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Decoding Social Systems: Agent-Based Modeling in Understanding Tourism Dynamics, with a Case Study on Phu Quoc Island

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Abstract

This presentation delves into information modeling methods within the realm of social sciences, specifically focusing on "Agent-based Modeling" (ABM). ABM involves the meticulous observation and analysis of computer entities known as "agents" in experimental simulations. The research emphasizes the application of ABM to study complex phenomena, using the example of tourism activities on Phu Quoc island. By scrutinizing the behavior of these agents, the study aims to enhance decision-making precision and quantify various aspects. Through simulations, cause-and-effect relationships can be identified, allowing for the testing of multiple scenarios and validation of initial hypotheses.

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1. Agents and Multi-Agent Simulation Associated with the GIS Environment

An agent, within the realm of computing systems, operates autonomously in a specific environment, possessing the capacity to sense and exert influence on its surroundings. As articulated by Agar (2005), an agent is broadly defined as "anything that can sense its environment through sensors and act on that environment through effectors." Further elucidating this concept, Bandini, Stefania, Manzoni, Sara, and Vizzari, Giuseppe (2009), describe an autonomous agent as a computing system situated in a complex and dynamic environment, functioning independently within this setting to accomplish predefined goals or tasks.

Expanding on this notion, Epstein (2002) characterizes an autonomous agent as a system intricately embedded in a specific environment, equipped with the capability to sense and operate autonomously over time. The agent diligently pursues its objectives, intending to impact its surroundings in alignment with its future perceptions. This perspective is reinforced by Espié (1995), Epstein and Axtell (1996), Johnston (2013), and Leykum (2012), collectively contributing to a comprehensive understanding of autonomous agents and their role in computing systems.

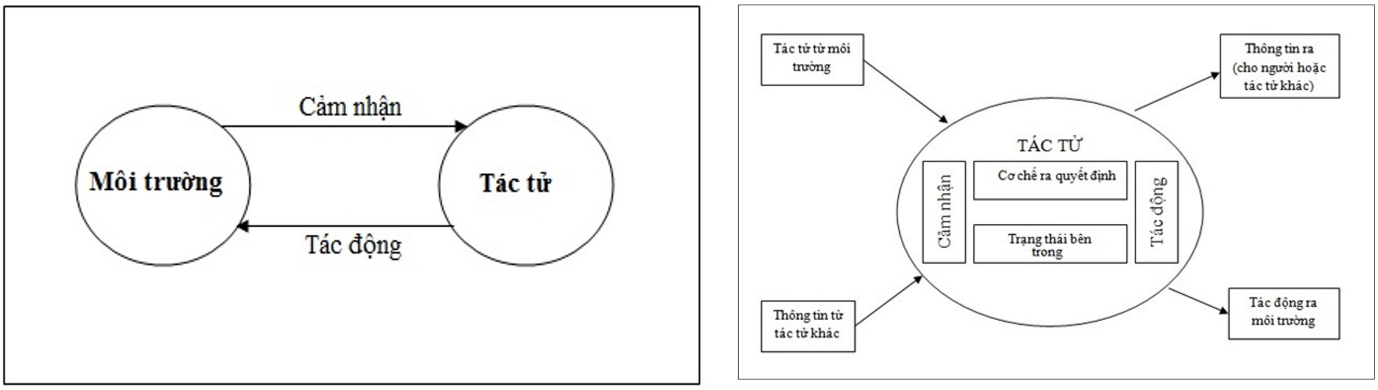
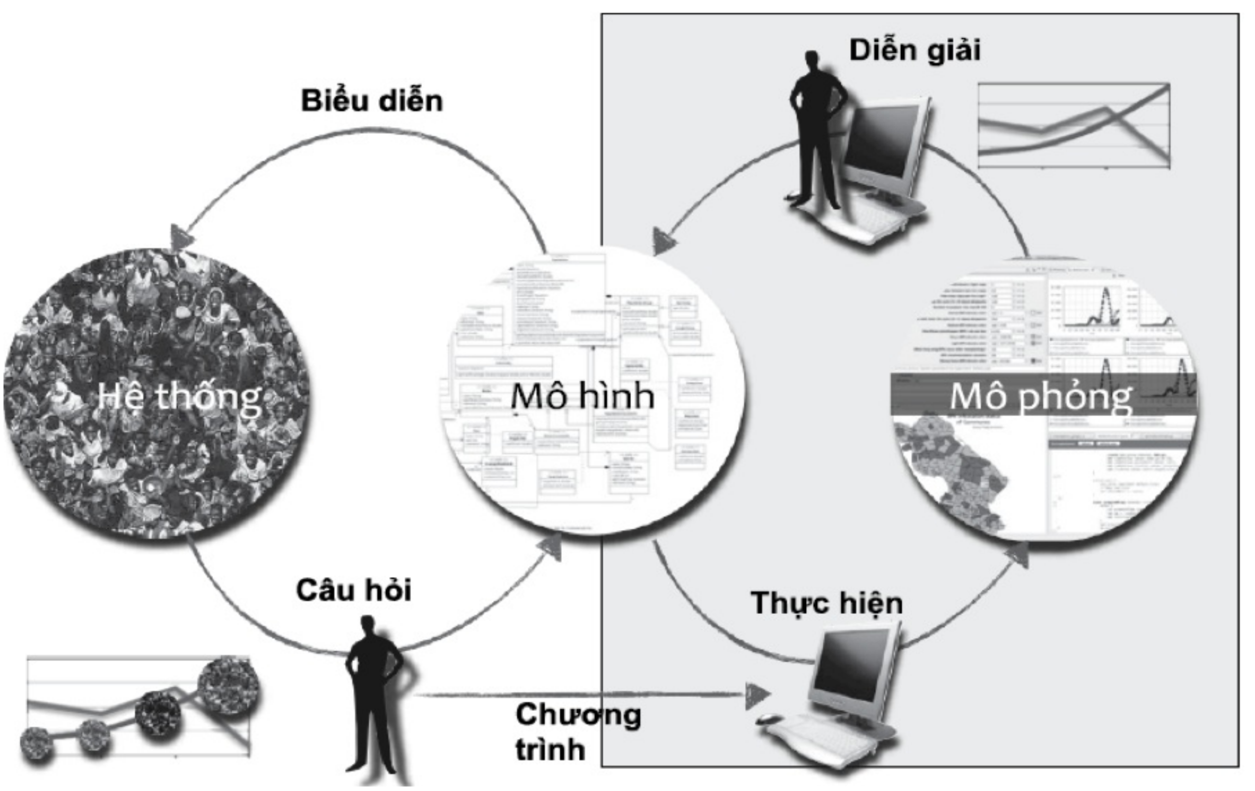


