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Activity-based process construction for participatory geo-analysis

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ABSTRACT

Due to its advantages in participation and collaboration, participatory geo-analysis has been used for solving different types of geographical issues. Participatory geo-analysis is usually a complicated process consisting of various tasks that may involve different multidisciplinary participants. Previous studies have focused primarily on how to improve participation in specific individual tasks, especially idea discussion and decision-making, but they have ignored collaboration throughout the entire process. During a complete participatory geo-analysis effort, the various participants should concentrate on their familiar work and fully exploit their talents to perform work collaboratively. Therefore, we propose an activity-based process construction method to assist different participants in understanding the geo-analysis process and in concentrating on their familiar work. Eight core activities are established for the geo-analysis process: (1) context definition and resource collection, (2) data processing, (3) data analysis, (4) data visualization, (5) geo-analysis model construction, (6) model effectiveness evaluation, (7) geographical simulation, and (8) decision making. By using a visualization-based method, different activities can be linked together to represent the entire analytical process. Moreover, each activity is designed via a specialized web-based workspace in which online tools and resources are accessed to assist the participants with their geo-analysis practices. A prototype system was developed based on the proposed method, and a case study on a participatory risk assessment of coronavirus disease 2019 (COVID-19) was demonstrated using this system. The result suggests that the proposed method can promote collaboration among participants with different backgrounds, and verifies its feasibility and suitability.

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1. Introduction

Geographical issues generally involve different geographic processes and phenomena, such as climate change, pollution exposure, and urban flooding (Ruiz, Faria, and Neumann 2020; Vieira et al. 2013; Almoradie, Cortes, and Jonoski 2015). To address these issues, the interactions and evolving processes among the factors in the geographic environment need to be clarified to understand geographic processes and phenomena (McGetrick, Bubela, and Hik 2015; Usón, Klonner, and Höfle 2016; Chen et al. 2020). The geo-analysis method can facilitate a better understanding of geographic environments and serve human beings by using various geography-related data, geo-analysis models, and geographical theories (Wood1999; Yue et al. 2016; Lü 2011).

Due to the complexity of geographical issues, the practice of geographic analysis usually requires participatory approaches to support stakeholder participation and interdisciplinary collaboration (Cutts, White, and Kinzig 2011; Lin et al. 2013b; Lin and Chen 2015). Because geographic issues are normally relevant to human life and usually attract the attention of both stakeholders and the public, geo-analysis cannot be exclusively an expert domain; it also requires the participation of different stakeholders and the public to supply useful resources and valuable feedback (Voinov and Bousquet 2010; Voinov et al. 2016; Jordan et al. 2018; Musch and von Streit 2020). By contrast, collaboration involves higher levels of participation and can help to address geographical issues through joint actions (e.g., co-modeling and co-decision-making) (Basco-Carrera et al. 2017). In collaborative contexts, experts from different domains can share valuable expertise and collaborate to analyze the distinct dimensions, scales, geographic boundaries, and complex interactions

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among geographic elements (Parrott 2017; Zhu et al. 2007; Li et al. 2015; Zhu et al. 2016). Therefore, participatory geographic approaches have been employed in different geographical applications, such as forest management (Suwarno, Nawir, and Kurniawan 2009; Kelly et al. 2012), water resource management (Gaddis et al. 2010), and disaster risk management (Almoradie, Cortes, and Jonoski 2015; Usón, Klonner, and Höfle 2016).

Geo-analysis is generally a complex process that includes various tasks, such as data processing and model building, and it requires different participants (Lin et al. 2013b; Torres et al. 2020; Badham et al., 2019; Chen and Lin 2018). To improve participation in an individual task, the existing studies have shown many achievements. For example, Chen et al. (2019) and Yue et al. (2019) focused on integrated modeling to conduct participatory research; other experts have focused on decision-making with the aim of sharing decisions and gaining feedback (Kelly et al. 2012; Almoradie, Cortes, and Jonoski 2015). However, it is still difficult to force data scientists, model experts, and stakeholders to work together from beginning to end. Specifically, model experts might be inexperienced in analyzing massive spatial data, and stakeholders may not be able to take responsibility for building models. Throughout the entire participatory process, it is necessary to help each participant engage in familiar work to give full scope to their talents.

To promote the practice of whole-process participatory geo-analysis, it is significant to assist different participants in understanding the geo-analysis process while also helping them to concentrate on their specialized work (Zhu et al. 2020). Because of the complexity of geographic processes and phenomena, the pathway of geographic problem-solving is generally different. Participants need to acquire an awareness of the geo-analysis process to determine which tasks are required. Additionally, to organize these tasks, the geo-analysis process needs to be represented in an appropriate way. Many studies have focused on understanding and representing the process for solving geography-related problems. In these studies, the process can be iteratively constructed using several basic parts (named "steps," "stages," or "phases") (Parrott 2017; Badham et al., 2019; Jakeman, Letcher, and Norton 2006; Elsawah et al. 2017; Hamilton et al. 2019). In this way, the activity for managing a series of tasks with similar purposes can be used to represent the geo-analysis process. Furthermore, to help participants devote themselves to the areas in which they are skilled, several workplaces may be needed for different geo-analysis activities (Lin, Chen, and Lu 2013a). Participants with different backgrounds can choose distinct workplaces and engage in the activity cooperatively. Thus, data scientists can focus on data analysis; model experts can concentrate on modeling and simulation; and stakeholders can communicate demands and provide feedback.

In this paper, we propose a process construction method for participatory geo-analysis based on several core activities that are designed to manage different tasks. Each activity has a specialized web-based workspace in which geographically distributed participants can perform geo-analysis tasks together with the support of online tools. By using this method, the geo-analysis process can be visualized to improve participant understanding of the complete geo-problem solution. Then, each participant can select appropriate activities and engage in familiar work.

The remainder of this article is structured as follows. Section 2 introduces the basic idea underlying the activity design for participatory geo-analysis. Section 3 explains the functions of each activity in detail. The implementation of the activity-based method for participatory geo-analysis is described in Section 4. Section 5 introduces a prototype system and Section 6 verifies the activity-based method with a simple case study. The article is concluded in Section 7 with further discussion.

2. Basic idea of the activity design for participatory geo-analysis

The activity that could constitute the problem-solving pathway is the key point of this proposed method for participatory geo-analysis (Voinov et al. 2018). These activities can generally be classified into four categories according to their different purposes: awareness-related activities, data-related activities, model-related activities, and application-related activities (Robson et al. 2008; Laniak et al. 2013; Blocken and Gualtieri 2012).

(1) The awareness-related activities include a series of tasks to gain awareness about how to conduct a geo-analysis. During these activities, geographic problem-related resources are collected to enhance our understanding of geographic phenomena in geographic problems. Additionally, the

background, limitations, accessible methods, and other valuable information about the problems need to be clarified. Therefore, it is important that interdisciplinary participants communicate about ideas and demands, prepare sufficient resources, and sufficiently understand the geographic problems (Badham et al., 2019).

