INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

Publisher
Sustainability for Regions

TOWARDS A UNIFIED REGIONAL VISION: SIMULATION TO FOSTER CROSS-MUNICIPAL COOPERATION AND PLANNING*

Victoria Kazieva [1*], Christine Große [2], Aron Larsson [3]

[1,2,3] Mid Sweden University, Department of Communication, Quality Management, and Information Systems, Sundsvall, Sweden*
[2] Luleå University of Technology, Department of Computer Science, Electrical and Space Engineering, 971 87 Luleå, Sweden
[3] Stockholm University, Department of Computer and System Sciences, 164 07 Kista, Sweden

E-mails: [1]victoria.kazieva@miun.se (Corresponding author); [2]christine.grosse@miun.se; [3]aron.larsson@miun.se*

Received 29 August 2024; accepted 27 October 2024; published 30 December 2024

Abstract. Simulation modeling is an effective tool that enables knowledge-based approaches to support decision-making for complex problems. Agent-based modeling (ABM) simulation is particularly powerful in the visualization of macro-outcomes of individual and group-specific behaviour, for example in urban and regional planning. However, the adoption of ABM in practice often overlooks its capabilities. Ineffective planning sets sparsely populated remote regions to risk of suffering from long-term consequences, such as population decline. In these settings, it is important to bring municipalities into a dialogue to share the advantages of common planning at a regional scale for their mutual advancement. This study aims to explore the potential of applying ABM and its visual capabilities to support regionwide planning. For this purpose, we develop a model of accessibility of a Swedish region to enhance awareness of common problems with regional accessibility and lift the planning focus from a local scale to a regional one. The model in this paper draws on empirical data from interactions with planners in a region of six municipalities with varying degrees of urbanization in a sparsely populated remote area in Sweden. The model visualizes the dynamic changes in accessibility and demonstrates how destination clustering outplays on a higher system level usually overlooked in planning. The simulation of the case shows that aggravated agglomeration effects will prevent municipalities from developing their centers if they do not consider the opportunities in neighbouring areas within the same region. The paper contributes insights that stimulate the adoption of simulation in complex domains, such as public planning that seeks to align local and regional perspectives.

Keywords: agent-based modeling (ABM); regional accessibility; regional planning; simulation; case study

Reference to this paper should be made as follows: Kazieva, V., Große, Ch., Larsson, A. 2024. Towards a unified regional vision: simulation to foster cross-municipal cooperation and planning. *Insights Into Regional Development*, 6(4), 54-81. http://doi.org/10.70132/n4934286437

JEL Classifications: C63, N94, O18, O21, R58

This research was financially supported by the co-operation agreements 2017/715, 2015/2147 and 2017/1014 between the Mid Sweden University and the municipalities of Sundsvall, Härnösand, and Timrå as well as Hudiksvall, Nordanstig and Ånge, Sweden.

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

1. Introduction

Decision-making in complex system domains, such as planning for regional development, is challenged on multiple levels. One of the key challenges applies to deploying digital practices, specifically simulation modeling, in the realm of policymaking and planning. The main hindrance that prevents the adoption of simulation is often the uncertainty associated with modeling as a method and the limitations of humans to understand the complexity of the modeled system (Sterman, 2000). At the same time, effective decision-making requires understanding the entanglement related to societal changes. Especially in the field of regional development, the demand for planning often requires tools to deal with complex technical, social, and economic systems and human behavior, which comprise the field. However, traditional analytical methods widely applied in planning cannot capture the dynamic changes arising from complex systems that consist of non-linear interactions typical for social mechanisms (Goldspink, 2002; Große, 2023).

Since one of the main reasons for the resistance of decision-makers to adopt simulation results often stems from distrust in data generated by the simulation of a particular scenario (Lawlor and McGirr 2017), the trustworthiness of simulation models receives attention. However, numerous studies emphasize that the understanding and interpretation of model design and simulation output are areas that are not sufficiently researched (Kelly et al., 2013) despite being acknowledged as one of the key contributors to practitioners' resistance (Davis et al., 2020; Belfrage et al., 2022).

In regional planning for sustainable development, planners face several major challenges regarding adopting digital practices. First, the complexity of contemporary societal challenges demands adequate tools for decision-making. Second, regional planning requires a cross-municipal vision to facilitate a collaborative approach to common problems. For example, European policies emphasize the advantage of landscape approaches and integrated spatial planning for sustainable regional development (Bjärstig et al., 2018). Yet, in many regions, including central Sweden, there is no established institutional framework for necessary cooperation, as municipalities and regions can independently interpret their planning rights and needs (Bergkvist Andersson, Schmitt, 2024) since spatial planning authority lies at the municipal level. Even though municipalities are expected to align their planning with higher-level policies to a certain extent, such strong municipal autonomy leads to low conformity with regional and national strategies (Adolphson, Jonsson, 2020). This issue is especially concerning for sparsely populated remote areas, which face limited resources and investment opportunities, potentially resulting in long-term consequences like population decline and socioeconomic inequality due to inefficient and segregated local planning (Kazieva et al., 2023).

To address the outlined problem, this study explores the potential of dynamic simulation modeling, specifically ABM, and its visual capabilities to support regionwide planning and cooperation between municipalities toward a unified regional vision. For this purpose, we develop a model of accessibility of one of the Swedish regions to enhance awareness of common problems associated with regional planning and lift the local focus to the regional scale for a wider perspective and cross-municipal cooperation.

The model design targets the visualization of dynamical changes in the system of interest. To evaluate the model, this study simulates the regional accessibility of a case region in the middle of Sweden, the Sundsvall region. This non-institutional region unites six municipalities that exhibit characteristics of sparsely populated remote areas to a different extent. By visualizing the regional accessibility concept at a high abstraction level, the ABM simulation of future states of the region enables the participating public planners to approach possible planning outcomes, which contributes to enhanced collaboration among municipalities in regional planning. In addition, this study addresses the need for empirical research related to understanding and interpreting model design and simulation output. It contributes valuable insights that stimulate the adoption of simulation modeling to decision-making in complex system domains. The paper's findings showcase the value of integrating dynamic simulations

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

in decision-making processes, which could be further utilized as a visual representation of common regional challenges to improve collective understanding and cross-municipal approaches to planning for regional development.

The article proceeds as follows. The next section provides the theoretical background for the study, followed by a method section that outlines the model development and research process. The result section first provides model specification and then analyses the model by simulating the accessibility of the case region. The discussion section evaluates the implications of this study for theory and practice. The conclusion section summarizes and completes the paper.

2. Extended background

2.1. Regional accessibility

Accessibility describes "the ease of access to activities, facilities and locations" (Jamei et al., 2022). Historically treated as a simple measure of distance, the concept of accessibility has transformed into a potential for interaction, and it is viewed as a system that affects regional development. Here, regional accessibility refers to the accessibility within a regional area. In particular, the interest in this paper is in rural areas that consist of several remote and sparsely populated adjacent municipalities. In areas of this type, limited resources and longer distances between opportunities, compared to urbanized areas, necessitate detailed planning for infrastructure investments to ensure proper resource allocation and prevention of negative long-term consequences of inefficient policymaking. A comprehensive representation of the dynamics of the accessibility system has been seen to help decision-makers prevent the trend of population decline (López Suárez et al., 2008).

Accessibility, as a constituent of sustainable development, consists of transport and land-use parts, which are integral elements of urban and regional settings and should be included in planning for these areas. Both parts become integrated into the research that investigates physical opportunities, such as various destinations related to work, leisure, and public services, that an individual can reach within a certain time/speed threshold (Straatemeier, Bertolini, 2019). Yet, most studies mainly address mobility-related issues that account for existing activity patterns, while strategies related to the planning of locations are not fully incorporated. This gap implies that the potential of opportunities may be disregarded in terms of the effect that their spatial distribution has on the region's accessibility in the long run. Consequently, the distribution of opportunities is likely to impact even the settling patterns of the population based on the availability of access to physical locations. The reason for this is that aside from macro spatial effects, such as congestion and an increase in land values (Boisjoly, El-Geneidy, 2017), accessibility can exhibit a negative influence. Increased accessibility may have different micro effects on opportunities, which in turn contribute to the area's attractiveness at the macro-regional level, where the dynamics of the accessibility system unfold.

2.2. Agglomeration economies and the role of clusters in regional planning

According to Rosenthal and Strange (2003), the theory of agglomeration economies advocates for "the benefits of cities" as concentrations of shared labor and infrastructure capabilities. The authors, however, highlight differences regarding work opportunities, as the benefits of agglomeration differ between industries. For example, clustering of opportunities can stimulate the development of small businesses as they make good neighbors, while larger-scale industries do not always exhibit the advantages of such concentration.

Conversely, there is less research available about the clustering effects of agglomeration on the image of a region from other types of destinations that relate to various human-based needs, such as socializing. Whereas it is harder to differentiate these clusters compared to work opportunities, their contribution to travel patterns formation is even greater due to their societal importance (Große, 2022). Therefore, these destination types need to be included in the discussions around the possible role that their clustering and development play in regional planning. The major obstacle, however, is that most regional and rural planning is based on the experiences and best practices of urban planning, even though sparsely populated areas do not exhibit the same prerequisites or priorities (Grundel, Magnusson, 2022). This implies that most approaches from urban planning are directly transferred to regional planning, which can be problematic since it is often taken for granted that the clustering of people and concentration of socio-economic activities are drivers of urban development (Ghafoor et al., 2021). At the same time, while the intensity of the concentration of opportunities reduces as the distances increase, less urbanized areas seem to suffer from a negative spiral of population decline followed by lower investments leading to further population decline, while the officials are tasked to resort to planning with strategies of urban clustering. Therefore, the question remains whether the positive effects of agglomeration could help such regions to mitigate the population decline trend, or whether they might aggravate the situation.

2.3. The perspectives of accessibility growth – the more, the better?

As accessibility levels rise, overcrowded destinations become less attractive to the population, and the positive experience of visiting such destinations declines (Oklevik et al., 2019). Regarding leisure opportunities, the perceived attractiveness may be a trade-off between attractive and overcrowded destinations, meaning that once a destination has passed a certain threshold of hosting visitors, its attractiveness as a popular site reduces. Consequently, while overly accessible opportunities run the risk of being disregarded as their attractiveness drops, the common approach towards destination development supports "boosterism" – promoting destinations as attractions despite associated risks (e.g., safety), aiming for a continuously growing number of visitors (Marcouiller, 2007). Simultaneously, visitor density per destination as a measure of crowding is insufficient to determine whether a destination will be perceived as overcrowded; instead, individual expectations and satisfaction of needs play a decisive role in this perception (Li et al., 2017). In sparsely populated remote areas, such as in the Swedish case, the perception of overcrowding may have an even lower threshold in less densely populated areas, as the expectations of tranquillity in rural life differ from those of a busy urban environment.

To explore the impact of increased visitor numbers and associated risks, the European Parliament's Committee on Transport and Tourism has requested research that can address the imbalance in objectives. The resulting study (Peeters et al., 2018) highlighted the need for cooperation between policymakers and destination stakeholders for the individual assessments of the bespoke approaches, as the complexity of the defined measures to redress the trend could not be summarized for general application. Thus, there is an urgent need to strengthen cross-municipal cooperation, specifically in remote, sparsely populated remote areas, such as in the middle of Sweden. In such regions, careful planning is required due to the regionally limited opportunities and greater distances visitors must travel compared to urban areas.

