System Design of Safety Road Network in Urban Morphology Prevention During COVID-19 Based on Digital Simulation Technology

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ABSTRACT
Starting in December 2019, Wuhan, China, the first round of outbreak of coronavirus, which began to transmission rapidly in urban Wuhan and extended all around Hubei Province within a short period. The Chinese government took active anti-pandemic measures on occurrence of this regional pandemic. As Wuhan locked down, the number of confirmed cases dramatically reduced. However, the pandemic began to accelerate in other cities around the country and then globally, and the secondary infection has become the primary method of spreading of the pandemic. Curbing secondary infection of the pandemic in urban areas has become an essential goal for prevention and control of COVID-19. This paper uses the digital platform Rhino & Grasshopper to simulate the possible traces of urbanites' activities, and visually combines the most widely used virus transmission model such as SEIR, and proposes a new M-SEIR model to control transmission of urban pandemics. By exploring the relationship between the morphology of urbanites' activities flow and the development of the pandemic, this study will generate fresh insight into the design of public transportation, prevention and control of urban pandemics.

CCS Concepts
• **Computing Methodologies→ Modeling and Simulation→ Model Development and Analysis→ Modeling Methodologies**

Keywords
COVID-19; Design Morphology; Digital Simulation; Safety Road Network

1. INTRODUCTION
1.1 Development of the COVID-19 Pandemic
Since the COVID-19 outbreak, the pandemic is accelerating. It took 67 days from the first reported case to reach the first 100,000 cases, 11 days for the second 100,000 cases and just 4 days for the third 100,000 cases. You can see how the virus is accelerating.[1] On April 1, 2020, the number of COVID-19 cases worldwide has exceeded 840,000. Although both corona-virus, COVID-19 is far more infectious than SARS in 2003, the SARS infection coefficient R_0 is 3.6, while as the news reported, the corresponding value of COVID-19 is 5.5. Later, the propagation speed of COVID-19 is far higher than SARS. On January 23, 2020, the Chinese government took locked down the city of Wuhan. From the macroscopic view, in the early phase of the outbreak, except for Wuhan, the growth of exogenous infection cases in various provinces and cities showed a positive correlation with the Wuhan imported case. Microscopically, with the lockdown of Wuhan, the secondary infection has become the primary way of spreading of COVID-19 in other cities. For one thing, the transmission rate of the pandemic is closely related to city population density and traffic routes. And for another, the transmission rate of the pandemic has a close relationship with the morphology of the city population movement. This study aims at exploring the relationship between the flow morphology of urban population activities during the pandemic and the development of the pandemic through with design morphological thinking and digital simulation tools to provide insights for pandemic prevention.

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1.2 Urban Morphology & Design Morphology
Urban morphology is the study of the form of human settlements and the process of their formation and transformation. [2]

The study seeks to understand spatial structure and character of a metropolitan area, city, town or village by examining the patterns of its components and ownership or control and occupation. Special attention is given to how the physical form of a city changes over time and how different cities compare to each other. Another significant part of this subfield deals with the study of social forms which are expressed in the physical layout of a city, and, conversely, how physical form produces or reproduces various social forms. Urban morphology is considered as the study of urban tissue, or fabric, as a means of discerning the environmental level normally associated with urban design. Tissue comprises coherent neighborhood morphology (open spaces, building) and functions (human activity). Neighborhoods exhibit recognizable patterns in the ordering of buildings, spaces and functions (themes), variations within which nevertheless conform to an organizing set of principles. Complexity science has provided further explanations showing how urban structures emerge from the uncoordinated action of multiple individuals in highly regular ways. [3] Amongst other things, this is associated with permanent energy and material flows to maintain these structures. [4] While structure refers to the internal relationship between the elements of things, morphology emphasizes the appearance characteristics of combination of elements. The complexity of the urban structure determines the diversity of urban morphology whose purpose is to construct a balance between time, space, and activity. The diversity of morphologies constitutes a reflection of the characteristics of urban life. Therefore, the formation and development of urban morphologies are affected by the internal dynamics of urban development all the time, and various current factors may affect its evolution. [5] In this pandemic, COVID-19 has served as the main internal factor affecting the morphology of the city.

