\_option)  
 ;let free ifelse-value (tie-houses-to-ses) [[(item ses-ind ses-maxpop) - (item ses-ind ses-counts)] of option] [[maxpop - totalpop] of option]  
 if (U\_option - U\_home > 0) or (always-move) [  
; print(ethn-ind)  
; print(ses-ind)  
; print(U\_option - U\_home)  
 ;if (free > 0) and (U\_option - U\_home > 0) [  
 set moves-count moves-count + 1  
 individual-moves option ethn-ind ses-ind indiv-ind indiv  
 ]  
 ]  
 ]  
end  
  
to individual-moves [option ethn-ind ses-ind indiv-ind indiv]  
 alter-popdata ethn-ind ses-ind -1  
 set indivs remove-item indiv-ind indivs  
 ask option [  
 alter-popdata ethn-ind ses-ind 1  
 set indivs fput indiv indivs  
 ]  
end  
  
to alter-popdata [ethn-ind ses-ind change] ; change should be 1 or -1  
 set popdata replace-item ethn-ind popdata (replace-item ses-ind (item ethn-ind popdata) (item ses-ind item ethn-ind popdata + change))  
 set ethnicity-counts replace-item ethn-ind ethnicity-counts (item ethn-ind ethnicity-counts + change)  
 set ses-counts replace-item ses-ind ses-counts (item ses-ind ses-counts + change)  
 set totalpop totalpop + change  
end  
  
;; REPORTERS DECISIONS TO SEARCH / MOVE  
; For selection of "a random person"  
to-report random-option [ethn-ind ses-ind]  
 report rnd:weighted-one-of districts [max list 0 (maxpop - totalpop) \* ifelse-value ethn-ses-recommendations [recommendation-probability ethn-ind ses-ind] [1]]  
end  
to-report random-ses-option [ethn-ind ses-ind]  
report rnd:weighted-one-of districts [max list 0 (item ses-ind ses-maxpop - item ses-ind ses-counts) \*  
 ifelse-value ethn-ses-recommendations [recommendation-probability ethn-ind ses-ind] [1]]  
end  
; For utility computation  
to-report utility [ethn-ind ses-ind thresh] report (observable-utility ethn-ind ses-ind thresh) + random-gumbel end  
to-report observable-utility [ethn-ind ses-ind thresh] ; the utility concept here is linear in similarity fractions, shifted such that 0 divides favorable and non-favorable  
 report (ifelse-value (others-ignore-ethn and ethn-ind = 3) [0] [beta-eth \* (item ethn-ind perc-sim-eth - thresh)]) +  
 beta-ses \* (item ses-ind perc-sim-ses - thresh)  
end  
to-report recommendation-probability [ethn-ind ses-ind]  
 ifelse (((ifelse-value (others-ignore-ethn and ethn-ind = 3) [0] [beta-eth]) + beta-ses) = 0)  
 [report 1]  
 [report ((ifelse-value (others-ignore-ethn and ethn-ind = 3) [0] [beta-eth \* item ethn-ind perc-sim-eth]) +  
 beta-ses \* (item ses-ind perc-sim-ses)) / ((ifelse-value (others-ignore-ethn and ethn-ind = 3) [0] [beta-eth]) + beta-ses) / 2]  
end  
to-report percent-similar-ethnicity-neighborhood [ethn-ind]  
 report (item ethn-ind ethnicity-counts + neighbor-weight \* sum [item ethn-ind ethnicity-counts] of link-neighbors) /  
 (totalpop + neighbor-weight \* sum [totalpop] of link-neighbors)  
end  
to-report percent-similar-ses-neighborhood [ses-ind]  
 report (item ses-ind ses-counts + neighbor-weight \* sum [item ses-ind ses-counts] of link-neighbors) /  
 (totalpop + neighbor-weight \* sum [totalpop] of link-neighbors)  
end  
  
;; VISUALIZATION AND PRINT OUTPUT  
  
to visualize  
 ask patches [set pcolor ifelse-value (data-source = "simulation (dynamic)") [77] [white]]  
 ask turtles [set size 0 set label ""]  
 foreach gis:feature-list-of townshp [ x ->  
 let dist ifelse-value (data-source = "empirical (static)")  
 [one-of staticempiricals with [id = (gis:property-value x "NAMOBJ")]]  
 [one-of districts with [id = (gis:property-value x "NAMOBJ")]]  
 let val value-for-monitoring dist  
 gis:set-drawing-color ifelse-value (is-number? val) [ifelse-value (val >= 0) [scale-color red val color-axis-max 0] [scale-color blue (0 - val) color-axis-max 0]] [gray]  
 gis:fill x 0  
; ask dist [ set size 0 set label ifelse-value is-number? val [precision val 2] [val] set label-color 114 set hidden? not show-labels ]  
 ]  
 ask links [hide-link]  
 gis:set-drawing-color grey  
 gis:draw townshp 1  
 gis:set-drawing-color black  
  
end  
  
to toggle-color-axis-max  
 set color-axis-max ifelse-value (color-axis-max = 1) [precision max fput 0.1 [abs value-for-monitoring self] of ifelse-value (data-source = "empirical (static)") [staticempiricals] [districts] 1] [1]  
; set color-axis-max ifelse-value (color-axis-max = 1) [precision max (list 0.1 [abs value-for-monitoring self] of ifelse-value (data-source = "empirical (static)") [staticempiricals] [districts]) 1] [1]  
end  
  
to print-town-data  
 clear-output  
 let all1674 (map [x -> gis:property-value x "TOTAL\_S"] gis:feature-list-of townshp)  
 output-print (word town ": demographic data used")  
 output-print (word "Population (SES): " (sum all1674))  
 output-print (word "Sub-districts (Kelurahan): " (length all1674))  
 output-print (word " Pop mean " round (sum all1674 / length all1674) ", min " (min all1674) ", max " (max all1674) )  
 output-print ""  
 output-print "Ethnicities (%)"  
 output-print ethnicities  
 output-print map [x -> precision ((100 / town-totalpop) \* x) 1] (town-ethnicity-counts)  
 foreach range length sess [x -> output-print (word " " item x sess ": " rounded-percentages matrix:get-column (matrix:from-row-list town-popdata) x)]  
 output-print ""  
 output-print "SES = Socio-Economic Status (%)"  
 output-print sess  
 output-print map [x -> precision ((100 / town-totalpop) \* x) 1] (town-ses-counts)  
 foreach range length ethnicities [x -> output-print (word " " item x ethnicities ": " rounded-percentages (item x town-popdata)  
 " AvSES " precision average-ses-from-list (item x town-popdata) 2)]  
 output-print ""  
 output-print "All subgroups (rows Ethn, cols SES)"  
 output-print matrix:pretty-print-text matrix:map [x -> precision x 1]  
 matrix:times-scalar (matrix:from-row-list town-popdata) (100 / town-totalpop)  
 output-print ""  
 output-print "Ethnic segregation measures"  
 output-print (word " Avg local Simpson index: " precision (sum [totalpop \* ethnic-simpson] of districts / sum [totalpop] of districts) 3)  
 output-print (word " Town Simpson index: " precision town-ethnic-simpson 3)  
 output-print (word " Excess avg local Simpson index: " precision (sum [totalpop \* (ethnic-simpson - town-ethnic-simpson)] of districts / sum [totalpop] of districts) 3)  
; foreach range length ethnicities [x -> output-print (word " Dissimilarity " item x ethnicities ": " precision (sum [totalpop \* dissimilarity x "all"] of districts / sum [totalpop] of districts) 3)]  
 foreach range length ethnicities [x -> output-print (word " Dissimilarity " item x ethnicities ": " precision (sum [dissimilarity x "all"] of districts / (2 \* town-totalpop \* item x town-ethnicity-counts / town-totalpop \* (1 - item x town-ethnicity-counts / town-totalpop ))) 3)]  
  