2.4. Challenges in Swedish regional planning

In Sweden, the public administration model is characterized by collective decision-making by the government, independent authorities, and strong local self-government at local and regional levels. That means municipal and regional authorities are tasked with developing their plans within their geographical area of responsibility. They are also obliged to collaborate with other authorities and societal actors to fulfil their responsibility; however, the organization and scope of cooperation are left to the mentioned actors. As mentioned, it results in many municipalities planning separately, which implies that cumulative macro results of their planning may not be sufficiently considered at a regional level. To address the issue, within the realm of national transportation, new planning guidelines, called the Regional System Analysis Method (RSAM), were developed to ensure that each region coordinates its needs to reach an equal transport system, a healthy environment, and a positive regional development (Adolphson, Jonsson, 2020). However, the analysis of Swedish regional planning documents and their implementation processes showed the gap between the theoretical stipulations of system analysis provided by the guidelines and the practice of incorporating the formulated requirements in the planning activities (ibid.). The reasons for this gap were associated with theoretical factors, such as a lack of systematic approach to applying theoretical knowledge to practice, and practical factors, such as the inhibited reflexive capabilities of

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

practitioners engaged in daily routine work (ibid.). It was emphasized that Swedish practitioners do not use a theoretical framework or have reached consensus on the theoretical foundations of planning or systems thinking but instead tend to rely on previous experience and heuristic approaches (ibid; Große, Olausson, 2019).

A recent study confirmed the lagging knowledge in regional planning practice in Sweden. Andersson and Schmitt (2024) explored the worrying realities of the planning development approaches in Sweden, where planning is not yet regulated by law in 18 out of 21 regions, resulting in various forms and scopes of planning among the regions as the latter choose their strategies. However, unlike regional planning, all Swedish counties must have a regional development strategy and a transport plan. This challenges creating a joint regional plan as the explored areas expressed a need for cross-municipal cooperation that could reduce intra-regional competition (ibid.).

3. Method

The research design used in this paper is grounded in the design-oriented research process of analysis, design, evaluation, and diffusion used in information system research (Österle et al., 2011). As mentioned, this study focuses on the potential of ABM and its visual capabilities to support regionwide planning and cross-municipal cooperation in sparsely populated remote areas. Therefore, the area in the middle of Sweden, namely the Sundsvall region, represents an appropriate case to develop and test an agent-based model of regional accessibility. This non-institutional region unites six adjacent municipalities that exhibit the characteristics of sparsely populated remote areas with various levels of urbanization.

There are several reasons for adopting ABM to the case study. Dynamic simulation methods of ABM and system dynamics support model designs that meet the requirements of the current study: modeling a concept with high levels of abstraction (Borshchev, Filippov, 2004) and system characteristics that can change over time (Law, 2007) to allow accessibility approaches unfold in terms of their long-term effects typical for lagging regional areas. However, only ABM implements interactions of individual agents and allows to trace the emergence of dynamic patterns from such interactions within the human-environmental systems (Sun et al., 2016), thus capturing both high levels of model abstraction and low levels of agent interaction (Ding et al., 2018). This provides an opportunity to create a representative image of a region and its development perspectives through the lens of the accessibility concept.

3.1. Data collection and analysis

A preceding study reviewed the state of the art regarding accessibility measures and indicators (Kazieva et al., 2023). In addition, the second pre-study empirically defined key variables essential for informed regional planning of accessibility in sparsely populated remote areas (Kazieva et al., 2024). The third preparatory study analyzed the challenges of adopting simulation modeling into decision-making practice and proposed a five-step framework (see section 3.2) to facilitate the understanding and use of modeling in complex system domains (Kazieva, forthcoming).

The insights gained from these preparatory studies provided a solid understanding of the problems with regional planning in sparsely populated areas. For the current study, we extended the data collection with textual material from municipal planning and the involvement of responsible officials from the case region in Sweden. Empirical data was gathered during meetings and workshops with planners and decision-makers from the six case study municipalities. These meetings engaged scientists active in research fields related to regional development within the fields of geography, transport, political science, decision-making analysis, and information systems research. The material included municipal documents, written notes, recordings of group discussions, and researchers' observations during the tests of the model together with the participants.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

After several introductory meetings set to familiarize participants with the collaboration form and the research objective, as well as exchange expectations about the form of the cooperation outcome, the initial interviews were collected. These interviews gathered the experiences of 26 participants from eight adjacent municipalities (including six case study ones and additionally from two nearby sparsely populated municipalities) regarding the existing strategies they apply, the perspectives of accessibility, and the long-term vision of the cooperation activities and regional development. The recurring theme identified the central challenge of isolated municipal planning and the drastic variety in decision-making processes among municipalities of different urbanization levels. The following workshops were designed to create a tighter cooperation framework within the region, which resulted in the second study mentioned above. The observations and documents from the subsequent meetings filled the gaps related to the theoretical underpinnings and expected outcome of the collaboration as a compliment after the third study. Finally, the prototype of the model was presented and discussed during a joint workshop with 9 planners and 6 researchers from the included municipalities of the region, allowing for intermediate model validation given the learning purpose of the model concept.

The collection and analysis of data focused on the design, development, and evaluation of the model. The gathered material was regularly reviewed with municipal representatives and engaged researchers to gain insights into how theoretical accessibility concepts can be modeled.

3.2. Design and development of the model

The model development targets the visualization of dynamical changes in the regional accessibility system and involves the spatial distribution of physical opportunities for land-use planning. To this end, the modeling approach in this paper adheres to the mentioned five-step research framework (Kazieva, forthcoming). The guiding principles of the framework allow for addressing complex concepts, such as regional accessibility, which often lacks a unified approach, theoretical underpinning, and consensus about its major constituents (Kazieva et al., 2024):

1. Articulate model purpose: The main purpose of the model is the explanation and visualization of regional accessibility to enhance awareness of common problems with regional planning and lift the local focus to the regional scale.

2. *Define key characteristics*: The key characteristics were derived from literature and developed based on the discussions with the participants in this study. They are presented in section 4.1, Table 1.

3. Transparent assumptions: The underlying assumptions are clarified in the introduction and the extended background section. In addition, insights from the model development and evaluation process are detailed in sections 4.2 and 5.2 as well as further scrutinized in the discussion section.

4. Engagement of a balanced stakeholder group: The study involved a reflexive group of municipal planners, responsible persons from regional and national authorities, and a multi-disciplinary group of researchers.

5. Visual representation of simulation results: The simulation presented the unified regional vision of accessibility to the stakeholders, which facilitated collaboration among the participating municipalities in regional planning. Examples of the visualization of the simulated region are presented in the sections 5.1 and 5.2.

Following the modeling purpose and the necessary level of abstraction for concept representation, the employed approach to modeling showed advantages in constructing a simple yet representative model. Hence, the modeling strategy in this paper follows the Keep-It-a-Learning-Tool approach (KILT) to tie the modeling purpose to the participation of practitioners, thus enhancing the capabilities of the model to support expert learning (Edmonds et. al, 2019). The approach enabled decision-makers to engage in the model design process, which contributed to its improvement but also tied the process to social learning of the artifact under construction – the ABM model.

The model is implemented in NetLogo. Its description follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al., 2006), as updated by Grimm et al.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

(2020). The model is dynamic (develops over time), stochastic (contains probabilistic characteristics), and continuous (system state is subject to change continuously as the simulation progresses).

The model comprises dynamic agents, which represent a synthetic population, and static agents, which represent destinations. By modeling a synthetic population, the model reflects the main attributes defined for the target population given the modeling purpose (Chapius et al., 2022) as the model artifact reflects the concept of regional accessibility. The key model variables and their attributes were developed through the exercises with the study participants, which served to minimize the ambiguity of the model design, facilitating easier interpretation and modeling while maintaining their alignment with the accessibility concept (see Table 1, section 4.1 and Appendix).

3.3. Evaluation and simulation

To evaluate the model, this study simulates the regional accessibility of the Sundsvall region in Sweden. To facilitate a dialogue about the explanatory capabilities of ABM for regional development, six scenarios were developed and tested. The six scenarios are described and evaluated in detail in section 5. Four scenarios had the purpose of visualizing the accessibility concept in general to enable a joint discussion about common problems with regional accessibility. The other two scenarios are more closely adapted to the case region to support cross-municipal cooperation and lift the planning focus from a local scale to a regional one.

During the joint exercises with the participants, we evaluated the proposed model by simulating a variety of incoming data settings to estimate the potential dynamics in regional development and to understand the logic of the model. Incoming data of the user-defined model parameters in the simulations comprised the range of the initial agent population, the number of work and leisure destinations, the agents' happiness levels, the range of people to immigrate, the weight of attractiveness for destinations, the weight of distance for destination and the attractiveness level of destinations. The incorporated statistical data was based on open-source information available from the Swedish Central Bureau of Statistics (Statistics Sweden), such as the average lifespan, emigration data (number of relocations on average), and birth statistics. The outgoing data showed the amount and the percentage of happy/unhappy agents, the time passed, the distance traveled, and the agents' movement dynamics (pattern) based on their interactions.

The evaluation of the simulations during the workshops alongside the development process informed adaptions of the model logic, as described in 5.2. Further insights from the model evaluation are addressed in the discussion section and inform further research in the subject area.

4. The model of regional accessibility

4.1. Main design concepts for the agent-based model of accessibility

The objective of the proposed model is to enhance awareness of common problems with regional accessibility and lift the planning focus from a local scale to a regional model objective; therefore, it corresponds to the high level of abstraction of the regional accessibility concept. This study differentiates between the predictive and explanatory capabilities of ABM. Here, the focus is on the latter, where ABM serves as a visual tool that can bring planners together to develop a common vision based on the lessons learned from modeling the relevant problem.

Based on the previous research (Kazieva et al., 2024) that developed the basis for the model development, this study uses a set of key variables that detail what planners associate with the accessibility concept. In particular, the key variables comprise attractiveness, distance (to and from a destination), and range of destinations, which enables exploration of how individuals choose opportunities depending on the characteristics of destinations. Attractiveness refers to the value attributed to a destination, implying that people have a higher interest in

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

reaching an attractive destination to gain a high utility. However, reaching a destination involves costs, such as time and money, to bridge the distance to and from the destination. Therefore, the model implies that people choose destinations that promise a high utility, preferably related to low transportation costs, and consider the range of available destinations, because a broader range of destinations in the same area reduces the costs to bridge distances. This way, through individual choices of destinations, the population influences the attractiveness of destinations similarly to how the availability of destinations influences the satisfaction of a population.

To explore the potential of ABM and its visual capabilities in supporting the study goal, the model proposed in this paper uses a synthetic population that reflects the target population. Dynamic agents represent the individuals of a population, while static agents (patches) represent the destinations within a region. The population agents strive to derive the greatest utility from their travel to destinations; thereby, the effects of individual choices form the dynamics of the regional accessibility system. The main design concepts are summarized in Table 1.

Table 1. Main design concepts for the agent-based model of accessibility within a region

Concept	Description
Agents	Dynamic agents represent the individuals of a population that act through their lifetime. Static agents (patches) represent destinations. Their range and spatial distribution are user-assigned at simulation launch as one of the key variables of regional accessibility.
Interaction	There are no direct interactions between agents of the same type except for reproduction. Reproduction happens by statistical probability and new agents have initiation similarly to the setup of the original agents – except for the age set to zero, the placement and resource points are simple yet reflective of the population growth without gender split. Population agents interact indirectly via visiting destinations, which increases the visitor count and affects the utility points that overcrowded destinations give to following visitors. The interactions between dynamic and static agents are described by the following concepts.
Adaptation by choice	Agents seek to maximize their initial resources and choose destinations based on the utility they can gain by visiting a destination depending on its attractiveness and distance.
Resources	Resources represent the agent's level of satisfaction (happiness). To reach a destination, a population agent must spend its own resources, which every reached destination rewards by its attractiveness points.
Happiness	Dynamic agents can be either "happy" or "unhappy". Happiness is defined here as whether an agent can satisfy its utility goal. Unhappy agents emigrate with statistically defined relocation periodicity.
Distance	Each step toward a destination costs an agent a certain number of resources. This reflects the real-life time (or distance) cost to visit a certain place.
Attractiveness	The more attractive a destination, the higher utility it provides, and the higher an agent's interest to reach it. Destinations can implement a visitor cost penalty when overcrowded. This logic reflects the decline in the attractiveness of over-visited destinations.
Fitness	The fitness of population agents is derived from their initial resources adjusted after moving towards a destination by the resource points that result from the difference of those gained from the destination's attractiveness and lost by bridging the distance towards it.
Prediction	Although not at the forefront of the model, it allows agents to relocate if they are unhappy. This means that every relocation period triggers emigration for unsatisfied residents.
Stochasticity	It relates to birth and death ages, initial amount of resource points, range of agents and destinations including their placement, update sequence of agents, and relocation periodicity.
Dynamics	The effects of the individual choices of the dynamic agents form the dynamics of the spatial interactions within the regional accessibility system.

