Scenario-based assessment of emergency management of urban infectious disease outbreaks

Pengwei Yuan[1*], Huifang Liu[2], Xiaoqing Dong[1]

[1]University of Jinan, China, [2]Tianjin University, China

Submitted to Journal:
Frontiers in Public Health

Specialty Section:
Environmental health and Exposome

Article type:
Original Research Article

Manuscript ID:
1368154

Received on:
10 Jan 2024

Journal website link:
www.frontiersin.org

Scope Statement

Since the outbreak of the COVID-19 epidemic at the end of 2019, the number of confirmed cases worldwide is increasing day by day, seriously affecting people's health and the stable and smooth functioning of the economy. The theoretical value of this study has three main points: (1) This study enriches the theoretical content of scenario theory, as previous studies have mainly applied scenario theory to earthquake disasters and artillery bomb attacks. However, this paper combines the scenario theory with the CIA-ISM model to construct a model for emergency management of urban outbreak infectious diseases, which is applied to the field of infectious disease prevention and control. (2) The research in this paper confirms the importance of the establishment of an emergency command centre and the timely isolation of confirmed personnel in emergency management measures. (3) This paper enriches comparative cases for subsequent scholars to further explore the field of emergency management of infectious diseases, and is a reference value for further exploration of infectious disease control.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest

CRediT Author Statement

Huifang Liu: Writing – original draft. Xiaoqing Dong: Writing – review & editing. Pengwei Yuan: Writing – original draft, Writing – review & editing.

Keywords

CIA-ISM, Scenario approach, COVID-19, Wuhan, pestilence 1Introduction

Abstract

Word count: 175

Infectious diseases pose a severe threat to human health and are accompanied by significant economic losses. Studies of urban outbreaks of infectious diseases are diverse. However, previous studies have neglected the issue of how to identify critical events and evaluate scenario-based modeling of urban infectious disease outbreak emergency management mechanisms. In this paper, we conduct an empirical analysis and scenario extrapolation using a questionnaire survey of 18 experts, based on the CIA-ISM method and scenario theory, to obtain the key factors influencing urban infectious disease outbreaks. Then, the effectiveness of the urban infectious disease outbreak emergency management mechanism is evaluated. Finally, the actual situation of COVID-19 in China is compared and verified, and the following conclusions and recommendations are drawn. (1) The scenario-based urban infectious disease emergency management model can be used to reproduce the development of urban infectious diseases. (2) The establishment of an emergency command center and the isolation and observation of people exposed to infectious diseases are the most critical key factors in the emergency management of urban outbreaks of infectious disease.

Funding information

Research on resilience evaluation and upgrading mechanism of urban connected lifeline system. (ZR2023MG044) Yuan Pengwei Associate Professor, Jinan University. His main research interests include urban resilience, human health and infectious disease control.

Funding statement

The author(s) declare financial support was received for the research, authorship, and/or publication of this article.

Ethics statements

Studies involving animal subjects
Generated Statement: No animal studies are presented in this manuscript.

Studies involving human subjects
Generated Statement: No human studies are presented in the manuscript.

Inclusion of identifiable human data
Generated Statement: No potentially identifiable images or data are presented in this study.

Data availability statement

Generated Statement: The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Scenario-based assessment of emergency management of urban infectious disease outbreaks

Abstract Infectious diseases pose a severe threat to human health and are accompanied by significant economic losses. Studies of urban outbreaks of infectious diseases are diverse. However, previous studies have neglected the issue of how to identify critical events and evaluate scenario-based modeling of urban infectious disease outbreak emergency management mechanisms. In this paper, we conduct an empirical analysis and scenario extrapolation using a questionnaire survey of 18 experts, based on the CIA-ISM method and scenario theory, to obtain the key factors influencing urban infectious disease outbreaks. Then, the effectiveness of the urban infectious disease outbreak emergency management mechanism is evaluated. Finally, the actual situation of COVID-19 in China is compared and verified, and the following conclusions and recommendations are drawn. (1) The scenario-based urban infectious disease emergency management model can be used to reproduce the development of urban infectious diseases. (2) The establishment of an emergency command center and the isolation and observation of people exposed to infectious diseases are the most critical key factors in the emergency management of urban outbreaks of infectious disease.

Keywords: CIA-ISM; scenario approach; COVID-19;Wuhan; pestilence

1Introduction

Among public health emergencies, infectious diseases have been seriously endangering human health due to their suddenness, contagiousness, epidemic nature, and unpredictability, and have become a serious public health problem and the prominent social problem to threaten the people's health and safety; Moreover, infectious diseases can cause a series of economic and social problems. New infectious diseases can cause severe human casualties, substantial economic losses, and other catastrophic consequences(Nicola, Alsafi, et al., 2020b). For example, the COVID-19 is ravaging the world. According to the latest statistics from Hopkins University, as of May 24, 2022, Beijing time, there were 523086544 cumulative confirmed cases of COVID-19 and 449678693 cumulative deaths worldwide. A report released by the Asian Development Bank states that the global economic damage caused by COVID-19 is equivalent to 5.5%-8.7% of global GDP in 2020 and 3.6%-6.3% of global GDP in 2021. The COVID-19 Updated Assessment of Potential, