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Visual Analysis and Exploration of COVID-19 Based on Multi-source Heterogeneous Data

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***Abstract*—The novel coronavirus pneumonia (COVID-19) has raged in many countries around the world. In the process of fighting against the COVID-19, unprecedented large-scale epidemic data have been produced such as case data, spatio-temporal data, public opinion data and so on. The increasingly complex data poses a significant challenge to understand. A two-level interactive visualization system named COVID-19Vis is proposed in this paper, which collects epidemic data from multiple sources and provides an interactive mode of multi-graph linkage. Users can not only easily analyze and interpret the spatial-temporal characteristics and potential rules of the epidemic, but also find the relationship between policy, online public opinion and the development of the epidemic situation. Through a large number of visualization effects and user feedback, the effectiveness and practicability of the COVID-19Vis are further verified.**

***Index Terms*—COVID-19, spatial-temporal transmission, Internet public opinion, multi-source heterogeneous data, visual analysis**

I. Introduction

The COVID-19 poses a huge challenge for China at the beginning of 2020, with the features of sudden outbreaks, rapid spread and high levels of social panic. The unprecedented large-scale data has been generated in the fight against the COVID-19. Therefore, we focus on the research of how to apply visual analysis methods rationally to dig out the data laws intuitively and interactively, to provide effective guidelines for epidemic prevention and control globally.

There have been many studies [1]–[4] on visual analysis methods for the epidemic data, which are multi-sources and heterogeneous. Among these visualization methods, the map and geographic information visualization technology is deployed in a wide range of applications. In [5], a visualized analysis method based on geography has been proposed, which displays a choropleth map colored by the density of the microblog topics attention in each country. In [6], a geospatial heatmap has been employed to show the distribution and variation trend of the public flow space caused by a massive hurricane called Sandy in the Manhattan area in New York City in 2012. In addition, an interactive visual analysis tool for exploring the correlation between animal migration and natural environment has been designed in [7]. It used the color and width attributes of the moving track to map the effects of various environmental factors on animal migration visually. For the futher comprehensive analysis of transmission route, scale, number of infections and other information, the combination with the line, column and pie charts attracted more attention. In [8], a dynamic model of global protein demand has been developed by applying heatmaps. It combined the bar chart, line chart and other visualization methods with the map, which is helpful to analyze the different aspects of the whole dataset. What's more, circular comparison chart is a kind of column graph, which shows the difference of various data more intuitively in limited visualization application space.

As a research hotspot in the field of visualization, many scholars have tried to use this technology in transportation, meteorology and other application fields, which has achieved good results. For instance, in [9], a 24-day taxi track data in Beijing was collected to show the evolution process of traffic congestion in time and space by multi-view which was then used to analyze the traffic situation of the whole city. In [10], a multi-angle collaborative visualization method was designed to help meteorologists deeply understand large-scale meteorological data and analyze possible climate phenomena and corresponding characteristics. The system in [11] focused on visualizing the epidemic development globally. It displayed the cumulative number of confirmed cases and China's foreign aid based on global maps, circular comparison chart, broken line and bar charts. The system in [12] focused on the visual analysis and dynamic display of public opinions during the epidemic in China. Interactive functions were used to show the changing trend of public opinion information at the national, provincial and municipal scales.

Based on the above research, we collect the multi-source data generated by the major official websites/media, and design a two-level multi-graph linkage analysis system named COVID-19Vis. The mixed data can be intuitively interpreted from multiple angles, such as the development of the national epidemic situation, comparative analysis of confirmed data, rate analysis, network public opinion, policy response, patients' psychological state, spatial and temporal evolution of the COVID-19 in Hunan province and so on. The laws behind the data are revealed in this paper and the main contributions are as follows:

- An interactive multi-functional collaborative visual analysis system is proposed to help users analyze the spatial-temporal distribution of the COVID-19.
- A multi-interaction line-column chart is designed based on user requirement, whose function is to check the comparison results and analyze the development trend of

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epidemic, public opinion and abnormal situations.

- A subinterface of patient anxiety information in the mobile cabin hospital is designed with the annular bubble chart to help doctors promote the patients' recover from the psychological level.
- The usability of the system is evaluated by case analysis.

II. Visual Analysis Design

A. Visual analysis tasks

The following design goals are summarized in this paper:

1) We require that this method can reflect the change of diagnosis data over time and region to analyze the transmission speed. Combined with relevant comparative data, this method should help us to explore the effect of defense and treatment;
2) Focus on the development of national epidemic situation, we require that the method can analysis of the role of national policies in epidemic prevention and explore the trend of Internet public opinion and public sentiment with the development of the epidemic in order to develop guidance strategy;
3) With the development of the national epidemic situation as the core, we require that the method can analyze the explore the trend of network public opinion to develop a guidance strategy;
4) Taking Hunan province as an example, we require that the method can analyze the mode of epidemic transmission, compare the differences among different places, and analyze the possible causes.

B. Visual design process

The COVID-19Vis proposed in this paper contains six closely connected modules, and its main logical relationship is shown in Fig. 1.

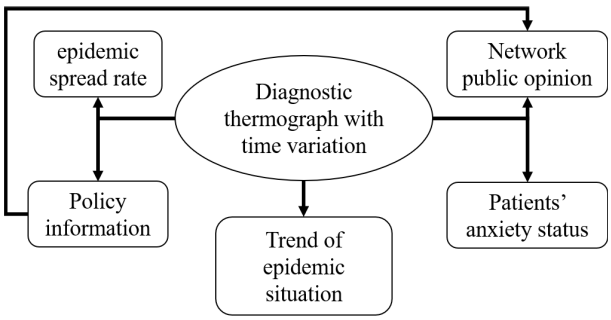


Fig. 1. System logic chart.

Taking the overall situation of the COVID-19 as the mainline, the development of the epidemic in China and its impact have been thoroughly understood from four aspects: time and space evolution, public policy, public opinion, and psychology. The visual design process is shown in Fig. 2. The COVID-19 data is selected from many data sources. Regular and valuable data is obtained through data processing and data mining. According to the data characteristics, the COVID-19Vis is designed based on a hierarchical layout. Users can use the system interactively, and can dynamically change the method from data selection to visual analysis and design process to form a human-in-the-loop analysis process.

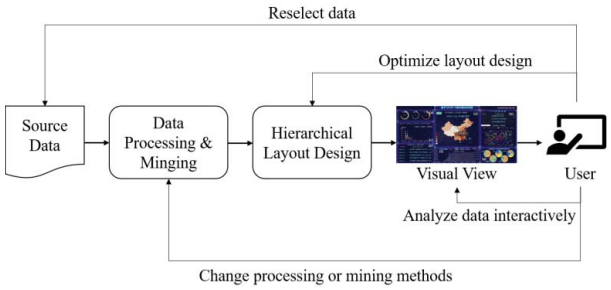


Fig. 2. Visual design and analysis process.

III. Data Processing and Visual Design

A. Date processing

The data sources used in the COVID-19Vis include time series data of the COVID-19 cases in China, hot search data of Sina net, epidemic policy and resumption of work and classes data, population migration data of Hubei province, psychological data of patients in mobile cabin hospitals and detailed case information of cities in Hunan province. In this paper, Python is used to crawl the relevant data for cleaning, and based on the time sequence, the unified format is established according to the hierarchical structure of the country, province and city. Then, original rule data is stored in the unified database after extracting the required fields.

Using the COVID-19 data of Hunan province, the epidemic diffusion ratio can be calculated according to (1). The incidence ratio of cities in Hunan province can be calculated according to (2). The K value was chosen as 1 million in this paper.

$$\text{diffusion ratio} = \frac{\text{diffuse cases}}{\text{imported cases}} \tag{1}$$

$$\text{incidence ratio} = \frac{\text{cumulative number of diagnoses}}{\text{total population of the city}} * K \tag{2}$$

B. Visual design

Based on the above analysis, the COVID-19Vis is designed as a two-level multi-graph linkage system. From the perspective of the map and geographic information, this paper analyzes the development trend and transmission mode of the COVID-19 situation in China and provinces step by step, reviews the prevention and control effect through policies, analyzes public psychology through network public opinion, and formulates intervention measures combined with anxious state of patients.

Fig. 3. Main interface of the COVID-19Vis. Seven interfaces are included in the COVID-19Vis, they show different the COVID-19 data in different types of graphs, including cumulative diagnosis, anxiety status, et al.

1) Main interface of the COVID-19Vis: The main interface of the COIVD-19Vis in this paper is shown in Fig. 3, it mixes layout map, word cloud, line map, circular contrast map and other visual graphics, and displays the development of domestic epidemic situation for three months.

The sequential thermal chart of cumulative diagnosis of each province in China is shown in figure (a). The top 10 hot topics of Sina every day and the corresponding emotional tendency and comment cloud are shown in figure (b). The diagnosis rate, cure rate, mortality rate and migration trend of Hubei province in China/Hubei region/non Hubei region are shown in figure (c). The cumulative diagnosis/cure/death data in China, the diagnosis/cure/death data of that day, and the TOP3 provinces with the highest number of confirmed cases per day are shown in figure (d). The daily policy release and resumption news are shown in figure (e). The comparison effect of new data, cumulative data, hot search of public opinion and emotional tendency are shown in figure (f). The anxiety status of 118 patients in mobile cabin hospitals according to gender, marital status, age, disease condition and education level is shown in figure (g) (self-rating anxiety scale is used).

2) Interaction design of sub interface: Aiming at the needs of patients' anxiety information and regional transmission mode, a visual analysis sub interface of patient anxiety information in mobile cabin hospital based on circular bubble chart and a regional communication mode sub interface based on input diffusion ratio are proposed in this paper.

As shown in Fig. 4, the overall anxiety situation and male/female anxiety comparison are displayed by gender. The score information of different anxiety items is reflected in the circular bubble chart.

Fig. 4. Anxiety state of patients in mobile cabin hospital. SAS score comparison of male and female in mobile cabin hospital is shown, where P value is set to 0.006.

The sub interface of spatial-temporal evolution analysis of the COVID-19 situation in Hunan province is shown in Fig. 5. Through layout map, column comparison chart and line chart, we can directly analyse and compare the COVID-19 situation from cumulative diagnosis, imported diagnosis, diffusion diagnosis, incidence rate, changes of the proportion of imported and diffused cases.

IV. Visualization Result Analysis

The COVID-19Vis is realized through the collaboration and interaction of five contents, including multi-graph linkage interactive visual analysis in the spatial-temporal evolution of epidemic cases across China and the provinces, policy releases,

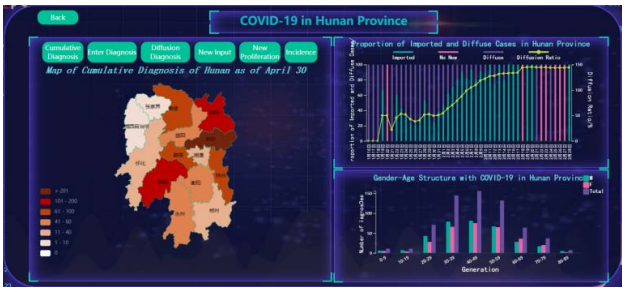


Fig. 5. Spatial-temporal evolution of the COVID-19 in Hunan province. The change in the proportion of imported and diffused cases, and gender and age structure of confirmed cases in Hunan province are shown.

the development of public sentiment, the anxiety of patients in mobile cabin hospitals, and the spatial-temporal evolution of epidemic outbreaks in Hunan province.