Source: the Authors

4.2. Agent action and interaction in detail

Activities of population agents consist of choosing from a set of available destinations and interacting with the destinations as they commute towards the chosen destinations. With every step towards a destination, own resources of the agents decrease, and as the agents reach the destinations, their resources increase with the amount of the destination's attractiveness level, (agents return home after this interaction). These actions of agents imitate

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

people's daily decisions and movements between different activities, that may cause relocation initiative to other areas if agents are not satisfied with available opportunities.

Destination agents are static and spatially distributed at the simulation launch. They build clusters of destinations in differently sized spatial centers of activities within a region. Dynamic population agents account for interactions with a destination of choice as the population travels to the destinations chosen based on the highest utility that can be gained from this move. Their utility represents an agent's resource of happiness as each agent chooses the destination with the highest resource reward expressed in the attractiveness level set for the destination. In this way, the happiness levels of agents in the model explain the ease of reaching destinations, that is, the accessibility levels that each agent experiences during the simulation based on its movement.

The pursuit of happiness as a resource measure is linked to reaching work and leisure destinations. The population agent's own resource is expressed as happiness resource points. The destination agent's resource is expressed as its level of attractiveness. Travel time that an agent evaluates when choosing a destination and loses by reducing its own resources when moving towards it is expressed as the number of steps from the agent's home to the destination, and these points are subtracted from the agent's happiness as cost for the movement constrained to a non-negative threshold. At the same time reaching the destination is rewarding as it increases the agents' utility: when an agent reaches the chosen destination, its happiness resource points are increased by the attractiveness points of the reached destination. To choose the destination that generates the most utility, each agent chooses between the attractiveness of a potential destination (beneficial) and the distance (non-beneficial) that it costs for the agent to travel to it. The cost of travel is deducted from the agent's resources. This trade-off logic is visualized in Figure 1.

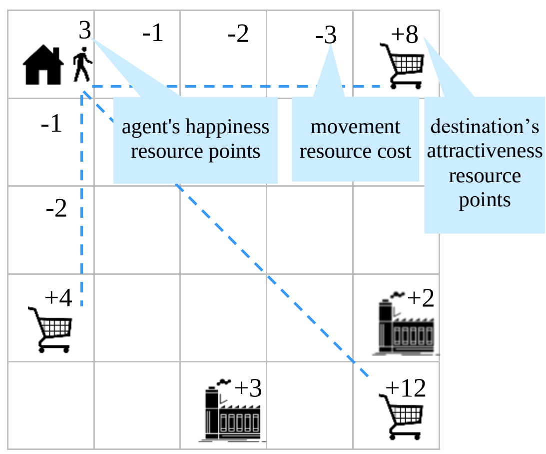

Fig 1. Destination choice utility logic visualization
Source: the Authors

A failure to reach the predefined utility goal of two destinations (one work and one leisure destination) classifies dynamic agents as discontented (socially unhappy). In the context of this study, the restriction to two destinations is done conditionally to simplify the modeling task without an empirical or theoretical implication.

The relocation feature incorporates the influence of accessibility on settlement dynamics and demographic trends in an area into the model as dynamic agents relocate if their utility goals have not been completed. As unhappy agents emigrate from the simulated region, the accessibility of the latter becomes indirectly dependent on the increase in emigration related to the retention rate of the region based on the accessibility of its destinations.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

Figure 2 shows the process flow performed at every simulation step as the model dynamics unfold from interactions between dynamic agents and static destinations.

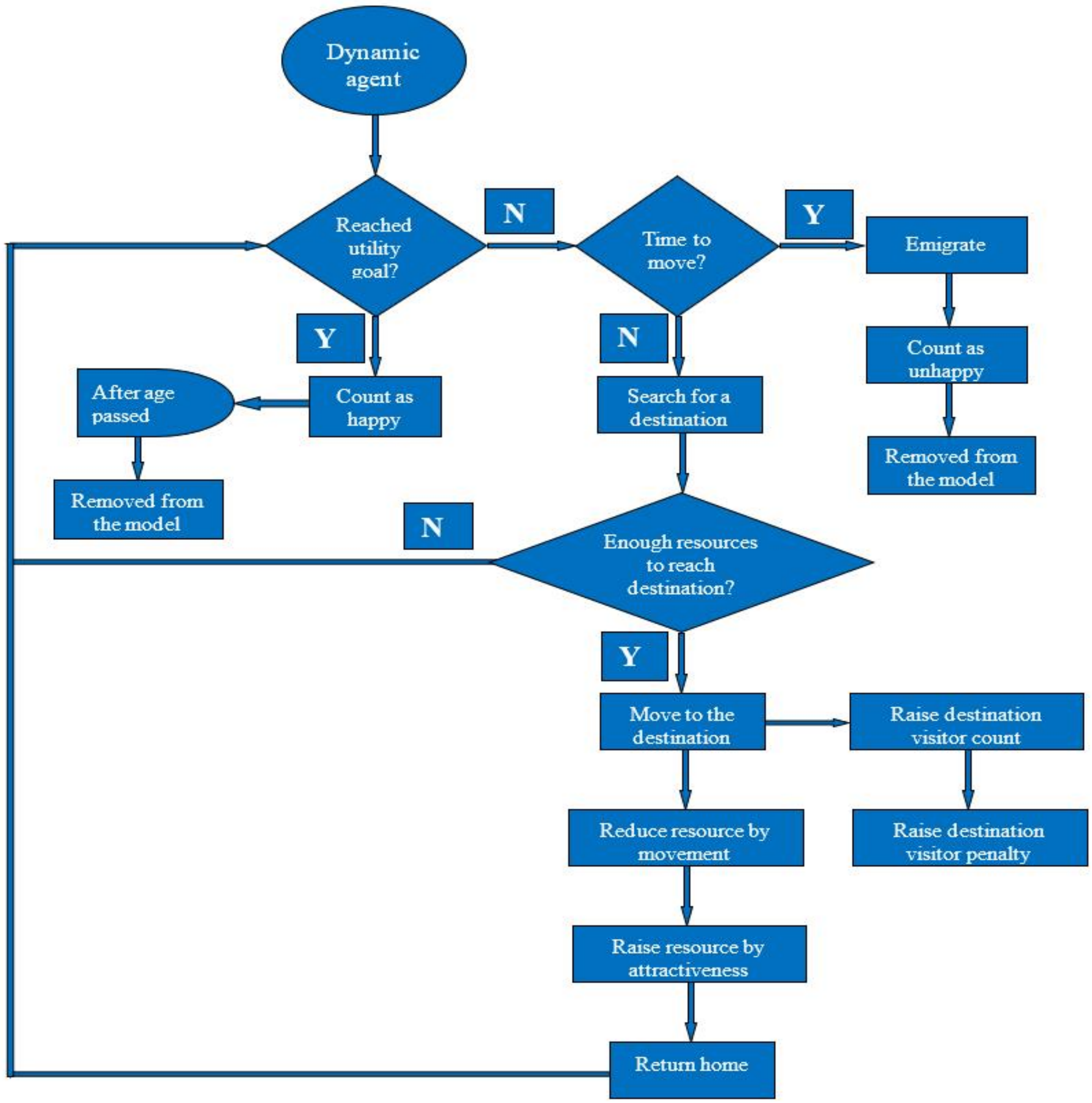

Fig 2. Decision making flow through the model
Source: the Authors

Since the daily travels of the agents contribute to the fulfillment of their primary goal of reaching destinations and accumulating the most value from those visits, the agents either reach this utility at the end of their choices and become content or remain unhappy. When there is no population left in the model, the simulation process terminates. As the relocation period counter triggers an initiative from unhappy agents to move, the model consequently reflects peoples' relocation decisions based on the accessibility of destinations.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

5. Simulating regional accessibility

5.1. The setting of the Swedish case

To facilitate a dialogue about ABM for regional development, the proposed model was evaluated by an adoption of a Swedish case in the Sundsvall region by testing six developed scenarios. The spatial distribution of destination agents was determined through three different patterns of clustering – a single centralized clustering, two distant clusters, and four clusters. The logic of the single cluster concentrates destinations around the only centroid of the most urbanized area in the region where most destinations currently exist. The double cluster scenario splits the number of destinations evenly into two centroids to test the effects of a decreased agglomeration approach. The final four-cluster option reflects the appearance of the case study region, reflecting the set of municipalities with different levels of urbanization. The size of the clusters reflects the population and destination density as a spatial distribution of destinations is often based on the clustering of opportunities in city centers. The last option is based on census data of the six municipalities in the case study region, see Table 2.

Table 2. Regional population statistics

Municipality	Inhabitants	Share of population in %
Sundsvall	99 361	50
Timrå	17 754	9
Härnösand	24 879	12
Ånge	9 143	5
Hudiksvall	37 688	19
Nordanstig	9 487	5

Source: Statistics Sweden, 2022

Nordanstig and Timrå were merged with their adjacent municipalities. Nordanstig does not exhibit a distinct destination cluster, hence it can be assumed that the Hudiksvall cluster is predominant. Timrå's center is very close to the Sundsvall cluster, therefore, they can be perceived as one large cluster in the simulation. Figure 3 shows the share of the regional centroids and destination range split for the four-cluster simulation.

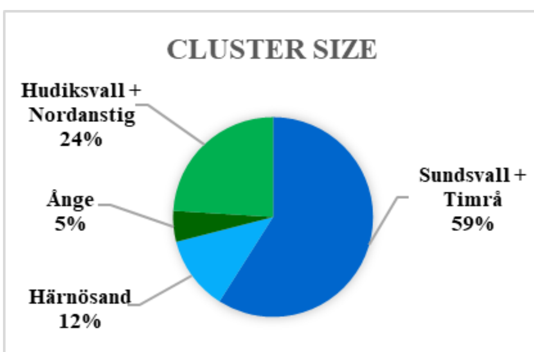

Fig 3. Four-cluster split pie
Source: the Authors

The spatial distribution of the four-cluster scenario is shown in Figure 4 as cluster 1 holds 59% of the input destinations, cluster 2, 3 and 4 hold 24%, 12% and 5%, respectively.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

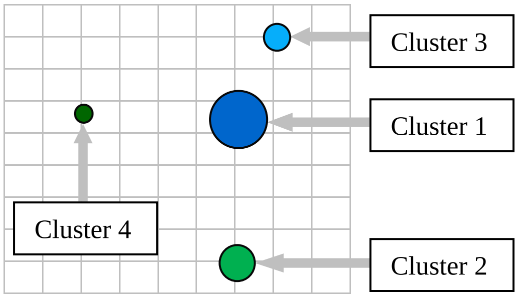

Fig 4. Four-cluster spatial distribution scheme
Source: the Authors

The three scenarios for the spatial distribution of destination agents – pink patches for leisure and brown ones for work – simulate various urbanization levels and cluster-sizing scenarios, as shown in Figure 5.