 ; Pi = item ethn-ind ethnicity-counts / totalpop  
 ; P = item ethn-ind town-ethnicity-counts / town-totalpop  
 ; ti = totalpop  
 ; T = town-totalpop  
  
; foreach range length ethnicities [x -> output-print (word " Dissimilarity " item x ethnicities ": " precision  
; (1 - (item x town-ethnicity-counts / town-totalpop / (1 - item x town-ethnicity-counts / town-totalpop)) \* ((1 / ((item x town-ethnicity-counts / town-totalpop) \* town-totalpop) \* sum [dissimilarity x "all"] of districts)) ^ (1 / (1 - b))) 3)]  
end  
  
;; REPORTER FOR MONITORING  
  
to-report color-explain-string  
 report (word measure  
 ifelse-value (substring measure 0 9 = "ethnicity") [word " " ethnicity] [""]  
 ifelse-value (substring measure 0 3 = "SES" or member? "-SES" measure ) [word " " ses] [""]  
 ifelse-value (data-source = "empirical (static)") [" (emp)"] [" (sim)"] )  
end  
to-report value-for-monitoring [dist]  
 report (ifelse-value  
 (measure = "Simpson index") [ [ethnic-simpson] of dist ]  
 (measure = "entropy index") [ [ethnic-entropy] of dist]  
 (measure = "excess Simpson index") [ [ethnic-simpson] of dist - town-ethnic-simpson]  
 (measure = "ethnic entropy") [ [ethnic-entropy] of dist]  
 (measure = "loss ethnic entropy") [ town-ethnic-entropy - [ethnic-entropy] of dist]  
 (measure = "pop / max pop") [ [totalpop / maxpop] of dist ]  
 (measure = "pop / mean pop") [ [totalpop ] of dist / town-totalpop \* count districts ]  
 (measure = "ethnicity fraction") [ [item (position (ethnicity) ethnicities) ethnicity-counts] of dist / [totalpop] of dist ]  
 (measure = "ethnicity dissimilarity") [ [dissimilarity (position (ethnicity) ethnicities) dissimilarity-ses] of dist ]  
 (measure = "ethnicity location quotient") [ [location-quotient (position (ethnicity) ethnicities)] of dist ]  
 (measure = "ethnicity-SES obs utility") [ [observable-utility (position (ethnicity) ethnicities) (position (ses) sess) threshold-mean ] of dist ]  
 (measure = "ethnicity-SES fraction") [ [ item (position (ses) sess) (item (position (ethnicity) ethnicities) popdata) ] of dist / [totalpop] of dist ]  
 (measure = "ethnicity-SES loc. quo.") [ [location-quotient-ses (position (ethnicity) ethnicities) (position (ses) sess)] of dist ]  
 (measure = "avg threshold") [ mean-threshold [indivs] of dist ]  
 (measure = "ethnicity avg threshold") [ mean-threshold [filter [y -> item 0 y = position (ethnicity) ethnicities] indivs] of dist ]  
 (measure = "SES avg threshold") [ mean-threshold [filter [y -> item 1 y = position (ses) sess] indivs] of dist ]  
 (measure = "ethnicity-SES avg thres") [ mean-threshold [filter [y -> (item 1 y = position (ses) sess) and (item 0 y = position (ethnicity) ethnicities)] indivs] of dist ]  
 (measure = "avg SES") [ [average-ses] of dist ]  
 (measure = "ethnicity avg SES") [[ethnicity-average-ses position (ethnicity) ethnicities] of dist ]  
 (measure = "SES fraction") [ [item (position (ses) sess) ses-counts] of dist / [totalpop] of dist ]  
 [1])  
end  
to-report simpson [p] report sum (map [x -> x ^ 2] p) end  
to-report entropy [p] report 0 - 1 / ln (length p) \* (sum (map [x -> x \* ifelse-value (x = 0) [0] [ln x]] p)) end  
to-report ethnic-simpson report simpson sublist (normalize-list ethnicity-counts) 0 (ifelse-value (others-ignore-ethn) [3] [4]) end  
to-report ethnic-entropy report entropy normalize-list ethnicity-counts end  
to-report ses-simpson report simpson normalize-list ses-counts end  
to-report ses-entropy report entropy normalize-list ses-counts end  
to-report town-ethnic-simpson report simpson sublist (normalize-list town-ethnicity-counts) 0 (ifelse-value (others-ignore-ethn) [3] [4]) end  
to-report town-ethnic-entropy report entropy normalize-list count-ethnicities town-popdata end  
to-report average-ses report (sum (map [[ x y ] -> x \* y] ses-counts range length sess)) / totalpop / (length sess - 1) end  
to-report ethnicity-average-ses [ethn-ind] report ifelse-value (item ethn-ind ethnicity-counts > 0)  
 [(sum (map [[ x y ] -> x \* y] item ethn-ind popdata range length sess)) / item ethn-ind ethnicity-counts / (length sess - 1)] ["NA"] end  
to-report average-ses-from-list [count-list] report (sum (map [[x y] -> x \* y] count-list range length count-list)) / sum count-list / (length count-list - 1) end  
  
 ; Pi = item ethn-ind ethnicity-counts / totalpop  
 ; P = item ethn-ind town-ethnicity-counts / town-totalpop  
 ; ti = totalpop  
 ; T = town-totalpop  
  
to-report dissimilarity [ethn-ind ses-str]  
 ifelse (ses-str = "all") [  
; report abs (item ethn-ind ethnicity-counts / totalpop - item ethn-ind town-ethnicity-counts / town-totalpop) /  
; (2 \* item ethn-ind town-ethnicity-counts / town-totalpop \* (1 - item ethn-ind town-ethnicity-counts / town-totalpop))  
  
 report totalpop \* abs (item ethn-ind ethnicity-counts / totalpop - item ethn-ind town-ethnicity-counts / town-totalpop)  
  
; report ((1 - item ethn-ind ethnicity-counts / totalpop) ^ (1 - b) \* (item ethn-ind ethnicity-counts / totalpop) ^ b \* totalpop)  
 ][  
 let ses-ind position ses-str sess  
 report abs (item ses-ind item ethn-ind popdata / totalpop - item ses-ind item ethn-ind town-popdata / town-totalpop) /  
 (2 \* item ses-ind item ethn-ind town-popdata / town-totalpop \* (1 - item ses-ind item ethn-ind town-popdata / town-totalpop))  
 ]  
end  
;to-report dissimilarity-string [ethn-ind ses-str] report (word (precision (sum [totalpop \* dissimilarity ethn-ind ses-str] of districts / sum [totalpop] of districts) 3)  
; " (emp " (precision (sum [totalpop \* dissimilarity ethn-ind ses-str] of staticempiricals / sum [totalpop] of staticempiricals) 3) ")") end  
  
to-report dissimilarity-string [ethn-ind ses-str] report (word (precision (sum [dissimilarity ethn-ind ses-str] of districts / (2 \* sum [totalpop] of districts \* item ethn-ind town-ethnicity-counts / town-totalpop \* (1 - item ethn-ind town-ethnicity-counts / town-totalpop))) 3)  
 " (emp " (precision (sum [dissimilarity ethn-ind ses-str] of staticempiricals / (2 \* town-totalpop \* item ethn-ind town-ethnicity-counts / town-totalpop \* (1 - item ethn-ind town-ethnicity-counts / town-totalpop))) 3) ")") end  
  