(2) The data-related activities include tasks that are primarily relevant to data operations (e.g., converting data formats and editing data). Data are crucial for demonstrating geographic phenomena and processes. However, due to the heterogeneity of data, it is sometimes infeasible to use data directly. The data-related activities aim to prepare appropriate data and discover valuable information by changing the format, structure, attribute, or representation of data. Through these activities, participants can share knowledge, communicate about data processing methods, and conduct data-related operations collaboratively.

(3) The model-related activities involve different tasks and operations that are related to models, such as conceptual model building, model calibration, and model evaluation. A geographic model is an abstract representation of knowledge on geographic systems, and this type of representation can be used in the simulation and analysis of geographic processes (Badham et al., 2019). However, using an appropriate method to build a qualified model is usually difficult. Therefore, these activities are needed during modeling practice to generate credible models. In the model-related activities, participant engagement can improve understanding of the interactions in the geographic environment and lead to better modeling outcomes (Jakeman, Letcher, and Norton 2006).

(4) The application-related activities involve the application of prepared data, models, and methods to address geographic problems in human life directly. Appropriate data and models that were previously processed or built are used in these activities. For example, a forest growth model was built, and the field data were processed. In the application-related activities, different tasks are required to use these data and models to forecast growth and yield for forest management. Furthermore, participatory application-related activities can help participants, including managers and stakeholders, to balance different viewpoints and obtain better outcomes while addressing geographic problems (Jakeman, Letcher, and Norton 2006; Jones et al. 2009).

To help manage different tasks and represent the geo-analysis process during participatory geo-analysis practices, eight core activities are defined from these categories, namely context definition and resource collection, data processing, data analysis, data visualization, geo-analysis model construction, model effectiveness evaluation, geographical simulation, and decision making, as shown in Figure 1 (Jakeman, Letcher, and Norton 2006; Elsawah et al. 2017; Badham et al., 2019). These activities are designed in accordance with the purpose of the different tasks in the geo-analysis process. For example, both context definition and resource collection are preparatory tasks for geo-analysis.

3. Functions of defined activities in participatory geo-analysis

These core activities are designed to construct the geo-analysis process. Subsequently, participants can understand the geo-analysis pathway and be guided to engage in different tasks to focus on achieving specialized functions. Therefore, to obtain better geo-analysis outcomes, the detailed functions of these activities in participatory geo-analysis must be clarified.

3.1 Context definition and resource collection

The context definition and resource collection activity is designed to understand the geo-problem and prepare the related resources. As defined by Badham et al. (2019), the context consists of geographic problem-related characteristics that could influence the geo-analysis processes, such as the geo-analysis purpose, spatiotemporal boundaries, dimensions or scales, and relevant techniques or methods. To improve the understanding of the geo-problem, related resources also need to be collected and shared (Simão, Densham, and Haklay 2009; Wen et al. 2013; Zhang et al. 2019; Wang et al. 2020).

However, it is unlikely that one person possesses all of the required resources and comprehensively understands the context of a geographic problem. Participation and collaboration can facilitate both context definition and resource collection. Specifically, in this activity, the context of geographic problems can be clarified through conflict negotiation and knowledge sharing among participants. In addition, the participants could share their data, models, tools,

Figure 1. Eight core activities for participatory geo-analysis. The gray rectangle indicate problem-oriented activities; the orange rectangles indicate data-related activities; the green rectangles indicate model-related activities; and the blue rectangles indicate application-related activities.

documents and other resources. With the assistance of these resources, multidisciplinary participants could explore the solution of geo-problems together.

3.2 Data processing

Data processing is a critical step in the process of understanding geographic environments. Because of the heterogeneity of data, valuable and appropriate data need to be prepared for different modeling and analysis processes (Famili et al. 1997; Visser et al. 2002; Wang et al. 2018).

However, performing data processing for distinct purposes, such as data conversion, data regeneration, and data editing, is usually difficult. The participatory approach is a good way to assist with various tasks, such as data characteristic analysis, method selection, and collaborative operation, thereby facilitating data processing. Here are some examples: (1) Due to differences in data formats, the data collected by participants may be inappropriate for modeling and analysis. By collaboratively determining and converting the data formats, participatory data conversion can provide useful data with proper formats. (2) For processing tasks that involve generating new data from existing data by using models or algorithms (e.g., data upscaling/downscaling, data fusion, and data interpolation), different data experts are usually required to share their knowledge on selecting and using models or algorithms for data processing. (3) Manual/semimanual data editing operations could also be used during this activity to modify or adjust the original data for quality improvement (e.g., outlier removal, topological error correction, and geometric correction). For these data processing operations, participatory approaches can play an important role by improving efficiency.

3.3 Data analysis

Data analysis generally involves analyzing both the original data and the resulting data. During this activity, mathematical or inductive methods can be used to perform quantitative and qualitative data analyses to detect notable geography-related information and patterns (Yilmaz 2013; Brunsdon 2016; Jung and Elwood 2010). In addition, to address spatial issues, spatial analysis and spatiotemporal analysis are needed. Different types of methods can be adopted to analyze geometric, topological, geographic, or temporal properties and explain spatial phenomena (Dixon et al. 2018; Schiappapietra and Douglas 2020).

Participatory approaches can promote the implementation of data analysis. Applying this activity during the geo-analysis process relies on a set of techniques that require professional knowledge and skills, especially spatial analysis and spatiotemporal analysis. Participatory approaches can support both quantitative and qualitative data analyses by collaboratively selecting alternative techniques and conducting professional co-analyses. For instance, some key parameters such as the weights of the primary factors in AHP (analytic hierarchy process) need to be discussed by participants. Therefore, sharing and communication among participants with multidisciplinary expertise and experiences are essential in data analysis.

3.4 Data visualization

Data visualization is also a data-related activity. Data are often represented in an unintuitive way such that valuable information and knowledge are hidden (Chen et al. 2013; Lin and Chen 2015). Data visualization can assist with mining information and knowledge from the confusing original data through the use of charts, graphs, maps, etc.

Through participatory approaches, participants can discuss the selection of visualization methods and valuable variables. In particular, through real-time visualization tools, experts can interact with data and other participants (Donalek et al. 2014; Taesombut et al. 2006). In addressing unfamiliar data, data visualization with participant engagement can provide novel ideas for presenting information in a creative way; for familiar data, the participatory approach can help forecast the likely outcomes and identify an appropriate visualization method (Viegas, Wattenberg, and Feinberg 2009). In addition, the effects of visualization can be judged by all participants together. Thus, during the participatory geo-analysis, participatory data visualization can assist users in understanding the data, identifying significant variables, performing outcome comparison and evaluation (Rinner 2007), and transmitting valuable information to the public (Pettit, Cartwright, and Berry 2006).