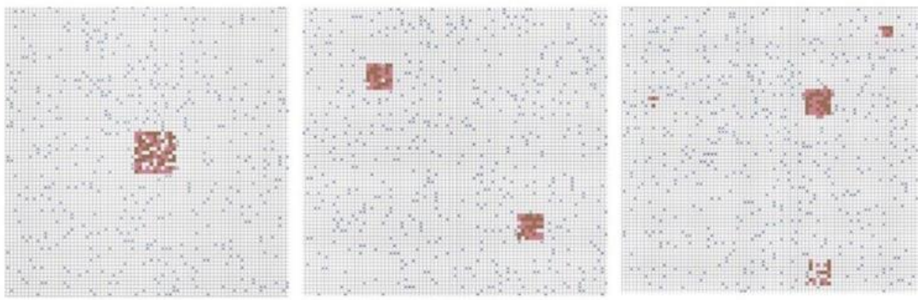

Fig 5. Destination spread scenarios: a) single centralized clustering, b) two distant clusters, and c) four clusters
Source: the Authors

Each of the three scenarios was simulated with destinations that apply the visitor cost penalty function and with scenarios that do not consider this factor for considering the effect of overcrowding. With this function enabled, the attractiveness of destinations is continuously adjusted based on the number of visitors. In addition, the value of attractiveness is set higher for leisure destinations compared to work ones, as around 25% of all trips in Sweden are work-related (Swedish Research Council and The Institute for Futures Studies 2023). The weight of the distance and attractiveness parameters is the same for the dynamic agents, regardless of their spatial placement.

5.2. The evaluation of the model in Sundsvall's region

The outlined scenarios combine criteria for social happiness, total travelled distance, and settling dynamics. The mean of the evaluation results after ten replications per scenario is presented in Table 3. Social happiness refers to the percentage of the population that has reached its daily utility goal.

Table 3. Simulation results

N	Scenario	Visitor cost penalty	Social happiness, %	Years passed	Distance traveled
1	Central single cluster	+	98.94	115.997	7828.3
2	Central single cluster	–	98.933	120.7	8161.3
3	Two distant clusters	+	94.247	121.729	6367.5
4	Two distant clusters	–	96.781	115.823	6462.2
5	Four clusters	+	94.159	117.961	6016.8
6	Four clusters	–	91.783	114.446	5917

Source: the Authors

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

The single and two-cluster scenarios were mainly used to explain and discuss the model's behavior with municipalities' representatives. From Table 3, it can be seen that the agents are most happy in the single cluster scenario while traveling less when a visitor penalty feature is applied. However, given the large geographical area of the region, the agents traveled even less in the two and four-cluster scenarios, with some decline in overall happiness. The four-cluster scenario, which best reflects the regional circumstances, shows that the visitor cost penalty positively influenced the happiness level in addition to only a slight increase in the traveled distance. One effect of the visitor cost penalty is a more even distribution of visitors among opportunities, see Figure 6.

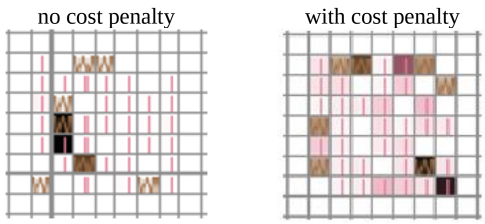

Fig 6. Destination popularity spread patterns
Source: the Authors

As the darker color of the square patches denotes a higher visitor count, the visitor penalty function induces a more even spread of visitors per destination, and it could be assumed that fewer individuals would maximize their utility. However, the results from the simulation of the Sundsvall region show that this assumption only applies to a low extent to the two-cluster scenario, where the lower traveled distance indicates a lack of alternative destinations when the most popular ones become overcrowded. In both cases (with or without the cost penalty), the patterns of population choice of destinations show a preference for visits to the larger clusters, causing abandonment of the smaller areas. An example of this preference is shown in Figure 7 – note that the smallest cluster at the bottom of the picture is not visible as its destinations suffer from a lack of visits and are therefore pale compared to more urbanized clusters.

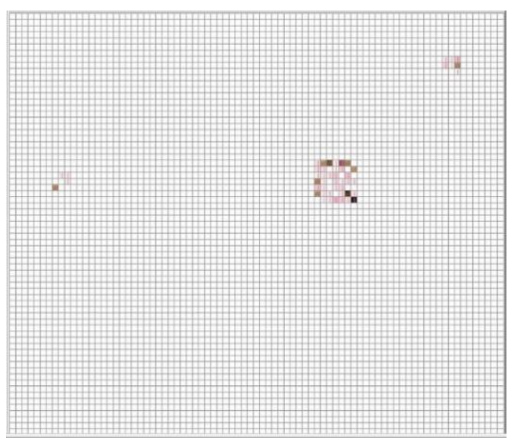

Fig 7. Prevail of preferential visits to larger destination clusters
Source: the Authors

The model design discussion with planners exposed that the latter have difficulties in understanding the processes used in the simulation model design and its application in daily practice. However, they expressed interest and value of model to contribute to the creation of a unified vision of the region. The evaluation of the model was challenged as the participants struggled with the need to understand several layers of simulation modeling design: from the construction of key variables to the coding execution of the agents' interactions in the implemented model. This shifted the focus of model discussion to the design implications in the practice of planning. However,

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

the recognizable clustering approach lifted the discussion focus from planning separate local routes and roads to a higher level of abstraction as the planners shared the vision about the agglomeration implications for different cluster formations. As the simulation dynamics started to unfold, the participants showed more engagement as they agreed that the model was representative of the regional dynamics, but having detailed visualization, such as adding various travel elements (for example, railways or walking paths), would make it more compelling. Consequent contemplations switched from the model functionality to the implications of using the model in the routine praxis of planning for sustainable development with a long-term vision.

6. Discussion

6.1. Implications for accessibility and regional development

In line with the study objective, the model generates learning about the aggregated effects of the regional accessibility system, based on the set of variables that describe the interaction between regional destinations and the population. The effects stress the influence of individual perspectives on dynamical changes in the preferential patterns of choosing among destinations from the available clusters, thus providing a visualization of the possible long-term perspectives of agglomeration planning on the image of a region. Following the model purpose, the decision on the structural complexity of the model was made in favor of the high level of abstraction at the expense of a multitude of details about the simulated phenomenon and its possible internal and external relationships. The reason was to mitigate the risk of affecting the model's usefulness “so that stakeholders and policymakers cannot pinpoint which inputs affect the outputs and by what order of magnitude” (Furtado 2023).

The simulation outcome emphasizes that the size of a community and the availability of destinations must be balanced to avoid the aggravated outcomes of agglomeration approaches where destination planning aims at developing separate municipal centroids. To minimize the risk of neglected destinations in smaller communities and avoid intra-regional competition, planners need to explore the optimal development of clusters from the perspective of the whole region. Such a shift of development focus from competing to sharing can help to decrease the risk of ineffective investments by using and developing common regional opportunities. The reason for this lies in the simulation results that depict agents’ tendency to prioritize certain destinations more despite the availability of other various nearby alternatives with similar attractiveness levels. This implies that there may be a risk of uneven distribution of destination popularity that cannot be diminished by the range of destination choices. The simulated opportunities that attracted most visitors from the beginning tend to continue to grow in terms of visitor count. This trend means that an area with a restricted range of alternative destinations may suffer from this prioritization because the “unpopular” destinations will remain largely ignored. If the destinations do not balance out the visitor load, they may subsequently face the risk of susceptibility to a predator competitor. While such competition can be meaningful within certain limits for shared common resources, such as concentration of skilled labor or road infrastructure for similar types of enterprises, it poses threats to smaller communities that cannot compete with their more urbanized neighbors.

Simultaneously, the simulation results showed that the visitor cost penalty approach can change the perception pattern of accessibility. As some destinations become more popular, their attractiveness may partially decrease for the visitors (Yin et al., 2020) in the long run. As a result, the simulation confirmed a more even distribution of choice among the destinations with the activated penalty function. This trend is specifically important for destinations that run a higher risk of being deprioritized in commuting decisions in favor of more attractive alternatives in adjacent larger clusters. Thus, regional population dynamic is important for consideration in regional development when exploring the behavior of the intra-regional accessibility system. Due to a characteristic time lag between cause and effects in regions, the illustrated effects are to be expected to occur in the long run and, therefore must be considered in current planning policies to achieve sustainable development where destinations complete the needs of a region rather than create internal competition, negatively affecting the demography and image of the area.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

6.2. Implications for planning

As the findings of the regional accessibility model demonstrate the possible discrepancies in the adoption of clustering strategies without considering the cross-municipal effects of segregated destination development, the potential of the ABM as a tool to visualize daily commutes affecting that pattern is largely underused in praxis. The implemented model defines destination choice prioritization patterns that change the accessibility image of a region, specifically in areas with varying levels of urbanization. This can lead to a neglect of areas with fewer opportunities, given the availability of a larger destination cluster in adjacent areas, as the latter may cannibalize their smaller counterparts. This can be specifically sensitive for remote regions similar to the case region as while peripheral areas may benefit economically from increased accessibility, these gains are often overshadowed by the larger scale of economic gain in core regions (Kotavaara et al., 2014). In case of regional Sweden, long distances between opportunities are common; therefore, accessibility to work opportunities is directly associated with sustainable economic development given the density of job destinations in this sparsely populated area (Östh et al., 2018). An example of a disadvantage of such agglomeration economies would be a major private actor leaving the area, causing a large gap for labor in the whole region. This implies that in such regions with various levels of urbanization, the risk of bigger clusters overshadowing opportunities in adjacent areas can neutralize the efforts of smaller peripheral areas to invest in destinations that may attract population and enterprise establishments. It is, therefore, crucial to approach planning in sparsely populated communities at a regional scale, with tailored strategies for each destination development case, to safeguard the overall socioeconomic well-being of the whole community rather than compete for it. The needs are, however, more sensitive for smaller communities and municipalities within the region, as their investments are more limited and require more careful consideration. At the same time, the emigration flow as a result of desolated smaller neighbors may eventually influence the adjacent areas as well, as the area fails to meet the living quality expectations, which may cause the whole region to suffer from the disadvantageous development of its less development and less urbanized areas.

7. Conclusion

The model of regional accessibility was designed, implemented, and evaluated by simulating the possible long-term development of a Swedish region. As the current institutional framework of Sweden significantly hampers addressing accessibility issues for sustainable regional development, the challenge necessitates a comprehensive cross-municipal approach. Firstly, the establishment of a unified vision, and secondly, the adoption of a high-level planning abstraction to incorporate decision-makers' perspectives into the concept development process. Given the complex nature of regional accessibility and the various ways to evaluate and plan for it, the presented model was designed to generate knowledge about the region of interest to enhance awareness of common problems of the intra-regional planning and lift the local focus to the cross-municipal scale. To facilitate this approach, the model embeds the responsible planners' interpretation of the regional accessibility concept and represents the unified regional approach through the visual capabilities of agent-based modeling. By doing so, the study provided insights into the dynamic changes that may occur in the regional accessibility system and allowed the involved planners to visualize the long-term consequences of their planning approaches in the region.

This is realized by exploring population agent interactions with destinations as main composites of regional accessibility to unravel the interplay between subjective perceptions and regional accessibility, and how this interaction contributes to regional demography. In particular, the modeling approach clarified the purpose of the model and actively involved regional planners in the modeling process. The conducted empirical research related to the understanding and interpretation of model design and simulation output focused on the application of the agent-based simulation model primarily for generating knowledge about the regional accessibility system. Therefore, the research contributed to lowering the hinders regarding the deployment of digital practices, such as simulation modeling, in regional planning. The findings showcase the value of integrating ABM in municipal decision-making processes. Such method could be further utilized as a visual representation of common regional

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

challenges to improve collective understanding and cross-municipal approaches to planning for regional development.

8. Contribution, Limitations and Future Research

This paper contributes valuable insights that stimulate the adoption of simulation in complex domains, such as public planning that seeks to align local and regional perspectives. In particular, the study offers practical value to planners working with municipal and regional planning in the case study region through the model by visualizing the long-term effects of current planning approaches to regional accessibility. The findings presented can also guide planners working in regions with similar characteristics of sparsely populated remote areas with unevenly distributed destinations. The practical value of the model lies in visualizing the long-term effects of regional accessibility, that can be used to support discussions during the policy design stage for sustainable development and minimizing intra-regional competition.

Further research could address the ABM adoption challenges and expand the model to include more case-tied regional characteristics. One of the key challenges is the adoption of ABM as a valid supportive tool for strategic planning, which is hindered by the complexity of underlying simulation processes. To address this, future efforts should prioritize early and extensive engagement of planners in multiple stages of the model design process, particularly when setting model assumptions. This will help to close the gap between model design and its practical use. Regarding this study, it should be kept in mind that ABM was used to demonstrate the expected consequences of accessibility development to awaken a long-term vision of planners for the need for a case-tied approach to destination planning.