The English word "city" and the related "civilization" is derived from Latin *civitas*, originally meaning citizenship or community members. The Roman *civitas* was closely linked with the Greek polis—another common root appearing in English words such as *metropolis*.[6] This also indicates that the birth of a city is a sign of the origin of human civilization. It is precisely because of human "creativity," which is the ability to transform from *the first nature* to *the second nature*, that makes human stand out from many creatures. [7]. The purpose of designing morphology is to explore the generation principles of natural and artificial morphology. In this article, it is to explore the evolution of urban morphology under the pandemic and to provide designing solutions for COVID-19 prevention.

1.3 Grasshopper & ELK

Elk is a set of tools to generate maps and topographical surfaces using open source data from OpenStreetMap.org and USGS. OpenStretMap.org is an open/crowd-sourced website of mapping data. It allows you to export XML formatted data of a selected area and then Elk will organize and construct collections of point and tag data so that you can begin creating curves and other Rhino/Grasshopper geometry. The Location component is primarily for preprocessing all of the nodes or point data from the OSM export. It wants a file path to an OSM file as it's input and will output OSM-Points, a Point3d with an OSM defined ID, the text string of the full XML file, and the latitude and longitude domains. [8] Through the collection of urban pandemic data, on the basis of digital software Rhino & Grasshopper platform, we may predict the relationship between the flow of population and the urban traffic road network, and propose a new anti-pandemic solution.

1.4 Models of Virus Transmissions

Regarding the mathematical model of the spread of the SARS Regarding the spreading mathematical model of the SARS, Liu Xunxu provides the following explanation in his paper [9]:

Assuming that the number of cases at the initial stage is N_0. The infecting amount of each single case is K per day (K is usually a decimal). The average time for each case to directly infect others is L days. Then within L days, it is referred with the model:

$$N(t) = N_0 \ (1+K)^t$$

As is seen from the model, if the limitation of SARS infection period is not considered, the number of cases will increase exponentially. Considering that changes after the infection period will deviate from exponential growth and the growth rate will slow down, which means this model has better applicability to early stages and has its specific reference value with the transmission of the virus. The K is gradually adjusted through the model, and the fitted data enters a normal state with better control of the pandemic after short-term adjustment. Although this model is only applicable to early phases, it provides a useful reference for the establishment of diverse virus models in the future. [10] In Yang Fuyi's paper, "The mathematical model of virus transmission, the most thoroughly researched and most widely used infectious disease models are SI model, SIS model, and SIR model and SIRS model." He proposes a method to predict the transmission of new coronavirus in combination with *the small-world network model*. The characteristics of commonly used virus propagation models are as follows: [11]

SI model: system individuals are divided into two categories, susceptible individual (S) and infectious individual (I);

SIS model: based on the above model, it creates a new situation that infected individuals recover and return to the susceptible state again;

SIR model: R is the number of recovered or immunized individuals;

SIRS model: proposes the situation where the individual R who has gained immunity loses immunity with a probability which is r;

SEIR model: after susceptible individual S is infected, susceptible individual S becomes exposed state E with a certain probability α, and then becomes infectious state I with a certain probability β. [12]

Each of the above models has its unique attributes, and its limits as the pandemic transmission data at the beginning phase are difficult to confirm. The lack of detailed statistical data required for macro prediction and quantitative analysis also increases the difficulty of project implementation. Therefore, these models have great theoretical significance in the early phases of virus transmission.

Chen Baoquan's team, Center on Frontiers of Computing Studies, Peking University, has optimized the SEIR model and introduced C-SEIR model. The so-called C of which is "community isolation." First of all, the advantage of C-SEIR model is that it considers government quarantine measures and categories the population into quarantined and non-quarantined. In the quarantine, there would be no infection of cases; Second, with the strengthening of government measures and the rise of public protection awareness, the basic reproduction number (R_0) changes with time. It is not a fixed value. Therefore, their team fitted a new virus infection rate curve with real-time data to replace R0. [13]

Later, Tang Sanyi et al., based on the pandemic data reported by the Health Commission of Hubei Province and the National Health Commission of the PRC, which mainly includes cumulative reported cases, tracking human quarantine numbers, suspected cases, multiple provinces imported cases, and local cases, etc. by the creation of the initial COVID-19 pandemic transmission model with various prevention and control strategies [14]. It is a mathematical model that adapted to the characteristics of isolation tracking in China. The R_0 in early phases calculated based on the model formula is 6.47. This coheres with the recent news report that the R_0 value of 3.7 and 5.5, and the model has relative validity.