A. Spatial-temporal evolution and trend analysis of the COVID-19

1) Analysis of the national spread situation of the COVID-19: According to the time series heat map of the cumulative diagnosis of all the provinces in Fig. 6, it's shown that on January 19, 2020, China's confirmed cases began to spread from Hubei to Guangzhou and Beijing. And in just three days, COVID-19 spread to 80% of the provinces in China, which indicates that the COVID-19 spread speed rate is fast and the spreading scale is wide. On April 31, 82,548 people were diagnosed in China, of which 68,128 were diagnosed in Hubei. The COVID-19 has become a major public health emergency that has the fastest spread, the widest infection range, and the most difficult prevention and control since the founding of New China.

Fig. 6. Spatial-temporal evolution of the COVID-19 in China. The COVID-19 began in Hubei and spread to 80% of provinces in China within three days.

2) Analysis of the national COVID-19 prevention and treatment effect: Three comparison charts respectively indicating the cumulative diagnosis/cure/death data, the diagnosis/cure/death data of the same day, and the provinces with the highest number of confirmed cases per day are shown in Fig. 7. Through the comparative analysis, the following rules are found:

1) With the closure of Hubei province and the release of policies in China, the cumulative cure has risen significantly, and the number of cures on the day is also gradually higher than the diagnosis on the day, which is enough to illustrate the effectiveness of China's national defense and treatment programs.

Fig. 7. The three circular comparison chart, which shows the diagnosis, cure and death cases and the TOP3 diagnosis provinces in China.

2) In the later stage of the COVID-19, the provinces with TOP3 diagnosis in China moved from Hubei, Guangdong, and Hunan to Shanghai and Inner Mongolia. As shown in Fig. 8, diagnosis in Shanghai and Inner Mongolia suddenly increased in March and April. It's the period when the COVID-19 is developing towards globalization, and imported cases occur in the country, which requires the country to pay high attention to prevent the rebound of the epidemic situation.

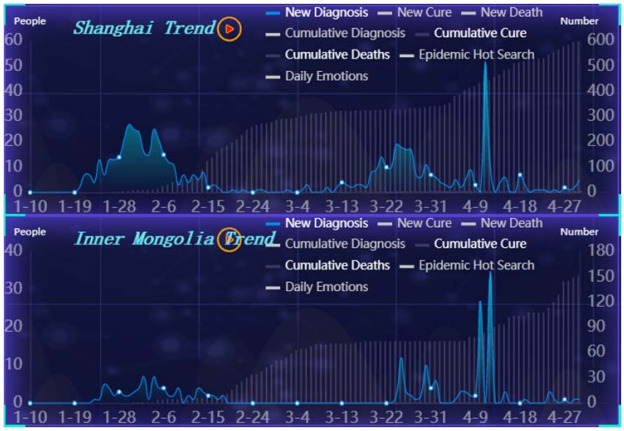


Fig. 8. Trend chart of new diagnosis in Shanghai and Inner Mongolia. Two sudden increases of the new diagnosis in March and April indicate the need to strengthen protection against epidemic from rebound.

As shown in Fig. 9, the fatality rate in China, Hubei and non-Hubei regions are U-shaped, which shows a trend of high in both end and low in the middle. The fatality rate will increase in the later stages of the epidemic, which is related to the lack of early preparations, the rapid increase in the number of diagnoses in the middle and the saturation of the number of diagnoses in the late stage. According to the chart, it is predicted that the final fatality rate of the COVID-19 may up to 5% [13], far exceeding common infectious diseases such as influenza, which needs to be highly valued by various countries.

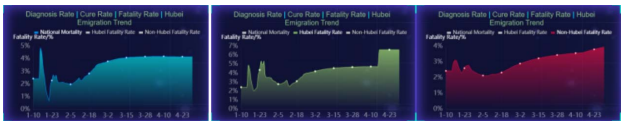


Fig. 9. Trend chart of fatality rate in China, Hubei and non-Hubei regions.

