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Research on the Prevention and Control of Infectious Diseases in Crowded Places Based on Mathematical Modeling Principles

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Abstract: With the rapid pace of urbanization, areas with high population densities are increasingly recognized as hotspots for the swift transmission of infectious diseases. This study focuses on urban subway stations, quintessential examples of crowded spaces, to model and predict the spread of infectious diseases in such environments. Utilizing the principles of mathematical modeling, we developed a specialized SEIR (Susceptible, Exposed, Infectious, Recovered) model that is tailored to the unique dynamics of crowds and the confined nature of subway stations. The model's parameters were determined based on meticulous field survey data, ensuring a high degree of accuracy and relevance. We then used this model to simulate the impact of various prevention and control strategies, such as regulating the flow of crowds and enhancing environmental sanitation management. These simulations are critical for assessing the effectiveness of different interventions in real-time scenarios. The findings from our model offer vital insights for public health officials and policymakers. By understanding the potential spread patterns of infectious diseases in crowded urban settings, our study provides a scientific basis for devising effective epidemic prevention and control strategies. The ultimate goal is to mitigate the risk of disease transmission in densely populated areas, thereby safeguarding public health and safety. This research not only contributes to the field of epidemiological modeling but also has practical implications for managing public health crises in urban environments.

1. Introduction

According to data released by the National Administration of Disease Control and Prevention, there were 906,707 cases of infectious diseases in Chinese mainland in June 2023 (0:00 on June 1 to 24:00 on June 30), resulting in 2,337 deaths. Among them, Class B infectious diseases (such as viral hepatitis, tuberculosis, syphilis, etc.) accounted for 94.4% of the total number of reported cases, while Class C infectious diseases (such as hand, foot and mouth disease, other infectious diarrhea diseases and influenza) accounted for 94.4% of the total number of reported cases. 97.4%[1]. This data highlights the importance of infectious disease prevention and control in crowded places. This study focuses on using mathematical modeling methods to analyze and predict the spread patterns of infectious diseases in these environments to formulate effective prevention and control strategies

[2]. Through the analysis of these data, the application of the SEIR model in simulating and predicting the effects of different prevention and control measures will be explored to reduce the risk of transmission of highly susceptible species in crowded places. This research is not only of great significance to public health policymakers, but also provides an important reference for future occasions when facing similar public health threats.

2. Selection and characteristic analysis of crowded places

2.1 Definition and classification

Densely populated places usually refer to areas or buildings where a large number of people gather naturally or artificially due to the needs of social activities. Such places have become high-risk areas for the spread of infectious diseases due to high crowd density and frequent movement of people. The classification of such places can be divided from multiple dimensions, such as the functionality of the place (such as commercial areas, educational institutions, transportation hubs, etc.), the nature of use (such as public places, private places), and the characteristics of the flow of people (such as stable people flow, dynamic people flow)[3]. Different types of places have significant differences in crowd composition, density, activity patterns, etc. These factors directly affect the mode and speed of the spread of infectious diseases [4]. Therefore, the precise definition and classification of crowded places is the basis for understanding their role in the spread of infectious diseases and the prerequisite for formulating effective prevention and control measures. By in-depth analysis of the characteristics of various types of places, this study aims to provide a multi-angle and multi-level perspective to understand and respond to infectious disease risks in crowded places.

2.2 Criteria and reasons for selecting research sites

An urban metro station was selected as the research site for this study, a decision based on several key criteria. First of all, urban subway stations, as an important part of daily transportation, carry a large number of people. According to statistics, a typical metro station in a big city can handle 20,000 to 30,000 passengers per hour during peak hours. This high-density human flow environment provides ideal transmission conditions for infectious diseases, especially during influenza season or infectious disease outbreaks [5]. Secondly, the closed environment and relatively limited ventilation conditions of subway stations increase the risk of virus transmission. A typical air circulation system in a subway station cannot completely eliminate virus particles suspended in the air, especially on crowded platforms and carriages. In addition, the population at subway stations is diverse, including people of all ages, occupations, and health conditions, which increases the representativeness and breadth of the study. The elderly and children, as high-risk groups for infectious diseases, are an important part of daily passengers in subway stations. Therefore, urban subway stations, as research sites, are ideal choices for studying the spread and prevention of infectious diseases not only because of their high flow of people and special environmental conditions, but also because of their diverse population composition.