to-report location-quotient [ethn-ind] report (item ethn-ind ethnicity-counts / item ethn-ind town-ethnicity-counts) / (totalpop / town-totalpop) end  
to-report location-quotient-ses [ethn-ind ses-ind] report (item ses-ind item ethn-ind popdata / item ses-ind item ethn-ind town-popdata) / (totalpop / town-totalpop) end  
  
  
to-report moran-I [dists]  
 let m mean [value-for-monitoring self] of dists  
 report (count dists / (sum [count link-neighbors] of dists)) \*  
 ((sum [sum [(value-for-monitoring self - m) \* (value-for-monitoring myself - m)] of link-neighbors] of dists) / sum [(value-for-monitoring self - m) ^ 2] of dists)  
end  
;to-report moran-I [dists]  
; let m mean [value-for-monitoring self] of dists  
; report ((sum [sum [(1 / count link-neighbors) \* (value-for-monitoring self - m) \* (value-for-monitoring myself - m)] of link-neighbors] of dists) / sum [(value-for-monitoring self - m) ^ 2] of dists)  
;end  
  
;; GENERAL REPORTERS  
; For computations on popdata-type lists of lists  
to-report count-sess [popd] report map [y -> sum map [x -> item y x] popd] range length sess end  
to-report count-ethnicities [popd] report map sum popd end  
to-report count-totalpop [popd] report sum map sum popd end  
; General  
to-report mean-threshold [indiv-list] report ifelse-value (length indiv-list > 0) [mean map [x -> item 2 x] indiv-list] [threshold-mean] end  
to-report normalize-list [x] report map [y -> y / sum x] x end  
to-report rounded-percentages [x] report map [y -> precision (100 \* y) 1] normalize-list x end  
to-report random-beta-musigma [m s]  
  
 ifelse (s > 0) [  
 let x random-gamma (alpha-musigma m s) 1  
 report ( x / ( x + random-gamma (beta-musigma m s) 1) )  
 ][ report m ]  
end  
to-report alpha-musigma [m s] report max list 0.001 (m \* ((m \* (1 - m)) / s ^ 2 - 1)) end  
to-report beta-musigma [m s] report max list 0.001 ((1 - m) \* ((m \* (1 - m)) / s ^ 2 - 1)) end  
to-report random-gumbel report (- ln ( - ln random-float 1)) end  
  
to-report simpson-index report precision (sum [(ethnic-simpson - town-ethnic-simpson) \* totalpop] of districts / sum [totalpop] of districts) 3 end  
  
to-report EGJ report precision (sum [dissimilarity 0 "all"] of districts / (2 \* sum [totalpop] of districts \* item 0 town-ethnicity-counts / town-totalpop \* (1 - item 0 town-ethnicity-counts / town-totalpop))) 3 end  
  
to-report CHN report precision (sum [dissimilarity 1 "all"] of districts / (2 \* sum [totalpop] of districts \* item 1 town-ethnicity-counts / town-totalpop \* (1 - item 1 town-ethnicity-counts / town-totalpop))) 3 end  
  
to-report EGS report precision (sum [dissimilarity 2 "all"] of districts / (2 \* sum [totalpop] of districts \* item 2 town-ethnicity-counts / town-totalpop \* (1 - item 2 town-ethnicity-counts / town-totalpop))) 3 end  
  
to-report OTH report precision (sum [dissimilarity 3 "all"] of districts / (2 \* sum [totalpop] of districts \* item 3 town-ethnicity-counts / town-totalpop \* (1 - item 3 town-ethnicity-counts / town-totalpop))) 3 end  
  
to-report moranI report precision moran-I districts 3 end  
  
 ;; BASELINE SETTINGS  
  
to baseline-further-parameters  
 set free-space 0.05  
 set turnover 0  
 set always-search false  
 set always-move false  
 set neighbor-weight 0.17  
 set others-ignore-ethn true  
end  
  
to baseline-core-parameters  
 set threshold-mean 0.3  
 set threshold-sd 0.1  
 set housing-constraints true  
 set beta-eth 8  
 set beta-ses 12  
end

**Code of Scenario 1 (Schelling\_on\_GIS-@Religion.nlogo)**

extensions [ matrix rnd gis profiler]  
breed [districts district]  
breed [staticempiricals staticempirical]  
  
globals [ townshp  
; admshp jakbarshp jakpusshp jakselshp jaktimshp jakutshp ; shapefiles  
 ethnicities religions ; lists of names  
 town-popdata town-ethnicity-counts town-rel-counts town-totalpop all-thresholds ; lists of constants for statistical purposes  
 decisions-count forced-moves-count searches-count moves-count  
 b  
]  
districts-own [ id popdata ethnicity-counts rel-counts totalpop maxpop rel-maxpop  
 perc-sim-eth perc-sim-rel  
 indivs]  
staticempiricals-own [ id popdata ethnicity-counts rel-counts totalpop maxpop rel-maxpop indivs] ; mirrors districts for statistical purposes and on the fly comparison  
  
  
;; SETUP PROCEDURES  
  
to setup  
 clear-all  
 load-gisdataset  
 let vars ["GM" "GC" "GO" "CM" "CC" "CO" "BM" "BC" "BO" "OM" "OC" "OO"]  
 set ethnicities ["EGJ" "CHINESE" "EGS" "OTHER"]  
 set religions [ "MUSLIM" "CHRISTIAN" "OTHER" ]  
 foreach gis:feature-list-of townshp [ x ->  
 let centroid gis:location-of gis:centroid-of x  
 create-districts 1 [  
 setxy item 0 centroid item 1 centroid  
 set id gis:property-value x "NAMOBJ"  
 let pops map [y -> round ((gis:property-value x y) / scale-down-pop)] vars  
 set popdata (list ( sublist pops 0 3) ( sublist pops 3 6) ( sublist pops 6 9) ( sublist pops 9 12))  
 setup-indivs-popdata-subcounts  
 set maxpop round (totalpop / (1 - free-space))  
 set rel-maxpop map [y -> round (y / (1 - free-space))] rel-counts  
 hatch-staticempiricals 1 [ set size 0 ]  
 ]  
 ]  
 ask districts [ create-district-neighbor-links ]  
 ask staticempiricals [ create-district-neighbor-links ]  
 set town-popdata matrix:to-row-list reduce matrix:plus [matrix:from-row-list popdata] of districts  
 set town-ethnicity-counts count-ethnicities town-popdata  
 set town-rel-counts count-rels town-popdata  
 set town-totalpop count-totalpop town-popdata  
 print-town-data  
 carefully [visualize] [print error-message]  
  
  
 reset-ticks  
end  
  
to load-gisdataset  
 set townshp gis:load-dataset (word town "/" town ".shp")  
 gis:set-world-envelope (gis:envelope-union-of (gis:envelope-of townshp))  
end  
  
to create-district-neighbor-links  
 let list-of-neighbors map [x -> one-of turtles with [breed = [breed] of myself and id = gis:property-value x "NAMOBJ"]]  
 (filter [x -> gis:intersects? x gis:find-one-feature townshp "NAMOBJ" id ] gis:feature-list-of townshp)  
 create-links-with other (turtle-set list-of-neighbors)  
end  
  
