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Research article

Biomimetic method of emergency life channel urban planning in Wuhan using slime mold networks ☆

Gangyi Tan [a,b,c], Yang Wang [a,b,c], Xiaomao Cao [a,b,c], Liquan Xu [a,b,c,*]

[a] *School of Architecture and Urban Planning, Huazhong University of Science and Technology, Wuhan 430074, China*
[b] *Hubei Engineering and Technology Research Center of Urbanization, Wuhan 430074, China*
[c] *Built Heritage Research Center, Huazhong University of Science and Technology, Wuhan 430074, China*

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ABSTRACT

This study investigated a bio-inspired approach to planning optimal routes for urban hospital life channels to enable better responses to urban public security incidents. An experimental slime mold network and an origin–destination (OD) network model in which the nodes were tertiary hospitals in Wuhan were constructed. Correlation metrics of the two network models were used for network analysis and visualization. The experimental results showed that the slime mold network was better than the OD network in terms of global optimization. Furthermore, significant polarization of the influence value of urban hospital nodes resulted in a power-law distribution. This paper presents an urban planning method in which the biological mechanism of slime mold foraging is applied to construct shortest path networks in an emergency life channels. The results can be used to examine the relationship between urban roads and hospital nodes and the rational of global optimization distribution when planning the locations of new hospitals. A set of replicable and sustainable methods for conducting a biomimetic slime mold experiment to model real environments are presented. This approach provides a novel perspective for modeling emergency life channels.

1. Introduction

With China's rapid urban expansion and increasing population, new challenges to urban development are arising and risks to society are increasing. Traffic congestion, disease transmission, urban crime and natural disasters have placed major restrictions to the high-quality development of cities and have seriously affected the health and safety of urban residents [1,2]. When the 2019 novel coronavirus (Covid-19) outbreak occurred, city roads were closed, vehicle use was restricted, clinics were closed, and citizens were quarantined at home [3,4]. Hospitals played a vital role in the city as emergency rescue sites for infected people. How to improve the efficiency of epidemic prevention and control, send infected people to the nearest hospital as soon as possible, and distribute medical emergency rescue material (e.g., medical equipment, ventilator, and patient) became an urgent problem. As important parts of an urban system, hospitals rely on the resources of the surrounding area as a supplement to their daily operations. They can also share resources with hospitals in other areas, thus forming an urban healthcare delivery system [5]. Individual hospitals can be abstracted as spatially distributed nodes, and the connections of each node form an urban medical network system. The accessibility of such

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* Corresponding author at: School of Architecture and Urban Planning, Huazhong University of Science and Technology, Wuhan 430074, China.
E-mail address: m202177117@hust.edu.cn (L. Xu).

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medical networks is an important consideration when establishing life channels. This paper targets the spatial distribution nodes of the tertiary hospitals in Wuhan and explores the planning of optimal routes for urban medical life-ways based on the existing road network to simulate a city in the context of a public safety event.

2. Review of related research

In high-risk conditions, it may be necessary to find ways to prevent communicable risks imported from other locations [6]. The construction of life channels within a city makes it possible to transport materials, dispatch rescuers, and transfer patients [7]. Studies of life channels, closely related to emergency route design in urban planning, have focused on disaster events requiring fire protection and medical treatment [8,9]. The latest achievements in urban emergency access for disaster relief can guide the construction of urban hospital life channels.

2.1. Research findings on life channels

An emergency access channel is a temporary one-way channel established between starting and ending points by restricting the passage of private vehicles to enable rescue vehicles to travel along a road network in the shortest possible time [10]. Rapid response plans have been established for the transport of rescue materials, first-aid personnel and sick patients. However, one-way channels are inadequate. When there is a traffic accident, emergency rescue is affected [2,11,12]. In an urban transportation network with one traffic source and multiple traffic attraction points [13,14], the design of emergency access needs to consider the impact on the rescue areas and ensure the effectiveness of the travel distance [15]. Related research has mainly focused on the channel reservation of a single project (such as an expressway or fire path) or organizing medical rescue. It is important to determine the optimal system of life channel routing to help decision-makers with technical support during unexpected public events in cities.

2.2. Life channel construction technologies

Life channel planning methods include the optimal route system method, routine operation based on GIS spatial analysis, weighted calculation, and optimization index evaluation. Research into emergency medical services in cities has become a hot topic since the outbreak of Covid-19 [16]. Optimal path selection of medical transportation is one of the effective methods of emergency rescue, especially in emergency medical service institutions [17]. It differs from the design of emergency life channels and focuses on finding the optimal path between multiple hospital choices in a city's hospital network. The essential principle is to build an accessible road network based on the shortest path principle and reduce rescue time by enabling fast access. Finding the shortest path is a common problem in various fields, and there is therefore a wealth of relevant technologies and methods [18–20]. Shortest paths are usually identified by finding the most efficient path from the source to the target node in a network model [21]. However, analyzing multiple paths to find the shortest path increases the amount of data computed and decreases computational efficiency [22]. Therefore, as a road network becomes increasingly complex, operational efficiency gradually decreases, so a method of calculating spatiotemporal accessibility has been proposed based on the empirical origin–destination (OD) travel time of motor vehicles [23]. Even though shortest-path methods for designing life channels are not perfect, they are still of great practical value.

2.3. Exploring the applications of slime mold biomimicry

In recent years, as biomimetic research on human settlements has increased, the growth pattern of the slime mold (Physarum polycephalum, Slime mould) has been a focus of transport network simulations [24]. Experimental and network models of slime mold behavior are of considerable interest to researchers studying the transport modes and network growth patterns of Myxomycetes spp. [25–28]. Mathematical models of transport-oriented network construction [29,30], have led to the wide use of slime mold models in urban planning research [31–34] (Fig. 1). Researchers reviewing the essential features of road traffic, which can be regarded as huge crowds of vehicles moving from one place to another, have suggested that the mechanism of traffic movement is almost identical to the foraging process of slime molds, which move nutrients from one cell nucleus to another [35,36]. Even though slime molds are single-celled organisms that lack centralized control, they are able to construct efficient networks [37,38], which have fault tolerance and cost advantages when compared with real-world infrastructure networks [39] (Fig. 2). The starting points of both slime mold networks and OD networks lead to multiple end points. They share the basic characteristics of a directionless network whose characteristics accord with the basic attributes of the network topology. The optimal structure of both types of network is determined by transport efficiency, which is why their construction is of great importance to life channels.

2.4. Network analysis

The network system built by life channels is a topological relationship created by hospital nodes and the connections between the nodes. Network analysis enables the effective evaluation of network systems [40]. Many networks are considered to be dominated by complex and universal laws. Their study is known as "Network Science" [41]. A network is a powerful way to represent and study simple and complex interactions. Network representations strip away many details of a particular system to focus on the interaction between its elements. Therefore, network-based methods have been used to study social networks [42], computer networks, and transportation systems [43]. It is almost inevitable that conflicts will be encountered when building transportation networks [44].