The primary novelty of this research lies in model design as a significant source of knowledge generation rather than the exclusive dependence on simulation results. This approach fills a gap in existing techniques by applying the developed systematic framework to model construction for interpreting and understanding complexity and its challenges. The refined model design process demonstrated a combination of the results from multiple studies that integrate the interpretation of complex concepts, such as regional planning, which allows us to move beyond the conventional focus of depending solely on simulation results.

On the one hand, limitations in understanding the underpinning simulation processes that hinder the adoption of the methodology in planning imply the need for early and comprehensive engagement of planners in the process of decision-making regarding the assumptions of the model design. On the other hand, model development requires integration of more detailed agent interactions at a lower level of abstraction for exploring case-related patterns that can be recognized and tied to more specific regional planning scenarios and concrete policies. The latter would also allow a closer investigation of how such models can be implemented in the practice of planners to support them with developing regional and potentially national visions and strategies for a more knowledge-based approach to the policy design for sustainable regional development with a long-term vision.

A few limitations related to the developed model can be acknowledged. The first relates to the high level of model abstraction, which is important for identifying dynamic patterns but limits the accuracy of interactions between agents and destinations. This restricts the model's ability to explore more complex and specialized planning decisions that may apply to decision-making for drafting concrete policies. Second, the model does not account for external factors, such as specific infrastructure developments at micro level (e.g., a bus stop), which may affect accessibility patterns. Finally, the characteristics of the studied case region representing sparse population interests in remote communities with large distances mean that the findings may not be fully generalizable to regions with more densely populated areas or different geographic and social conditions. Further refinement of the model could involve integrating more detailed agent behaviors and external variables to increase its applicability across various contexts.

References

Adolphson, M., & Jonsson, D. 2020. Uncover the theory practice gap in Swedish transport planning: An interdisciplinary approach. *European Planning Studies*, 28(11), 2237-2260. https://doi.org/10.1080/09654313.2020.1715927

Belfrage, M., Lorig, F., & Davidsson, P. 2022. Making Sense of Collaborative Challenges in Agent-Based Modelling for Policy-Making. *Proceedings of the 2nd Workshop on Agent-based Modeling and Policy-Making (AMPM 2022)*, Vol. 3420. Ed. By Sileno G., Lettieri N., Becker C. December 14, Saarbrücken, Germany. Retrieved from CEUR Workshop Proceedings (CEUR-WS.org).

Bergkvist Andersson, H., & Schmitt, P. 2024. Disclosing the logics of non-statutory regional planning: The case of Sweden. *European Planning Studies*, 32(8), 1793-1812. https://doi.org/10.1080/09654313.2024.2337308

Bjärstig, T., Thellbro, C., Stjernström, O., Svensson, J., Sandström, C., Sandström, P., & Zachrisson, A. 2018. Between protocol and reality – Swedish municipal comprehensive planning. *European Planning Studies*, 26(1), 35-54. https://doi.org/10.1080/09654313.2017.1365819

Boisjoly, G., & El-Geneidy, A. M. 2017. The insider: A planners' perspective on accessibility. *Journal of Transport Geography*, 64, 33-43. https://doi.org/10.1016/j.jtrangeo.2017.08.006

Borshchev, A., & Filippov, A. 2004. From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools. *The Proceedings of the 22nd International Conference of the System Dynamics Society*. July, 2004, Oxford, England. Retrieved from http://www2.econ.iastate.edu/tesfatsi/systemdyndiscreteeventabmcompared.borshchevfilippov04.pdf

Chapuis, K., Taillandier, P., & Drogoul, A. 2022. Generation of Synthetic Populations in Social Simulations: A Review of Methods and Practices. *Journal of Artificial Societies and Social Simulation*, 25(2), 6. https://doi.org/10.18564/jasss.4762

Davis, M. C., Hughes, H. P. N., McKay, A., Robinson, M. A., & van der Wal, C. N. 2020. Ergonomists as designers: Computational modelling and simulation of complex socio-technical systems. *Ergonomics*, 63(8), 938-951. https://doi.org/10.1080/00140139.2019.1682186

Ding, Z., Gong, W., Li, S., & Wu, Z. 2018. System Dynamics versus Agent-Based Modeling: A Review of Complexity Simulation in Construction Waste Management. *Sustainability*, 10(7), Article 7. https://doi.org/10.3390/su10072484

Edmonds, B., Le Page, C., Bithell, M., Chattoe-Brown, E., Grimm, V., Meyer, R., Montañola-Sales, C., Ormerod, P., Root, H., & Squazzoni, F. 2019. Different Modelling Purposes. *Journal of Artificial Societies and Social Simulation*, 22(3), 6. https://doi.org/10.18564/jasss.3993

Furtado, Bernardo Alves. 2022. Simulation Modeling as a Policy Tool. In *The Routledge Handbook of Policy Tools*, edited by Michael Howlett, 270-81. https://doi.org/10.4324/9781003163954-27

Ghafoor, N., Fayyaz, S., Nisa, M.-U.-, & Akbar, M. R. 2021. An empirical investigation of socio-economic impacts of agglomeration economies in major cities of Punjab, Pakistan. *Cogent Economics & Finance*, *9*(1), 1975915. https://doi.org/10.1080/23322039.2021.1975915

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., Goss-Custard, J., Grand, T., Heinz, S. K., Huse, G., Huth, A., Jepsen, J. U., Jørgensen, C., Mooij, W. M., Müller, B., Pe'er, G., Piou, C., Railsback, S. F., Robbins, A. M., … DeAngelis, D. L. 2006. A standard protocol for describing individual-based and agent-based models. *Ecological Modelling*, 198(1), 115-126. https://doi.org/10.1016/j.ecolmodel.2006.04.023

Grimm, V., Railsback, S. F., Vincenot, C. E., Berger, U., Gallagher, C., DeAngelis, D. L., Edmonds, B., Ge, J., Giske, J., Groeneveld, J., Johnston, A. S. A., Milles, A., Nabe-Nielsen, J., Polhill, J. G., Radchuk, V., Rohwäder, M.-S., Stillman, R. A., Thiele, J. C., & Ayllón, D. 2020. The ODD Protocol for Describing Agent-Based and Other Simulation Models: A Second Update to Improve Clarity, Replication, and Structural Realism. *Journal of Artificial Societies and Social Simulation*, 23(2), 7. https://doi.org/10.18564/jasss.4259

Große, Ch. 2022. Towards a Holistic Perspective on Future Transportation Systems: A Swedish Case and a Conceptual Framework. *Future Transportation* 2(4), 846-867. https://doi.org/10.3390/futuretransp2040047

Große, Ch.. 2023. A Review of the Foundations of Systems, Infrastructure and Governance. *Safety Science* 160: 106060. https://doi.org/10.1016/j.ssci.2023.106060

Große, Ch., & Olausson, P.M. 2019. Blind spots in interaction between actors in Swedish planning for critical infrastructure protection. *Safety Science*, 118, 424-434. https://doi.org/10.1016/j.ssci.2019.05.049

Grundel, I., & Magnusson, D. 2022. Planning to Grow, Planning to Rock on – Infrastructure Management and Development in Shrinking Municipalities. *European Planning Studies*, 31(6), 1184-1202. https://doi.org/10.1080/09654313.2022.2108311

Goldspink, C. 2002. Methodological Implications of Complex Systems Approaches to Sociality: Simulation as a foundation for knowledge. *Journal of Artificial Societies and Social Simulation, Journal of Artificial Societies and Social Simulation,* 5(1). https://www.jasss.org/5/1/3.html

Jamei, E., Chan, M., Chau, H. W., Gaisie, E., & Lättman, K. 2022. Perceived Accessibility and Key Influencing Factors in Transportation. *Sustainability*, 14(17), 10806. https://doi.org/10.3390/su141710806

Kazieva, V. Forthcoming. 2024. Unpacking Complex Concepts to Enhance Use of Dynamic Simulations. In *The Proceedings of the 28th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems* (KES 2024).

Kazieva, V., Große, C., & Larsson, A. 2023. Accessibility Measures and Indicators: A Basis for Dynamic Simulations to Improve Regional Planning. In I. Czarnowski, R. J. Howlett, & L. C. Jain (Eds.), *Intelligent Decision Technologies* (pp. 25-34). Springer Nature. https://doi.org/10.1007/978-981-99-2969-6_3

Kazieva, V., Große, C., & Larsson, A. 2024. Accessibility in Sparsely Populated Remote Areas: Key Variables for Informed Regional Planning. In K. Gao, Y. Bie, R. J. Howlett, & L. C. Jain (Eds.), *Smart Transportation Systems* 2024 (pp. 25-35). Springer Nature. https://doi.org/10.1007/978-981-97-6748-9_3

Kelly (Letcher), R. A., Jakeman, A. J., Barreteau, O., Borsuk, M. E., ElSawah, S., Hamilton, S. H., Henriksen, H. J., Kuikka, S., Maier, H. R., Rizzoli, A. E., van Delden, H., & Voinov, A. A. 2013. Selecting among five common modelling approaches for integrated environmental assessment and management. *Environmental Modelling & Software*, 47, 159-181. https://doi.org/10.1016/j.envsoft.2013.05.005

Kotavaara, O., Pukkinen, M., Antikainen, H., & Rusanen, J. 2014. Role of Accessibility and Socio-Economic Variables in Modelling Population Change at Varying Scale. *Journal of Geographic Information System*, 6(4), Article 4. https://doi.org/10.4236/jgis.2014.64034

Law, A. M. 2007. *Simulation Modeling and Analysis*. 4. ed. McGraw-Hill Series in Industrial Engineering and Management Science. McGraw-Hill. Retrieved from https://search.ebscohost.com/login.aspx?direct=true&db=cat09049a&AN=miu.oai.miun.se.103210&lang=sv&site=eds-live, pp. 71-76.

Lawlor, J. A., & McGirr, S. 2017. Agent-based modeling as a tool for program design and evaluation. *Evaluation and Program Planning*, 65, 131-138. https://doi.org/10.1016/j.evalprogplan.2017.08.015

Li, L., Zhang, J., Nian, S., & Zhang, H. 2017. Tourists' perceptions of crowding, attractiveness, and satisfaction: A second-order structural model. *Asia Pacific Journal of Tourism Research*, 22(12), 1250-1260. https://doi.org/10.1080/10941665.2017.1391305

López, E., Gutiérrez, J., & Gómez, G. 2008. Measuring Regional Cohesion Effects of Large-scale Transport Infrastructure Investments: An Accessibility Approach. *European Planning Studies*, 16(2), 277-301. https://doi.org/10.1080/09654310701814629

Marcouiller, D. W. 2007. "Boosting" Tourism as Rural Public Policy: Panacea or Pandora's Box? *Journal of Regional Analysis and Policy*, Mid-Continent Regional Science Association, 37(1), 1-4. https://doi.org/10.22004/ag.econ.132975

Oklevik, O., Gössling, S., Hall, C. M., Steen Jacobsen, J. K., Grøtte, I. P., & McCabe, S. 2019. Overtourism, optimisation, and destination performance indicators: A case study of activities in Fjord Norway. *Journal of Sustainable Tourism*, 27(12), 1804-1824. https://doi.org/10.1080/09669582.2018.1533020

Peeters P., Gössling, S., Klijs, J., Milano, C., Novelli, M., Dijkmans, C., Eijgelaar, E., et al. 2018. Research for TRAN Committee - Overtourism: Impact and possible policy responses. European Parliament. *Brussels: Policy Department for Structural and Cohesion Policies.* Retrieved from https://policycommons.net/artifacts/1335648/research-for-tran-committee-overtourism/1942316/

Rosenthal, S. S., & Strange, W. C. 2003. Geography, Industrial Organization, and Agglomeration. *The Review of Economics and Statistics*, *85*(2), 377–393. Retrieved from https://www.jstor.org/stable/3211587

Statistics Sweden. 2021. Average Life Expectancy in Sweden. Örebro: *Statistics Sweden.* Retrieved from https://www.scb.se/hitta-statistik/sverige-i-siffror/manniskorna-i-sverige/medellivslangd-i-sverige/.