to shuffle-population  
 ifelse housing-constraints [  
 ; The following sets popdata in each district such that ethnicity counts in each religious group are proportional to town-wide ethnicity counts in each religious groups.  
 ; The rel counts in each district remain as original. This makes the ethnic mean local Simpson index minimal (entropy maximal) while keeping religion structure as in reality.  
 let townrelfrac map [x -> normalize-list x] matrix:to-column-list matrix:from-row-list town-popdata  
 ask districts [ set popdata matrix:to-row-list matrix:map round matrix:from-column-list (map [ [x vec] -> map [y -> x \* y] vec] rel-counts townrelfrac) ]  
 ][  
 let towntotalfrac matrix:to-row-list matrix:map [x -> x / sum [totalpop] of districts] matrix:from-row-list town-popdata  
 ask districts [ set popdata matrix:to-row-list matrix:map round (matrix:from-row-list towntotalfrac matrix:\* totalpop) ]  
 ]  
 ask districts [ setup-indivs-popdata-subcounts ]  
 carefully [visualize] [print error-message]  
 clear-all-plots  
 reset-ticks  
end  
  
to setup-indivs-popdata-subcounts  
 set ethnicity-counts count-ethnicities popdata  
 set rel-counts count-rels popdata  
 set totalpop count-totalpop popdata  
  
 set indivs reduce sentence map [z -> reduce sentence map [y -> n-values item y item z popdata [x -> (list z y random-beta-musigma threshold-mean threshold-sd)]] range length item z popdata] range length popdata  
 set all-thresholds reduce sentence [map [x -> item 2 x] indivs] of districts  
  
end  
  
  
;; GO PROCEDURES  
  
to go  
 reset-timer  
 set decisions-count 0 set forced-moves-count 0 set searches-count 0 set moves-count 0  
 ask districts [compute-percentage-similar]  
 repeat town-totalpop [ ask one-of districts [  
 let nummoves totalpop / (town-totalpop / count districts)  
 repeat floor (nummoves) [individual-decides]  
 if random-float 1 < (nummoves - floor (nummoves)) [individual-decides] ; to make the expected number of moves per tick equal to the number of individuals  
 ]]  
 carefully [visualize] [  
 print error-message  
 stop  
 ]  
 print (word  
 ifelse-value (always-search) [""] [(word decisions-count " decisions, ")]  
 ifelse-value (turnover > 0) [(word forced-moves-count " randomly replaced via turnover (" precision (100 \* forced-moves-count / decisions-count) 1 "%), ")] [""]  
 searches-count " searches (" precision (100 \* searches-count / decisions-count) 1 "%), "  
 moves-count " moves (" precision (100 \* moves-count / decisions-count) 1 "%) in " timer " seconds")  
 tick  
; if ticks = stop-tick or (moves-count / decisions-count < 0.01) [visualize stop]  
 if ticks = stop-tick [visualize stop]  
end  
  
to compute-percentage-similar  
 set perc-sim-eth (list percent-similar-ethnicity-neighborhood 0 percent-similar-ethnicity-neighborhood 1 percent-similar-ethnicity-neighborhood 2 percent-similar-ethnicity-neighborhood 3)  
 set perc-sim-rel (list percent-similar-rel-neighborhood 0 percent-similar-rel-neighborhood 1 percent-similar-rel-neighborhood 2)  
end  
  
to individual-decides ; in a districts select a "virtual" person and let this decide to move  
 set decisions-count decisions-count + 1  
 let indiv-ind random length indivs  
 let indiv item indiv-ind indivs  
 let ethn-ind item 0 indiv  
 let rel-ind item 1 indiv  
 ifelse random-float 1 < turnover [  
 set forced-moves-count forced-moves-count + 1  
 let option ifelse-value (housing-constraints) [random-rel-option ethn-ind rel-ind] [random-option ethn-ind rel-ind]  
 individual-moves option ethn-ind rel-ind indiv-ind indiv  
 ] [  
 let thresh item 2 indiv  
 let U\_home utility ethn-ind rel-ind thresh  
 if U\_home < 0 or always-search [  
 set searches-count searches-count + 1  
 let option ifelse-value (housing-constraints) [random-rel-option ethn-ind rel-ind] [random-option ethn-ind rel-ind]  
 let U\_option [utility ethn-ind rel-ind thresh] of option  
 if (U\_option - U\_home > 0) or (always-move) [  
 set moves-count moves-count + 1  
 individual-moves option ethn-ind rel-ind indiv-ind indiv  
 ]  
 ]  
 ]  
end  
  
to individual-moves [option ethn-ind rel-ind indiv-ind indiv]  
 alter-popdata ethn-ind rel-ind -1  
 set indivs remove-item indiv-ind indivs  
 ask option [  
 alter-popdata ethn-ind rel-ind 1  
 set indivs fput indiv indivs  
 ]  
end  
  
to alter-popdata [ethn-ind rel-ind change] ; change should be 1 or -1  
 set popdata replace-item ethn-ind popdata (replace-item rel-ind (item ethn-ind popdata) (item rel-ind item ethn-ind popdata + change))  
 set ethnicity-counts replace-item ethn-ind ethnicity-counts (item ethn-ind ethnicity-counts + change)  
 set rel-counts replace-item rel-ind rel-counts (item rel-ind rel-counts + change)  
 set totalpop totalpop + change  
end  
  
;; REPORTERS DECISIONS TO SEARCH / MOVE  
; For selection of "a random person"  
to-report random-option [ethn-ind rel-ind]  
 report rnd:weighted-one-of districts [max list 0 (maxpop - totalpop) \* ifelse-value ethn-rel-recommendations [recommendation-probability ethn-ind rel-ind] [1]]  
end  
to-report random-rel-option [ethn-ind rel-ind]  
report rnd:weighted-one-of districts [max list 0 (item rel-ind rel-maxpop - item rel-ind rel-counts) \*  
 ifelse-value ethn-rel-recommendations [recommendation-probability ethn-ind rel-ind] [1]]  
end  
; For utility computation  
to-report utility [ethn-ind rel-ind thresh] report (observable-utility ethn-ind rel-ind thresh) + random-gumbel end  
to-report observable-utility [ethn-ind rel-ind thresh] ; the utility concept here is linear in similarity fractions, shifted such that 0 divides favorable and non-favorable  
 report (ifelse-value (others-ignore-ethn and ethn-ind = 3) [0] [beta-eth \* (item ethn-ind perc-sim-eth - thresh)]) +  
 beta-rel \* (item rel-ind perc-sim-rel - thresh)  
end  
to-report recommendation-probability [ethn-ind rel-ind]  
 ifelse (((ifelse-value (others-ignore-ethn and ethn-ind = 3) [0] [beta-eth]) + beta-rel) = 0)  
 [report 1]  
 [report ((ifelse-value (others-ignore-ethn and ethn-ind = 3) [0] [beta-eth \* item ethn-ind perc-sim-eth]) +  
 beta-rel \* (item rel-ind perc-sim-rel)) / ((ifelse-value (others-ignore-ethn and ethn-ind = 3) [0] [beta-eth]) + beta-rel) / 2]  
end  
to-report percent-similar-ethnicity-neighborhood [ethn-ind]  
 report (item ethn-ind ethnicity-counts + neighbor-weight \* sum [item ethn-ind ethnicity-counts] of link-neighbors) /  
 (totalpop + neighbor-weight \* sum [totalpop] of link-neighbors)  
end  
to-report percent-similar-rel-neighborhood [rel-ind]  
 report (item rel-ind rel-counts + neighbor-weight \* sum [item rel-ind rel-counts] of link-neighbors) /  
 (totalpop + neighbor-weight \* sum [totalpop] of link-neighbors)  
end  
  