Diagram 1. Architecture of agents in any environment

Simulation is a purposeful endeavor wherein, utilizing an experimental method known as a simulator, the input data of a dynamic model undergoes manipulation, execution, and results in output data. This process aids in comprehending the functions and characteristics of the model [28], [32]. Consequently, simulation proves highly apt for modeling the process of disease spread.



Multi-agent simulation entails a system comprising numerous entities, commonly referred to as agents. These agents evolve within a shared environment, which is specifically designed as a distinct entity for other agents to inhabit [29], [30], [31]. Each agent possesses distinct attributes, behaviors, as well as cognitive and communication capabilities. The collective set of attribute values for an entity at a particular instance constitutes the state of that entity. Behaviors, serving as rules, govern changes in state by intervening in the states of agents executing these behaviors and those of other agents involved in events, actions, communication, or interactions.

In the realm of multi-agent simulation systems, the pivotal components are the environment, agents, and agent behaviors [Agar, M. 2005], [Edmonds, B. 2012].

2. Social Science with Models and Simulations

In the social sciences, simulation offers the possibility of conducting controlled computer experiments. The purpose of simulation is not to build theories but to produce in a controlled manner analyzable data, typically coming from the experiments themselves rather than from system observation results.

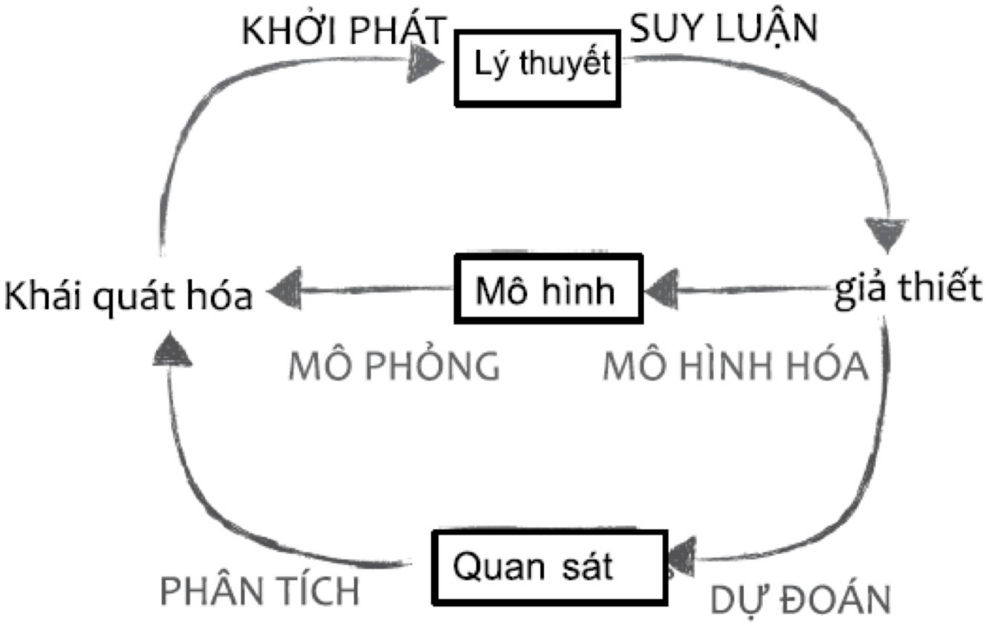


Diagram 2. Simulation process from practice

Utilizing models and simulations in social science research is imperative for several reasons: (a) When testing hypotheses becomes challenging through direct observation. (b) In cases where the actors within the system lack uniformity. (c) When intermediary relationships or organizations influencing the system's dynamics can be identified. (d) When the level of analysis is ambiguous and subject to variation. (e) When changes at the macro level need to be outputs rather than model inputs.