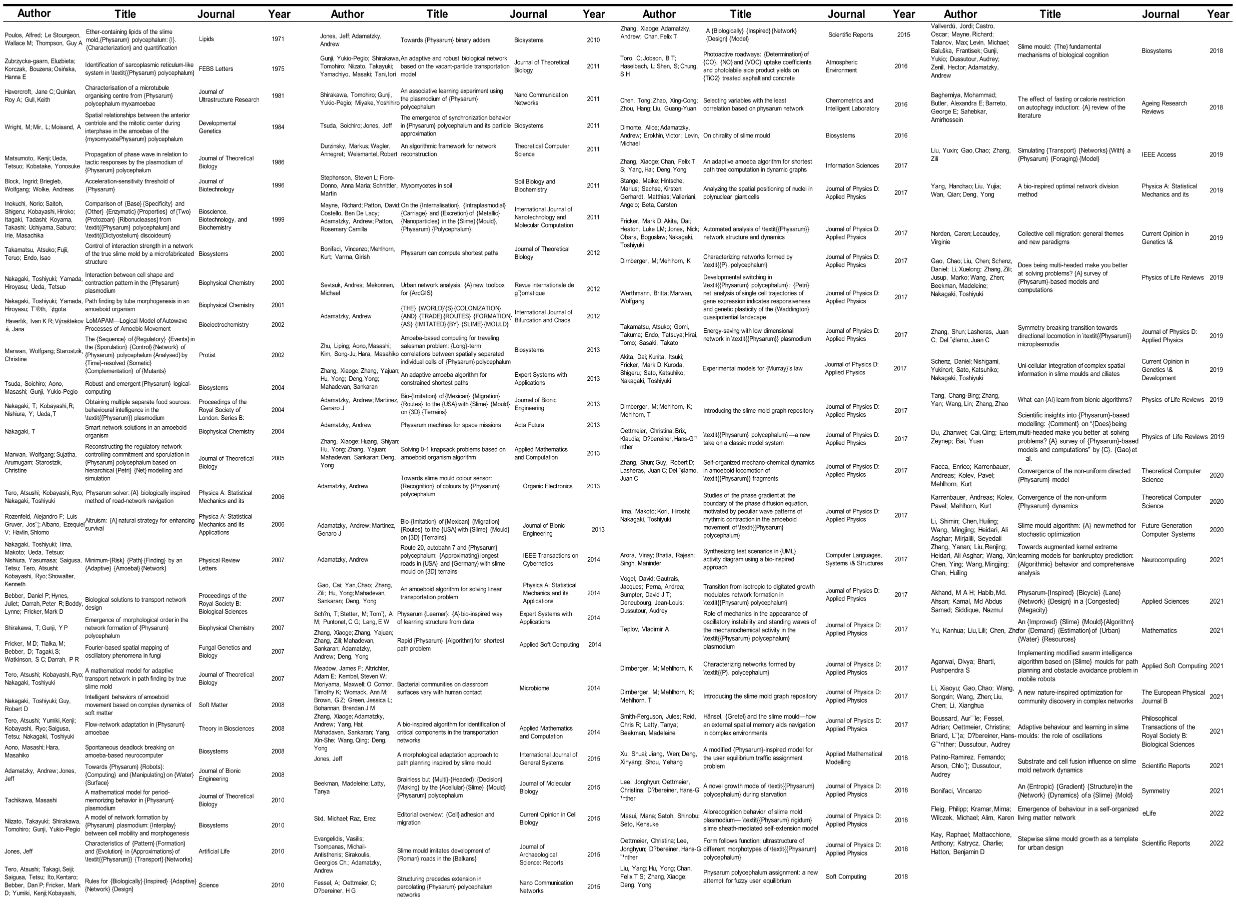

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Fig. 1. Literature statistics of slime molds.

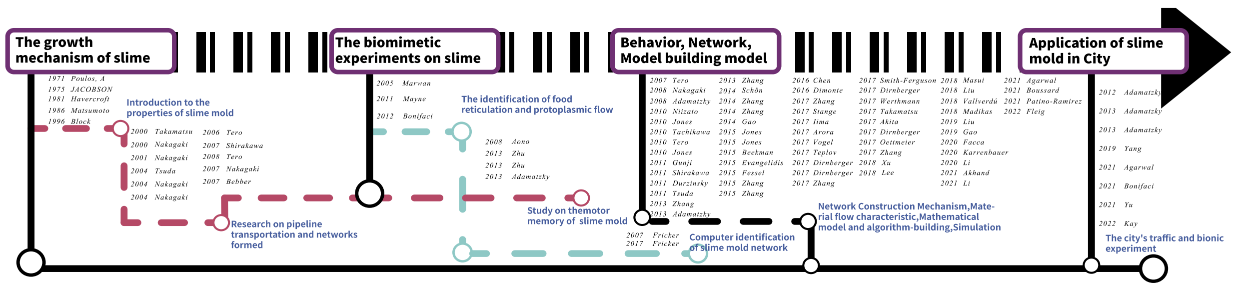


Fig. 2. Knowledge mapping analysis.

For all but the simplest vertex distributions, a network that minimizes route factors looks very different from a network that minimizes total length [45]. To facilitate the analysis of complex factors and values in networks based on topological properties, the following metrics are usually used to evaluate the network structure (Table 1): average degree, average path length, average aggregation coefficient, average network diameter, and other related metrics [46–48].

Reviewing previous studies, it can be concluded that the essence of urban life path construction is building an accessible road network based on the shortest path principle. Most calculation methods calculate the optimal route using OD path analysis. Using a slime mold network has significant advantages for identifying the shortest path in urban traffic accessibility scenarios. This paper compares slime mold network and OD path allocation methods and examines how slime mold biometry can be used in urban planning, using the example of urban medical life channels in Wuhan.

Table 1
The indicators of network analysis [49,50].

Indicators	Description
Average degree	A key attribute of each node is its degree, indicating the number of links to other nodes.
Average path length	The average distance between all nodes in the network (average of the shortest path between all nodes). The average shortest path is the average distance between all pairs of nodes in the network.
Average clustering coefficient	The clustering coefficient reflects the degree of connection between neighbors of a given node. The average clustering coefficient reflects the clustering degree of the whole network.
Network diameter	The diameter of a network is the maximum length of all shortest paths in the network, i.e., the maximum distance between all nodes in the network.

3. Research context and methods

3.1. Study area

Wuhan is located in Hubei Province, China, in the middle reaches of the Yangtze River (29°8′ ~31°22′ N, 113°41′ ~115°05′ E) It is the largest city in central China and is experiencing a critical period of accelerated regional integration and economic transformation. Wuhan has a variety of mineral and biological resources and a high degree of agricultural development. It is also an important industrial, scientific, and educational base and a comprehensive transportation hub. Due to resource utilization, industrial development, and urban expansion, Wuhan's infrastructure has greatly improved and expanded. However, rapid urbanization has made the prevention of viral risks increasingly challenging, and there is an urgent need to improve the efficiency of hospital circulation channels. This study was conducted at a tertiary hospital in the central district of Wuhan. This tertiary first-class hospital is classified according to current Chinese hospital classification provisions as the highest level of the "tertiary, sixth-grade" hospitals in mainland China [51,52] (Fig. 3).

3.2. Research overview

Twenty-nine tertiary hospitals inside Wuhan's Third Ring Road were chosen as the research objects (https://page.om.qq.com/page/OL3Vk9-Y8jizK2H94HIcXUuA0,11/03/2022). The Google Earth platform (https://www.google.com/intl/zh-CN/earth/,11/03/2022) was used to find the hospitals, calibrate them, and clean the data spatially. Road data were extracted from OpenStreetMap (https://www.openstreetmap.org/#map=14/30.5761/114.2871,11/03/2022). The advantages and disadvantages of using a slime mold experiment and an OD pathway assignment simulation were compared. Relevant indicators in the network analysis were used as the comparative evaluation criteria. Finally, QGIS software (2.18/OSGeo, Boston, MA 02110-1301 USA) was used to calibrate the generated urban medical life channel network against the actual road network to form medical life channel planning routes in Wuhan.

3.3. Research methods

3.3.1. Slime mold experiment

Physarum polycephalum 156190 (Carolina Biological Supply Company, Burlington, USA) was used for activation, cultivation, and extraction of plasmodium (Activation of Dried slime molds) [32] (Fig. 5). Food was placed at nodes representing 28 tertiary hospitals, and One of the hospital nodes serves as a source of slime mold emission (Zhongnan Hospital Of Wuhan University). The food sources were 0.15 g (±0.03 g) pieces of rice cake measuring 0.5 cm × 0.5 cm × 0.3 cm (±0.1 cm) (Huangchifeng weiyuan Food Co., Ltd in Maanshan city, china). Sterile, moistened air-laid paper (Product model: WIP-0609, Cleanmo Technology Co., Ltd in ShenZhen city, china) cut to 11.0 cm × 17.0 cm was placed inside a rectangular culture plate (11.5 cm × 17.5 cm × 2 cm) for the simulation environment (Fig. 6). The plasmodium was placed on a red circle on top of the paper (representing Wuhan City), and the culture plate was kept at a constant temperature of 25 °C (the outdoor temperature was 28.7 °C) and photographed using infrared monitoring (Product model: DH-IPC-HFW4243F-ZYL-SA, Dahua Stock Technology Co., Ltd in Zhejiang, China.) as the slime mold network was generated from 9 p.m. on July 22, 2020 to 10 p.m. on July 27, 2020. The experiment was repeated five times and divided into groups A-E (Fig. 7).

The slime mold images were vectorized using previously developed vesselness technology (MathWorks 2017a License:40588452) [53]. Vesselness (Equation (1)) generated for slime mold is provided the network characteristic behavior for a filamentous structure on ridge-like features that can be extracted from the eigenvalues and eigenvectors of the Hessian. GIS was used to fit the slime mold network to the urban expressway. The vectorization of the slime mold network was geometrically corrected and spatially overlaid on the geography of Wuhan to transform it into an urban road network without considering topographic factors (Fig. 8).

$$H_\sigma = \begin{bmatrix} \frac{\delta^2 I}{\delta x2} \times G\sigma & \frac{\delta^2 I}{\delta x \delta y} \times G\sigma \\ \frac{\delta^2 I}{\delta x \delta y} \times G\sigma & \frac{\delta^2 I}{\delta y^2} \times G\sigma \end{bmatrix} \tag{1}$$

Here, H_σ is the intensity landscape as estimated from the Hessian, xy is the image coordinates, I is the intensity image, G_σ is the Gaussian kernel.

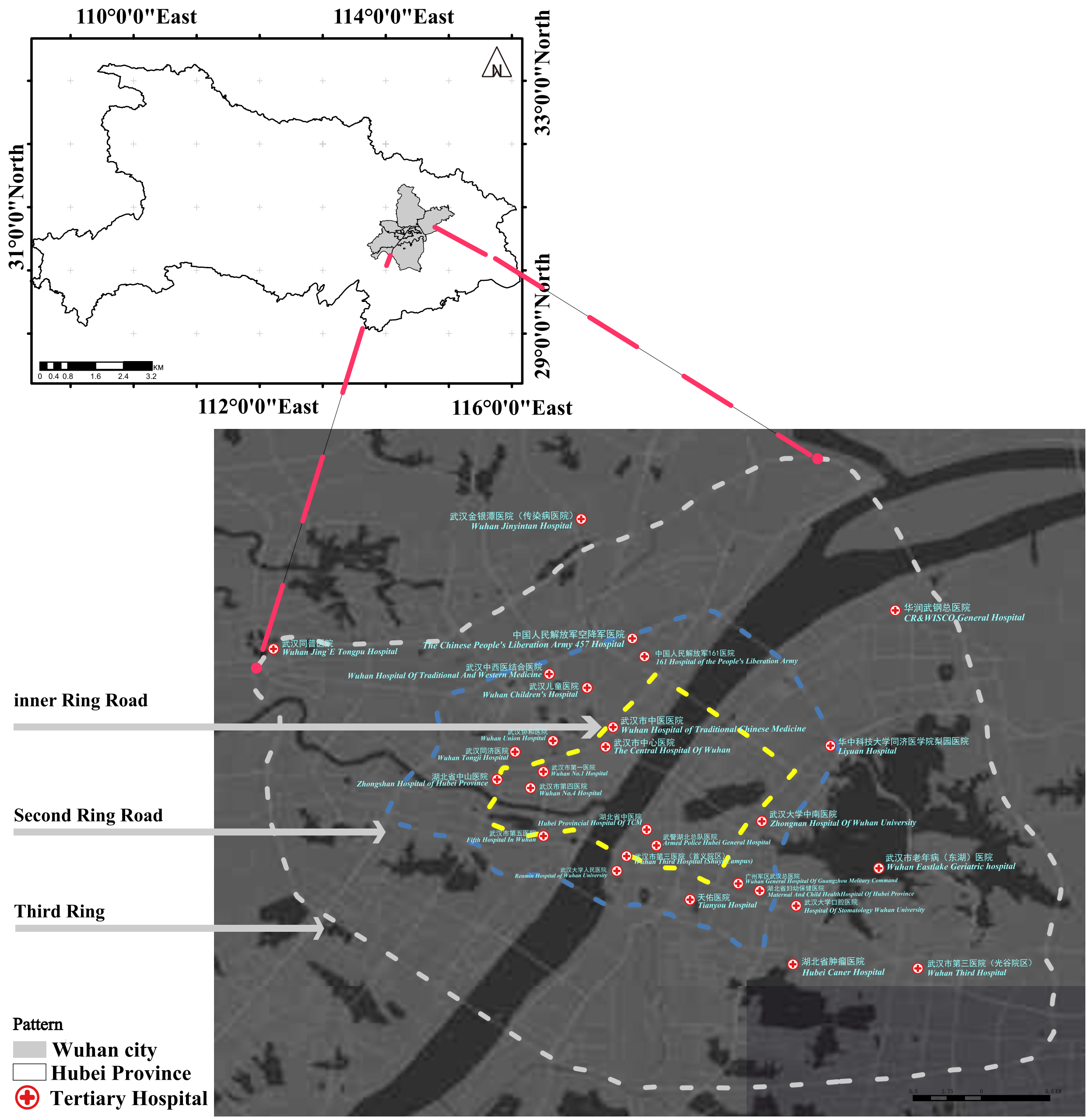


Fig. 3. Scope of Research.

3.3.2. OD path assignment simulation

The TransCAD platform (Demo 6.0/Caliper, Newton, MA, USA) was used to simulate OD shortest path assignment to find the shortest paths between hospital nodes and construct the shortest path network (Fig. 4). An advantage of OD shortest path assignment is that only one path between two points needs to be found to form the shortest path network [53–58]. OD shortest path assignment was used to form a distance matrix by applying a Euclidean distance calculation to Wuhan tertiary hospital distribution points. The shortest path was searched on the OD matrix estimation module (Equation (2)) of the TransCAD platform combined with the fast channel data to form the shortest path network (Fig. 9).

$$V_a = \sum_{ij} T_{ij} P_{ij}^a \left(0 \le P_{ij}^a \le 1\right) \tag{2}$$

Here, V_a is the volume of the road section, T_{ij} is the traffic volume between zone i and zone j, P_{ij}^a is the traffic proportion through the road section a, between zone i and j.

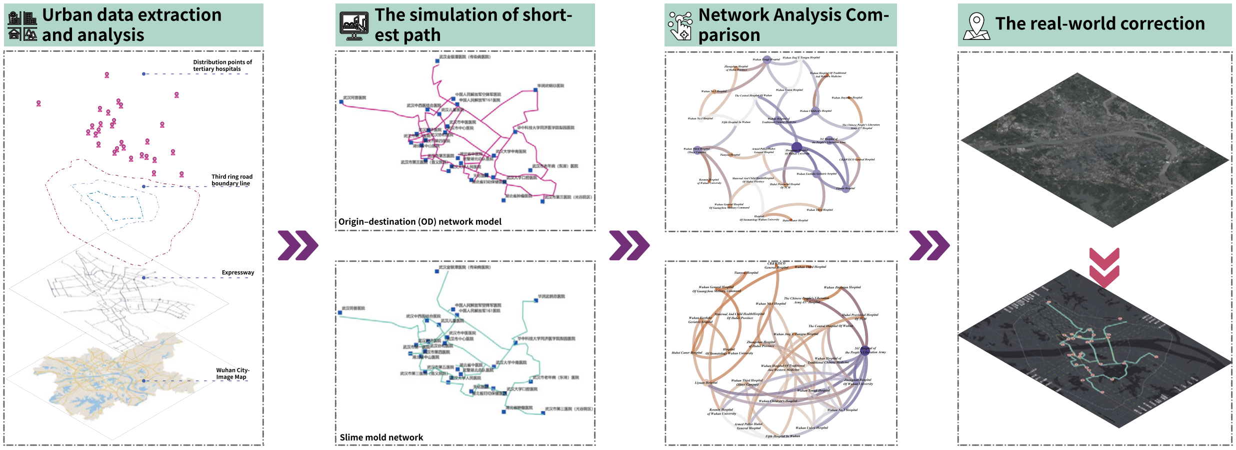


Fig. 4. Overall study of technical framework.