3.5 Geo-analysis model construction

Geo-analysis model construction is an important activity that can lead to an abstract representation of knowledge about a geographic phenomenon or process for different purposes, such as prediction, interpolation, geo-process understanding, and hypothesis testing (Badham et al., 2019; Jakeman, Letcher, and Norton 2006). Generally, the model construction process comprises several main tasks: (1) building conceptual models, (2) selecting model features and families, (3) determining algorithms and criteria for model calibration, and (4) identifying model structure and parameters (Jakeman, Letcher, and Norton 2006).

Participatory model construction approaches have several advantages over traditional approaches (Badham et al., 2019; Sieber 2006). In general, by collecting different standpoints and knowledge from engaged model builders, users can obtain common ideas about the modeling strategy selection. Through participatory approaches, co-analysis and co-modeling can be achieved with the engagement of multidisciplinary participants, which can provide insights into the geographic process and help determine the model structure (and model parameters).

Participation and collaboration can also play significant roles in different modeling processes, such as individual model construction and integrated model construction. (1) During participatory individual model construction, participants can share knowledge regarding geo-processes and cooperatively use the appropriate modeling methods (e.g., statistical methods, system dynamics methods, and agent-based methods) to formalize these geo-processes as equations or rules (Badham et al., 2019). (2) By contrast, during participatory integrated model construction, participatory approaches can benefit the co-analysis of subelements, subprocesses, and relations in the geographic system and the co-selection of individual models (model components and model services) for integration (Chen et al. 2019; Elsawah et al. 2017; Ma et al. 2019; Lü et al. 2019).

3.6 Model effectiveness evaluation

Once a model is built, its effectiveness needs to be evaluated. To improve the credibility and usability of models before they are applied, their uncertainty and performance must be evaluated through specific methods, such as a discussion on the model assumptions and the model error analysis (King, Fu, and Kelly 2011; Bennett et al. 2013). During this activity, participants might conduct several different tasks, such as model validation, sensitivity analysis, uncertainty analysis, and model comparisons (Eker et al. 2018; Koo et al. 2020; Matott, Babendreier, and Purucker 2009; Yue et al. 2020).

Without adequate knowledge of the model effectiveness evaluation, it is difficult to take responsibility for this work as an individual researcher. Thus, participatory approaches are needed to support the evaluation of the model effectiveness. For example, model effectiveness evaluations usually require expertise on various statistical methods (e.g., Monte Carlo, Bayesian, and ANOVA approaches) and metrics (e.g., R-square (coefficient of determination), RMSE (root mean square error), and AIC (Akaike information criterion)) (Bennett et al. 2013; Crosetto and Tarantola 2001). The participatory approach can help to identify the appropriate methods and metrics for the uncertainty analysis, model validation, model comparison, etc. In addition, participants can share alternative evaluation methods of model uncertainty and performance to reduce the probability of obtaining the "wrong" outcomes.

3.7 Geographical simulation

The geographical simulation is another significant step in the geo-analysis process. Through appropriate models and data, the geographic processes and phenomena can be demonstrated in this activity, such as typhoon disaster simulation (Takagi et al. 2017; Chen et al. 2011), labor mobility simulation (Whalley and Zhang 2007), and traffic noise simulation (Nejadkoorki, Yousefi, and Naseri 2010).

With a participatory approach, it is possible to perform co-simulations among geographically distributed participants. Especially for a comprehensive geographic simulation, different participants may be familiar with only geographical models or simulation tools from their own fields. Therefore, when participants collaborate to optimize the simulation outcomes, they can identify the appropriate models, data, and parameters through cooperative model selection, data configuration, and parameter adjustments. Furthermore, the simulation results need to be tested. Thus, by using participatory approaches, the participants can collaborate to normalize and evaluate the resulting data.

3.8 Decision making

To solve geographic problems that directly affect human lives (e.g., forest management, urban planning, and disaster responses), decision making is a crucial activity (Kelly et al. 2012; Almoradie, Cortes, and Jonoski 2015; Torres et al. 2020). Generally, geographic decision-makers identify alternatives for management and planning. These alternatives are then weighed and compared based on modeling and analysis results from previous activities. Lastly, one or more appropriate alternatives are selected to address the actual geographic problems that affect human life.

Participation and collaboration are also required for the decision making activity (Kelly et al. 2012; Almoradie, Cortes, and Jonoski 2015). There are a number of tools that can be used to support decision making, such as the multi-objective decision-making tool and the multi-attribute decision-making tool. The selection and use of tools generally require the engagement of experienced participants. In addition, decision making is not the exclusive work of managers and experts. Stakeholders and members of the public can also play roles in decision making by providing proposals and making demands. Although some stakeholders have little knowledge of models, algorithms, and other technical matters, the participatory approach can improve the transparency of geo-analysis and produce more credible results (Mendoza and Prabhu 2006).

4. Implementation of the activity-based method

This activity-based method is implemented through two steps. First, the core participants who are organizing and managing the geo-analysis practice use the eight activities described above to construct the geo-analysis process. The other participants then engage in the activities and pursue their goals in the corresponding web-based workspaces with the help of specialized tools.

4.1 Visualized geo-analysis process construction

Based on these activities, the geo-analysis process can be constructed in web environments. A visualization-based method is designed to customize the geo-analysis process according to the different geographic problems and it uses the DCG (Directed Cyclic Graph) to visualize and depict the geo-analysis process (supported by ECharts, https://www.echartsjs.com). As shown in Figure 2, each node in the DCG represents an activity, and the type of activity is distinguished by

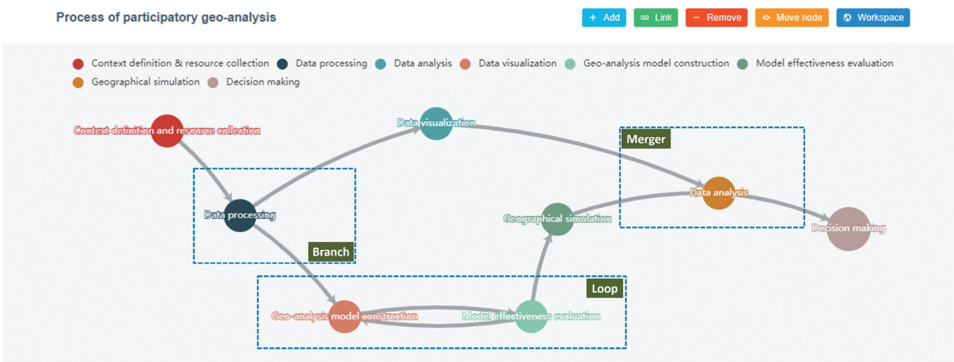

Figure 2. A geo-analysis process constructed by the visualization-based method.

the node color. The workspaces that are prepared for particular activities are attached to these nodes in the DCG. The successive relationships among these activities are symbolized by arrow lines. According to the relationship, the outcomes of previous activities can be reused in the subsequent activities for collaboration among activities. Thus each participant can understand the pathway for solving a geographic problem and the purpose of every geo-analysis activity.