Yang Bingru points out that: "Graph theory simulates various mathematical models through the composition of points and lines, and analyzes according to the nature of the graph, providing scientific and smart research methods for various systems. Any system that contains a binary relationship can be analyzed by graph theory, and it often has intuitive characteristics." [15] Graph theory research has a wide range of applications in various fields. The relationship between viruses and receptors is also a typical binary relationship. In the study of design methods, we will also try to use graph theory to combine with the prevention and control of the pandemic to study pandemic models.

The Pearl curve is a special curve initially proposed by the Belgian mathematician P. F. Verhulst in 1938. Later, modern biologists Raymond Pearl and L.J. Reed employed this curve to study growth of population. And the special curve is thus called *the R. Pearl growth curve*, or *Pearl curve*, also called *the Logistic Curve*, and its mathematical expression is also called *the Logistic Mathematical Model*. [12] *The Pearl Curve* is widely applied to various natural and social sciences. The paper also attempts to test the transmission of COVID-19 with this model of the curve.

2. METHODOLOGY

2.1 Data Source Collation

The official website of the National Health Commission of the PRC only publishes the number of confirmed diagnoses in different regions. It does not clearly show the location of the confirmed cases. It is thus difficult for the public to grasp the transmission traces of the surrounding pandemic intuitively. Therefore, they can only roughly predict the growth trend of the pandemic in different stages and cannot adequately predict the COVID-19 transmission trend through urban traffic road networks. This data source is mainly from the Tsinghua Database Research Group Qatar Computing Research Institute, which collects a large number of pandemic data from diverse news websites. Including data from the National Health Commission, etc., which can be inferred that the source of test data is relatively reliable.

The testing data source is mainly from the pandemic transmission data issued on the platform on March 28, 2020. The distribution of the COVID-19 map is shown in Fig.1 and Fig.2.

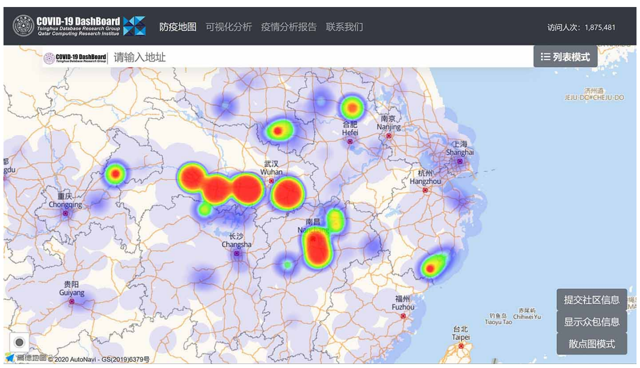

Figure 1. Thermal distribution of the Yangtze River Delta Pandemic [16]

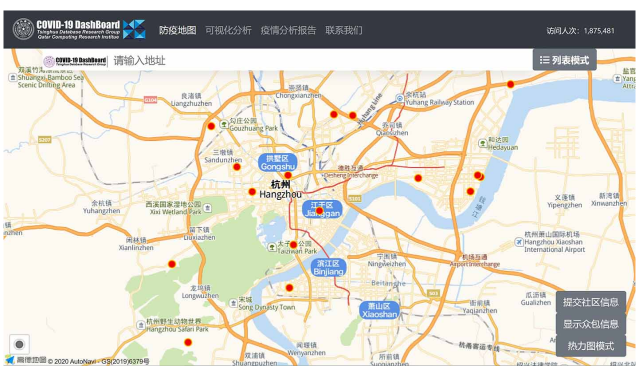

Figure 2. Distribution of Infected People in Hangzhou [16]

2.2 Through the Rhino & GH Platform to Extract Urban Epidemic Traffic

First, by obtaining the OSM map of the main urban area of Hangzhou, then the paper extracts the road features of the central urban area of Hangzhou through an ELK plug-in and using the Python algorithm to preprocess the output urban road network points for the next simulation experiment.

In this paper, five main infection areas on the northern bank of the Qiantang River in the urban area of Hangzhou are selected for simulation. There are 5 main infected areas, each with 10 concentric circles. By simulating the range of infected activities and potential cases, the smallest circle radius is one kilometer. The random points in each circle represent the potentially-infected person activities, including starting and ending points, as is shown in Fig. 4 and Fig. 5.