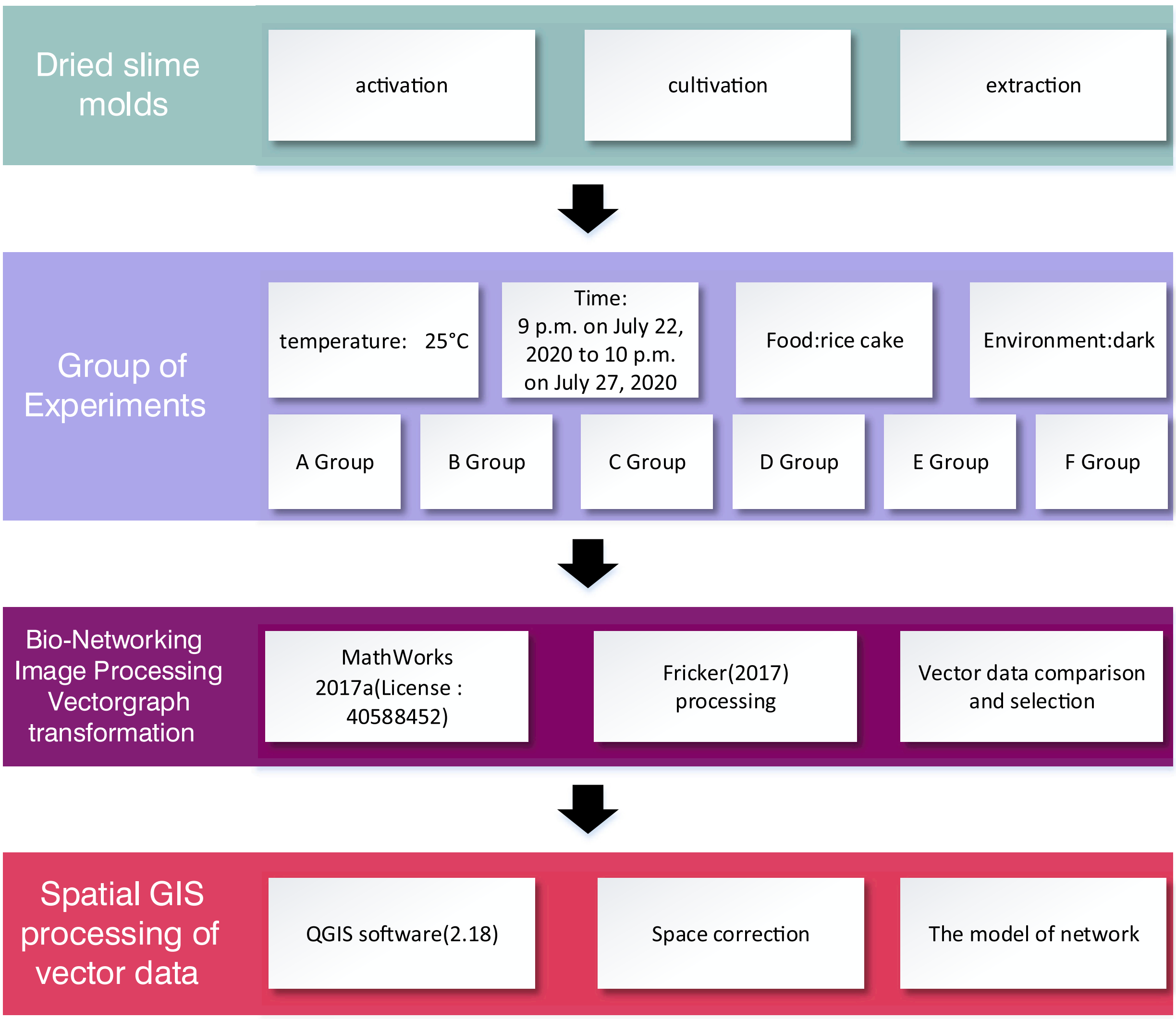


Fig. 5. Slime mold experiment flow chart.

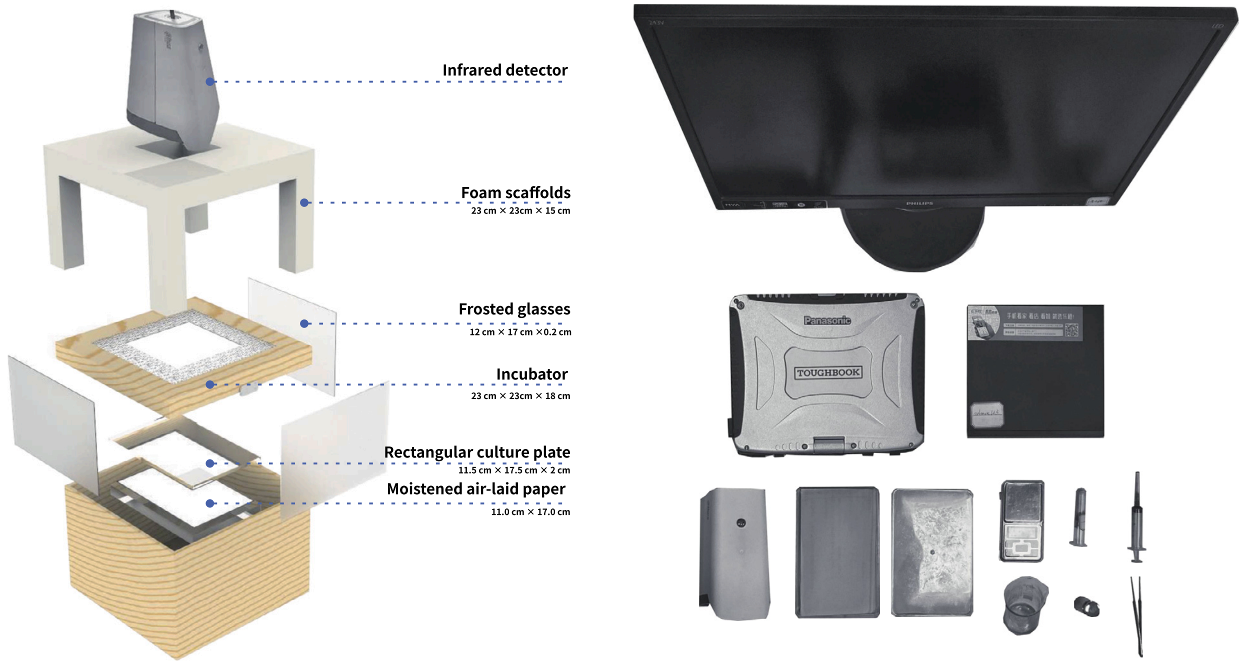
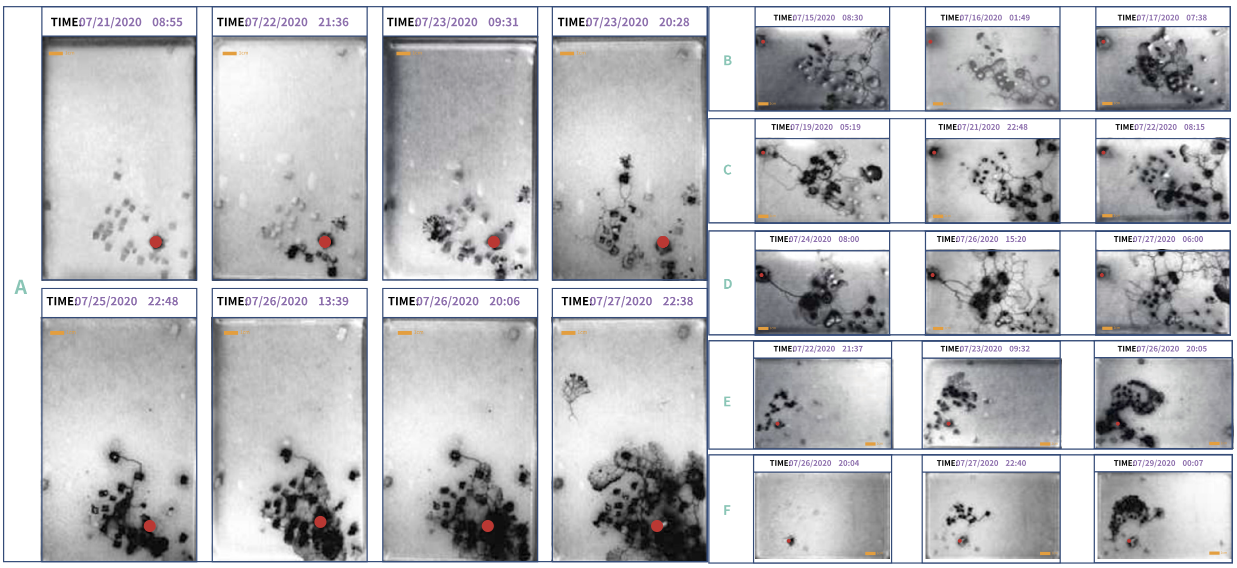


Fig. 6. Laboratory equipment.



Note：The experimental slime mold protoplasm was placed in a 1cm×1cm square in municipal district of wuhan (the red circle represents the location of the slime mold protoplasm)

Fig. 7. Comparison Bionic experiments of slime mold.

3.3.3. *Network analysis*

To select the global optimal shortest path network, network analysis was used to compare the two models. Four indicators—the average degree, average path length, network diameter, and average clustering coefficient—were used to evaluate the networks. The slime mold network and the OD shortest path network were calculated through a link matrix, and the calculation result was converted into a network. The link matrix is represented by A_{ij}, where each row and column represent a hospital node [48]. The set of hospital-linked edges is represented by the $N \times N$ matrix A_{ij}, where N is the number of nodes [49]. The average degree (Equation (3)) and the average path length (Equation (4)) in the link matrix reveal the average connection weight between the nodes of the whole network and the number of connected edges between the network nodes. To consider the maximum distance