Multi-agent models offer numerous advantages in the realm of social sciences: (i) The capability to represent both quantitative and qualitative data. (ii) No restrictions on data format. (iii) No limitations on the level of data representation. (iv) Ability to conduct testing procedures for small worlds or miniature environments. (v) The potential for applying a participatory approach, allowing sub-worlds to blend seamlessly. (vi) The capacity to represent diverse agents of heterogeneous nature. (vii) The option to utilize real spatial or statistical data for analysis and testing [Espié, S.1995], [Epstein, JM 2002], [Epstein JM & Axtell R L.,1996], [Agar, M.2005], [Bandini, 2009], [Edmonds, B. 2012], [Johnston, K.M., 2013].

This approach underscores the flexibility and universality of multi-agent models, positioning them as valuable tools in current and future research options. The ability to choose from a multitude of experiments represents a novel method in scientific research, particularly when generating data that may not originate from the real system but is intrinsic to system models. For addressing real-world issues, scenarios built on forecast results and models representing reality become essential, enabling the preference for solutions closer to the actual situation.

3. Gis Integration for Agent - Based Projective Models

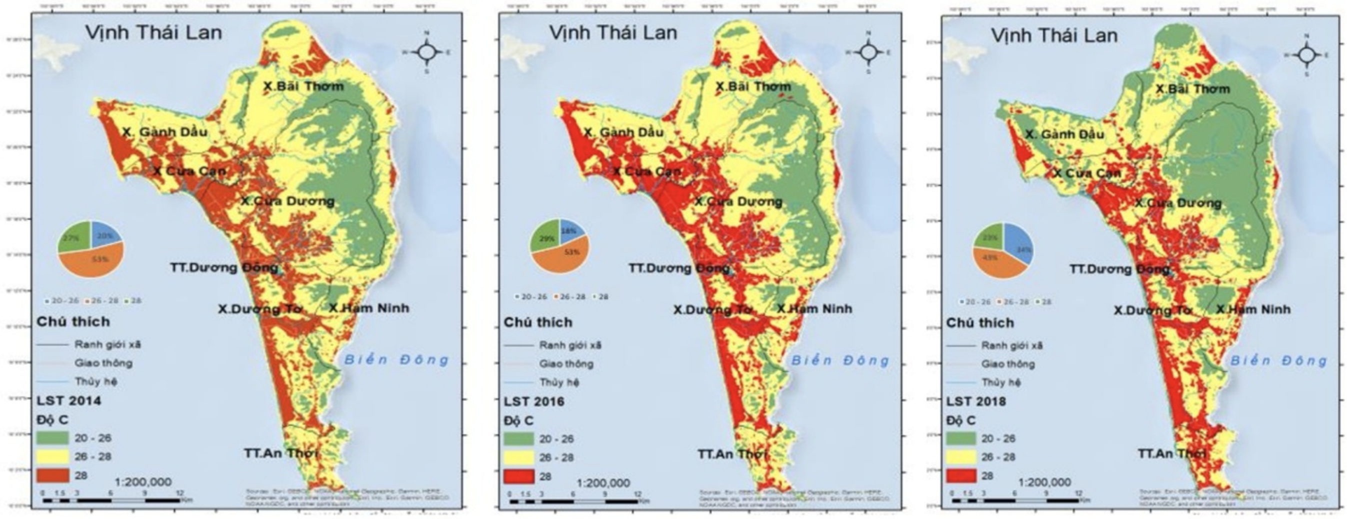
Over the last two decades, the adoption of modeling methods has witnessed significant growth across various research disciplines and scientific fields, with a notable emphasis on the social sciences (Schurr et al., 2005; Sun & Naveh, 2004; Kaminka, 2004; Kubera et al., 2010). These methods provide a means to replicate and scrutinize intricate facets of the real world by conducting "in-silico" experiments or simulations in a computer environment, mirroring natural processes.

Advancements in multi-agent modeling have paved the way for exploring and applying solutions to complex problems (Treuil JP, 2008). Several multi-agent simulation platform software options cater to modeling needs, including Repast, Netlogo, Cormas, and GAMA. Each platform has distinct strengths, with the GAMA software, in particular, offering robust tools for supporting visual multi-agent modeling (Taillandier P., 2014; Burrough, P. et al., 2015). Notably, GAMA stands out for its capability to work with agents derived from Geographic Information System (GIS) data, incorporating various processing and computing tools for geographic data (Taillandier P. et al., 2014) — a feature not strongly supported by other simulation software (Gignard A. et al., 2013).