During the construction of the geo-analysis process, these eight activities are iterative and alternating, and thus the activity use is open and flexible. Therefore, the relationships among the different activities are usually complicated. Note that a geo-analysis process rarely develops linearly (Simão, Densham, and Haklay 2009). Some nonlinear relations, such as the "branch," "merger," and "loop," are also possible relations in the geo-analysis process, as shown in Figure 2.

(1) A branch relation is very common in a geo-analysis process. If the process constructor wants to take on several activities at the same time to improve their efficiency, a branch relation is needed. Alternatively, when process constructors are conscious that one task is so complicated that it cannot be completed by one activity, they might want to launch branched activities for task assignments. For example, to select an optimal model for forest management, three different methods can be used for building forest growth models: the linear mixed-effect model, the 3-PG (physiological principles predicting growth) model, and the ANN (artificial neural networks) model. Branched model construction activities are established separately by three professional teams, and a branch relation is built in the process.

(2) As the reverse process of the branch relation, the merger is also common in geo-analysis. If an activity requires the outcomes of several previous activities, a merger is usually needed. For example, during the model effectiveness evaluation, three different forest growth models need to be compared. The outcomes (e.g., model codes and test data) of previous activities need to be used during the model effectiveness evaluation activity. At that moment, a merger is added to the geo-analysis process.

(3) A loop is necessary for iterative activities in geo-analysis. For some purposes, such as optimization, two or more activities are performed iteratively and form a loop in the geo-analysis process. For instance, during water resource modeling, model tuning can improve the accuracy of the models. While model optimization is conducted, model tuning and model effectiveness evaluations may be used alternately, and a loop can be formed.

In this visualization-based method, participants can discuss the possible geo-analysis process by using nodes and arrow lines to construct the process. According to the particular goals of problem-solving, process constructors can decide to create an activity node or select an appropriate node for performing a new activity (data processing, model construction, simulation, etc.). Furthermore, this method also supports iterative attempts in the geo-analysis process for different geographic problems. If an activity within the process cannot successfully meet the user goals, the process could be modified by removing the nodes and recreating new ones.

4.2 Participatory geo-analysis based on workspace

To help participants concentrate on their specialized work, a node-to-workspace strategy was proposed. In this strategy, each geo-analysis activity represented by the node can be identified by the name, type, and description. The understanding of different activity purposes can help geographically distributed participants choose their experienced or desired activities. Additionally, web-based workspaces are designed for participatory work and attached to different nodes along the geo-analysis process. Every activity can be performed collaboratively in the corresponding workspace. Different online tools (e.g., visualization and analysis tools) and resources can be accessed by participants who selected and entered the workspace to achieve the activity functions.

The connections between nodes and workspaces are depicted in Figure 3. Through the nodes of the DCG-based geo-analysis process, different groups of participants can enter specialized workspaces for collaboration. By using these resources and online tools, the participants can exchange ideas, process data, develop analysis, build models, simulate geographic processes, and make decisions in different types of web-based workspaces. For example, to complete the purpose of participatory model building, the modelers could select the "Geo-analysis model construction" activity and enter the corresponding workspace. They could use some of the participatory modeling tools and related data to build models together. In addition, the resulting resources from one activity can be shared and accessed during subsequent activities. Thus, different activities could also be made to cooperate with one another to solve complex geo-problems.

The WebSocket and HTTP techniques are employed in implementing workspaces for communication and interaction among participants, resources and tools (Figure 4). Specifically, the interactions among geographically distributed participants, online tools and resources are realized by HTTP technique. Thus, participants can enter the workspace and use the needed tools and resources for geo-analysis. Through the WebSocket technique, participants in the same workspaces can communicate with each other and synchronize operations. Accordingly, the participants can exchange knowledge and experiences for participatory geo-analysis.

5. Prototype system

5.1 Prototype system design

To apply the proposed method to participatory geo-analysis, we developed a prototype system (https://geomodeling.njnu.edu.cn/PExploration). As shown in Figure 5, to obtain solutions to geographic problems, the system can be used to construct the different processes for participatory geo-analysis. The system includes four primary parts: the project center, the resource center, the online tool center, and workspaces.

(1) The project center is developed to organize geographic problems. To address the problems, the participants can establish projects to manage all the related resources, tools, and activities. During the project, the resources and tools stored in the resource

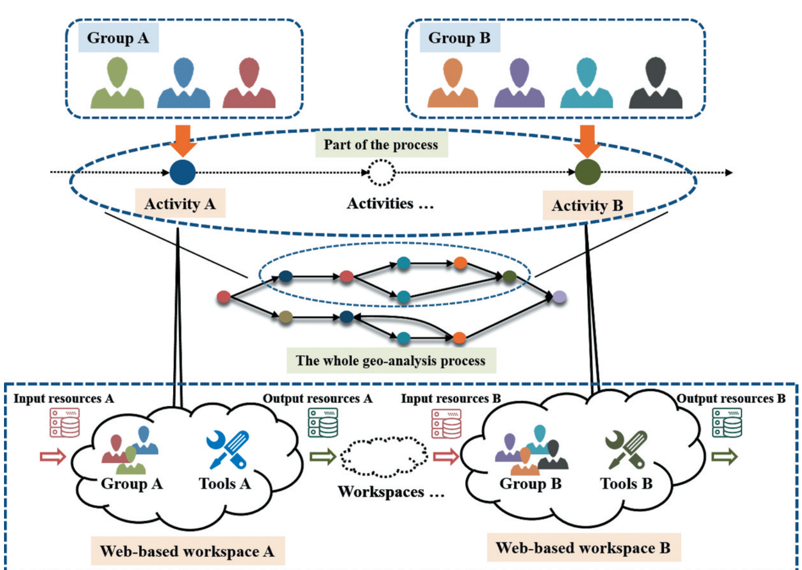

Figure 3. Connections between nodes and workspaces in the node-to-workspace strategy.

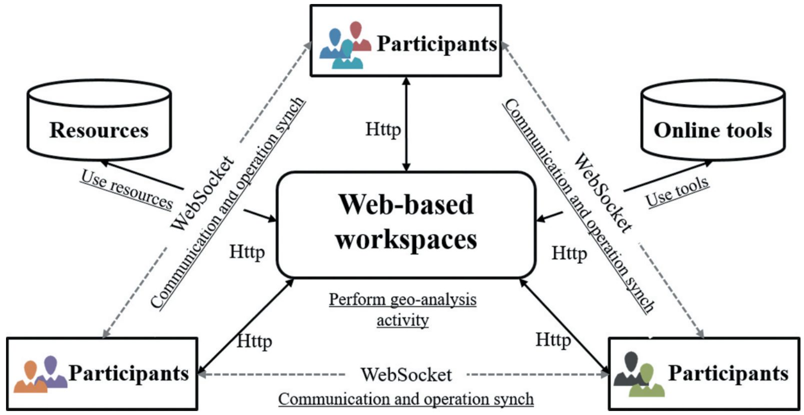

Figure 4. Technical implementation of the geo-analysis workspace.