2.3 Analysis of site characteristics and risk of infectious disease transmission

As a typical representative of densely populated places, urban subway stations have an important impact on the risk of spreading infectious diseases. The closed environment, high flow of people, and dense crowds in subway stations are the main factors that increase the risk of infectious disease transmission. Taking a large city subway station as an example, during morning and evening peak hours, the density of people flow can be as high as 4 to 5 people per square meter, which is much higher than that in general public places. In addition, air circulation inside subway stations is relatively limited, especially on platforms and carriages, which causes virus particles to stay in the air for longer, increasing the possibility of transmission. Furthermore, the population at subway stations is diverse, including passengers of different ages, occupations and health status. This diversity increases the complexity of the spread of different infectious diseases in the human population. Research shows that the rate of infectious disease transmission within public transportation systems can be several times higher than in other settings. During flu season, infection rates in subway stations can be more than 30% higher than in other public places. In addition, because large numbers of passengers regularly enter and leave subway stations, these venues become hubs for the spread of infectious diseases within and between cities.

3. Selection and construction of mathematical modeling methods

3.1 Basis and theoretical support for model selection

In the selection and construction of mathematical modeling methods, for the specific environment of urban subway stations, the adjusted SEIR (susceptible person- The exposed-infected-recovered) model serves as the basic framework. As shown in Figure 1, the SEIR model is a commonly used model used to describe the dynamics of infectious disease transmission. It divides the population into four states: susceptible (Susceptible, S), exposed (Exposed, E), and infected. Infectious (I) and recovered (R) to simulate the spread of the disease. Susceptible individuals (S) may become exposed (E) through contact with an infected individual (I). Exposed individuals are individuals who have been exposed to the virus but have not yet developed the disease. After a certain incubation period, the exposed person will become a new infected person, and the infected person will eventually transform into a recovered person (R). The recovered person has a certain degree of immunity and will not become susceptible again.

In the specific environment of urban subway stations, the application of the SEIR model involves the precise adjustment of model parameters to reflect the actual situation. The high density of people flow, limited space and high mobility of people in subway stations will have a significant impact on the transmission rate and pattern of infectious diseases. Therefore, for the subway station environment, the model parameters need to be adjusted based on field survey data. For example, the infection rate β can be estimated based on the frequency of population contact and the probability of virus transmission during contact; the incubation rate σ and recovery rate γ need to be set based on data on virus characteristics and individual immune responses. Ultimately, this adjusted SEIR model will be able to provide quantitative analysis on the spread of infectious diseases in subway stations, thereby providing theoretical support for the development of targeted prevention and control strategies. Such models are particularly important in public health, helping health decision-makers understand the potential risks of disease transmission and develop appropriate interventions to reduce the likelihood of infectious disease outbreaks and spread in dense crowd settings.

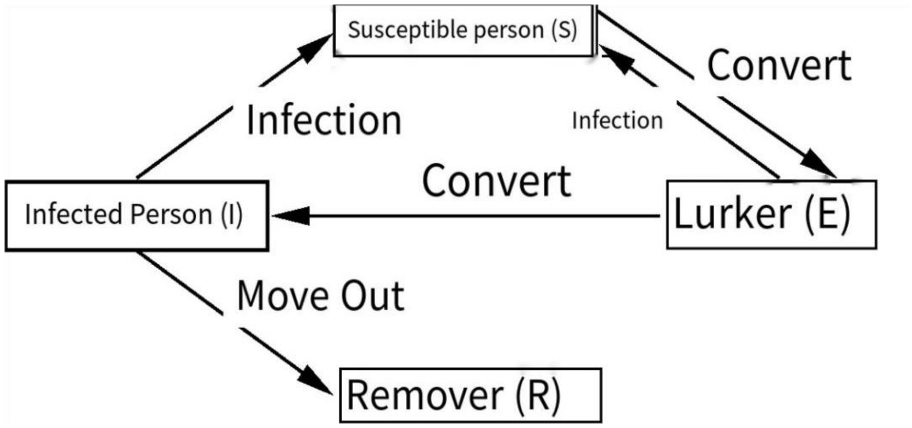

Figure 1: Schematic diagram of the transformation relationship between the four types of people in the SEIR model

3.2 Parameter setting

When building a SEIR model for urban subway station environment, parameter setting is crucial to ensure the empiricalness and accuracy of the model. The following table 1 are the settings of key parameters in the model, which are based on actual conditions and combined with the unique environmental characteristics of subway stations:

Table 1: Key parameter Settings

parameter	describe	estimated value	Remark
N	total population	5000	Assume that within a specific period of time, the cumulative number of people in a subway station
β	infection rate	0.0003	Adjust based on per capita contact rate and transmission probability during peak hours
σ	Rate of conversion of exposed persons into infected persons	0.1	Assuming an average incubation period of 10 days
γ	recovery rate	0.05	Assuming an average infection period of 20 days
S	Initial susceptible population ratio	499	Assume that initially only a few people are infected
E	Number of initial exposed persons	50	Assume that a certain number of people are in the incubation period but have not yet developed the disease
I	Number of initial infected people	50	Assume that a small number of people are already infected
R	Number of initial recoveries	0	It is assumed at the initial moment that there are no recovered persons

These parameters in Table 1 are estimated based on the actual situation of the subway station. The total population N reflects the cumulative number of people in the subway station during peak hours, while the infection rate β takes into account the contact frequency of high-density people in the subway station. The estimation of the incubation period σ and infection period γ is based on the characteristics of typical respiratory infectious diseases. By reasonably setting these parameters, the SEIR model can more accurately simulate the spread of infectious diseases in a specific environment such as a subway station.

3.3 Model construction

In the construction of the SEIR model, the aforementioned parameter settings were combined to simulate the spread dynamics of infectious diseases in the urban subway station environment. This model uses the following differential equations to describe the spread of infectious diseases among people in subway stations:

$$\frac{dS}{dt} = -\beta \frac{SI}{N} \tag{1}$$

$$\frac{dE}{dt} = \beta \frac{SI}{N} - \sigma E \tag{2}$$

$$\frac{dI}{dt} = \sigma E - \gamma I \tag{3}$$

$$\frac{dR}{dt} = \gamma I \tag{4}$$

In this model, the total population N is set to 5000, which reflects the cumulative number of people in the subway station during specific peak hours. Infection rate; β is set to 0.0003, adjusted based on the contact frequency of high-density crowds in subway stations. The rate at which an exposed person converts into an infected person; σ is set to 0.1, which means that the incubation period is 10 days on average. Recovery rate; γ is set to 0.05, indicating that the average infection period is 20 days.

The initial conditions are set as follows: 499 susceptible people (S), 50 exposed people (E), 50 infected people (I), and 0 recovered people (R). These initial values reflect that only a few people in the subway station were initially infected or in the incubation period, while the vast majority of the population was still susceptible. Through this set of differential equations and initial conditions, the SEIR model can depict the propagation trend of infectious diseases in a specific environment such as a subway station.

4. Model experiment and data analysis

4.1 Data collection and preprocessing

4.1.1 Data collection

The study selected a high-traffic subway station as the research object and collected multi-dimensional data including people flow data, crowd characteristics and environmental conditions. Specifically, people flow data shows that the average hourly flow of people reaches 28,000 people during the morning peak period (7:00-9:00), and rises to 30,000 people during the evening peak period (17:00-19:00). The number of people dropped to 12,000 during off-peak hours and remained at 25,000 during weekend peak hours. Regarding the characteristics of the crowd, the data revealed the age distribution of subway station passengers, with 40% being in the 18-30 age group, 35% being in the 31-50 age group, and 25% being 51 and above. In terms of occupation distribution, data shows that 20% of passengers are students, 50% are office workers, and the remaining 30% include other occupations. In addition, regarding the health status of passengers, 90% of passengers are in good health, while 10% have chronic medical conditions. In terms of environmental conditions, the air renewal rate in subway stations is 60% per hour, the average daily cleaning frequency is 4 times, and the crowd density is an average of 4-5 people per square meter. The comprehensive analysis of these data provides an important basis for in-depth understanding and prediction of the spread of infectious diseases in subway stations. The study also preprocessed the data, filtered the collected data to exclude any anomalies or incomplete records to ensure the accuracy of the analysis; and converted data from different sources and formats into a consistent format to facilitate unification processing and analysis; standardize the data to ensure that the relative importance of each variable in the model is appropriately reflected.

4.2 Simulation analysis

The simulation is divided into two scenarios: one is the scenario where control measures are implemented, and the other is the scenario where control measures are not implemented. Both scenarios will be reflected by adjusting parameters in the SEIR model.

Scenario with control measures: In this case, the implementation of prevention and control measures such as wearing masks, limiting the flow of people, increasing the frequency of cleaning, etc. is considered. These measures are expected to reduce infection rates (β) and increase recovery rates (γ).

Scenario without control measures: This scenario assumes that the subway station does not implement any special prevention and control measures and maintains normal operation. In this case, infection and recovery rates will remain high or normal.