The software's objective is to construct intricate models enabling the integration of diverse data to capture the behaviors of agents and observe real-world scenarios. By integrating geographical data and employing a multi-level model development method, the software facilitates simplicity in managing and fostering interaction between levels of Agent-Based Models (ABMs). To enhance the complexity of models, the software incorporates mathematical, statistical, or artificial intelligence tools to harness the capabilities of agents. Decision algorithms and clustering play pivotal roles in the analysis of agent-based modeling. This approach is particularly apt for research on modeling with GIS data, a type of data integral to land management and agriculture.

4. Experimental Case of Urbanization of Phu Quoc Island

Land surface temperature (LST) is considered one of the indicators and factors that have a close relationship with assessing the speed of urbanization, urban heat island, urban formation, and development with related environmental factors. LST is an environmental parameter expressed by emissions from ground elements. LST shows the process occurring below ground in a positive or negative direction through the temperature progression monitored over a specified period of time. Land surface temperature is expressed as a raster; the polygon hierarchical area of emission area values with equal compatibility will show the same level through the most intuitive color representation.



Bản đồ LST đảo Phú Quốc qua các năm 2014, 2016, 2018 (Long Ngo biên tập, 2019)

Diagram 3. Depicts the Land Surface Temperature (LST) of Phu Quoc Island from 2014 to 2018, conducted by the author in 2019.

Analyzing the surface temperature chart reveals a discernible upward trend in temperatures, particularly concentrated in specific regions such as the west coast of Phu Quoc Island. Notable temperature changes are observed in the northwest and southwest areas between 2018 and 2014, as well as between 2016 and 2018. The Duong Dong area exhibits an expansion both north and south, with increased density, particularly evident around residential clusters. Over the years, the region has experienced relatively high and consistent temperatures, with lower temperatures concentrated in the northern fault zone of the island and towards the east.

The distribution of heat density appears to emanate from the central area of Duong Dong, extending along the west coast and gradually increasing along the north-south axis, encroaching on mountainous areas. Combining this with vegetation cover complicates the determination of how construction shapes socio-economic activities and influences the urbanization rate of Phu Quoc Island.

To address this issue, the research team employed NetLogo (Axelrod, R., 1997; Axtell RL, 2003) and integrated GIS into NetLogo. This software, known for its GIS extension, enables the reading of data files from GIS and facilitates the transfer of values from previous GIS results into the NetLogo environment for simulations. Loading the shapefile, along with the associated *.dbf and *.prj attributes, is accomplished using the following syntax: [syntax example may be provided here, code 1]:

```
set dc-dataset gis:load-dataset "data/DC.shp"
```