B. Data trend and policy analysis of the COVID-19

By analyzing the cumulative diagnosis compared with the new diagnosis, the cumulative cure compared with the new cure and the cumulative death compared with the new death trend charts in China and provinces, the following conclusions can be drawn:

1) As shown in Fig. 10, the line chart reflecting newly diagnosed data in China show a rapid decline after peaking. The cumulative diagnosis data are gradually calm down, which indicates that the effect of epidemic control in China after the closure of Wuhan is effective.
2) By checking the diagnosis of each province, there are two peak fluctuations in new diagnosis cases in some coastal provinces and cities from January to the end of February and mid-March to mid-April. As shown in Fig. 8, the second fluctuation mainly stems from imported cases abroad. The diagnosis of inland provinces is concentrated from January to the end of February, which shows that in the post-epidemic period, China should focus on preventing the rebound of the COVID-19 caused by overseas imports.
3) According to the trend charts of the new diagnoses in the country and provinces, many abnormalities can be found through the peak of the broken line. As shown in Fig. 11, the number of new diagnosis across the country suddenly increased by 15,151 on February 12. Combining with the policy release on the left, it can be seen that due to the release of the new diagnosis definition of the COVID-19 on February 9, there is an obvious increase of the confirmed diagnosis on February 12.

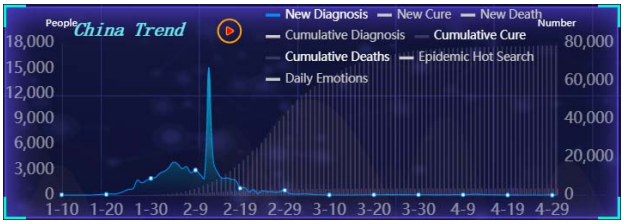


Fig. 10. Comparison chart of the new diagnosis and cumulative diagnosis in China.

C. Analysis of the mood and sentiment of people with the COVID-19

By analysing the microblog hot search, the hot search title collection, word cloud of the key words and sentiment category are presented in Fig. 13. The public mood and sentiment can be divided into three stages:

Fig. 11. The policy release influence on the new diagnosis and cumulative diagnosis in China.

1) The first stage is the panic with anxiety period, which is a period of concentrated the COVID-19 treatment and prevention in China. As shown in Fig. 12, from the beginning of January to February 28, the public sentiment fluctuated up and down with an equal rate. As shown in Fig. 13(a), the public attention key words are mainly focused on Wuhan, wildlife, China, mask, doctor and so on.
2) The second stage is the undulating stage. As shown in Fig. 12, from March 1 to April 1, the amplitude of emotional fluctuations is relatively large. As illustrated in Fig. 13(b), the public obviously has negative emotions about imported cases abroad, especially concealing the COVID-19. With regard to the domestic the COVID-19 situation, the post-epidemic period has entered, and people's lives gradually return to normal.
3) The third stage is a positive and optimistic stage. As shown in Fig. 12, from April 1 to April 30, the public sentiment was tilted in a positive direction. The negative sentiment at this stage mainly stems from the serious development of foreign the COVID-19 situation, and the trend of globalization has not eased.

D. Analysis of health status of patients with the COVID-19

According to the anxiety of 118 diagnosed patients in a mobile cabin hospital. The patients' anxiety state classification pie chart is summarized in this paper. As shown in Fig. 14, exploring the differences of the patients in terms of gender, marital status, age, education level and health condition, and then get the major patients group that needs intervention.

1) As shown in Fig. 4, the unfortunate premonition, sitlessness, dyspnea, stomach pain and indigestion, sweating and sleep disorder of 118 patients are highlighted and need to be given attention and adjusted in time. As illustrated in Fig. 15, it is found that men and women have significant differences in anxiety, panic, headache, fatigue, dizziness, fainting feeling, nightmare, etc. And the proportion of women is higher than that of men.
2) As shown in Fig. 16(a), through the comparison of marital status, it is found that there is a significant difference between unmarried and married groups, and the anxiety of married groups is significantly higher than that of unmarried groups. While in Fig. 16(b), it can be seen that unequal degrees of the health conditions have different levels of anxiety. It can be inferred from Fig. 16(c) that through the comparison of education level, there is a significant difference in anxiety. Among

them, the patients with junior high school and below education level anxiety are obviously high.