;; VISUALIZATION AND PRINT OUTPUT  
  
to visualize  
  
 ask patches [set pcolor ifelse-value (data-source = "simulation (dynamic)") [77] [white]]  
 ask turtles [set size 0 set label ""]  
 foreach gis:feature-list-of townshp [ x ->  
 let dist ifelse-value (data-source = "empirical (static)")  
  
 [one-of staticempiricals with [id = (gis:property-value x "NAMOBJ")]]  
 [one-of districts with [id = (gis:property-value x "NAMOBJ")]]  
 let val value-for-monitoring dist  
 gis:set-drawing-color ifelse-value (is-number? val) [ifelse-value (val >= 0) [scale-color red val color-axis-max 0] [scale-color blue (0 - val) color-axis-max 0]] [gray]  
 gis:fill x 0  
; ask dist [ set size 0 set label ifelse-value is-number? val [precision val 2] [val] set label-color 114 set hidden? not show-labels ]  
 ]  
 ask links [hide-link]  
 gis:set-drawing-color grey  
 gis:draw townshp 1  
 gis:set-drawing-color 130  
  
end  
  
to toggle-color-axis-max  
 set color-axis-max ifelse-value (color-axis-max = 1) [precision max fput 0.1 [abs value-for-monitoring self] of ifelse-value (data-source = "empirical (static)") [staticempiricals] [districts] 1] [1]  
; set color-axis-max ifelse-value (color-axis-max = 1) [precision max (list 0.1 [abs value-for-monitoring self] of ifelse-value (data-source = "empirical (static)") [staticempiricals] [districts]) 1] [1]  
end  
  
to print-town-data  
 clear-output  
 let all1674 (map [x -> gis:property-value x "TOTAL\_S"] gis:feature-list-of townshp)  
 output-print (word town ": demographic data used")  
 output-print (word "Population (religion): " (sum all1674))  
 output-print (word "Sub-districts (Kelurahan): " (length all1674))  
 output-print (word " Pop mean " round (sum all1674 / length all1674) ", min " (min all1674) ", max " (max all1674) )  
 output-print ""  
 output-print "Ethnicities (%)"  
 output-print ethnicities  
 output-print map [x -> precision ((100 / town-totalpop) \* x) 1] (town-ethnicity-counts)  
 foreach range length religions [x -> output-print (word " " item x religions ": " rounded-percentages matrix:get-column (matrix:from-row-list town-popdata) x)]  
 output-print ""  
 output-print "Religious adherents (%)"  
 output-print religions  
 output-print map [x -> precision ((100 / town-totalpop) \* x) 1] (town-rel-counts)  
 foreach range length ethnicities [x -> output-print (word " " item x ethnicities ": " rounded-percentages (item x town-popdata)  
 " AvRel " precision average-rel-from-list (item x town-popdata) 2)]  
 output-print ""  
 output-print "All subgroups (rows Ethn, cols Rel)"  
 output-print matrix:pretty-print-text matrix:map [x -> precision x 1]  
 matrix:times-scalar (matrix:from-row-list town-popdata) (100 / town-totalpop)  
 output-print ""  
 output-print "Ethnic segregation measures"  
 output-print (word " Avg local Simpson index: " precision (sum [totalpop \* ethnic-simpson] of districts / sum [totalpop] of districts) 3)  
 output-print (word " Town Simpson index: " precision town-ethnic-simpson 3)  
 output-print (word " Excess avg local Simpson index: " precision (sum [totalpop \* (ethnic-simpson - town-ethnic-simpson)] of districts / sum [totalpop] of districts) 3)  
; foreach range length ethnicities [x -> output-print (word " Dissimilarity " item x ethnicities ": " precision (sum [totalpop \* dissimilarity x "all"] of districts / sum [totalpop] of districts) 3)]  
 foreach range length ethnicities [x -> output-print (word " Dissimilarity " item x ethnicities ": " precision (sum [dissimilarity x "all"] of districts / (2 \* town-totalpop \* item x town-ethnicity-counts / town-totalpop \* (1 - item x town-ethnicity-counts / town-totalpop ))) 3)]  
  
 ; Pi = item ethn-ind ethnicity-counts / totalpop  
 ; P = item ethn-ind town-ethnicity-counts / town-totalpop  
 ; ti = totalpop  
 ; T = town-totalpop  
  
; foreach range length ethnicities [x -> output-print (word " Dissimilarity " item x ethnicities ": " precision  
; (1 - (item x town-ethnicity-counts / town-totalpop / (1 - item x town-ethnicity-counts / town-totalpop)) \* ((1 / ((item x town-ethnicity-counts / town-totalpop) \* town-totalpop) \* sum [dissimilarity x "all"] of districts)) ^ (1 / (1 - b))) 3)]  
end  
  
;; REPORTER FOR MONITORING  
  
to-report color-explain-string  
 report (word measure  
 ifelse-value (substring measure 0 9 = "ethnicity") [word " " ethnicity] [""]  
 ifelse-value (substring measure 0 3 = "religion" or member? "-religion" measure ) [word " " religion] [""]  
 ifelse-value (data-source = "empirical (static)") [" (emp)"] [" (sim)"] )  
end  
to-report value-for-monitoring [dist]  
 report (ifelse-value  
 (measure = "Simpson index") [ [ethnic-simpson] of dist ]  
 (measure = "entropy index") [ [ethnic-entropy] of dist]  
 (measure = "excess Simpson index") [ [ethnic-simpson] of dist - town-ethnic-simpson]  
 (measure = "ethnic entropy") [ [ethnic-entropy] of dist]  
 (measure = "loss ethnic entropy") [ town-ethnic-entropy - [ethnic-entropy] of dist]  
 (measure = "pop / max pop") [ [totalpop / maxpop] of dist ]  
 (measure = "pop / mean pop") [ [totalpop ] of dist / town-totalpop \* count districts ]  
 (measure = "ethnicity fraction") [ [item (position (ethnicity) ethnicities) ethnicity-counts] of dist / [totalpop] of dist ]  
 (measure = "ethnicity dissimilarity") [ [dissimilarity (position (ethnicity) ethnicities) dissimilarity-religion] of dist ]  
 (measure = "ethnicity location quotient") [ [location-quotient (position (ethnicity) ethnicities)] of dist ]  
 (measure = "ethnicity-religion obs utility") [ [observable-utility (position (ethnicity) ethnicities) (position (religion) religions) threshold-mean ] of dist ]  
 (measure = "ethnicity-religion fraction") [ [ item (position (religion) religions) (item (position (ethnicity) ethnicities) popdata) ] of dist / [totalpop] of dist ]  
 (measure = "ethnicity-religion loc. quo.") [ [location-quotient-rel (position (ethnicity) ethnicities) (position (religion) religions)] of dist ]  
 (measure = "avg threshold") [ mean-threshold [indivs] of dist ]  
 (measure = "ethnicity avg threshold") [ mean-threshold [filter [y -> item 0 y = position (ethnicity) ethnicities] indivs] of dist ]  
 (measure = "religion avg threshold") [ mean-threshold [filter [y -> item 1 y = position (religion) religions] indivs] of dist ]  
 (measure = "ethnicity-religion avg thres") [ mean-threshold [filter [y -> (item 1 y = position (religion) religions) and (item 0 y = position (ethnicity) ethnicities)] indivs] of dist ]  
 (measure = "avg religion") [ [average-rel] of dist ]  
 (measure = "ethnicity avg religion") [[ethnicity-average-rel position (ethnicity) ethnicities] of dist ]  
 (measure = "religion fraction") [ [item (position (religion) religions) rel-counts] of dist / [totalpop] of dist ]  
 [1])  
end  
to-report simpson [p] report sum (map [x -> x ^ 2] p) end  
to-report entropy [p] report 0 - 1 / ln (length p) \* (sum (map [x -> x \* ifelse-value (x = 0) [0] [ln x]] p)) end  
to-report ethnic-simpson report simpson sublist (normalize-list ethnicity-counts) 0 (ifelse-value (others-ignore-ethn) [3] [4]) end  
to-report ethnic-entropy report entropy normalize-list ethnicity-counts end  
to-report rel-simpson report simpson normalize-list rel-counts end  
to-report rel-entropy report entropy normalize-list rel-counts end  
to-report town-ethnic-simpson report simpson sublist (normalize-list town-ethnicity-counts) 0 (ifelse-value (others-ignore-ethn) [3] [4]) end  
to-report town-ethnic-entropy report entropy normalize-list count-ethnicities town-popdata end  
to-report average-rel report (sum (map [[ x y ] -> x \* y] rel-counts range length religions)) / totalpop / (length religions - 1) end  
to-report ethnicity-average-rel [ethn-ind] report ifelse-value (item ethn-ind ethnicity-counts > 0)  
 [(sum (map [[ x y ] -> x \* y] item ethn-ind popdata range length religions)) / item ethn-ind ethnicity-counts / (length religions - 1)] ["NA"] end  
to-report average-rel-from-list [count-list] report (sum (map [[x y] -> x \* y] count-list range length count-list)) / sum count-list / (length count-list - 1) end  
  