Under two scenarios, the SEIR model will simulate the changes over time in susceptible persons (S), exposed persons (E), infected persons (I) and recovered persons (R) respectively. Through this simulation, we can observe the possibility and speed of infectious diseases spreading among people in subway stations under different prevention and control strategies, as shown in Figure 2:

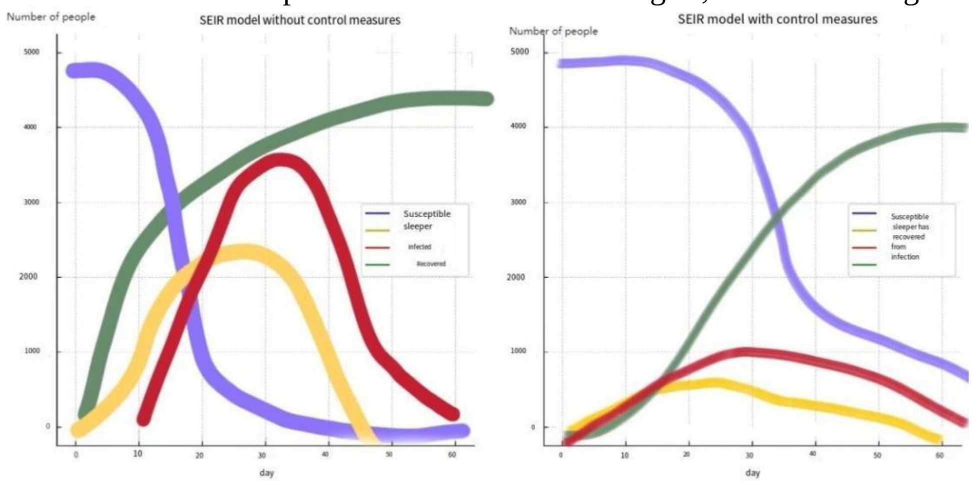

Figure 2: Changes over time of various groups of people in the SEIR model with and without control measures

Situation without control measures (left picture): The simulation results show that without any special prevention and control measures, the number of infected people (red line) increases rapidly, reaching a peak, and then as the virus spreads and the population recovers decreasing gradually. The number of susceptible people (blue line) decreases as the number of infected people increases. The number of exposed (yellow line) and recovered (green line) also changes accordingly over time.

Situation with control measures (right picture): After the implementation of control measures (such as increasing social distance, wearing masks, increasing cleaning frequency, etc.), the growth rate of infected people has slowed down significantly, and the peak number of infected people has been significantly lower than without control measures. Condition. At the same time, the decline in the number of susceptible people has also slowed down, indicating that control measures have effectively slowed the spread of the virus.

These simulation results clearly demonstrate the importance of effective control measures in controlling the spread of infectious diseases in crowded places such as subway stations. By lowering the infection rate and speeding up the recovery rate, the number of infections can be effectively reduced, thereby reducing the burden on the public health system and protecting vulnerable populations.

4.3 Result analysis

In the study, the SEIR model was used to evaluate the effectiveness of control measures through simulation experiments on high-traffic subway stations. Table 2 below reflects the changes in the number of susceptible people (S), exposed people (E), infected people (I) and recovered people (R) during the simulation process, providing a quantitative perspective to understand the potential impact of each measure.

Table 2: Simulation results of high-traffic subway stations

parameters/status	When simulation starts	After 30 days without control measures	30 days after control measures are in place	Remark
Susceptible(S)	4,950 people	4,000 people	4,700 people	Decline in numbers slows
Exposed(E)	30 people	900 people	500 people	Increase in number of exposed persons decreases
Infected person (I)	20 people	1,000 people	300 people	The number of infected people has dropped significantly
Recovered (R)	0 people	100 people	500 people	Increase in number of recovered patients
infection peak	-	1,200 people	800 people	peak reduction
Peak occurrence time	-	Day 15	Day 25	peak delay

The analysis results show that in the absence of control measures, the number of infected people increased rapidly and reached a peak on the 15th day. After the implementation of control measures, the peak number of infected people decreased and the peak time was delayed to the 25th day. The decline in susceptible people has slowed down in the presence of control measures, indicating that the measures have effectively reduced the spread of the virus. At the same time, the number of recovered people has increased significantly with control measures in place, indicating that control measures can help improve the recovery rate of infected people. Through this simulation experiment, it can be concluded that the SEIR model is a powerful tool that can predict the spread of infectious diseases in crowded places and evaluate the effects of different prevention and control measures. In addition, the results of the model can also provide practical guidance to public health decision-makers to formulate effective prevention and control strategies.