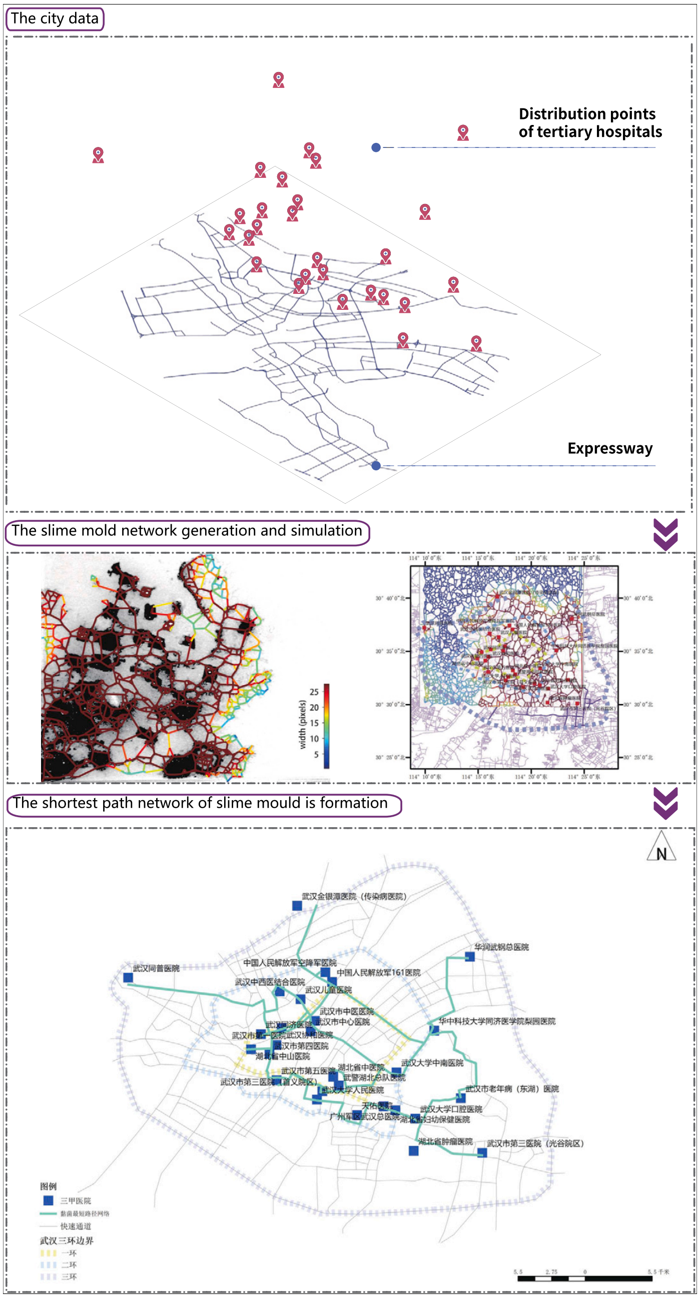


Fig. 8. Slime mold network simulation process.

and average degree of aggregation of hospital node pairs, the network diameter (Equation (5)) and average number of clustering coefficients (Equation (6)) are used to indicate the degree of global optimization in the network.

$$\langle k \rangle = \frac{1}{N} \sum_{i=1}^{N} k_i \tag{3}$$

$$N_{ij}^{(n)} = \sum_{k=1}^{N} A_{ik} A_{kj} = \left[A^n\right]_{ij} \tag{4}$$

$$D(G) = \max\{d(i,j) \mid i,j \in A\} \tag{5}$$

$$C_i = \frac{1}{k_i(k_i - 1)} \sum_{j,k=1}^{N} A_{ij} A_{jk} A_{ki} = \frac{1}{k_i(k_i - 1)} [A^n]_{ij} \tag{6}$$

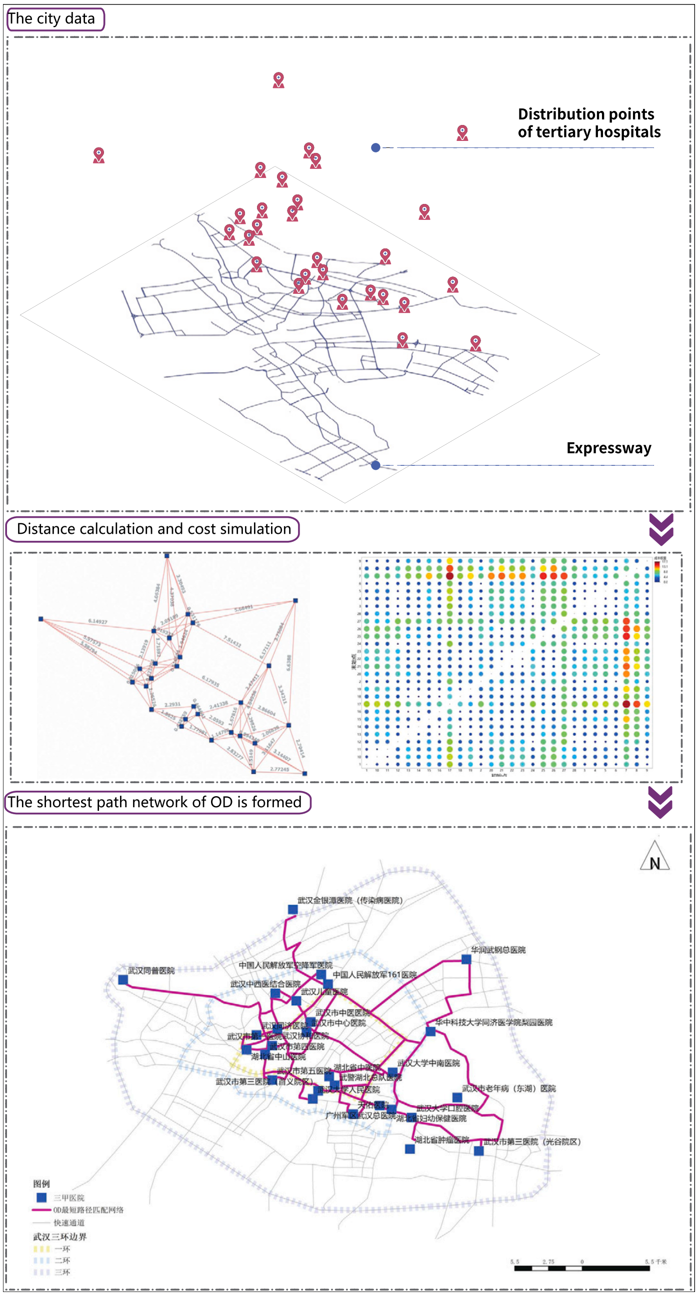


Fig. 9. OD Shortest path network simulation process.

Here, N represents the number of nodes, k_i represents the degree of each node, n represents the distance between node i and node j, and A_{ik} and A_{kj} represent nodes i to node k. $D(G)$ is the network diameter, the distance $d(i,j)$ in row i and column j. C_i represents the clustering coefficient of the hospital node.

4. Results

4.1. Calculation results

A comparison of the OD-generated shortest path network and the slime mold network shows intuitively that both exhibit similar global distribution of the shortest path network (Fig. 10). However, the local details are very different, so further network analysis is needed to compare the two networks accurately.

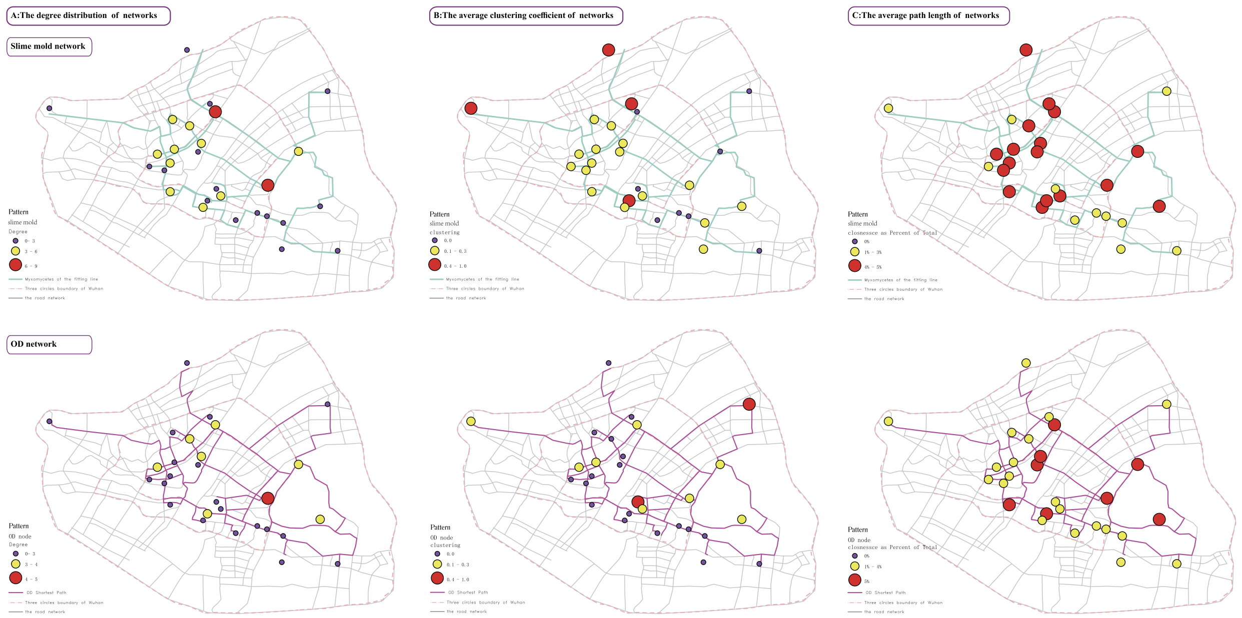


Fig. 10. Comparative analysis of networks, A: The degree distribution of networks, B: The average clustering coefficient of networks, C: The average path length of networks.