Statistics Sweden. 2022. Population in the state, counties and municipalities 31 December 2022 and population changes in 2022. *Statistics Sweden*. Retrieved from https://www.scb.se/hitta-statistik/statistik-efter-amne/befolkning/befolkningens-sammansattning/befolkningsstatistik/pong/tabell-och-diagram/folkmangd-och-befolkningsforandringar---helarsstatistik/folkmangd-i-riket-lan-och-kommuner-31-december-2022-och-befolkningsforandringar-2022/

Sterman, J. D. 2000. Business dynamics: Systems Thinking and Modeling for a Complex World. USA: Irwin/McGraw-Hill.

Straatemeier, T., & Bertolini, L. 2020. How can planning for accessibility lead to more integrated transport and land-use strategies? Two examples from the Netherlands. *European Planning Studies*, 28(9), 1713-1734. https://doi.org/10.1080/09654313.2019.1612326

Sun, Z., Lorscheid, I., Millington, J. D., Lauf, S., Magliocca, N. R., Groeneveld, J., Balbi, S., Nolzen, H., Müller, B., Schulze, J., & Buchmann, C. M. 2016. Simple or complicated agent-based models? A complicated issue. *Environmental Modelling & Software*, 86, 56-67. https://doi.org/10.1016/j.envsoft.2016.09.006

Swedish Research Council, & The Institute for Futures Studies. 2023, April 20. *Offentliga samtal: Samtida konflikter om framtida transporter. Vem tar ansvar?* [Video]. Retrieved from https://www.youtube.com/watch?v=8hNlYMpwImw

Yin, J., Cheng, Y., Bi, Y., & Ni, Y. 2020. Tourists perceived crowding and destination attractiveness: The moderating effects of perceived risk and experience quality. *Journal of Destination Marketing & Management*, 18, 100489. https://doi.org/10.1016/j.jdmm.2020.100489

Österle, H., Becker, J., Frank, U., Hess, T., Karagiannis, D., Krcmar, H., Loos, P., Mertens, P., Oberweis, A., & Sinz, E. J. 2011. Memorandum on design-oriented information systems research. *European Journal of Information Systems*, *20*(1), 7-10. https://doi.org/10.1057/ejis.2010.55

Österle, H., Becker, J., Frank, U., Hess, T., Karagiannis, D., Krcmar, H., Loos, P., Mertens, P., Oberweis, A., & Sinz, E. J. 2011. Memorandum on design-oriented information systems research. *European Journal of Information Systems*, 20(1), 710. https://doi.org/10.1057/ejis.2010.55

APPENDIX – ODD description of the implemented agent-based model of regional accessibility

1. Purpose and patterns

Accessibility is an essential part of sustainable regional development, as it defines the ease of access to activities, facilities, and locations. As sparsely populated remote areas have been experiencing population decline, there is a need to halt the trend by effective knowledge-based planning. Accessibility, as one of the key factors of regional development, is suffering from a diffuse approach towards planning and segregated policymaking from separate municipalities in Sweden. To incorporate a practice-tied interpretation of accessibility in sustainable planning and overcome the neglect of a cross-municipal approach, it is necessary to equip decision-makers with a simply interpretable common vision of the effects of regional development. Therefore, the purpose of the model is to develop a tool that visualizes the dynamics of regional accessibility to create a unified cross-municipal approach towards planning; namely to deploy explanatory capabilities of ABM based on the lessons learned from modeling the case study of accessibility. Thus, the model of the shared vision is set to support social learning through scenario simulation and exploration of the emergent patterns of preferential destination choices.

Three key variables define the basis of what constitutes the interpretation of regional accessibility based on empirical pre-study: range of destinations, attractiveness of destinations, and time that it takes to reach destinations. The model is done at a high level of abstraction to allow the planners to recognize the underpinning ideas that decision-makers use in practice and associate with accessibility when planning for regional development. The results of simulations based on two major agent interplay – population and destinations, that the population chooses to reach, showed the emerging patterns of preferences towards few destinations despite the availability of alternative ones. On the regional scale, the effect confirms the aggravated agglomeration outplay as larger destination clusters cannibalize neighboring smaller ones, indicating the need for a case-based approach towards developing destinations considering the advantages of adjacent municipalities and their capabilities on the whole regional area scale.

Currently, quantitative data is not available to confirm the outcomes. Yet, the emergent preferential patterns of destination choice are consistent with theoretical predictions regarding the aggravated effects of destination clustering in terms of competitiveness between different levels of urbanization within the clusters, and the expected need for individual planning for destination development. The region is represented by the artificial world built from patches – destinations, and spaces between them, where the synthetic population moves.

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

Given the high level of abstraction of the model based on the key variables that describe the modeled concept, the emergent patterns are simple determinants of the model's usefulness. The determinant of system performance in terms of pattern formation in the basic model refers to preferential visits to destinations, which become visibly popular compared to their counterparts. Based on this principle, the model where overly visited destinations become less attractive is tested pattern-wise in terms of a more even spread of visitors. This is achieved through the visitor cost penalty function which simulates a drop in attractiveness levels of overcrowded destinations, resulting in subsequent visitors choosing alternative ones, thus achieving a more even spread of visitors between the destinations. This defines the actual influence of the initial clustering of destinations, their range, attractiveness value, and closeness on individual decisions to choose the most advantageous destination to visit, which on the scale of population leads to a definite preference towards certain destinations, whose visitor count drastically differs from that of others.

The model world is designed as an approximation to reflect the case study region of Sundsvall in central which is characterized as a sparsely populated remote area. The model allows us to trace agglomeration outplay on accessibility to learn lessons from system behavior to apply to the practice of planning for making informed decisions regarding sustainable regional development.

2. Entities, state variables, and scales

The model entities are individuals (turtles), work (brown-colored patches), and leisure destinations (pink-colored patches). There are no collectives.

Agent state variables:

Destinations (patch agents) have state variables for attractiveness – the level of how attractive on a scale each destination can be. They also have an extra color variable apart from the inbuilt one to differentiate between brown patches of work and pink leisure patches (visually in runtime the colors change on a color scale between pale and dark pinks and browns, denoting the number of visitors – the darker the patch, the more the visitor count – for this reason the inbuilt color of patch variable is used to not mix up the original color denoting type of destination and changing the color denoting number of people who have visited this patch). Variable counter-visitors count the number of individuals that have visited this patch during a current simulation run.

Individuals (turtle agents) have state variables for age, number of destinations to visit (a measure of visitor satisfaction or in this model, social happiness), level of (social) happiness (denotes if the person has reached successfully its utility, i.e., number of destinations to visit), reproduction probability rate, average death-age, coordinates of original home location as agents travel to and from destinations, variable for migration that defines periodicity with at which individuals move if they have not yet reached the utility goal, as well as variables to count and compare social satisfaction (happy and unhappy individuals) to memorize if individuals have reached their predefined utility goal of the number of destinations to visit.

Global state variables that do not change over time:

Range of initial population, number of work destinations, number of leisure destinations, average living age of individuals, counter of happy and unhappy individuals based on the completed utility goal of reaching the predefined number of destinations, total distance that all people have traveled within the given simulation run, distance to center of a cluster (defines the radius of the destination spread based on range of destinations that user sets in interface), visitor cost factor switcher turns on/off functionality for reducing the attractiveness of overcrowded destinations.

Global state variables that change over time:

The current population, number of (un)happy people over time, percentage of the currently happy population, years passed (1 year is 365 simulation runs as 1 run is 1 day), total travel distance of all people during a given simulation run, the mean number of visitors to work and to leisure destinations.

The space is a toroidal (wrapped) 2-D grid of 81x81 cells with patch size 8. It is assumed as a border-free regional area consistent with individual patches – destinations – and spaces between them, that dynamic agents of population can freely cross. Each time step represents a decision by the individuals and patches to define which destination to travel to (visit), availability of resources to move, and the actual physical movement, while the patches update their visitor counts to reflect destination popularity. The individual agents are spread randomly in the world. The simulation is running continuously – there is a possibility to run only for 20 years if activating the switcher in the model interface, otherwise, the model stops when there is no population left (due to the emigration decision of unhappy population and dying rates, both statistical). The model does not use any (GIS) map.

The temporal scale of the model is set to days – each simulation step (tick in NetLogo) is 1 day as the model represents the daily commuting decisions of individuals. Thus, each decision to travel to a destination occurs daily, assuming activities happen during daytime hours (not a specific time). There is no representation of nighttime.

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

3. Process overview and scheduling

Every simulation step the model performs the following scheduling including hierarchical actions:

1. If the model has no population or the switch for "run-for-20-years?" is on and the model has been running for 20 modeling years, the simulation is stopped. Otherwise, the population agents in random order execute:
2. The "update-age" submodel, which:
   2.1 Increases the age by 1 day.
   2.2 If it is time to migrate, set migrate? to true.
   2.3 If current age = death age, remove agent and increment global happy people counter.
3. The "update-counter-unhappy" submodel:
   3.1 If current destination count < 2 and resources <= 0, count as unhappy.
4. The "move-to-destinations" submodel:
   4.1 If reached destination count = 2, set own variable count as happy to true, increment global happy counter, return home.
   4.2 If current destination count < 2 and not happy, call submodel "find-nearest-destination" for work:
   4.2.1 Find the closest patch of the same type
   4.2.2 Find the patch with max level of attractiveness
   4.2.3 Send distance of the closest patch and max attractiveness to the "calculate-trade-off" submodel.
   4.2.3.1 Submodel "calculate-trade-off" normalizes the distance and attractiveness criteria to the same scale and compares them, returning -1, 1, 2 or 3 to the calling procedure.
   4.2.4 The caller submodel "find-nearest-destination" checks which values it received: if result = -1, no movement, if 1, move to the closest, if 2 more to the most attractive, otherwise if both criteria were equal, choose randomly from the closest/most attractive patch with 50% probability chance for each.
   4.2.5 If the movement was performed:
   4.2.5.1 Increment the visitor count of the patch
   4.2.5.2 Update the global travel time of all the agents
   4.2.5.3 Return the distance that the agent travelled to the calling submodel "move-to-destinations".
   4.3 The submodel "move-to-destinations":
   4.3.1 Set agent's happiness = old happiness + attractiveness of the reached destination – travel cost
   4.3.2 Increment number of reached destinations
   4.3.3 Compare number of reached destinations to the utility goal (here: 2):
   if number of reached destinations = 2: send home, increment global happy counter, set counted as happy to true; else if < 2 destinations and happiness > 0: do steps 3.2.1 – 3.3.3 for pink patches too.

The destination patches in randomized order execute:

5. The "update-view" submodel to reflect if the model interface has enabled the switches to show the age and/or happiness of agents.
6. Executing the "update-patch-colouring" submodel to re-color destination patches through color scaling based on number of visitors – the more visitors the destination has the darker its shade of brown or pink.