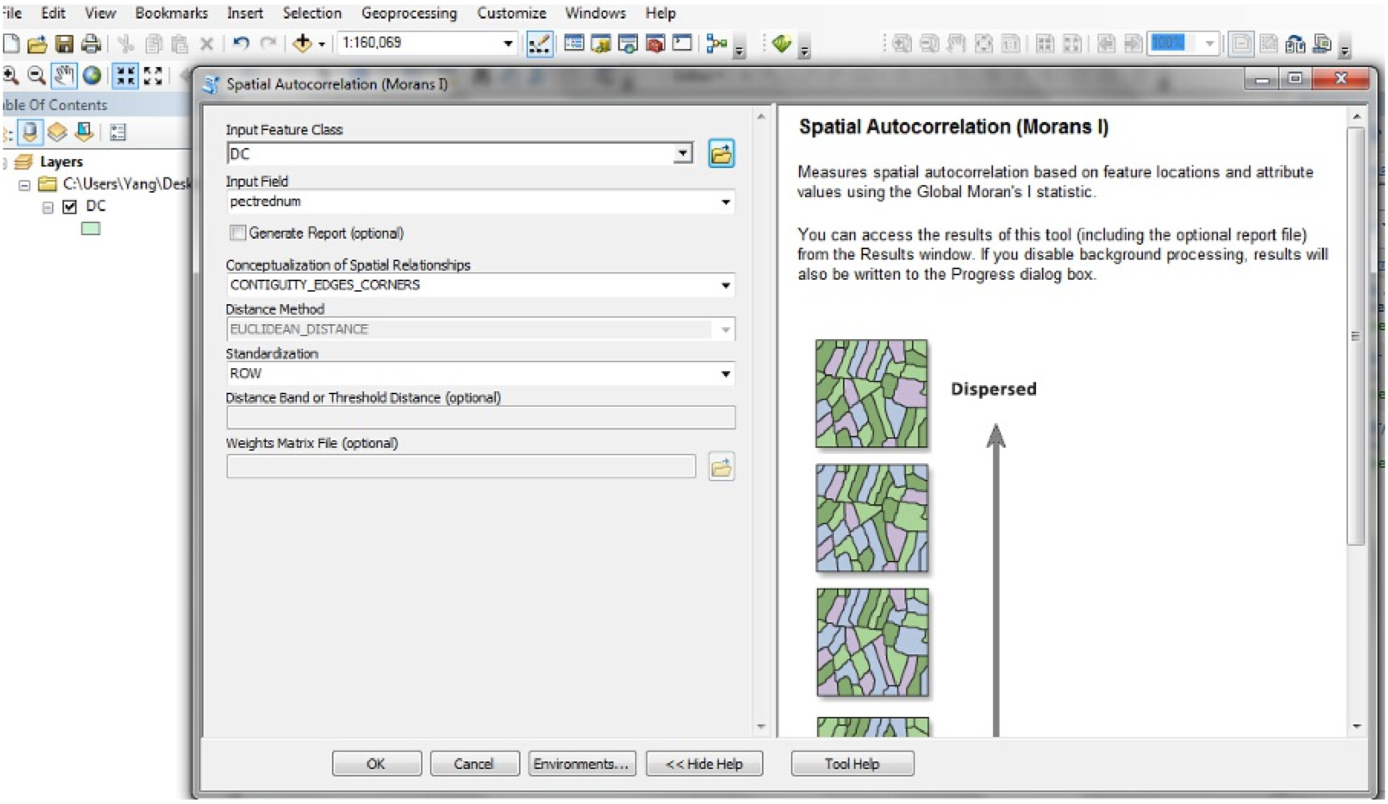
In ArcGIS, there is a tool called Polygon Neighbor. For polygons, the tool finds all polygons with matching edges and arranges the information in a table using the following important syntax: [syntax example may be provided here code 2]:

```
;;drawing map
 foreach gis:feature-list-of dc-dataset
[ if gis:property-value ? "SOC" = "RED" [ gis:set-drawing-color red  gis:fill ? 2.0]
  if gis:property-value ? "SOC" = "BLUE" [ gis:set-drawing-color blue  gis:fill ? 2.0]
  if gis:property-value ? "SOC" = "UNOCCUPIED" [ gis:set-drawing-color grey  gis:fill ? 2.0]
  ]

gis:set-drawing-color white
gis:draw dc-dataset 1


file-close
file-open "data/neighbors.txt"

while [not file-at-end?] [
let x file-read let y file-read
ask patches with [ID = x ] [set myneighbors (patch-set myneighbors patches with [ID = y ]) ]
]
file-close
```




```
;;each polygon identifies a patch at centroid, which records the color and population here
let n 1
foreach gis:feature-list-of dc-dataset
[ let center-point gis:location-of gis:centroid-of ?
  ask patch item 0 center-point item 1 center-point [
    set ID n
    set mycolor gis:property-value ? "SOC"
    if mycolor != "UNOCCUPIED" [sprout 1 [ ht set tcolor [mycolor] of myself setcolor]
]]
  set n n + 1]
```

The findings reveal that the total area of the island is 557 km². Within a span of just two years, the construction area on the island has surged by 56%, escalating from 17.8 km² in 2012 to 27.7 km² in 2016. However, in 2018, due to inspections, construction underwent a temporary halt, with some projects on the island either suspended or awaiting trial due to legal violations. The observable change is predominantly concentrated on the west coast of the island. A clear developmental shift is evident in the northwest of the island, particularly in the Ganh Dau area, characterized by the establishment of resorts, hotel restaurants, and townhouses. Notably, Cua Can commune and the urban center of Duong Dong witness a denser transformation in 2018.