Table 2
Comparative analysis of networks.

	slime mold network	OD network
Average degree	3.571	2.786
Average path length	3.021	3.534
Average clustering coefficient	0.45	0.168
Network diameter	6	8

4.2. Network analysis comparison

4.2.1. Global optimization of the slime mold network is better than that of the OD shortest path network

The average degree of the slime mold network is higher than that of the OD shortest path network, with a value of 3.571. This finding indicates that the urban-hospital nodes of the slime mold network have more connections than those of the OD shortest path network. This higher connectivity is conducive to mutual influence between hospital nodes. The average shortest path of the slime mold network is shorter than that of the OD network. Its value is 3.021, which reduces the number of connections between hospital nodes, leading to greater road accessibility. The average shortest distance maximum expresses the network diameter of the slime mold. The smaller value of the network diameter, the shorter node connection distance between hospitals. Table 2 shows that the global shortest path of the slime mold network is lower than that of the OD network. The comparison transmission efficiency between the slime mold network and the OD network is calculated based on the network diameter in network science. The diameter of a network is the length of the longest shortest path [47]. According to the network diameter formula, when two networks have the same diameter and nodes, the advantages of the network are influenced by the distance and the number of connected edges. The reciprocal proportion of the distance between the corresponding edges of the network reflects the speed of transmission efficiency. Therefore, the greater the distance between network nodes, the less efficient the traffic transfer. Thus, less time is required for global transport in the slime mold network relative to the OD network (Fig. 11). The average clustering coefficient in the network represents the degree of global aggregation of hospital nodes, i.e., the connection between hospital nodes. The difference between this metric and the average degree is that the average degree is influenced globally by individual nodes. In contrast, all hospital nodes influence the average clustering coefficient globally. Therefore, a higher average clustering coefficient indicates that all hospital nodes are more closely connected and the network is more globally optimized. From a global point of view, the slime mold network has a higher level of optimization than the OD shortest path network.

4.2.2. Hospital node network impact values are clearly polarized and show power-law distribution characteristics

The network influence values of each hospital node in the slime mold network show that the most influential are the 161 Hospital of the People's Liberation Army and the Zhong Nan Hospital of Wuhan University (Fig. 12). Spatial location analysis shows that these hospitals are distributed in Hankou and Wuchang. They become the network's most important core nodes and are in close contact with the surrounding hospitals. For example, From the distribution of spatial nodes, 161 Hospital of the People's Liberation

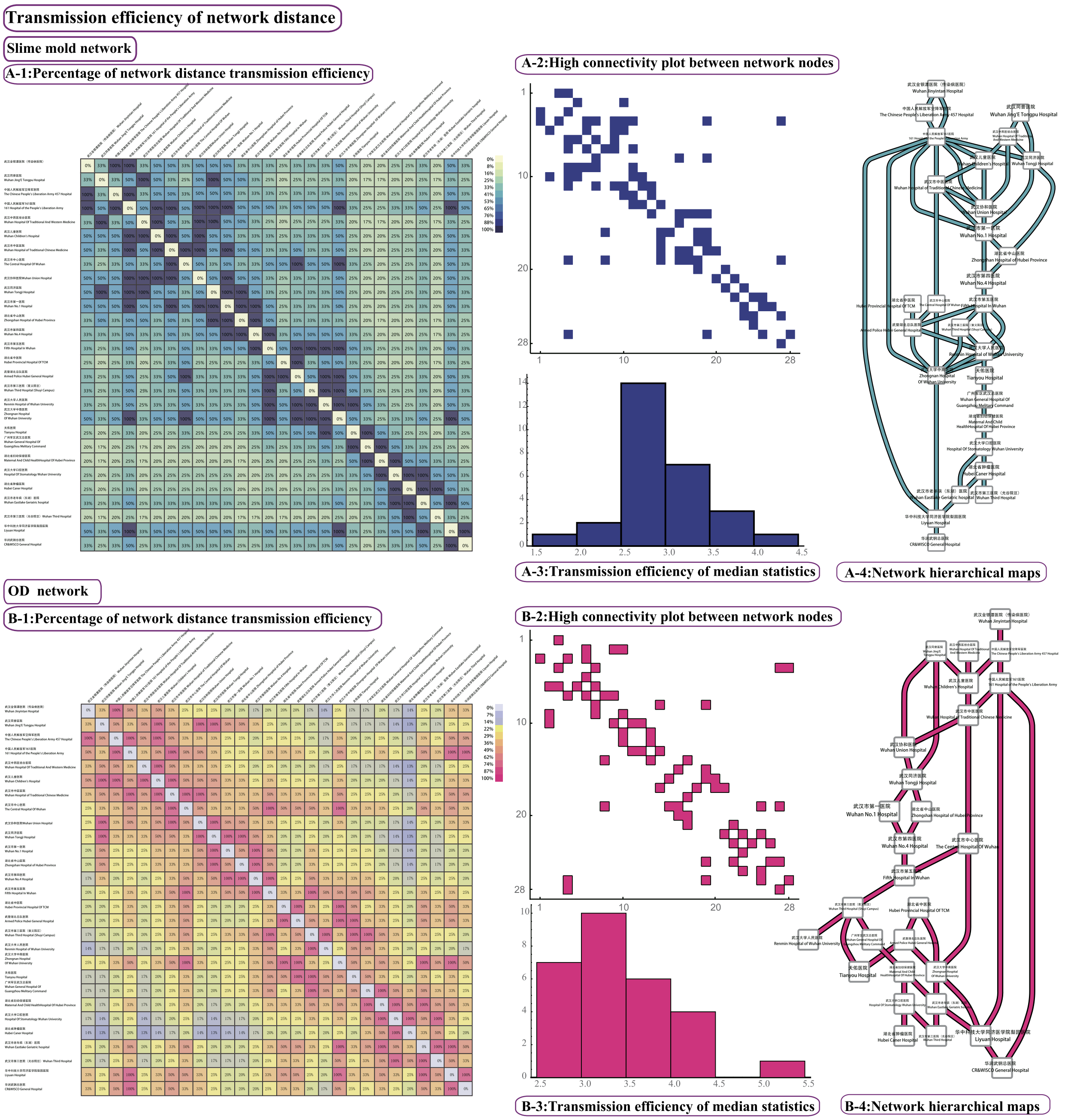


Fig. 11. Transmission efficiency of network distance, A-1, B-1: Percentage of network distance transmission efficiency, A-2, B-2: High connectivity plot between network nodes, A-3, B-3: Transmission efficiency of median statistics, A-4, B-4: Network hierarchical maps.

Army is located in the Hankou of the second ring road of Wuhan near the Yangtze River Second Bridge. It connects to The Chinese People's Liberation Army 457 Hospital on the Third Ring Road and Liyuan Hospital in Wuchang. Thus, 161 Hospital of the People's Liberation Army tends to be centrally located in terms of the degree of connectivity of the slime mold network. At the same time, the distribution of 161 People's Liberation Army hospitals on the slime mold network has different degrees of association and shortest paths for the whole network and each hospital node in the network. 161 Hospital of the People's Liberation Army and The Chinese People's Liberation Army 457 Hospital, Wuhan Hospital of Traditional Chinese Medicine, Liyuan Hospital, and CR and WISCO General Hospital have high connectivity based on the route transfer efficiency calculation. The Zhong Nan hospital of Wuhan University is located in the center of the tertiary hospitals in Wuchang and it is closely connected to other hospitals. These two hospitals are the strongest in terms of global connections. The proportion of the shortest paths of hospital nodes was subjected to double exponential fitting to reveal differences in data between hospital nodes. The proportions of shortest paths among hospital