The population agents in randomized order execute:

7. The submodel "let-visits-cost" first for work, then for leisure patches if interface has enabled the function of penalty for overcrowded destinations, calling the submodel "let-destination-visit-cost", which:
   7.1 Compares the number of total visits to each given patch to the mean number of visits that patches of the same type (color) have.
   7.2 If the current patch has more visits than the mean of all the patches of the same color, its attractiveness will be adjusted through the called submodels "pinkAttractivenessUpdate" or "brownAttractivenessUpdate".
   7.3 The "brownAttractivenessUpdate" accepts the value of current attractiveness 5, 4, 3, 2 (but not 1 here, which is already the minimal possible value) and proportion of visitors (proportion = number of visitors of the most visited patch / visitors of the current patch), searches the matrix for inverse proportionate attractiveness and returns the new attractiveness value based on the matrix of current values and proportions.
   7.4 The "pinkAttractivenessUpdate" accepts values of current attractiveness 20, 16, 12, 8 (but not 4 here as it is already the minimal possible value), and proportion of visitors the same way as the brown patch procedure, but the matrix is different due to the attractiveness values of leisure patches.
   7.5 In the "let-destination-visit-cost" the current attractiveness is set to the new returned value.
8. The model increments the step in the simulation run and goes to the next cycle of the simulation run.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

4. Design concepts

Basic principles

At the system level, the model addresses the planning problem of accessibility in regional rural systems, posing questions like how land-use and transport systems can be incorporated into rural planning to achieve sustainable regional development. The problem is that the current institutional framework based on a segregated municipal approach significantly hampers the overall initiative of addressing accessibility issues for sustainable regional development. As the challenge necessitates a comprehensive approach, the model investigates the consequences of the existing planning which uses the agglomeration theory of destination clustering. Destinations, as conglomerates of land-use and transport, have been empirically shown to represent the concept of regional accessibility, and therefore their development is central to the problem. To address the lack of institutional framework in solving the accessibility issues, the model addresses the problem from two perspectives. First, the establishment of a unified vision, and second, the adoption of a high-level abstraction of the regional accessibility concept, allows for the simulation of the cross-municipal model that can help visualize the regional effects of current approaches. This has not yet been integrated into planning practices in the case study region of Sweden. By embedding the responsible planners' interpretation of the regional accessibility concept and representing the unified regional approach through the visual capabilities of ABM, the study provided insights into the dynamical changes that foster the development of a unified regional vision through ABM as the visual support tool.

While the literature on the agglomeration approaches explores the benefits of clustering in urban settings, there is a lack of integration of the planners' vision into the interpretation of the actual concept in the practice of decision-making. This model differs from many traditional approaches to exploring accessibility concepts by simulating separate accessibility indicators or land-use effects, as it functions at a high level of abstraction that allows us to dive into the dynamics of interaction between the key components of the system that the planners associate with the explored concept. This way, exploring the possible results of using agglomeration in regions with varying levels of urbanization leads to exploring the consequences of cluster development at a regional level where a daily commuting decision of individuals forms the image of the region and its possible future.

Investigating system reactions to different conditions can help with generating knowledge for other systems or parts of systems that exhibit similar characteristics. It can provide insights for rural sparsely populated areas that suffer from a time lag problem, as it becomes hard to plan their development since the effects of conducted policy may have a delayed impact, so such regions may benefit from exploring the agglomeration policy effects.

Emergence

The key emergent outcome is that variations in the size of the population, initial spatial distribution of individuals, and number of destinations do not affect the dynamics of the system unless the variations are extreme. The primary results emerge from the spatial distribution of the destination clusters, their size (number of destinations within the cluster), and the availability of alternative destinations in nearby clusters. The pattern of preferential travels to destinations that individuals choose shows that certain destinations become more popular despite the availability of alternatives – large clusters cannibalize opportunities in less urbanized destination concentrations, which can be diminished by considering the overcrowding effects. With introduction of the overcrowding, the dispersion of popularity between destinations becomes less drastic within the same clusters, yet larger concentrations often prevail, causing less travel to their less urbanized neighbors.

Adaptation

The model agents use adaptive behavior as they decide which destination to choose to visit. This decision is modeled as direct objective seeking: each agent moves following its objective to get the best utility of the commuting decision to maximize its resources that are filled with the attractiveness value of the reached destination and reduced by the number of steps that it costs to travel to it. Therefore, the agents make a trade-off between the distance to travel and the attractiveness of a destination. Each decision is therefore intended to maximize the agent's utility expressed as its parameter called happiness, which reflects the agent's level of social content.

Another adaptation is incorporated through the visitor cost penalty alternative, which, in addition to the above-mentioned choice, constantly adjusts the attractiveness of each destination as a penalty for its overcrowding. This way, the attractiveness of the patches adapts to the overall attractiveness of the same type of patches and to the number of visits that each patch experiences – if a destination has a drastically higher number of visitors compared to the mean value of its counterparts, its attractiveness falls in inverse ratio to its popularity.

Objectives

Agent behavior is adjusting to environmental changes in order to pursue its *objective* of increasing the resources by commuting. Dynamic population agents therefore seek the destination that refills agents' own resources with the destination's value of attractiveness, however as traveling to the destination consumes resources, the agents strive to choose the destinations that provide the best trade-off decision between the non-beneficial distance and beneficial attractiveness (submodel "find-nearest-destination" implements that functionality with auxiliary hierarchical submodels as described in process overview chapter and more detail in the chapter with submodels).

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

The visitor cost functionality that introduces the penalty for overcrowding lowers the utility gained from visiting certain destinations, but, since this is not something that the agents learn to do, i.e., the agents do not change their behavior based on the results they learned but based on the new parameters of the system.

Learning
There is therefore no agent *learning* represented in the model as a result of the adaptive behavior.
Prediction

The adaptive behavior of the population does not deploy an explicit *prediction*. Instead, the system allows the agents to choose from the clustered destinations to classify the agents as socially satisfied when they reach their utility goal. For this purpose, the model links the dissatisfaction and consequent emigration to the expressed utility of reaching the set number of destinations as a goal to distinguish happy people who will stay in the area from unhappy who will move out in search of better living conditions.

Consequently, instead of learning from the past of developing a future commuting plan, the system with the visitor penalty function is constantly adjusting the attractiveness of destinations based on the number of visitors.

Sensing
The individuals are assumed to have immediate access to information about overcrowded destinations in the visitor cost cases. The reason for that is to show the effects at the level of the whole region about the consequences of crowding to explore the interplay of its effects in the long run. As the region is split into patches each of which readjusts its attractiveness based on the mean levels of attractiveness of the destinations of the same type, each agent subsequently chooses different destinations that generate more utility as compared to the dropped attractiveness of the overcrowded ones. The population is therefore aware of the current attractiveness levels of all the patches in the region, and destination planners are assumed to know the current state of the art with visits at the counterpart opportunities. The mechanism of visitor cost adjusts the attractiveness of destinations in inverse proportion to their overcrowding when compared to the number of visits to other opportunities. Thus, the model assumes that the higher the rates of overcrowding, the less attractive such rural opportunities become, which is reasonable specifically in sparsely populated areas that often exhibit long-term consequences of similar downfalls.

Interaction
Destination patches' interaction is direct as they adjust their attractiveness based on their number of visits. At the same time, they indirectly compete for the largest number of visitors to attract. Population agents do not have direct competition with each other for the destination with the most utility to derive, however as destinations become over-visited, the influence of these visits affects the whole population.

Stochasticity
The model applies stochastic processes in several different ways. To achieve variability in initial conditions and variation in agent behavior so that they do not change states at the same time:

- initialization of population is in pseudorandom in turn order and randomized home placement
- initial resources are set considering the toroidal space size to allow the agents reach most destinations
- the age and living span of individuals are also in a pseudorandom manner for the variation in agent behavior
- initialization of destinations is in turn order with work destinations being initialized first
- destination placement is random with restriction to choosing empty patches within the current cluster size
- the update sequence of all the agents is in pseudorandom in turn order
- population agent relocation periodicity is based on averaged statistical data and is set to every 12 years in the model based on average living age and life span (for more details see Initialization and Input data)

Collectives
The model doesn't use any collectives. Aggregations of work and leisure destinations are done by setting different levels of attractiveness and color. The difference in coloring is done for the sake of visual representation and attractiveness levels are executed to simulate the difference in visits to work destinations and other opportunities since work in the Swedish case constitutes only for a quarter of all travels. There are no differences in social groups, genders, or age, such as working age. Temporal agentset aggregations are done for coding purposes.

Observations
Data analysis consists of graphical representations via cell grids, graphs, and plots. It is primarily based on the individual choices of the population regarding the commuting decisions to destinations. The locations of the preferential destinations are shown in the space grid, including patterns of overly populated opportunities that belong to larger clusters neighboring less urbanized areas, so the agglomeration patterns can be observed. Numerical data alongside plots representing happy versus unhappy populations and distances traveled depict long-term changes in the dynamics of the region that do not develop overnight, confirming the need for exploring the lagging effects of destination development policies for cross-municipal planning.

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

5. Initialization

The range of the initial population and their resource levels of what account for social satisfaction, as well as the number of work and leisure destinations, are defined by the user during initialization. As the happiness resource defines how far an agent can travel to reach a destination, this allows the cases with a variety of initial interests to travel far away as compared to maximalized capabilities when the population is assumed to not be initially restricted by the inability to travel.

The simulation is built with the following global parameters: initial population size – 320; number of work destinations – 16; number of leisure destinations – 30; initial agent resources (happiness level) – 50.

As the decision as to which destination to choose is based on the trade-off between the attractiveness and closeness of opportunities, the user can choose different weights for setting these parameters.

Given the model objective to explore long-term dynamics of the system, the simulation is run as long as there is any population left, however, for observing short-term effects, a run for 20 years can be initialized.

In order to observe the change in agglomeration effects and dispersion of visitors once certain destinations become overcrowded, the function of visitor penalty cost can be enabled or disabled for the comparative analysis. With this function on, the overcrowded destinations constantly adjust their level of attractiveness – the patches whose visitor count is bigger than the mean count of all other alternatives, drop the attractiveness in proportion to the visitor count, i.e., the higher the overcrowding, the less the attractive they become.

Average living age and its standard deviation are initiated with values 83.03 and 18.00 respectively, see chapter Input data for details. The counters for socially happy and unhappy population are set to value 0. The population is spread randomly in the grid with statistically given reproduction rates set with random probability from 0 to 100, and the expected death age with random distribution given the average life span and standard deviation (with most agents having the death rate at the standard average life span with variability falling within one standard deviation from the mean to simulate a scenario that follows a normal distribution pattern).

All the population agents randomly in each turn set the initial age, living span (death age), reproduction rate, home coordinates, happy and unhappy counters to false and the number of reached destinations to zero.

All destination patches set their level of attractiveness randomly to one of the following numbers: work destinations between 1 and 5, leisure 4, 8, 12, 16, or 20. The levels are chosen to reflect that destinations are created with different attractiveness measures depending on the type of destination. Since only ¼ of all trips are to work, work trips have lower attractiveness than leisure trips (for this model a simplification is made that there are only those 2 types of trips). The other patches are not restricted or defined as specific transport needs, i.e., agents travel freely over the whole world and all the patches to reach their destinations.

Based on the destinations' visitor count, the patches are repainted to reflect the number of visits in the shades of respective color (the lighter shade of pink for leisure and brown for work denotes the destination has fewer visits, while darker ones reflect the higher concentration of population throughout the whole simulation, not only current number of agents on the patch).

Scenarios
The model uses three different initialization scenarios to explore the effects of different agglomeration patterns: a region with a single central cluster, two clusters of the same size in opposite parts of the region, and four cluster scenarios to explore the effects of a region with different levels of urbanization as each cluster varies in size (the larger the cluster the higher its urbanization and consequently, the more destinations are planned within this cluster to accommodate its population). The reason for this split between scenarios is to study and learn from the dynamics of the accessibility system how can different clusters affect the image of the region – as currently, the case study region suffers from a lack of cross-municipal approach, the different levels of destination concentrations usual for municipal level planning may exhibit different behavior. As in many cases, agglomeration, i.e., clustering of destinations leads to planning focused on concentrating opportunities centrally in the same place, it is important to ensure that the approach is beneficial for the region. Non-beneficial simulation outcome would mean that the current approach to planning based on the theory of agglomeration creates an uneven distribution of opportunities as some may become overly popular causing cannibalization of other less advantageous destinations to become abandoned, which can potentially mean desolation of the area. Therefore, apart from investigating the simulation outcome, it is important to explore whether individual choices create certain preferential patterns causing some destinations and clusters to become more prioritized than their counterparts.