Based on the analysis above, in response to the anxiety characteristics of the COVID-19 patients in the mobile cabin hospital, more attention should be paid to women, low education, married, ordinary and older patients during the COVID-19 outbreak, and timely intervention measures should be taken.

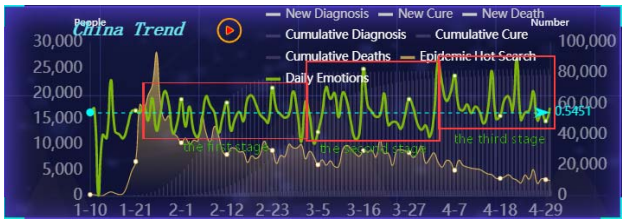
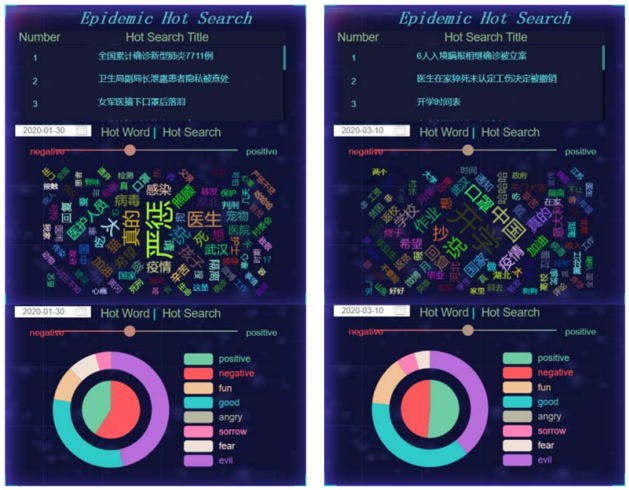


Fig. 12. The three stages of the public mood and sentiment. The first stage is the panic with anxiety period. The second stage represents the undulating stage and the third stage shows the positive and optimistic stage.



(a) (b)

Fig. 13. The epidemic hot search title, the word cloud of the epidemic key words and the public mood and sentiment.

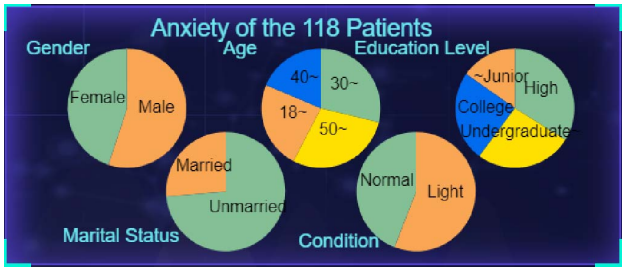


Fig. 14. The classification pie chart on gender, marital status, age, education level and health condition of 118 patients in mobile cabin hospital.

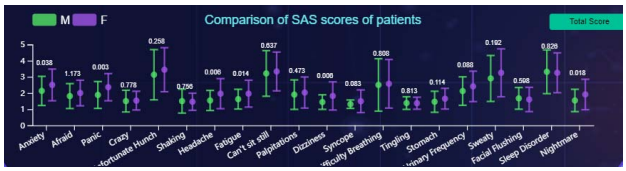


Fig. 15. The comparison chart of SAS scores of patients with different gender in mobile cabin hospital.

(a) (b) (c)

Fig. 16. The SAS scores comparison chart with different marital status, health condition and education level of 118 patients in mobile cabin hospital.