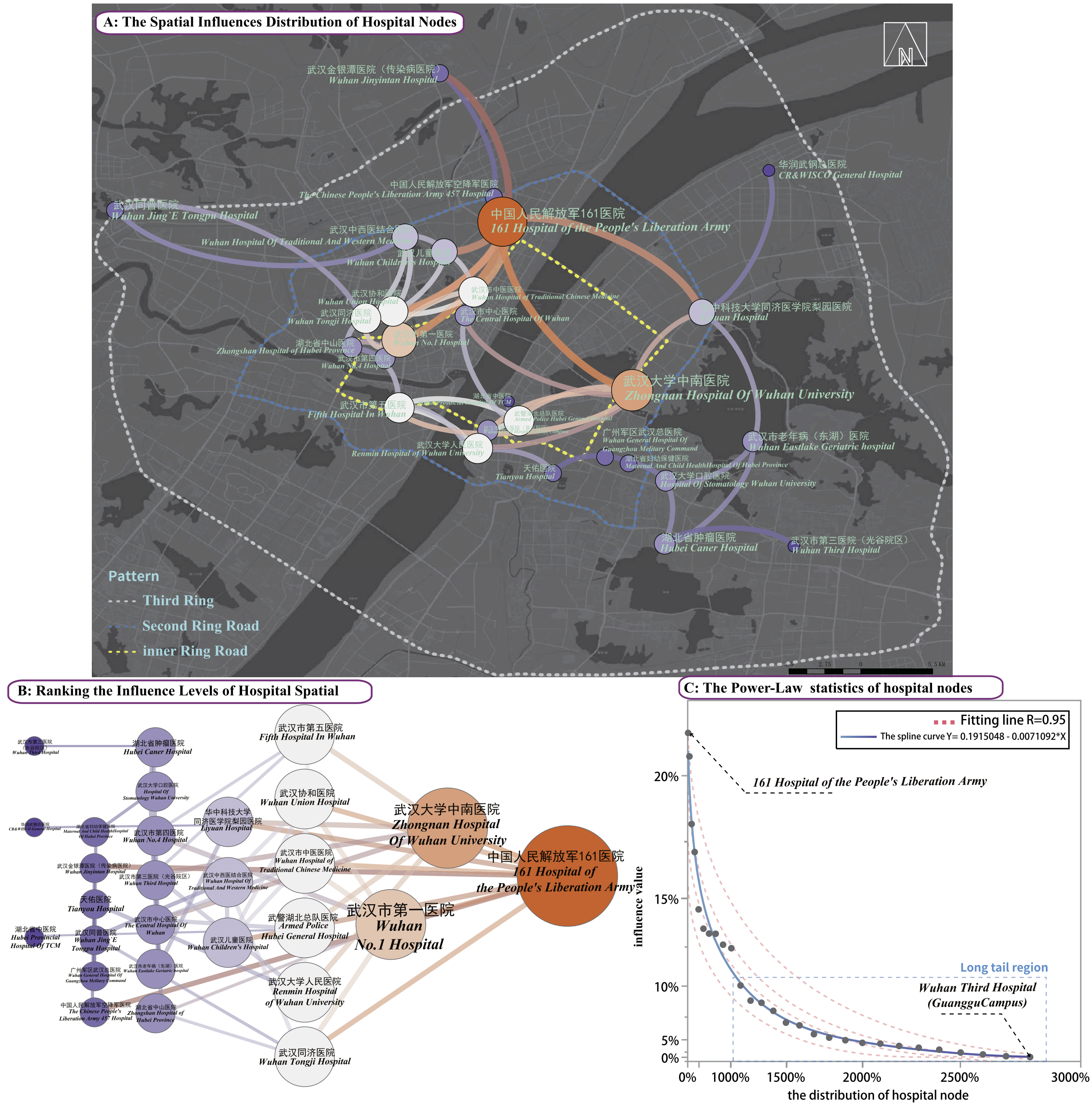


Fig. 12. Power-law distribution of hospital nodes, A: The Spatial influences distribution of hospital nodes, B: Ranking the influence levels of hospital nodes, C: The power-law statistics for hospital nodes.

nodes showed power-law distribution characteristics (Fig. 12) [41,48,49], indicating that the spatial location of hospital nodes was unevenly distributed with signs of polarization. The higher the influence value, the stronger the connectivity of hospital nodes; 161 Hospital of the People's Liberation Army had the highest value. The lowest value was for the Wuhan Third Hospital (Guanggu Campus).

5. Discussion of methods and results

In this study, a hospital life channel network model was constructed based on the growth behavior of the slime mold. The model effectively reflected the degree of node connectivity and distribution of tertiary hospitals in Wuhan. To verify the optimization degree of the slime mold network, an OD model was used to simulate the shortest path network of urban roads, and the two networks were compared. The evaluation metrics used in the network analysis showed that the connectivity of the slime mold network was better than that of the OD shortest path network. Slime molds use biological feedback mechanisms established through food induction and the distance between food sources. This efficient biological method of constructing networks makes it straightforward to use slime molds as a simple tool to provide ideas for the design and optimization of existing urban infrastructure.

5.1. Discussion of methodology

This study is based on a conventional computer and bionic simulation for network construction. Its purpose is to analyze the differences and properties of the two methods for generating networks and further explore the mechanisms of network methods used in urban space. OD network generation is based on existing data of the city and model algorithms generated under computer simulation. OD network generation considers road and origin-destination nodes in city data for cost matrix calculation, forming the shortest path network. The method has a mature calculation and simulation platform, making the generated network reproducible and deterministic. On the contrary, network generation using slime mold organisms is random. The reasons for this are the type of food, environmental factors, and the network generation process. In order to reduce the uncertainty during the growth of the slime mold network, several control experiments were required during the experiment. The slime mold generates a network to the nearest food and then gradually spreads to the surrounding area. This preying phenomenon is entirely consistent with the growth mechanism of the slime mold network. According to the order of disappearance of the network tubes: longer tubes disappeared earlier than shorter ones. In order to verify the reproducibility of the slime mold network generation, six experiments were conducted, of which five groups were used as control experiments. As a result of the biological network reproducibility experiments, the final networks formed by groups A, E, F, and C were the same. In contrast, groups B and D showed the longest disconnection of the network management. The network images generated based on the six groups of experiments are transformed by the image vector data technique [53]. These vectorized data will be selected for correlation analysis to verify the experiment's reproducibility. Comparing the six groups of data, the best network generation is group A and has a high overlap with the data of groups E and F. Therefore, group A samples are used for network space analysis.

A system of foraging pipeline networks resulting from the foraging of food by slime mold. In order to reduce their energy consumption in the shortest time to choose the nearest food to form a foraging pipeline and, at the same time, absorb much energy from multiple food points, the foraging pipeline for the shortest path optimization to form a food point network connection. The present study of the slime mold experiment uses this biological mechanism to construct a network pathway connection of tertiary hospitals in an ideal condition where the city is closed by an epidemic disaster, excluding other private vehicles on the road and road speed limit, and only medical transportation emergency. The traditional method uses slime mold to calculate the shortest path connections of origin-destination. The method requires consideration of the number of flows in the slime mold foraging tubes, the thickness of the tube walls, and the food energy transfer time. In order to construct a global network from the perspective of global network analysis, the structural characteristics of the network itself and the connectivity properties between nodes are used to avoid the factors considered by traditional methods for the spatial arrangement points of the tertiary hospitals in Wuhan. During the experiment, the traditional use of oatmeal as the food was abandoned in favor of regular rice cakes. The reason for choosing rice cakes is that slime mold forage for starch is on the surface of the food, and the choice of food is related to the surface area, not the food's weight. Therefore, the network constructed by the slime mold considers the location of food points and the global network structure formed. Global analysis of slime mold networks according to network science analysis methods. The network diameter analysis reveals the variation in path distance and transmission efficiency to determine node-to-node connectivity.

The study was limited to identifying shortest paths with the aim of selecting life paths in urban medical emergencies, based on the optimal paths and shortest transport times to maximize medical assistance and mutual aid of medical resources. The results of network analysis were evaluated, and the globally optimal network was assessed as a model for the construction of urban medical life paths. There is now a wealth of research on OD and slime mold methods. In particular, increasingly sophisticated techniques for OD path assignment and slime mold shortest paths are often used to select the shortest paths for traffic [22,37,38]. For OD path allocation, the intuitive analysis of transport efficiency is characterized by a low cost, ease of operation, and high practical value. In the absence of historical data, it is possible to calculate the traffic volume in a given interval and reduce the pressure on traffic surveys [54]. As a result, traffic path selection by OD path allocation has become established in recent years and is used for flexible route planning and to minimize total distances traveled [56]. Slime mold shortest path bionomics have been studied in the field of intelligent transport systems. Slime mold foraging behavior has become a popular research area in the field of intelligent path design because slime mold foraging models can simulate efficient and robust urban transport networks [24,31,32,34]. In this study, OD and slime mold approaches were used to simulate urban lifeways, and the optimal network was sought by comparing the two results. Both the slime mold simulation and the OD shortest path network assignment were able to identify the globally shortest path network. The OD shortest path network assignment focuses on connecting hospital nodes and uses a cost matrix assignment to form the shortest path network. The results indicate that the two shortest path networks are similar (A network of paths is generated from the start to the end) in how they are generated and can be used as a pre-existing basis for comparison. To provide insight into the extent to which the slime mold shortest path network was superior, a network analysis approach was used to calculate the features of the network structure, from the fine nodes of the network to global optimization, and progressively deeper analysis was carried out to compare the two networks. The analysis showed that the network formed by the foraging slime mold outperformed the network formed by OD path planning in terms of global optimization. Therefore, the slime mold network was chosen as the basic network for life-path construction, and spatial route fitting was carried out to plan urban medical life paths. For the establishment of medical life paths, the shortest path in the slime mold network selects the existing road, which is analyzed and predicted from the perspective of the global road network of the Wuhan primary road. Fitting the spatially corrected slime mold network with the existing roads shows that the highest accessibility is mainly for the Yangtze River Tunnel, the Yangtze River First Bridge, the Yangtze River Second