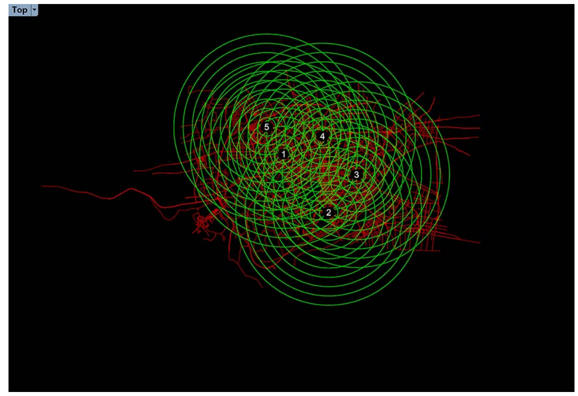

Figure 3. Define the transmission scope of the source of infection

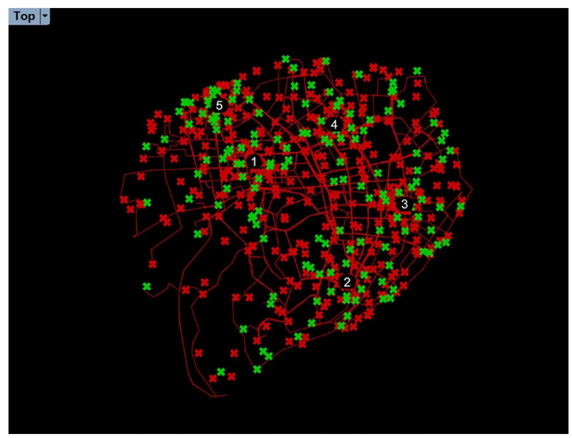

Figure 4. Simulate the starting and ending points of activities of potentially infected people

Then, setting the starting and ending points of the route of confirmed cases separately, and finding the nearest ending points of the activities of these people through the Grasshopper closest point plug-in. Through the shortest walk plug-in in Grasshopper, the shortest traffic paths that people pass along the urban road network to destinations are calculated. [17]

2.3 Analysis of Design Morphology of Road Network

Finally, the urban road network through which confirmed cases and suspected cases pass through is parameterized to strengthen the characteristics of the path of the virus transmission. The wider the road is, the higher the virus infection index is. And vise versa. In order to predict the transmission of COVID-19 in the urban road network through visual information interaction.

Table 1. Test data of city epidemic flow test

No.	Confirmed Cases	Activity Locations	Random Probability	Offset Distance	Morphological Characteristics	Morphological Contrast
1	155	384	0.90	110m	Central diffusion	
2	155	384	0.90	150m	Central diffusion	
3	155	384	0.90	200m	Central diffusion	
4	750	384	0.50	120m	Reach suburb	
5	750	384	0.50	150m	Reach suburb	
6	750	384	0.90	200m	Reach suburb	
7	3221	384	0.50	120m	Spread outskirt	
8	3221	384	0.50	90m	Spread outskirt	
⋮	/	/	/	/	/	/

● obvious ● moderate ● saturated

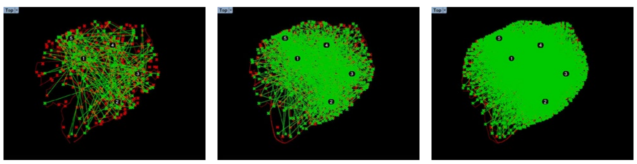

Figure 5, Figure 6, and Figure 7 are the starting and ending points of the experimental samples numbered 1, 4, and 7, respectively

Figure 8, Figure 9, and Figure 10 are the traffic morphology characteristics of the experimental samples numbered 1, 4, and 7, respectively

Tab. 1 Referred to the data of Yang Fuyi's coronavirus model, and the numbers are approximate numbers in the calculation table, such as 154, 752, 3222. When R_0 of COVID-19 is 5, simulated the third, fourth, and fifth-generation COVID-19 transmission morphology. This paper selects 8 data samples to test of which there are 4 variables, including infected people, activity addresses, random factors, and the road offset distance. With the variables increased, the morphology of the spreading path is also changed. This can be easily recognized in table 1 and the corresponding experiment pictures. With the increase in the number of confirmed cases of COVID-19 in the city, the initial stage of the pandemic mainly spreads along the main urban roads with large population flow, such as the Zhonghe Viaduct and Desheng Viaduct, etc.. In the later period, the virus of the fifth generation spreads all over the city fringe, the virus begins to transmission out of the city, and the contrast of the virus transmission morphology also tends to be relatively moderate.