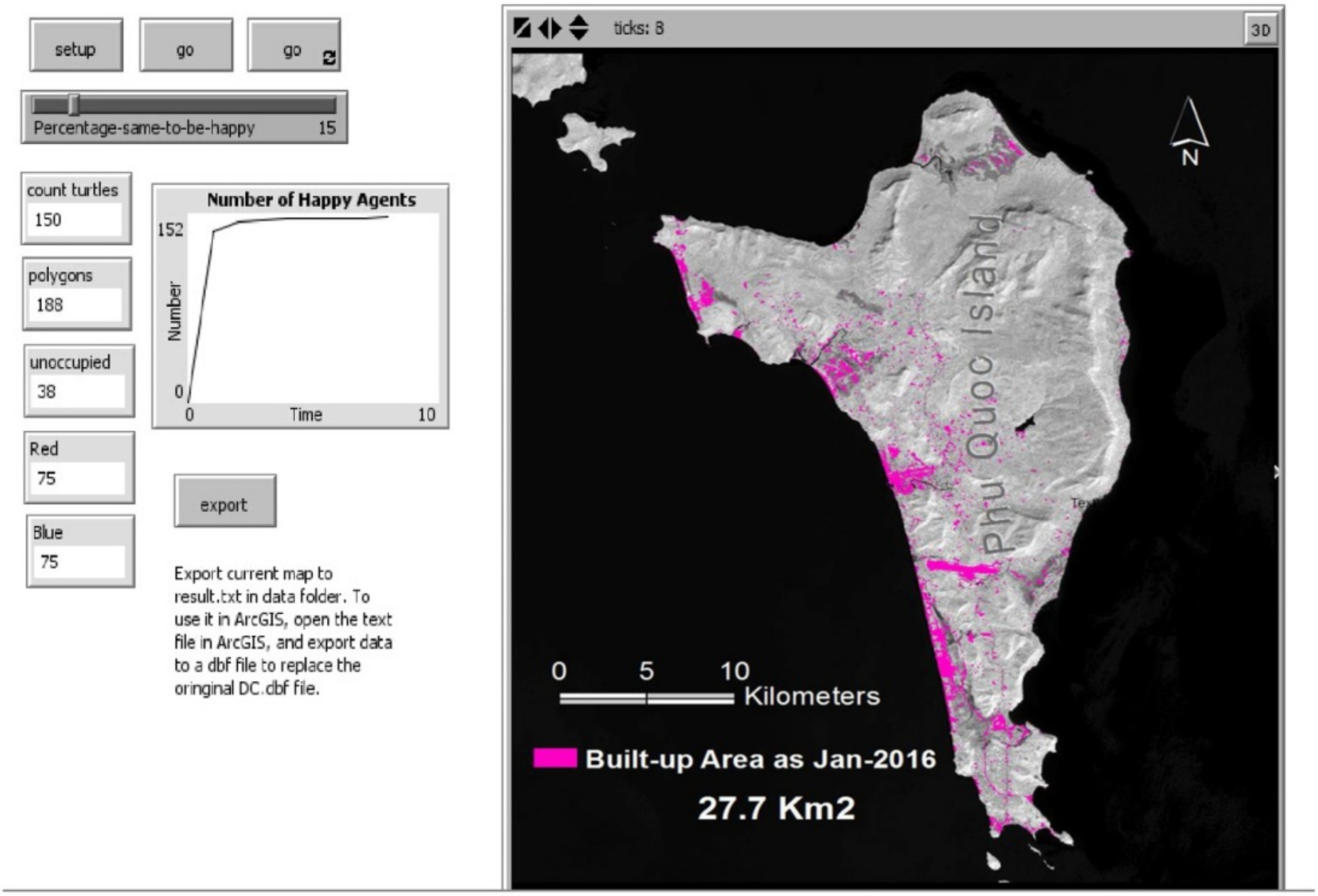


Figure 1. Simulation analysis from the NetLogo software for construction on Phu Quoc island

It is especially easy to spot a road about 15km long stretching from Phu Quoc airport to the central area of An Thoi in the south of the island. However, on the west side of the island (east of the main road), too dense construction has blocked the drainage path for rainwater, causing local flooding. The results of this simulation analysis are reproducible according to independent analysis by the P-GIS company [2]. These data are analyzed from Sentinel-1 radar satellite images obtained on August 10, 2019, by P-GIS. GIS in progress.

Comparative practice shows that up to 63km of roads across the Phu Quoc island district were flooded with an average depth of 0.7m, and the deepest flooded place was up to 2m; as a result of this local flooding, 23 houses were damaged. Roofs were blown off, collapsed, cracked, and more than 8,400 houses were flooded. Nearly 2,000 people were evacuated to shelters. The total damage is estimated at more than 107 billion VND. (according to the Tuoi Tre newspaper) [3].

Figure 2. An independent analysis from P-GIS company from Phu Quoc, 2019

5. Results and Discussion

The adjusted general construction plan for Phu Quoc Island, Kien Giang province, until 2030, as approved by the Prime Minister in Decision No. 633/QD-TTg dated May 11, 2010 (Plan 633), outlines the land use model for the entire island by 2030. The adjustments include approximately 4,003 hectares for tourism land, 3,325 hectares for tourism and residential service complexes, 37,430 hectares for forestry land (including 6,666 hectares for protective forest land), and 3,953 hectares for agricultural land (with 2,719 hectares for agricultural production land and 1,234 hectares for land in rural craft villages).

Furthermore, Phu Quoc National Park, established by the Prime Minister in Decision No. 91/2001/QD-TTg dated June 8, 2001, converting the North Phu Quoc Island Nature Reserve into a National Park, covers 29,420.6 hectares, constituting 49.9% of the total natural area of Phu Quoc Island. Over the decade from 2008 to 2018, Phu Quoc's population increased from 84,873 to 101,629 people, with a notable mechanical increase. The natural population growth rate decreased from 1.51% to 1.25%. The remarkable economic growth by the end of 2016, leading to a 4.5-fold increase in total production value at real prices compared to 2011, significantly influenced changes in land use and the urbanization process of Phu Quoc Island.

The application of agent-based modeling, combining ArcGIS with ABM modeling software, is deemed feasible for Phu Quoc Island. Various suitable software options are available, including Johnston, KM (2013), Kevin M. Johnston (2006). However, integration remains challenging, and compatibility issues with Repast have been complicated by changes in ArcGIS 10.x versions.