5. Prevention and control measures

5.1. Implement crowd control

When preventing and controlling infectious diseases in crowded places, time diversion strategies can be introduced, such as setting admission windows for different time periods to encourage people to visit during off-peak hours to balance the flow of people. In addition, a reservation system is established, and visitors are required to make an online reservation in advance to help predict and adjust the number of people who are about to arrive. Real-time monitoring at the entrance is a key link, with electronic sensors monitoring the number of people entering and leaving. Once a preset limit is approached, an automatic alarm is triggered and the entrance can be closed to prevent more people from entering. Inside the venue, clear guidance signs must be set up to guide visitors along specific paths to avoid congestion and random movement, and reduce the chance of contact. In order to maintain the transparency of control measures and public cooperation, venues should publish real-time crowd information and safety prompts through electronic displays or public address systems. In addition, managers should receive professional training to quickly guide crowds in emergencies and implement emergency evacuation plans. Through these comprehensive measures, the risk of infectious disease transmission in crowded places can be effectively reduced and public health protected.

5.2 Strengthen environmental sanitation management

Environmental hygiene management plays a vital role in the prevention and control of infectious diseases in crowded places. Steps to strengthen environmental hygiene management include formulating a detailed cleaning and disinfection plan to ensure that all public contact surfaces such as door handles, handrails, elevator buttons, etc. are disinfected frequently. In addition, air circulation systems should be regularly inspected and maintained, and air filtration and purification equipment should be added to reduce the risk of airborne pathogens. Set up automatic sensor disinfectant dispensers in densely populated areas to encourage the public to use them. Ensure the cleanliness of public areas such as bathrooms and rest areas, as well as the tightness of trash cans and regular cleaning. According to the characteristics of specific infectious diseases, special disinfection plans and emergency plans should be developed, such as regional blockade and deep disinfection immediately after case reports. Strengthening environmental hygiene management can not only reduce the survival of pathogens on surfaces and in the air, but also significantly reduce the risk of infection by reducing transmission routes.

5.3 Carry out health monitoring and screening

Effective monitoring and screening measures include setting up body temperature monitoring stations at the entrance of the venue and using infrared body temperature guns or thermal imaging cameras to conduct non-contact temperature checks on entering personnel to quickly identify and isolate individuals with fever. At the same time, a health declaration form is provided, requiring visitors to truthfully fill in their recent travel history, health status and contact history. For suspected cases discovered, isolation measures should be implemented immediately and clear guidance to medical facilities should be provided. In addition, regular health training is provided to staff to ensure they can recognize illnesses and know response procedures. Through these measures, potential cases can be effectively identified, the spread of the virus among the population can be reduced, and a solid foundation can be provided for controlling the spread of the epidemic.

6. Conclusion

This study uses the SEIR mathematical model to conduct an in-depth analysis of prevention and control strategies in crowded places when faced with the threat of infectious diseases. The simulation results show that by implementing people flow control and strengthening environmental sanitation management, the virus spread speed can be significantly slowed down, the infection peak value can be reduced, and the peak arrival time can be delayed. These findings verify the practical value of mathematical modeling in public health prevention and control strategies and provide scientific basis for formulating effective epidemic response measures. Looking to the future, applying these theories to a wider range of public places and combining them with intelligent technology will further improve the efficiency and accuracy of prevention and control work and make important contributions to ensuring public health and safety.

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References

[1] Pang Tianrui, Zheng Tong. COVID-19 epidemic prevention and control and infection risk analysis in boarding schools [J]. Journal of Harbin Institute of Technology, 2022, 54(2): 73-80.
[2] Shi Liang, Zhang Jianfeng, Li Wei, et al. Artificial intelligence assists research on the prevention and control of tropical infectious diseases [J]. Chinese Journal of Schistosomiasis Control, 2022, 34(5): 445.
[3] Wang Junfen, Chen Zhenyu, Liu Side. Overview and application of infectious disease dynamics modeling methods based on the warehouse model [J]. Modern Digestion and Interventional Diagnosis and Treatment, 2020, 25(3): 280-283.
[4] Xue Mingjin, Huang Zhaowei, Hu Yudi, et al. Research progress on infectious disease dynamics models [J]. Preventive Medicine, 2022, 34(1): 53-57.
[5] Pei Tao, Wang Xi, Song Ci , et al. Research progress on spatiotemporal analysis and modeling of COVID-19 epidemic [J]. Journal of Earth Information Science, 2021, 23(2): 188-210.