The general model of Peel's growth curve is:

$$y = \frac{k}{1 + e^{f(x)}}$$

In the formula, k is a constant value, f (x) = a + bx + cx2+... In the application, the data after the square term is omitted, then f (x) = a + bx. This is the mathematical model of *the small-world network*. The model parameters are explained as follows, k is the total number of elements in the domain; *x* is the relationship layer (degree or time); *y* is the total number of infections, which is equivalent to the reachable point of the directed network; *a* is the horizontal offset, the initial attribute of the data; *b* indicates that the curve rising rate is related to the infection rate. [12]

This model has a certain reference significance in the early phase of virus transmission. As COVID-19 develops into the fifth generation and further phases, human intervention gradually plays a role in the pandemic. This paper mainly selects the early transmission data of COVID-19 for simulation. It can be clearly seen that with continuous improvement of the x relationship level (degree or time), when COVID-19 develops to the fifth generation, if active anti-pandemic measures are not taken, the main roads of the city will gradually be occupied by the pandemic, as shown in Fig.11.

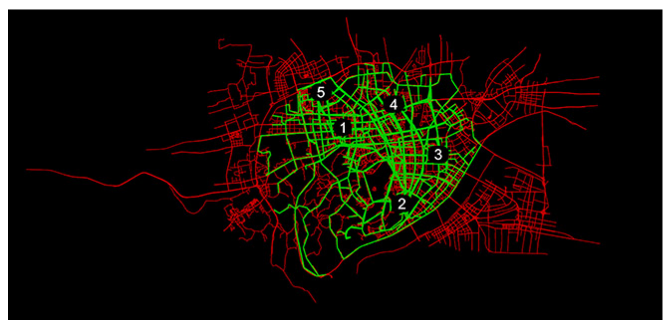

Figure 11. Urban Morphology of the Fifth Generation of COVID-19 Transmission

3. RESULTS

3.1 Introduction of M-SEIR Model

Compared with the previous model, the new model has the following improvements:

The so-called M is the morphology. Considering human intervention of the government public departments on urban public transportation in the later stages of the pandemic, and have clearly collected activity traces of the confirmed cases and suspected cases, through M-SEIR model, it can be predicted that the development of the pandemic in urban areas, providing innovative designing solutions for the prevention and control of pandemics from the perspective of urban morphology, as shown in Fig.12.

In the M-SEIR model, the population is mainly divided into Susceptible (S), Exposed (E), Infectious (I), Recovered (R), and hospitalized (H) groups, etc. f is the rate of suspected cases, and q is the quarantine rate of contacts population. If susceptible cases S_q develops into confirmed cases, they will be quarantined in the E_q area. Otherwise, they will continue to be quarantined in the Sq area or returned to the S area. The susceptible population S is diagnosed and segregated by fever diagnosis, which is called S_f.

Among them, the close contacts of susceptible (S_q), quarantine susceptible (S_f）, quarantine exposed (E_q）and hospitalized cases (H) are the sources of infection that need to be tracked and quarantined at the second-level, because they are already in the quarantine zone or the hospital, the route of virus transmission is relatively limited. However, the susceptible population (S), the exposed population (E), the infected population (I), and the recovered population (R) are the main observation and research objects of this tracking quarantine. They are also called the first-level quarantine range, as shown in Fig.12.

The next step is data collection, including static road frameworks, urban traffic dynamic flows, and the location of infection sources, etc.

After collection of the data, the two levels of tracking and quarantine data sources can be classified and simulated according to different development phases. By simulating the main traffic through the algorithm, the preliminary high-risk traffic trace can be obtained. With this, optimization of urban traffic patterns by restricting the flow of people, and the optimization of route network distribution can be done and then conduct a risk assessment. If there is still a risk of a pandemic, it is suggested to return to the higher-level program to continue to improve public control and enhance personal protection measures. Otherwise, the city may output the design plan, propose a relatively reasonable public transportation travel plan and urban safety road network prevention design solution, as shown in Fig. 12.