Given the objective of the simulation to explore the agglomeration effects for social learning, the three initialization scenarios are combined with the visitor cost penalty function that allows to exploration of the possibility of incorporating the influence of destination overcrowding on dynamic changes in population preferences towards previously less attractive destinations. This becomes possible if overcrowding causes the attractiveness of overly populated destinations to decline, generating less utility from visits to popular destinations. Exploring these effects is crucial for planning for destination development, specifically for cases where opportunities are related to tourist attractions

INSIGHTS INTO REGIONAL DEVELOPMENT
ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

that tend to disregard the costs and risks of crossing the overcrowding threshold (this can be an issue in rural Sweden, an example can be disruption on the tranquility experience as a certain destination fails to accommodate the increasing number of tourists).

6. Input data

Input data does not include parameter values or data used to initialize the model. However, the code uses certain assumptions and statistical data (all statistical data is available open source from the Swedish Statistics).

Incoming data of user-defined parameters comprises the range of initial population, number of work and leisure destinations, agent happiness level, range of people to immigrate, weight of attractiveness for destinations, weight of distance for destination, and attractiveness level of destinations. The formation of the four-cluster destination spread scenario clustering is based on statistical data of the population of the six municipalities of the case study with the Sundsvall region (Statistics Sweden 2022). Two of the geographically adjacent municipalities were combined into a bigger cluster to explore their shared dynamics. Visualization of the spatial distribution of this representation is given in Fig. 4. Cluster 1 holds 59% of the input destinations, cluster 2 - 24%, cluster 3 - 12%, and cluster 4 - 5% respectively. This cluster sizing reflects the population split between respective areas.

Average living age is the average age between men and women as per Statistics Sweden (2021). The distribution of age for initiation is asymmetrically skewed to the right curve that can be approximated to a normal distribution. The standard deviation for normal distribution of age - as according to Statistics Sweden the majority of people live over 65 years old, so we let this define the standard deviation to 18 (83-65) as it allows us to approximate the curve after 83 years to symmetric downfall. This means that we disregard many deaths up to 65, so the synthetic population may potentially be older than the average observation of a real-life case. Death age (83.03 if averaged between men and women) and birth statistics (approx. 0.009 per person as of 2022, Statistics Sweden) per person are also statistically defined variables.

The number of destinations per person could not be retrieved, therefore it does not reflect the correspondence range of the population initialized, as the variables are user-assigned in the model interface. Normally only people within a certain age, e.g., between 18 and 65 years old should have a job destination, but we set both destinations for simplicity for the whole population as the utility to reach.

Migration periodicity is set to true if it is time to move away. Since on average 1 person moves every 12 years, based on statistical data, it becomes approx. 6,9 times per life, with the average life expectancy here set to 83.03, thus every 12 years in this model.

One simulation step (tick) corresponds to an agent's choice of decision and movement towards it.

Population agents spread is initiated randomly for age and placement. Newborns are placed together with their parents at their home coordinates.

Outgoing data shows the amount and the percentage of happy/unhappy people (the people who have reached their utility goal), time passed, distance traveled, and agents' movement dynamics (pattern) based on the interactions between individuals and destinations.

7. Submodels

The overview below covers a total of 11 submodels implemented at each time step.

1. Aging

The "update-age" submodel ages individuals by one day at each time step. Since the migration periodicity is every twelve years, it ensures that agents that have not reached their utility by then and have no resources left for exploring future travel possibilities are defined are socially unhappy to emigrate outside the region. When the agent reaches its set death age, it is removed from the model and as a happy person – at this point, the model does not check if agents have reached their utility to be counted as a consent population. The reason for that is that as the death age removes them from the model, it stops them from chasing their utility since there are migration intervals at which the (un)happiness conditions are checked for this functionality instead.

2. Social satisfaction status control

The "update-counter-unhappy" submodel ensures that the population utility goal completion that defines their social happiness in the model is regularly updated. The population that has not completed their utility goal but has resources to consider deciding on the next simulation run to travel to their destinations needs to be kept in the system; otherwise, they are counted as unhappy, which raises the total number of dissatisfied people. Such agents decide to move out at the next cycle of the emigration wave. The need for the submodel arises from the sequence of the traveling decision to different types of destinations since individuals must make several choices that take them to different destinations in between the simulation runs for daily commutes.

3. Individual decision-making and traveling for daily commute

The "move-to-destinations" submodel that the population agents execute covers the major functionality of the simulation regarding daily commute. The functionality includes trade-off decision-making of individuals as they try to maximize their utility of reaching work and a leisure destination. The submodel consists of several steps and two auxiliary submodels split hierarchically to cover the functionality for defining the potential destination for the agent to move to and calculate the trade-off of the key variables to derive the best utility from the travel. By reaching a destination, the satisfaction level increases as individuals are rewarded with the destination attractiveness value that is added to the resources of the agents. At the same time, the cost to reach such a destination is non-beneficiary as it consumes the agents' resources (time) to get there. Agents who have reached their utility goal and have not yet been updated as happy, update their happiness status and travel back home, contributing to the happy population as soon as the utility goal is completed. If the agent has not yet completed its utility goal and its own happy counter is set to false, then these agents call the submodel "find-nearest-destination" first for work destination and then for leisure for defining the destination to move to and executing the movement. In case of the successful find of the potential patch and travel to it, the agent updates its satisfaction via resource update after the move, and if the agent still has any resources left, but has not yet reached its utility goal, then it proceeds with the same actions as described above for the second destination (leisure) unless it is time to migrate. In the latter case, the agent is removed from the system as an unhappy individual who chooses to search for better living conditions. However, if the agent has reached its utility goal, it is counted as happy in global and own variables, and it returns home to prevent the agent from continuing to make decisions and travel for the utility.

4. Defining the potential patch to travel to

The "find-nearest-destination" submodel defines the potential patch (destination) for an agent to move to and executes the movement after defining the potential patch. Traveling to such a patch rewards the agents with the highest utility in terms of satisfaction (model wise – increasing their own resources). Observe, that the model defines either the nearest or the most attractive destination to reflect both key characteristics of land-use and transport that contribute to the accessibility concept as it is empirically defined at the regional scale. The population movements are not limited to searching the best option within its area (cluster), instead, the model allows regionwide travel to explore how accessibility to various clusters of opportunities plays out on the individual choices. The submodel finds the closest destination and the most attractive one in the model and compares the utility of the alternatives through the "calculate-trade-off" auxiliary submodel that executes the movement in case the potential fit is found.

5. Key variable trade-off calculation

To apply the trade-off decision and define the patch that generates the highest utility, the "calculate-trade-off" submodel is called. It normalizes the values of distance and attractiveness to the same scale and chooses the patch with the highest value so that the agent moves either to the closest or most attractive destination of the given type – first work, then leisure. In this simulation, both key variables have the same weight. Once the highest value is chosen, the agent checks whether it has enough resources to travel to that patch. If the agent can execute the travel to the selected patch (enough resources and the potential patch that matches the conditions have been identified except for the current location), then the move is performed, updating the total global travel time of all the agents and the visited patch updates its visitor count to reflect the increase in destination popularity.

6. *Tracing dynamic changes in aging and social happiness*

The "update-view" submodel enables the visuals of the agent's states to be dynamically updated to ensure they reflect the interface commands. This allows us to trace whether the population with the age tends to become socially satisfied or if many young agents are emigrating early into the relocation period activation.

7. Updating visuals of destination popularity dynamics

Color of destinations is rescaled at each simulation step in random order through the "update-patch-coloring" submodel to reflect the destination popularity among the population. The more visitors the destination has the darker its color, while paler destinations denote lack of visits. When the visitor cost penalty function is active, the current functionality reflects how destination overcrowding affects the changes in preferential choices.

8. Visitor cost penalty

When the user interface has enabled the function that casts penalty on overcrowded destinations, the submodel "let-visits-cost" is performed at scheduled for execution with every step of the simulation – first for work, then for leisure destinations (brown patches, respectively pink patches) if there are any. The submodel adopts three auxiliary submodels to adjust the attractiveness of overcrowded destinations for different destination types according to their levels of attractiveness and popularity in comparison to their counterparts. This is performed through "let-destination-visit-cost", "pinkAttractivenessUpdate" and "brownAttractivenessUpdate" submodels.

9. *Evaluation of destination overcrowding*

In the auxiliary "let-destination-visit-cost" submodel each destination's level of attractiveness is compared to the mean value of its counterparts (visitors to the patches of the same type (color)). If the number of visitors of the current patch is bigger than the mean of all the patches of the same color, then the attractiveness of the current patch is adjusted via one of the two additional submodels "pinkAttractivenessUpdate" or "brownAttractivenessUpdate" depending on which scale of attractiveness the current patch has (brown and pink patches have different values for attractiveness). Both submodels have the same functionality but are scaled to the values of different

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

patch types since the work destinations have different values of attractiveness given that only a quarter of all the travels in Sweden are to work opportunities.

10. Adjusting the attractiveness of work destinations
As the effects of destination overcrowding, cause consequent visitors to avoid overly popular destinations, the model adopts the adjustment of the attractiveness levels of such opportunities via the "brownAttractivenessUpdate" submodel. The proportion of visitors compared to the mean number of visitors of the most popular patch together with the value of current attractiveness defines how the new attractiveness is calculated. The assumption is that as the destination starts to become more popular than the mean of its counterparts, this can cause unpredicted complications in terms of the experience and risks related to the drastic difference. Thus, the more overcrowded the destination is, the more value in attractiveness it loses, i.e., the dependency is inversely proportional to the levels of attractiveness.

11. *Adjusting the attractiveness of leisure destinations*
The leisure destinations adjust their attractiveness based on the same conditions and logic as work destinations through the "pinkAttractivenessUpdate" submodel. The only difference is the actual values as work and leisure destinations have different scales.

The literature and statistical data mentioned in the appendix are cited in the main article.

Acknowledgments: The authors express gratitude to the participants within the project research programs for their insights and efforts. However, the usual disclaimers apply.

Disclosure statement: No potential conflict of interest was reported by the authors.

Funding: This research was financially supported by the co-operation agreements 2017/715, 2015/2147 and 2017/1014 between the Mid Sweden University and the municipalities of Sundsvall, Härnösand, and Timrå as well as Hudiksvall, Nordanstig and Ånge, Sweden.

Data Availability Statement: More data can be provided on request.

Appendix: ODD description of the implemented agent-based model of regional accessibility.

Author Contributions: Conceptualization: *All authors*; methodology: *All authors*; data analysis: *Victoria Kazieva, Aron Larsson*; writing—original draft preparation: *Victoria Kazieva*, writing; review and editing: *Victoria Kazieva*, *Christine* Große; visualization: *Victoria Kazieva*. All authors have read and agreed to the published version of the manuscript.

ISSN 2669-0195 (online) https://jssidoi.org/ird/
2024 Volume 6 Number 4 (December)
http://doi.org/10.70132//n4934286437

Victoria KAZIEVA is a PhD student in Information Systems at Mid Sweden University, Department of Communication, Quality Management, and Information Systems. Research interests: regional planning, complexity, simulation modeling.
ORCID ID: https://orcid.org/0000-0003-2560-5818

Dr. Christine GROßE is an associate professor in Information Systems at Luleå University of Technology, Division of Digital Services and Systems at Department of Computer Science, Electrical and Space Engineering and a researcher in Information Systems at Mid Sweden University, Department of Communication, Quality Management, and Information Systems. Research interests: critical infrastructure protection, information/cyber security, systemic/multi-level governance, systems science, policy and decision making, risk and crisis management, societal security, accessibility.
ORCID ID: https://orcid.org/0000-0003-4869-5094

Dr. Aron LARSSON is a professor in Computer and Systems Sciences at Mid Sweden University and Director for the Risk and Crisis Research Center. He is also an associate professor at the Department of Computer and Systems Sciences at Stockholm University. Research interests: system analysis, simulation and modeling, decision and risk analysis for policy and the evaluation of action plans.
ORCID ID: https://orcid.org/0000-0003-0310-0018

This is peer-reviewed scientific journal https://jssidoi.org/ird/page/peer-review-policy