 ; Pi = item ethn-ind ethnicity-counts / totalpop  
 ; P = item ethn-ind town-ethnicity-counts / town-totalpop  
 ; ti = totalpop  
 ; T = town-totalpop  
  
to-report dissimilarity [ethn-ind rel-str]  
 ifelse (rel-str = "all") [  
 report totalpop \* abs (item ethn-ind ethnicity-counts / totalpop - item ethn-ind town-ethnicity-counts / town-totalpop)  
 ][  
 let rel-ind position rel-str religions  
 report abs (item rel-ind item ethn-ind popdata / totalpop - item rel-ind item ethn-ind town-popdata / town-totalpop) /  
 (2 \* item rel-ind item ethn-ind town-popdata / town-totalpop \* (1 - item rel-ind item ethn-ind town-popdata / town-totalpop))  
 ]  
end  
  
to-report dissimilarity-string [ethn-ind rel-str] report (word (precision (sum [dissimilarity ethn-ind rel-str] of districts / (2 \* sum [totalpop] of districts \* item ethn-ind town-ethnicity-counts / town-totalpop \* (1 - item ethn-ind town-ethnicity-counts / town-totalpop))) 3)  
 " (emp " (precision (sum [dissimilarity ethn-ind rel-str] of staticempiricals / (2 \* town-totalpop \* item ethn-ind town-ethnicity-counts / town-totalpop \* (1 - item ethn-ind town-ethnicity-counts / town-totalpop))) 3) ")") end  
  
to-report location-quotient [ethn-ind] report (item ethn-ind ethnicity-counts / item ethn-ind town-ethnicity-counts) / (totalpop / town-totalpop) end  
to-report location-quotient-rel [ethn-ind rel-ind] report (item rel-ind item ethn-ind popdata / item rel-ind item ethn-ind town-popdata) / (totalpop / town-totalpop) end  
  
  
to-report moran-I [dists]  
 let m mean [value-for-monitoring self] of dists  
 report (count dists / (sum [count link-neighbors] of dists)) \*  
 ((sum [sum [(value-for-monitoring self - m) \* (value-for-monitoring myself - m)] of link-neighbors] of dists) / sum [(value-for-monitoring self - m) ^ 2] of dists)  
end  
;to-report moran-I [dists]  
; let m mean [value-for-monitoring self] of dists  
; report ((sum [sum [(1 / count link-neighbors) \* (value-for-monitoring self - m) \* (value-for-monitoring myself - m)] of link-neighbors] of dists) / sum [(value-for-monitoring self - m) ^ 2] of dists)  
;end  
  
;; GENERAL REPORTERS  
; For computations on popdata-type lists of lists  
to-report count-rels [popd] report map [y -> sum map [x -> item y x] popd] range length religions end  
to-report count-ethnicities [popd] report map sum popd end  
to-report count-totalpop [popd] report sum map sum popd end  
; General  
to-report mean-threshold [indiv-list] report ifelse-value (length indiv-list > 0) [mean map [x -> item 2 x] indiv-list] [threshold-mean] end  
to-report normalize-list [x] report map [y -> y / sum x] x end  
to-report rounded-percentages [x] report map [y -> precision (100 \* y) 1] normalize-list x end  
to-report random-beta-musigma [m s]  
 ifelse (s > 0) [  
 let x random-gamma (alpha-musigma m s) 1  
 report ( x / ( x + random-gamma (beta-musigma m s) 1) )  
 ][ report m ]  
end  
to-report alpha-musigma [m s] report max list 0.001 (m \* ((m \* (1 - m)) / s ^ 2 - 1)) end  
to-report beta-musigma [m s] report max list 0.001 ((1 - m) \* ((m \* (1 - m)) / s ^ 2 - 1)) end  
to-report random-gumbel report (- ln (- ln random-float 1)) end  
  
  
to-report simpson-index report precision (sum [(ethnic-simpson - town-ethnic-simpson) \* totalpop] of districts / sum [totalpop] of districts) 3 end  
to-report EGJ report precision (sum [dissimilarity 0 "all"] of districts / (2 \* sum [totalpop] of districts \* item 0 town-ethnicity-counts / town-totalpop \* (1 - item 0 town-ethnicity-counts / town-totalpop))) 3 end  
to-report CHN report precision (sum [dissimilarity 1 "all"] of districts / (2 \* sum [totalpop] of districts \* item 1 town-ethnicity-counts / town-totalpop \* (1 - item 1 town-ethnicity-counts / town-totalpop))) 3 end  
to-report EGS report precision (sum [dissimilarity 2 "all"] of districts / (2 \* sum [totalpop] of districts \* item 2 town-ethnicity-counts / town-totalpop \* (1 - item 2 town-ethnicity-counts / town-totalpop))) 3 end  
to-report OTH report precision (sum [dissimilarity 3 "all"] of districts / (2 \* sum [totalpop] of districts \* item 3 town-ethnicity-counts / town-totalpop \* (1 - item 3 town-ethnicity-counts / town-totalpop))) 3 end  
to-report moranI report precision moran-I districts 3 end  
  
;; BASELINE SETTINGS  
  
to baseline-further-parameters  
 set free-space 0.05  
 set turnover 0  
 set always-search false  
 set always-move false  
 set neighbor-weight 0.17  
 set others-ignore-ethn true  
end  
  
to baseline-core-parameters  
 set threshold-mean 0.3  
 set threshold-sd 0.1  
 set housing-constraints true  
 set beta-eth 8  
 set beta-rel 12  
end