E. Analysis of the COVID-19 in Hunan province

The population migration chart of Hubei province after the occurrence of the COVID-19 can be obtained through Fig. 17. An analysis of the proportion of Hubei's emigration revealed that Hunan province had TOP1 in the total emigration percentage. Therefore, it is necessary to analyze the transmission mode of the COVID-19 based on the cumulative diagnosis chart of Hunan province to explore prevention and control measures from the aspects of input type, diffusibility, morbidity, diffusion ratio, personnel structure, etc.

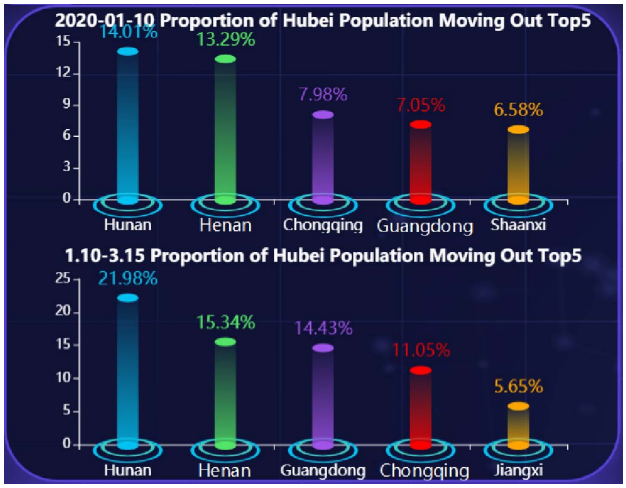
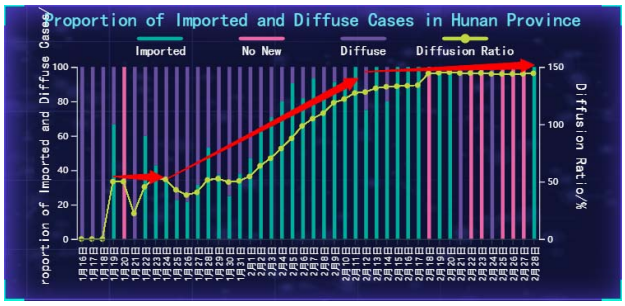


Fig. 17. Proportion of Hubei province population moving out TOP5.

The trend chart of the COVID-19 in Hunan province is shown in Fig. 18(a). The newly confirmed diagnosis in Hunan are divided into three stages. The first stage is the rapid diffusion stage in Fig. 18(b), with one diagnosis on January 21 and reaching its peak on January 28, which needs to be given full attention and prevention. The second stage is the

centralized prevention and treatment period from January 28 to February 6. It can be seen in Fig. 18(b), during this stage, the proportion of diffuse cases has gradually decreased, indicating that the prevention and control measures of Hunan province have a satisfactory effect. The third stage is the prevention and control stabilization phase. From February 6 to February 18, the new diagnosis declines rapidly. With reference to Fig. 18(b), it can be concluded that this period is basically the imported case, indicating the COVID-19 prevention and control in Hunan province is effective, and the COVID-19 situation is effectively controlled.

(a)



(b)

Fig. 18. (a) The trend chart of the COVID-19 in Hunan province. (b) The trend chart of the proportion of the imported and diffuse confirmed cases in Hunan province.

As shown in Fig. 19(a), Changsha, Yueyang, and Shaoyang are cities with more than 100 people diagnoses. Changsha, as the provincial capital, has more floating population. Yueyang is close to Hubei province, which leads to a larger number of diagnoses and Shaoyang is mainly due to cluster cases. As for the imported diagnosis, Fig. 19(b) shows that Yueyang has the largest number
imported diagnoses. In addition, 46 cases of imported confirmed cases were found in Changde, and a total of 82 cases were diagnosed, and 36 cases were spread, which means Changde's measures are well implemented and worth learning. In terms of incidence rate shown in Fig. 19(c), it is found that Changsha and Yueyang have a higher incidence. Although Shaoyang has a large number of cumulative diagnoses due to clustering cases, the overall population mobility is low, which causes the incidence is not high. In summary, in Hunan province, special attention needs to be paid to the COVID-19 situation in Changsha and Yueyang, and the COVID-19 in Changde must not be neglected.