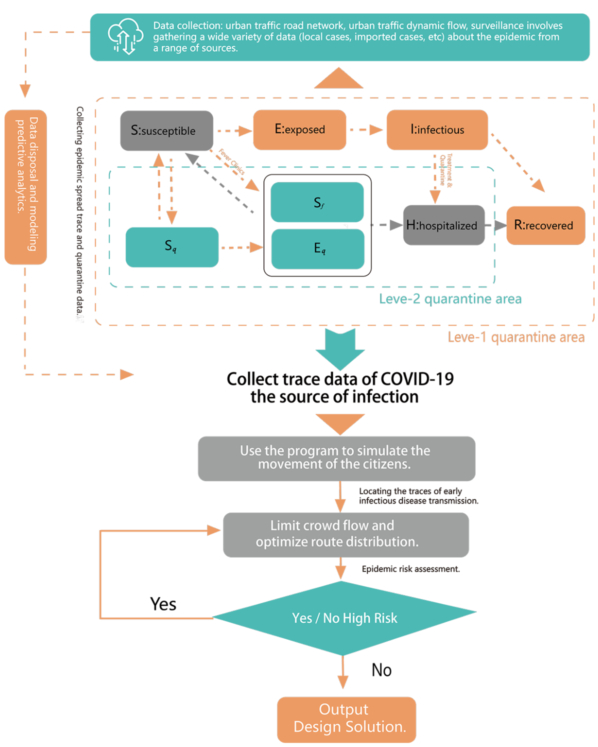

Figure 12. M-SEIR urban epidemic prevention model

3.2 Taking Pandemic Prevention and Control of Hangzhou as An Example

As can be seen from the visualized pandemic situation, the pandemic mainly spreads along the five infected areas in the main area of Hangzhou. The pandemic spreads outward along West Lake District, Cuiyuan Street, Shangcheng District Ziyang Street, Jianggan District Kaixuan Street, Gongshu District Daguan Street, West Lake District Sandun Town. Most of the main roads, including Zhonghe Expressway, Nanshan Road, Tianmu Road, and Jianguo North Road, are the roads most affected by the pandemic. In order to prevent and control transmission of the pandemic, Hangzhou also implements measures to restrict the number of Non-local vehicles to strictly inspect imported cases. As shown in Figure 14, the main dangerous roads simulated in the above experiment were also restricted. As shown in Figure 13, it is a schematic diagram of the urban traffic restriction measures implemented in Hangzhou. Residents in this city advocate reducing travel and wearing masks. Someone does need to goi out of the city are encouraged the use of non-motorized travel methods such as cycling, so as to reduce the concentration of population and block the transmission of viruses and strictly inspect imported cases. Therefore, Hangzhou has achieved obvious anti-pandemic results.

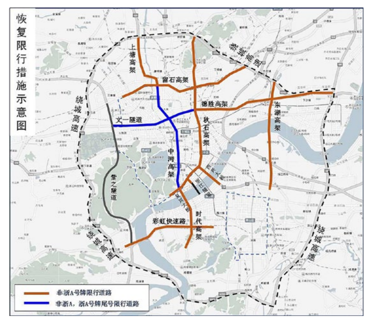

Figure 13. Schematic diagram of restoration of traffic restrictions in Hangzhou. [18]

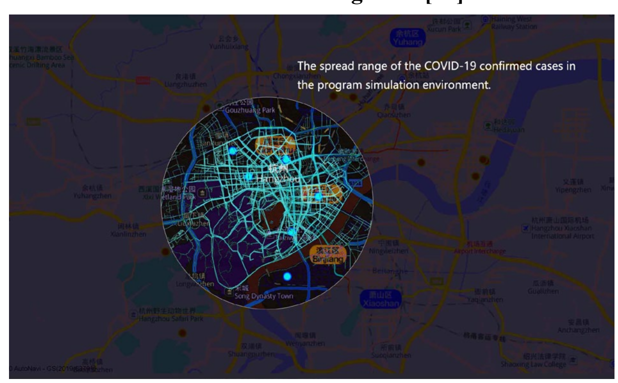

Figure 14. Map of Hangzhou pandemic situation under assumptions

4. DISCUSSION

Later, this article also conducted a simulation experiment on the transmission of COVID-19 in San Francisco. As of 9:32 am on March 30, 2020, according to the statistics of Johns Hopkins University (JHU), the number of confirmed cases in the United States has reached 142,328. The pandemic has transmission to almost every state in the country, as shown in Figure 15. Among them, 4767 people recovered, and 2489 died. A total of 340 cases were confirmed in San Francisco and 5 of them died, as shown in Fig.16.

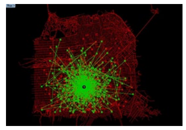

Figure 15. Distribution of COVID-19 in the United States [19] Figure 16. Distribution of COVID-19 cases in San Francisco. [19] Figure 17. Simulate the starting and ending points of the activities of potentially infected people in San Francisco

Assuming the number of confirmed cases in San Francisco is currently 350, their target activity location is 385, and the human activity random probability is 0.5, then conduct simulation experiments. As shown in Figure 17, set the road offset distance to 15 m, and bring it into the model for visual analysis, as shown in Fig. 18.