**Appendix B: Case Study of Bradford, UK**

**Dissimilarity Index**

|  |  |
| --- | --- |
|  | Chart, line chart  Description automatically generated |
| Chart, line chart  Description automatically generated | |

**Moran Index and Excess Average Simpson Index**

|  |  |
| --- | --- |
| Chart, line chart  Description automatically generated | Chart, line chart  Description automatically generated |

**Appendix C: Supplementary Data**

**A comparison table with a scale of 1:1 (Scenario 1 and 2)**

|  |  |
| --- | --- |
| A screenshot of a computer  Description automatically generated with low confidence |  |

**Parameter sweeping with BehaviorSpace NetLogo**

|  |  |
| --- | --- |
| **Scenario 1** | **Scenario 2** |
| ["town" "Jakarta"]  ["free-space" 0.05]  ["scale-down-pop" 100]  ["data-source" "simulation (dynamic)"]  ["measure" "ethnicity fraction"]  ["ethnicity" "CHINESE"]  ["ses" "LOW"]  ["threshold-mean" 0.3]  ["threshold-sd" 0.1]  ["housing-constraints" false true]  ["beta-eth" 8]  ["beta-ses" [0 4 30]]  ["color-axis-max" 1]  ["dissimilarity-ses" "all"]  ["turnover" 0]  ["always-search" false]  ["always-move" false]  ["ethn-ses-recommendations" true]  ["neighbor-weight" 0.17]  ["others-ignore-ethn" true]  ["stop-tick" 1000] | ["town" "Jakarta"]  ["free-space" 0.05]  ["scale-down-pop" 100]  ["data-source" "simulation (dynamic)"]  ["measure" "ethnicity fraction"]  ["ethnicity" "CHINESE"]  ["religion" "OTHER"]  ["threshold-mean" 0.3]  ["threshold-sd" 0.1]  ["housing-constraints" false true]  ["beta-eth" 8]  ["beta-rel" [0 4 30]]  ["color-axis-max" 1]  ["dissimilarity-religion" "all"]  ["turnover" 0]  ["always-search" false]  ["always-move" false]  ["ethn-rel-recommendations" true]  ["neighbor-weight" 0.17]  ["others-ignore-ethn" true]  ["stop-tick" 1000] |

**A snapshot of the data query**

*Table

Description automatically generated*

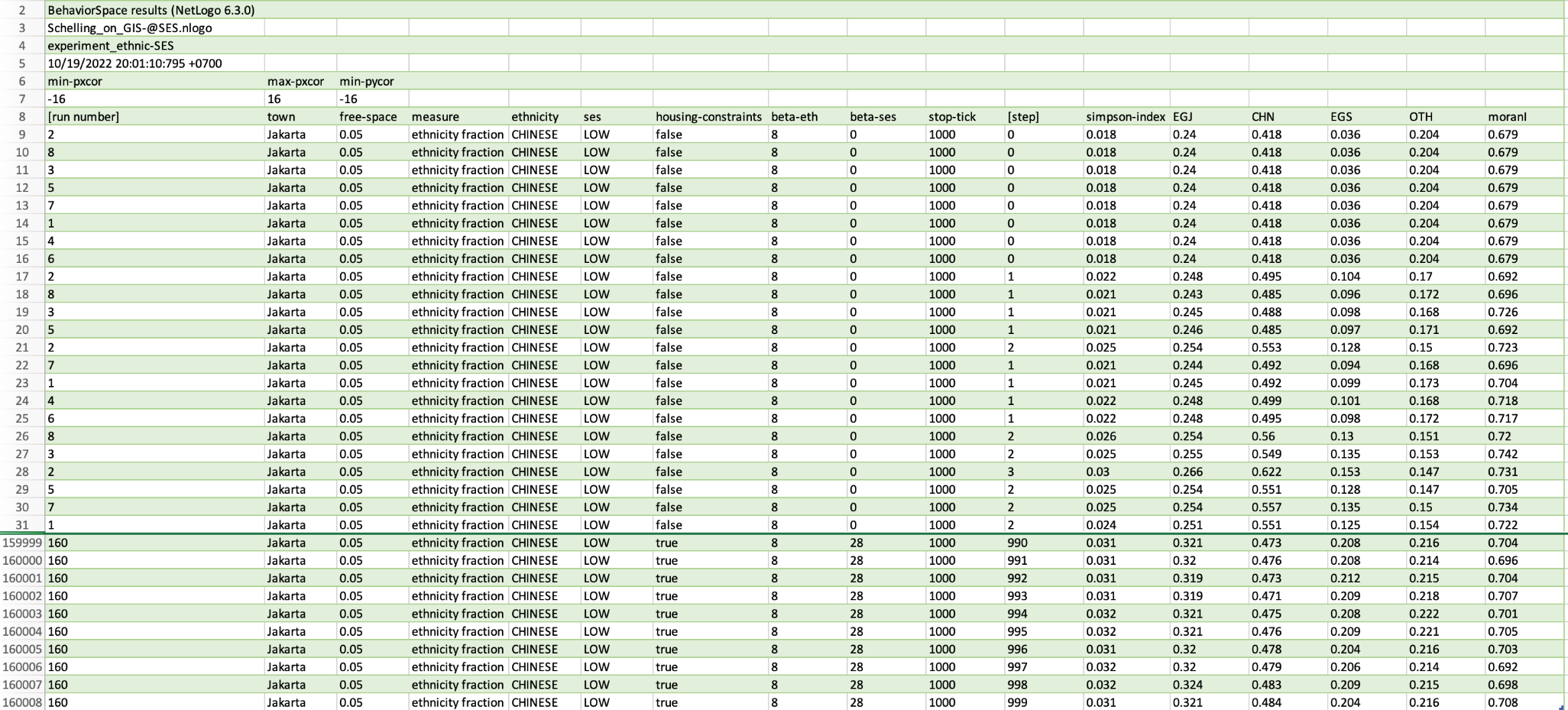
|  |  |  |
| --- | --- | --- |
| **Variable** | **Format** | **Description** |
| Tahun | Time | Census year |
| Kabupaten/ Kota | String | The name of Regency/City |
| Kecamatan | String | The name of District |
| Kelurahan | String | The name of Sub-district |
| Islam | Numeric: Integer | The number of Muslim population |
| Kristen | Numeric: Integer | The number of Christian population |
| Katolik | Numeric: Integer | The number of Catholic population |
| Hindu | Numeric: Integer | The number of Hindu population |
| Buddha | Numeric: Integer | The number of Buddhist population |
| Konghucu | Numeric: Integer | The number of Confucian population |
| Aliran Kepercayaan | Numeric: Integer | The number of believers population |