(a) (b) (c)

Fig. 19. (a) The cumulative diagnosis in cities of Hunan province. (b) The cumulative imported confirmed cases in cities of Hunan province. (c) Morbidity rate of cities in Hunan province.

V. Visual Analysis Conclusions and Using Feedback

A. Visual Analysis Conclusions

The visual method proposed in this paper is used to analyze the spread and influence of the COVID-19 in China. The following conclusions can be made clear:

1) The COVID-19 was confirmed in Wuhan and spread all over the country in only three days. Internet public opinion also reached its peak on January 26, the third day after the closure of Wuhan city;
2) The COVID-19 was globalized in March, and at the same time, it was basically controlled in China. However, the imported cases caused the spread of related cases, which reminding the our government to prevent the rebound of epidemic situation;
3) The emotion of people has been fluctuating for three months, which indicates that the psychological impact of the COVID-19 on people lasts longer than the physiological impact. Our government should pay attention to protect people's physical and mental health in the future;
4) The Internet public opinion mainly focused on Wuhan, masks, doctors, overseas epidemic situation and other topics in different periods. Among them, Rumors and lies caused people's negative emotions. Relatively, people held a positive attitude towards doctors, support, cure and so on;
5) Through the study of the anxiety state of patients in mobile cabin hospital, we know that different factors will have a significant difference in the psychological impact of patients. We need to carry out corresponding psychological intervention to help patients better accept physiological treatment;
6) The spatio-temporal evolution and propagation characteristics of the COVID-19 in Hunan province were visualized to explain the differences between cities. As a result of the analysis, we can see effective measures for prevention and control have been used in stages.

B. Using Feedback

In order to further verify the practicability of the COVID-19Vis, an infectious diseases physician and a psychology expert are invited to evaluate the system function. The two

experts spoke highly of the system in terms of data reading and visual analysis, mainly including the following aspects:

1) By playing the national heat map, users can intuitively feel the transmission speed and scope of the COVID-19. Through the circular contrast chart, the timeliness and effectiveness of the COVID-19 prevention policy can be proved;
2) Through the interactive comparison between the line chart and the column chart, the abnormal situation of statistical quantity is found, which is convenient to further explore the causes and laws;
3) Combined with Internet public opinion analysis module, the emotional line chart can help psychological experts rapidly grasp the overall law, the dynamic of public concern. Then, the formulation and implementation of guiding strategies can be employed effectively;
4) The visual analysis of patients' anxiety in mobile cabin hospital can help doctors understand the major sufferers according to corresponding influencing factors. As a result, patients can be psychologically encouraged to receive physical treatment;
5) Through the ranking of emigrants from Hubei province, Hunan province can be find out and then the epidemic mode of the COVID-19 is studied. According to the imported cases, transmission cases and incidence rates, the difference between transmission patterns in cities is effectively analyzed, and the effectiveness of the municipal government's control measures is also reflected.

VI. Conclusions

In this paper, to explore the development trend of the COVID-19 in China as the starting point, firstly, the spatial-temporal distribution characteristics and transmission trend of the epidemic development are studied, combined with the policy release, compare and summarize the effect of the COVID-19 prevention and treatment, and analyze the causes of abnormal. Secondly, according to the changes of Internet public opinion, the impact of the COVID-19 on people's psychology and emotion is explored, so as to provide a reasonable basis for the state to attach importance to psychological guidance in the post epidemic period. Especially, patients' anxiety in mobile cabin hospital is analysed to help doctors to find major intervention patients, and assist in body healing. Finally, we analyzed and compared the COVID-19 transmission mode in Hunan province. According to the feedback of psychology researchers, the COVID-19Vis has both theoretical and practical value in intuitively displaying data, mining hidden information, guiding decision-making and so on.

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