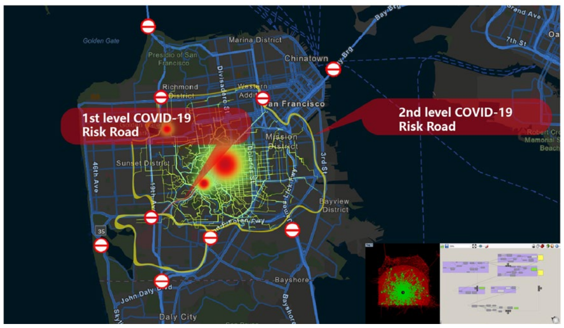

Figure 18. Schematic diagram of San Francisco pandemic prevention and control

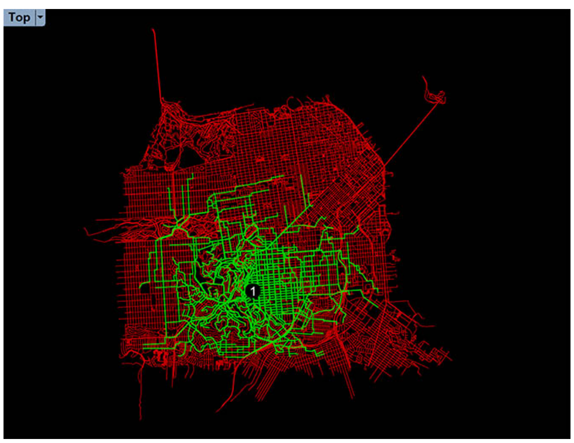

Figure 19. Infected population morphology transmission range

Figure 20. The transmission of the San Francisco infected population in the simulation.

From Fig.19, it can be easily seen the transmission of COVID-19 confirmed cases in the program simulation, and then import the San Francisco pandemic map for analysis, as shown in Fig.20. The source of infection gradually transmission outside along the areas of John F. Foran Freeway, Mission District, and Park Presidio Boulevard, etc. Among them, the 19th Avenue, Geary Boulevard, John F. Foran Freeway and some other roads are relatively high-morbidity areas, which need strictly traffic inspections and quarantines. Therefore, it is necessary to restrict and quarantine the main intersections of cities and adjust the quarantine methods promptly according to the development of the pandemic situations, and roads can also be divided into *1st level COVID-19 Risk Road* and *2nd level COVID-19 Risk Road*, as shown in Fig. 18.

Also, the article from Science mentioned that while the Wuhan travel ban was initially effective at reducing international case importations, the number of cases observed outside Mainland China will resume its growth after 2-3 weeks from cases that originated elsewhere. Furthermore, the modeling study shows that additional travel limitations up to 90% of the traffic have a modest effect unless paired with public health interventions and behavioral changes to achieve a considerable reduction in disease transmissibility. [20] At the same time, it also shows that under the premise that there are no specific vaccines and drugs, only large public departments such as governments and medical institutions actively participate in management, quarantine the infectious source, protect the susceptible population, cut off the virus transmission route, and improve personal protection awareness, only in these ways can we suppress COVID-19 the rapid transmission of the pandemic.

5. CONCLUSION

In this paper, based on the M-SEIR urban morphology pandemic prevention model, data migration the urban pandemic situation through the Grasshopper digital platform, combined with the design morphology research ideas, with visual information interaction, which is used for urban safety road network planning and urban crowd flow supervision to provide an anti-pandemic strategy. It reflects that the environmental form has a decisive effect on its simulation results, and it also explains the reason why the urban morphology determines urban human behavior. [21] The relationship between urban morphology and human behavior itself is a mutually beneficial ecological collection. Only the continuous enhancement of urban public management and personal protection awareness is the fastest remedy to suppress the pandemic. On account of the authors who do not have professional medical knowledge, it is unlikely to conduct in-depth analysis and testing through professional infectious disease models, human experimentation, etc.. Part of the data involved in this article is just theoretical experimental data. Secondly, the accuracy of the collected map information, infection source location and other data will also affect the experimental results, which may be inconsistent with the actual situation. Hoping professionals could provide criticisms and suggestions.

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