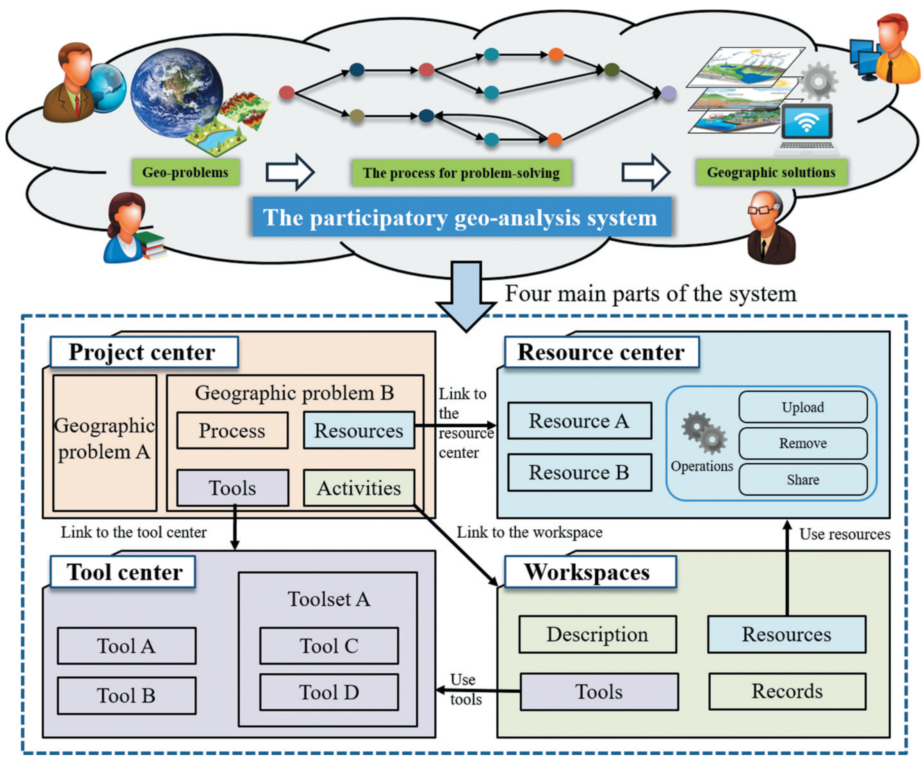

Figure 5. Design of the prototype system.

and tool centers can be accessed by users. These users can construct the geo-analysis process, which links different activities and is attached via activity-corresponding workspaces.

(2) The resource center is designed to collect and manage resources for geo-analysis. Several operations (e.g., collecting, removing, and sharing resources) are available in the resource center. The resources that are uploaded by the project participants can be accessed and used in the workspaces. Furthermore, the resource center also provides the ability to support resource transmission throughout the geo-analysis process.

(3) The tool center manages all the accessible online tools (and toolsets). To improve the capabilities of the participatory system, online participatory toolsets and tools could be accessed on the system. Specifically, the toolset contains a set of tools with similar functions or copyrights. These tools can be categorized as either real-time or non-real-time participatory tools, both of which can be used for geo-

analysis. Participants in the workspace can select the needed tools or toolsets from the tool center to perform geo-analysis activities. In addition, the tool center is open to each participant. Users can register important information (e.g., the URLs, functions, and privacy of their tools) about their tools in the tool center to furnish their own tools.

(4) The workspace corresponds to a specific activity. Resources and tools can be used in the workspace when participants conduct geo-analyses together. Specifically, tools can be matched to the specific type of workspace by the tool function. After users create an activity, the matched tools can be accessed in the activity-corresponding workspace.

This participatory geo-analysis system is developed by using the JavaScript language (for front-end) and Java language (for back-end). MongoDB is employed as the database to store information about the projects, tools, and resources.

5.2 Online participatory tools

To support the functional implementation of the geo-analysis activities, several online participatory toolsets and tools were provided on the prototype system. They are introduced as follows:

(1) Communication tool. This tool was developed using the WebSocket technique. It provides a place where participants can communicate with each other. The participants can use this tool for discussing ideas and viewpoints on geo-analysis.

(2) Mind map tool. The mind map tool was developed using KityMinder-editor (https://github.com/fex-team/kityminder-editor). It is a real-time participatory tool that can help participants to clarify their ideas and share knowledge.

(3) Map editing tool. The map editing tool is a real-time participatory tool supported by the WebSocket technique. It was developed to help understand the spatial characteristics of geographic data and edit the vector data.

(4) Table editing tool. The table editing tool was developed with the support of an open-source project named jExcel (https://github.com/paulhodel/jexcel). It can provide real-time editing for table data.

(5) Conceptual modeling tool. The conceptual modeling tool that we incorporated into the system is a real-time participatory tool based on Mxgraph (https://github.com/jgraph/mxgraph). As indicated by Chen et al. (2019), participants can employ it to analyze geographic processes and understand relations among geographic elements and systems.

(6) JupyterHub tool. The JupyterHub tool (https://jupyter.org/) was integrated into our system as a tool. JupyterHub is prepared to serve different Jupyter notebooks for multiple project participants. Based on its powerful capabilities, the Jupyter notebook can be a significant platform for model construction and evaluation. In this system, all project participants can share the same Jupyter notebook environment and write model code (in R or Python language) together.

(7) Chart visualization toolset. This toolset was developed based on ECharts (https://echarts.apache.org) (Li et al., 2018). It consists of important visualization tools that can support real-time participation. Different charts, graphs, and maps can be used to visualize different data.

(8) Agent-based epidemic simulation tool. This tool was developed using AgentMaps (https://github.com/noncomputable/AgentMaps). It is a real-time participatory tool. The epidemic model was integrated with the agent-based model in this tool. Participants can set different epidemic parameters and quarantine measures in the tool to simulate the infectious disease transmission process based on a set of autonomous decision-making agents.

6. Case study: Risk assessment of coronavirus disease 2019 (COVID-19)

Epidemic risk assessment is usually regarded as a geographic-related issue. Many geographic analysis techniques can help experts overcome the challenges associated with epidemics, including risk mapping (Dong, Du, and Gardner 2020), GIS (Zhou et al. 2020; Wang 2020), and modeling and simulation (Barton et al. 2020).

6.1 Overview of participatory risk assessment

At the early stage of the COVID-19 pandemic, people sometimes ignored the suggestion to stay at home and distrusted warnings on the disease, and they continued living their normal community lives. To understand the disease transmission process in a community and figure out its potential risk, 5 geographically distributed people with different backgrounds decided to work together. However, their collaboration required them to overcome the spatial barriers and coordinate among different participants for the corresponding tasks.