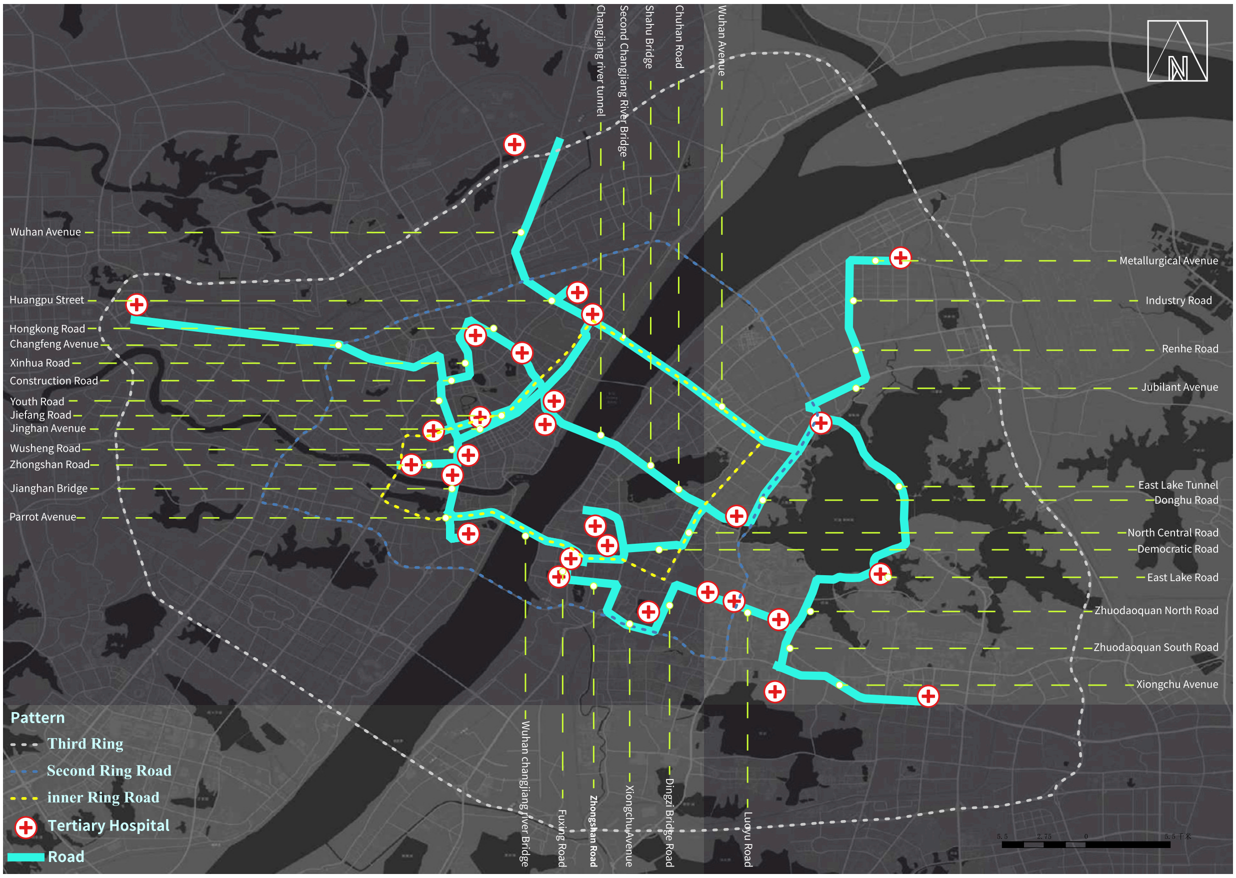


Fig. 13. The emergency life channel of tertiary hospitals in wuhan city.

Bridge, and the streets within the Second Ring Road connecting Wuchang and Hankou. For example, the shortest path formed by Wuhan Hospital of Traditional And Western Medicine and Western Medicine and Zhongnan Hospital of Wuhan University is mainly Hong Kong Road - Zhongshan road - Jiefang road - Wuhan Yangtze River Second Bridge - Wuhan road - Second Ring Road. The medical life paths considered in this study are somewhat different from those in traditional planning scenarios. The use of biological mechanisms to construct the shortest paths provides a new planning perspective.

5.2. Discussion of results

Comparison of the OD and slime mold networks revealed that the global optimization of the slime mold network was better than that of the OD shortest path network. The slime mold network and map of Wuhan were combined to form the planned urban medical life channel (Fig. 13). One of the results of this study shows that the distribution of tertiary hospitals is better in the Hankou District than in the Wuchang District. This characteristic may be due to the excessive aggregation of hospital nodes in some regions, making the global distribution of hospital nodes imbalanced and leading to power-law distribution characteristics. The reason for the distribution of tertiary hospitals was based on the economic development and population of the region. With the massive expansion of the area outside the second ring of Wuhan city, the distribution of hospitals could not accommodate the needs of the current urban development. Fig. 11 shows that Wuhan's tertiary hospitals are located in the inner ring road and second rings road, and the distribution of hospitals within the third ring road is sparse. Among the fast-growing regions of Hanyang region (southwest region), as well as the Wuchang region in Optics Valley East (southeast region) and Baishazhou (south region). For the site selection of new hospitals, existing tertiary hospitals can connect the additional hospitals in the network as new nodes based on the formed slime mold network. The advantages of choosing the site in this way strengthen the connectivity between the network nodes. It also weakens the aggregation of nodes to avoid the isolation of nodes in the network as much as possible. It promotes the optimization of the global network system of tertiary hospitals. For example, among the existing network nodes, Wuhan Jing E Tongpu Hosptial and Wuhan Jinyintan Hospital have node isolation, which reduces the impact on other nodes. Therefore, new hospital sites are established in the region between these nodes and the nearest nodes to enhance their connectivity. Also, for establishing a new hospital site in the Hanyang region (southwest region), the node Fifth Hospital In Wuhan can be considered the base point for building a new node connection. Therefore, careful consideration should be given to future hospital locations, particularly the influence range between hospital nodes and the global optimization relationship between roads and hospital nodes. From the perspective of global network optimization, the diameter of the slime mold network is smaller than the OD network, and thus the maximum path length of the slime mold network is smaller than the OD network. In a network system, the path length maximum represents the network diameter, and the distance size between network nodes is inversely proportional to the traffic transfer efficiency. Therefore, the smaller the network diameter, the smaller the transportation cost. Meanwhile, The network transfer efficiency reflects the degree of network structural robustness and global optimization of the network with the median. In Fig. 11, the high connectivity plot between network nodes is compared (Fig. 11 A-2, B-2) for the slime mold network, which is more concentrated than the OD network, which has a disconnected condition. In the transmission efficiency of median statistics (Fig. 11 A-3, B-3), the high connectivity of the slime mold network is more robust than the OD network, indicating that the node-to-node connectivity of the slime mold network is more robust than the OD network. According to the network hierarchical maps (Figs. 11 A-4, B-4), it can be seen that there are more critical nodes in the slime mold network than in the OD network (important nodes upward), and the nodes are evenly distributed in the slime mold network. On the contrary, many nodes are downward (unimportant nodes are downward) and accompanied by a slope to the right in the OD network. Therefore, the comparison of the network global to the local network shows that the connectivity between nodes and the efficiency of path transport transmission has a meaningful relationship and a significant impact on the construction of life channels. After the outbreak of Covid-19, the Wuhan municipal government instigated temporary closures of urban roads and used public transport groups, online taxis, and cruising taxis to form emergency convoys to prevent transmission of the disease. As the main means of transportation in the emergency corridor, buses played a very important role in the emergency response to Covid-19 due to their large passenger capacity. However, although taxis carry a small number of passengers, their time cost is less than that of buses. This research provides a simple way to assess and quantitatively evaluate urban life channel development. The construction of life channels is often based on a computer simulation to determine the shortest path, which requires many calculations and processes. Network models based on slime mold generation can inform the construction of life channels for existing and future urban road facilities and thereby provide an effective method of risk management for future urban emergencies. This study has some shortcomings. The research scope was limited to the area within the Third Ring Road of Wuhan. Therefore, tertiary hospitals outside this area were not included. In addition, the hospital node data for the study area were based on the existing hospital node distribution, and did not include planned hospitals. Therefore, the construction of the life channel has certain limitations. Nevertheless, the results indicate that this research method is superior to the traditional shortest path calculation method and has high value in applications involving urban medical life channels.

6. Conclusion

The construction of an urban medical life channel is a powerful form of technical support in high-risk situations and an important guarantor of urban medical resource deployment and patient assistance. This study used a slime mold biomimetic experiment to construct the optimal paths of urban life channels. The results demonstrate that this method can help to identify the intrinsic mechanisms of life channel networks and thus provides a new method for urban planning. A shortcoming of the study is that the study area did not include all of the tertiary hospitals in Wuhan, meaning the constructed life channels have some limitations. In addition, an undirected network was used in the network structure analysis. This should be transformed into a directed network in future research. Nevertheless, the bio-mimetic approach adopted in this study provides a new perspective on the construction of urban medical life channels. It also provides a set of extendable and replicable methods for applying slime mold biomimetics in the field of human urban environments.

CRediT authorship contribution statement

Gangyi Tan: Conceived and designed the experiments. **Yang Wang:** Performed the experiments; Analyzed and interpreted the data; Wrote the paper. **Xiaomao Cao:** Performed the experiments; Contributed reagents, materials, analysis tools or data. **Liquan Xu:** Contributed reagents, materials, analysis tools or data; Wrote the paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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