**Raw Data Sample (Jakarta.dbf)**

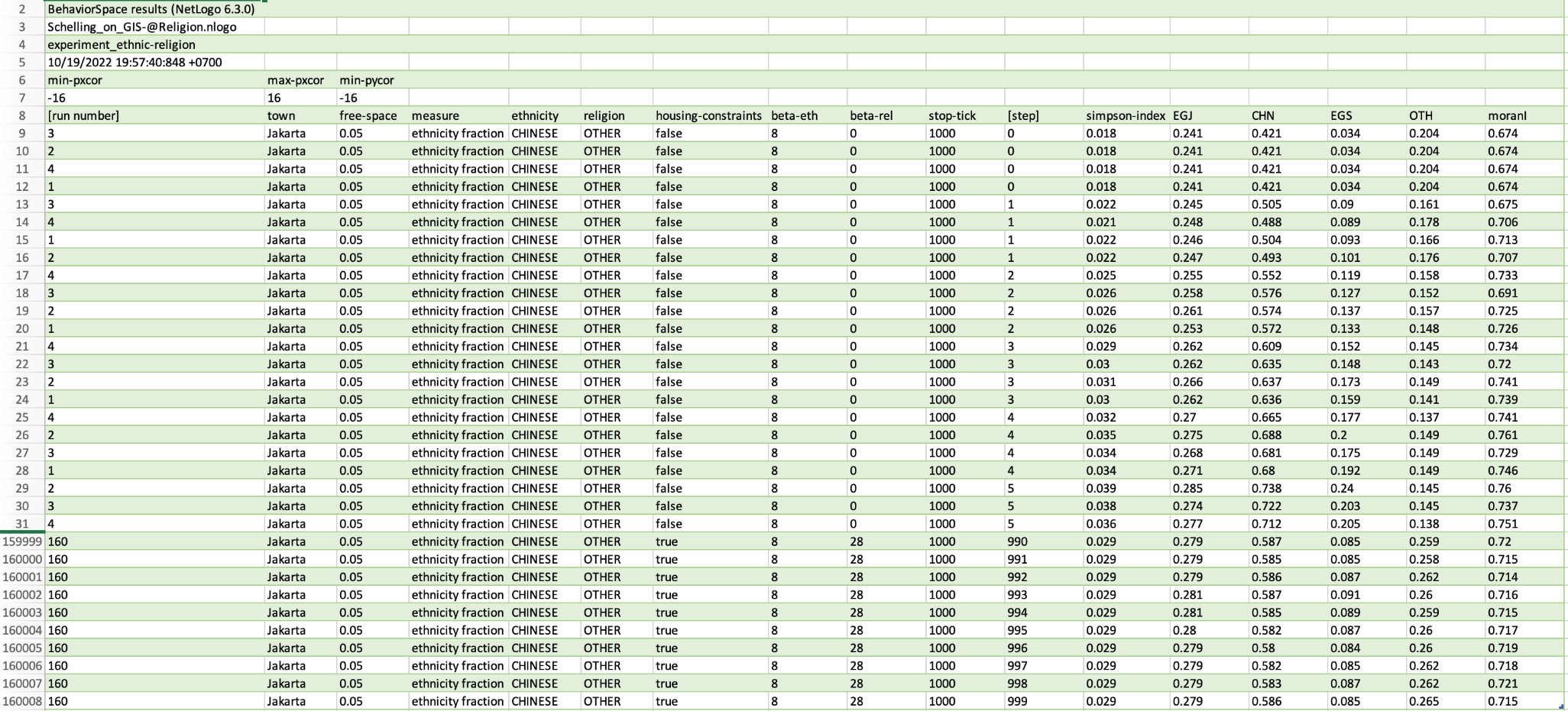
Table

Description automatically generated

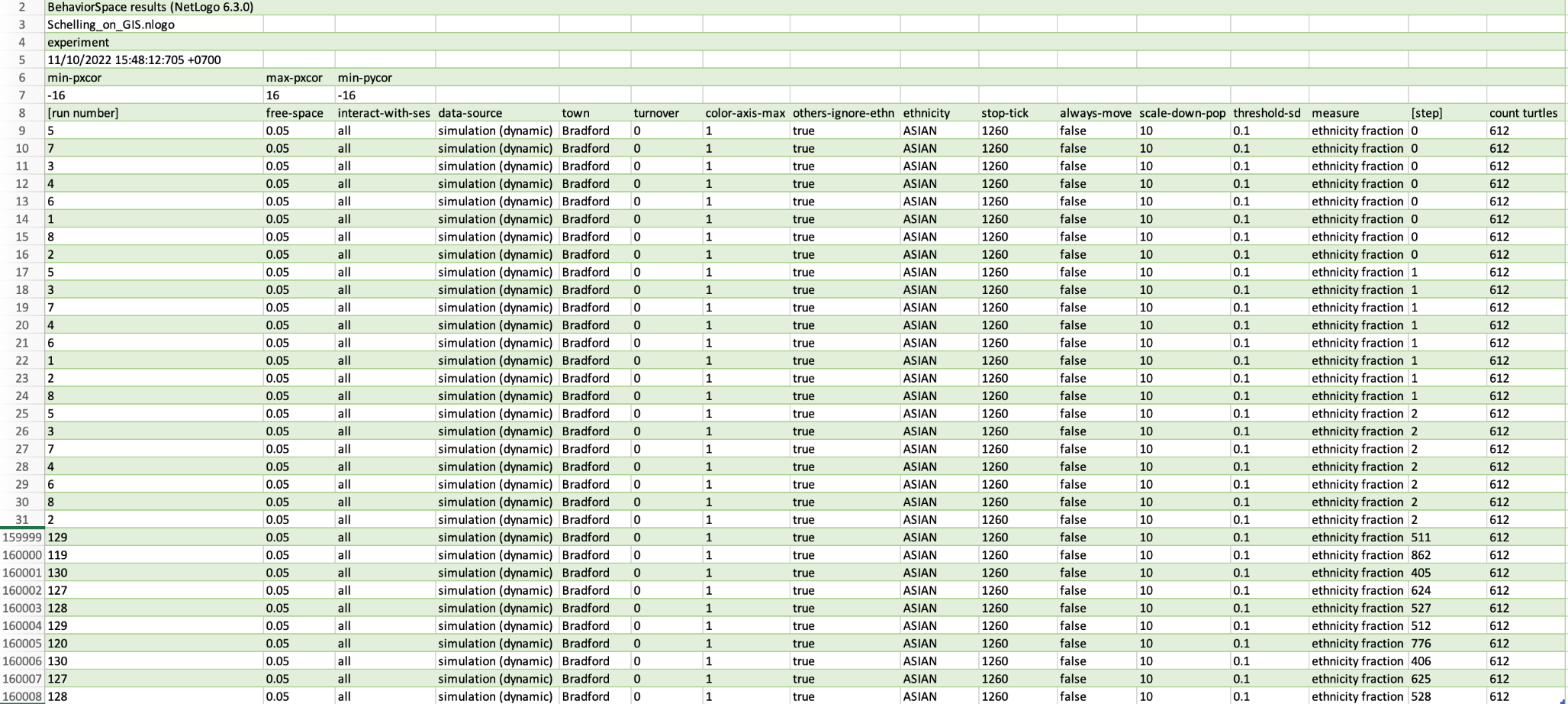
**Raw Data Sample of Scenario 1 simulation result (Schelling\_on\_GIS-@SES experiment\_ethnic-SES-table.csv)**



**Raw Data Sample of Scenario 2 simulation result (Schelling\_on\_GIS-@Religion experiment\_ethnic-religion-table.csv)**



**Raw Data Sample of Bradford Case Study simulation result (Schelling\_on\_GIS experiment-table.csv)**

****

1. 1. ﻿The Gumbel distribution is also known as generalized extreme value distribution type-I. It has a mean of 0.577 and a standard deviation of 1.283. In decision to move, two random numbers are compared, one for each alternative. The difference of two Gumbel random variables has a logistic distribution with mean zero and standard deviation 3.29.

   [↑](#footnote-ref-1)
2. 1. The scale-down of the number of agents results in an accumulation of rounding that results in the values between scenarios 1 and 2 differing. The values for both are identical if the number of agents is equal to the actual population of Jakarta (see Appendix C, a comparison table with a scale of 1:1).

   [↑](#footnote-ref-2)