The participatory geo-analysis system provides an appropriate environment for their risk assessment work. During the collaboration, the participants who are experts in epidemic models, agent-based modeling, and visualization employed the geo-analysis system to assess the disease risk in a community. All the participants focused only on tasks from their specialties.

To conduct the participatory risk assessment, 10 activities were employed in constructing the geo-analysis process, as listed in Table 1. The risk assessment pathway for COVID-19 is presented in Figure 6. After understanding the whole process, different participants selected the appropriate activities and entered the corresponding workspaces in accordance with their expertise and experience. The participatory online tools are accessed in specialized workspaces and used by the participants for different geo-analysis tasks. Thus, the participants could collaboratively analyze the epidemic risk context, collect related data, develop epidemic models, and simulate the disease transmission process.

Table 1. List of participatory risk assessment activities.

Activity	Name	Type of activity	Participant
Activity 1	Preparation of COVID-19 risk assessment	Context definition and resource collection	All participants
Activity 2	Data preprocessing for visualization	Data processing	Experts in epidemic models and visualization
Activity 3	Visualization of epidemic data	Data visualization	Experts in epidemic models and visualization
Activity 4	Data preprocessing for epidemic modeling	Data processing	Experts in epidemic models and agent-based modeling
Activity 5	Epidemic model construction	Geo-analysis model construction	Experts in epidemic models
Activity 6	Evaluation of epidemic models	Model effectiveness evaluation	Experts in epidemic models
Activity 7	Agent-based epidemic simulation	Geographical simulation	Experts in epidemic models and agent-based modeling
Activity 8	Visualization of simulation results	Data visualization	Experts in visualization
Activity 9	Risk analysis of COVID-19 in a community	Data analysis	All participants
Activity 10	Suggestions for COVID-19 risk management	Decision making	All participants

6.2 Method definition and data collection

During Activity 1, the participants used the communication tool to understand the context of the risk assessment, especially the analysis methods. Within the communication tool, the participants first discussed the COVID-19 disease background, and they confirmed the goal of this risk assessment that is using the actual epidemic data to build models and analyze the disease transmission process in a community. They then discussed the methods for COVID-19 risk assessment with the help of the mind map tool and the conceptual modeling tool. The epidemic model expert used these tools and shared several mathematical models of epidemic diseases, including the SIR (susceptible-infectious-recovered) model (Brauer, Driessche, and Wu 2008) and the SEIR (susceptible-exposed-infectious-recovered) model (Lekone and Finkenstädt 2006), and they explained their mechanism and parameters (in Figure 7). Because the SEIR could consider 4

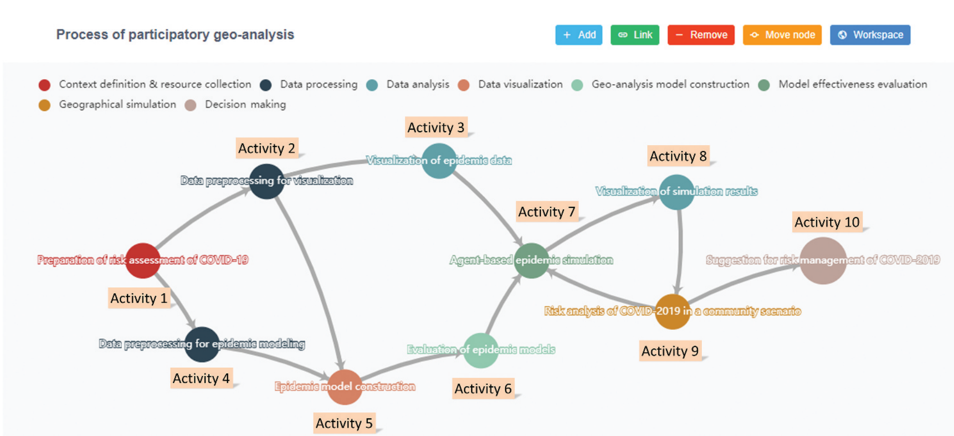

Figure 6. Risk assessment pathway for COVID-19.

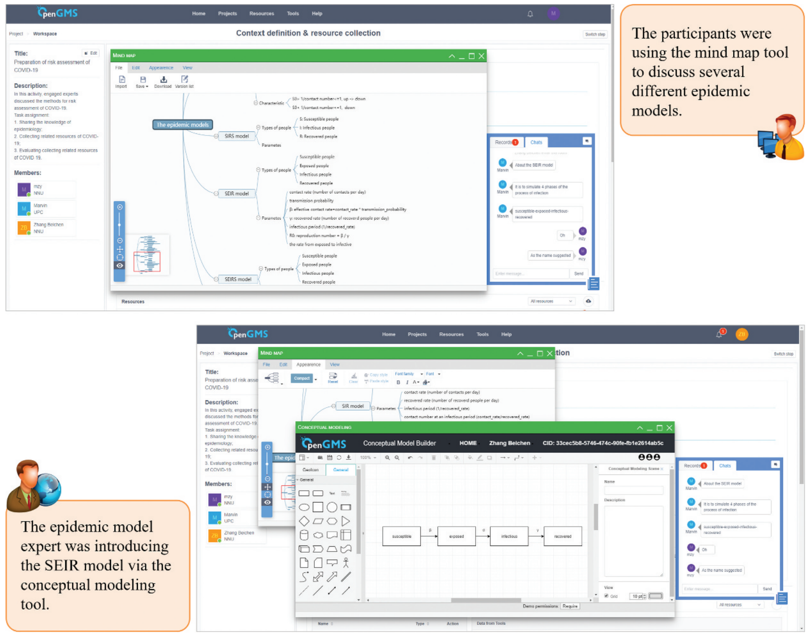

Figure 7. Sharing knowledge of epidemic models.

different health statuses that are more in line with the infectious characteristics of COVID-2019, it was selected to build the epidemic model for the risk assessment.

At that time, the feasibility of an agent-based epidemic simulation was evaluated. Agent-based modeling has a powerful simulation ability with a collection of agents (Bonabeau 2002). Because the agent-based models have advantages in human mobility simulation and discovering individual information, they have been successfully applied to many disease transmission studies (Frias-Martinez, Williamson, and Frias-Martinez 2011; Venkatramanan et al. 2018; Hackl and Dubernet 2019). In this case study, to simulate the stochastic process of disease transmission, a set of rules are defined to control the status and behavior of each agent (Hoertel et al. 2020). Specifically, different agent colors can represent the health statuses that correspond to the four statuses of the SEIR model. The quarantine behavior and periodic human behaviors (e.g., going out and going home) can be simulated by controlling the movement of each agent. All agents are ruled to move only along the road, and they can also stop in their "home" on both sides of the road, which simulates individual behaviors in a community scenario. The infection process from person to person can be simulated by touch among agents.