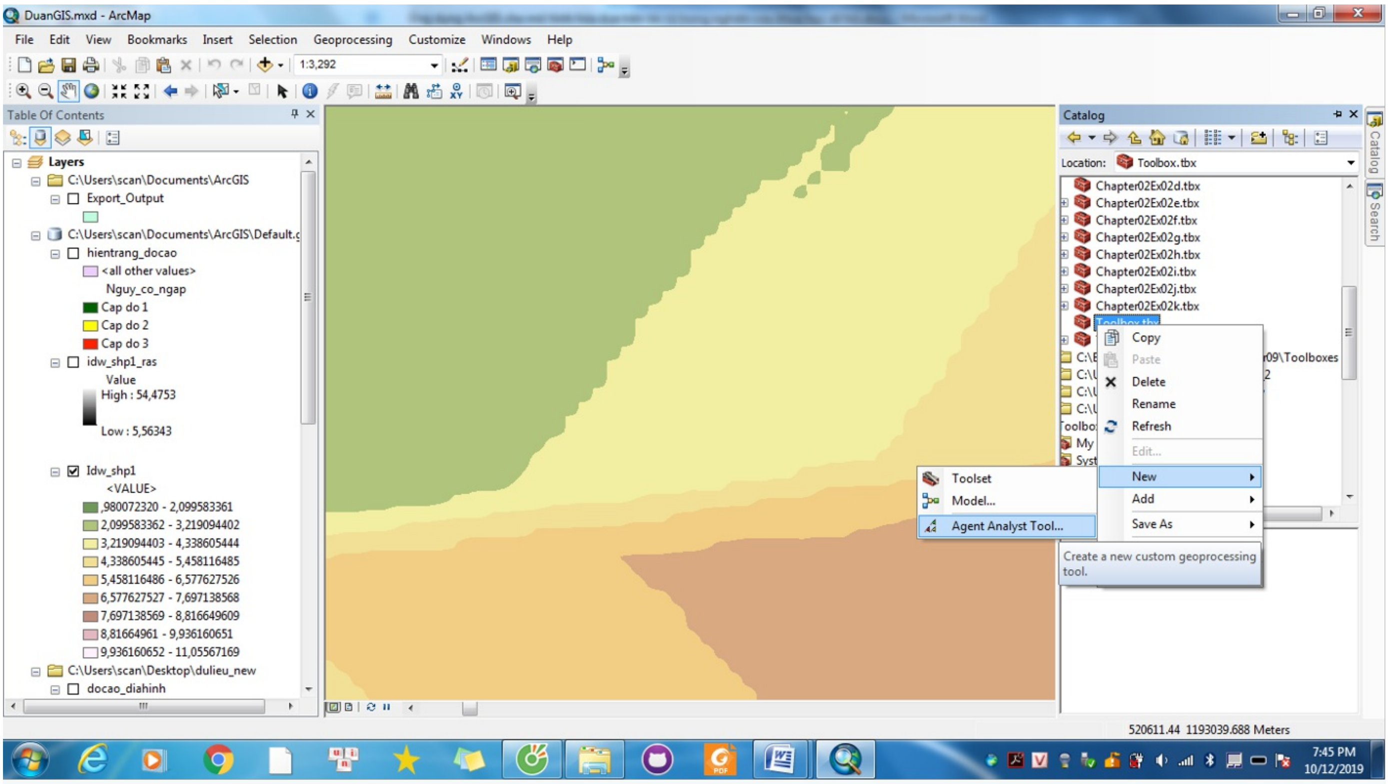


Figure 3. Screenshot from Repast software analysis

On the other hand, some commercial software, such as AnyLogic (see photo below), a Russian-exclusive version of ABM, is also quite difficult to access for those who care about this issue due to copyright reasons. Therefore, for researchers and academics to study and exploit GIS data, NetLogo is still a good choice because of its simple simulation, straightforward programming, and diverse and powerful library. Many applications at small and medium scales are very suitable; especially for social scientists, learning a software with many complex functions is quite difficult.

These simulation models also allow for concretization with adjustable algorithms, interdisciplinary, multidisciplinary, and even cross-disciplinary exchanges with the same research object, and the collection of quantitative and qualitative data from social science research disciplines into the same general model to test accuracy, thanks to the ability to express, through direct contact with the real world.

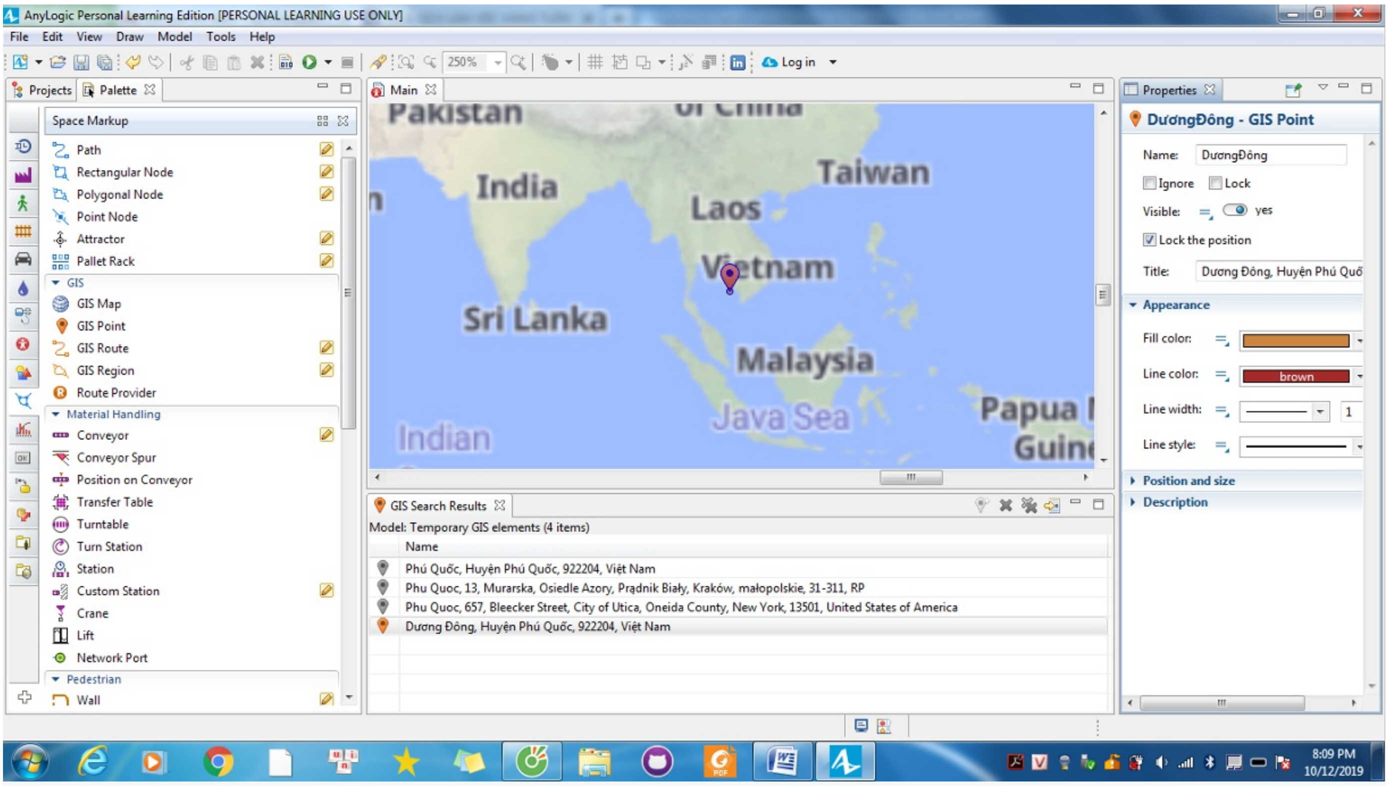


Figure 4. Screenshot from AnyLogic software analysis

In summary, choosing software to apply ABM in studies like the Phu Quoc case will help support more accurate decision-making.

6. Conclusion

In the last five years, over 1,500 hectares of forests and forest land from Phu Quoc National Park have been reallocated from special-use forests for the implementation of economic development plans. Forests and forest vegetation cover play a crucial role in regulating and maintaining fresh water resources, a pivotal factor in determining the island's capacity for tourism and services development.

Phu Quoc Island boasts a favorable starting point, marked by a high economic growth rate, a substantial Gross Regional Product (GRDP) per capita, and numerous modern investment projects. The GRDP growth rate for Phu Quoc reached approximately 22% per year from 2011 to 2018, which is about three times higher than the national growth rate (5.9% per year). In 2018, the average GRDP per capita for Phu Quoc reached $5,569/person/year, surpassing the national average by more than 2.6 times. The island is experiencing rapid urbanization. However, the use of control tools to promptly provide effective solutions to decision-makers is crucial. To address these complexities, the application of experimental simulations using specialized software such as ArcGIS, NetLogo, and others becomes essential. These simulations, employing "agent" information technology entities (agents), are meticulously observed and analyzed down to the smallest detail.

This approach aims to support more accurate decision-making, particularly in the planning and development strategy for Phu Quoc Island as it aspires to become a special administrative-economic zone of the country.

Footnotes

[1] Ph.D. candidate of the Environmental Resource Management program, class of 2017

[2] See more at: Severely flooded area in Duong To commune, Phu Quoc, Kien Gianghttp://www.p-gis.com/2019/08/phu-quoc-ngap-chua-tung-thay.html?fbclid =IwAR3oZfLq60_mkCrl1kYw_FWND_q8nQkpkpZcZTDezXqTav4nc5J25UOubaQ

[3] https://tuoitre.vn/bang-hoang-nhung-ngay-dao-ngoc-phu-quoc-thanh-dao-ngap-2019081022144861.htm

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