Other participants were responsible for collecting resources related to COVID-19. For example, participants collected disease data (as of 23 February 2020) from an open-source project in GitHub (https://github.com/BlankerL/DXY-COVID-19-Data) and map data from OpenStreetMap (https://www.openstreetmap.org). The collected resources were uploaded onto the participatory system to make them accessible for other participants.

6.3 Detailed collaboration for risk assessment

From Activity 2 to Activity 8, the participants engaged in collaboration through the activity-corresponding workspaces for COVID-19 risk assessment. Figure 8 shows four different collaborative scenes for the epidemic risk assessment.

Activity 2: Because the collected data were so messy that they could not be used directly, data processing was required. As shown in Figure 8a, the participants in the same workspace discussed and selected several important variables (e.g., confirmed, suspected, recovered cases and locations) and manually modified the data. Specifically, by using the table editing tool, all the participants in the current activity could open and view the collected epidemic data at the same time. Because the epidemic model expert understood the attribute meaning of the epidemic data, they introduced the data content through the communication tool. The expert who knows the required data structure for visualization is charged with the responsibility of modifying the data (e.g., removing useless attributes and adding location attributes). Simultaneously, the epidemic model expert inspected the data and fixed errors synchronously.

Activity 3: Different visualization methods (e.g., charts, graphs, and maps) were discussed and selected to discover information about the disease after the discussion about the epidemic visualization. By using the processed epidemic data, the participants used the appropriate tools from the chart visualization toolset for visualization with significant variables. As shown in Figure 8b, the line chart, histogram, and scatter map were used to visualize the trend and distribution of COVID-19 in China (as of 23 February 2020).

Activity 4: The goal of this activity was to formalize the data for model construction and simulation. To perform model building and simulation, data cleaning, data conversion, and other tasks were necessary. All of these tasks required participant collaboration. Specifically, this activity was conducted through a combined online-offline approach. During the offline data processing tasks, the agent-based modeling expert converted the map data format from OSM to GeoJSON and uploaded the new data to share it in this activity. Within the online tasks, the participants manually edited the GeoJSON data and synchronously removed the useless points, lines, and polygons using the map editing tool. In addition, the epidemic model expert employed the table editing tool to extract important variables and build modeling and test data (Figure 8c).

Activity 5: Because of the clear incubation period of COVID-19 (Wu, Leung, and Leung 2020), the SEIR model was selected by epidemic modeling experts for model construction. Some parameters (e.g., the basic reproduction number (R_0) and the mean incubation period (D)) of the SIER model were identified from existing studies (Liu et al. 2020; Li et al. 2020), and other parameters (e.g., the recovery rate (γ_c) and the mortality rate (γ_m)) were calculated based on the epidemic data (as of 23 February 2020). Using the JupyterHub tool, the participants built different SEIR models. The future COVID-19 trends were predicted.

Activity 6: The SEIR models were evaluated by comparing the differences between the predicted data and the actual data. For example, by using the JupyterHub tool, epidemic model experts built an SEIR model to simulate the COVID-19 trend on the Diamond Princess and used the actual data (from February 5th to 23rd) to test this model. The comparative result is shown in Figure 9. In the beginning, the predicted data are similar to the actual data; after applying disease control and prevention measures, the number of actual confirmed cases was smaller than the number of predicted confirmed cases on the Diamond Princess.

Activity 7: Based on the collaboration of participants who were experienced in epidemic and agent-based modeling, an agent-based epidemic simulation tool was developed. This tool was provided in the participatory system and could be accessed by other

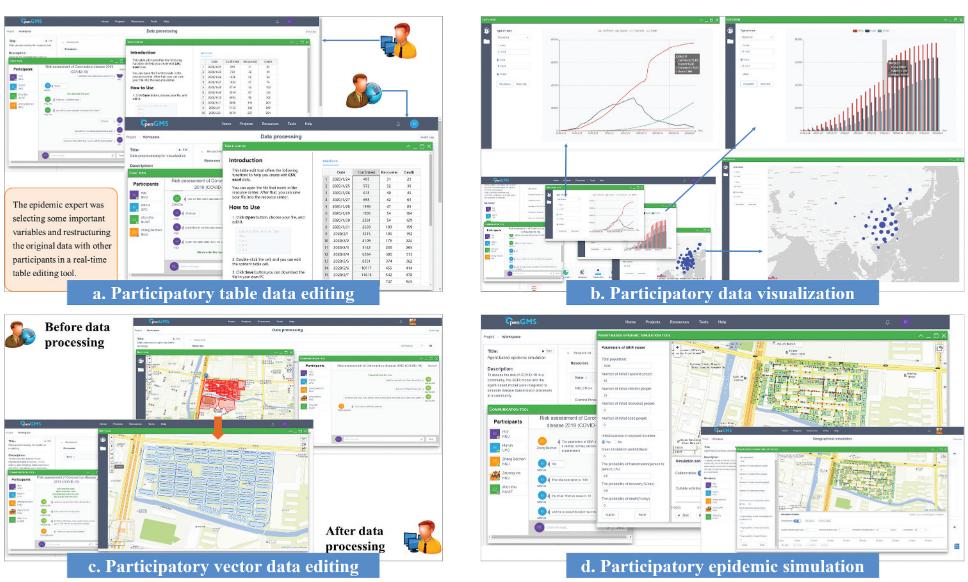

Figure 8. Collaborative scenes for epidemic risk assessment.

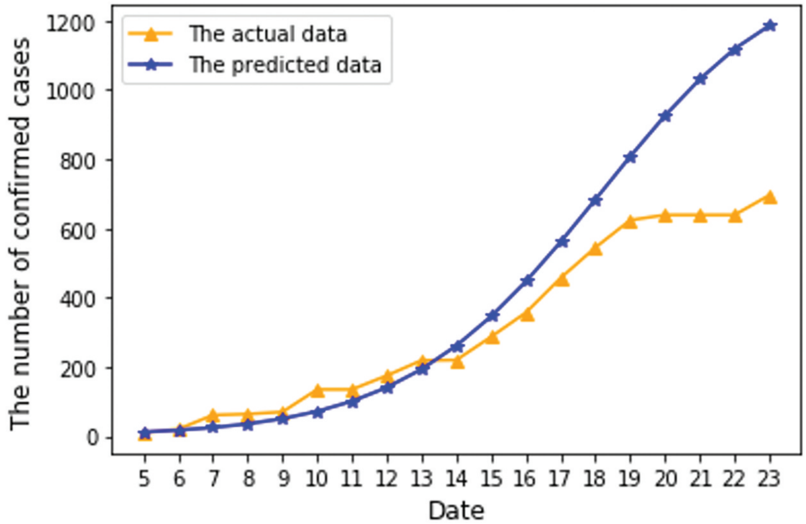

Figure 9. Comparison between the predicted data and the actual data.

participants. The SEIR model parameters, various prevention and control measures, and the agent-based simulation tool were employed to simulate the disease transmission processes in a community, as shown in Figure 8d. Community map data were used in the agent-based epidemic simulation tool to demonstrate the community life scenario (a 1,000-individual population community with 10 initially infected and 10 initially exposed people). The parameters of the built SEIR model (e.g., the mean incubation period, the probability of transmission, and the probability of recovery) were set as the control parameters of the agent-based SEIR model. Measures to prevent and control COVID-19 (no quarantine and quarantining infected people) were discussed and set in the model by the participants in a real-time participatory manner.

Activity 8: Visualization of simulation results. Some visualization experts engaged in this activity. The simulation results were visualized during this activity. Figure 10 shows the influences of distinct prevention and control measures. Figure 10a corresponds to the scenario with 0 initially exposed people, 10 initially infectious people, and no quarantine; Figure 10b corresponds to the scenario with 10 initially exposed people, 10 initially infectious people, and no quarantine; and Figure 10c corresponds to the scenario with 10 initially exposed people, 10 initially infectious people, and quarantining the symptomatic infectious people. The visualization results showed some small differences among different simulation scenarios.

6.4 Discussion of the risk assessment result

For Activities 9 and 10, two meetings were held through the communications tool to evaluate the COVID-19 risk assessment work and to discuss suggestions for risk management.

The participants evaluated the work from two perspectives. From the results perspective, despite the low number of initially infectious people, all the simulation results implied the high infection risk in a community. In addition, a comparison of three simulation results suggested that the number of initially exposed people could impact the trends in epidemic and quarantine measures, which could lead to an earlier decline in infected people. Furthermore, human-to-human transmission could also occur during the asymptomatic exposed period (Rothe et al. 2020), and only quarantining people who are experiencing the symptomatic infectious period is not a good measure for controlling the epidemic. Considering the randomness of the process, these simulations should be conducted more times. From a methodological perspective, the use of the agent-based simulation was admired by participants and it was successfully applied to discover the influence of individual behaviors and infectious status on disease transmission. However, the validation of the agent-based simulation still needed to be addressed and more effects (e.g., vaccination, immunity, and death) need to be considered.

To control the transmission of COVID-19, participants made decisions and proposed several suggestions, such as testing and quarantining all the infected

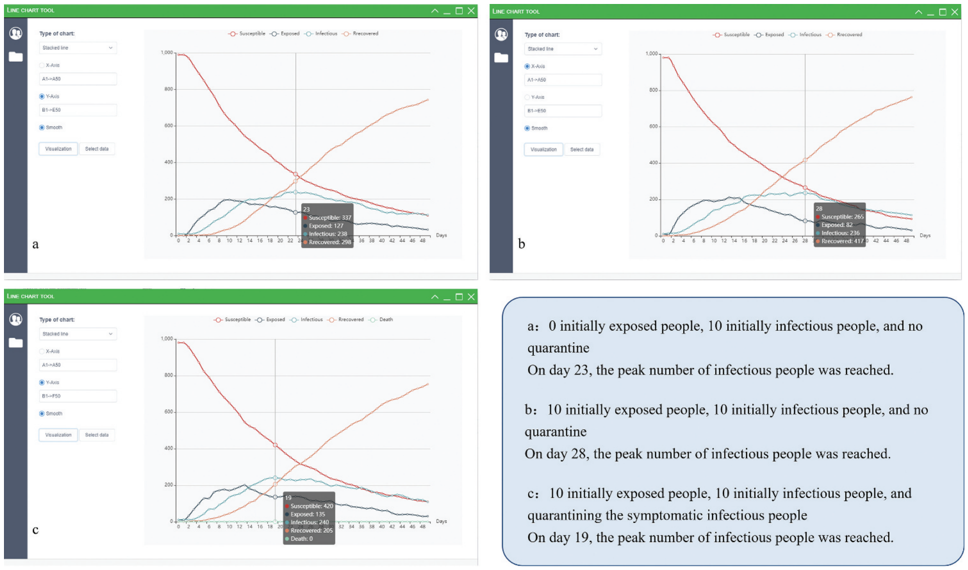

Figure 10. Visualization of three different simulation results.

people (symptomatic and asymptomatic patients). In addition, other experts gave some different possible measures, such as decreasing outside activities. However, the influence of these measures on epidemic control also requires further simulation and quantitative analysis.

7. Conclusion

In this paper, a process construction method for participatory geo-analysis was designed based on eight core activities. This method helps participants, including experts, stakeholders, and the common public, to understand the entire geo-analysis process and focus on their skilled activities. In the case study, the proposed method and its prototype system have been applied to support geographically distributed participants in working together. These participants are guided toward focusing on appropriate tasks, including data visualization, data processing, epidemic modeling, and agent-based disease transmission simulation. The result of the case study shows that this proposed method could facilitate collaboration and reduce the difficulty of addressing interdisciplinary issues to some extent. In addition, the proposed method also lays a foundation for participatory solution construction. The solution for a geographic problem is usually a structured set of processes (Voinov et al. 2018). Based on these core activities, potential methods of collaboratively constructing and adaptively adjusting the geo-problem solution are available. Therefore, when participants have dissimilar insights into how to address geographic problems, we hope the proposed method will help users to exchange ideas and gradually identify the geo-problem solution.

Nevertheless, the complexity of geographic processes and phenomena usually causes difficulties during geo-analysis. Although participants can conduct a geo-analysis together, the following aspects of the proposed method still need to be improved:

(1) In the proposed method, the functions of one geo-analysis activity are performed with the support of the specialized workspaces and online tools. To address more complex geographic problems, it is crucial to prepare more powerful participatory tools for communication, data visualization, spatial analysis, model construction, etc. However, providing sufficient tools for geographic problems in different domains is difficult to complete individually or by any individual team. Thus, to enrich the participatory tool repository, several methods that can help participants to easily share existing valuable web services (e.g., model services, data services, and other geoprocessing services) and support users in developing participatory geo-analysis tools need to be investigated (Wen et al. 2017; Zhang et al. 2020).

(2) To conduct a participatory geo-analysis successfully, the engagement of different participants in suitable activities must be coordinated, and the quality of each activity must also be ensured and controlled. These tasks require the management of the frequent interactions and operations during participatory geo-

analysis activities to avoid conflicts. Additionally, the results of each activity need to be evaluated to ensure that the goal of each one is reached. Thus, strategies are needed to ensure and control the quality of activities to facilitate the complete geo-analysis process.

(3) The participatory geo-analysis system still requires further development to improve its capabilities. In particular, field surveys are usually required for geographic problems. The current participatory system is an office worker-oriented system that is not convenient for field workers. Thus, project management and workspace design need to support collaboration between office and field workers. In addition, the robustness of the participatory system should also be improved to support the inclusion of additional participants in more complicated participatory geo-analysis processes.

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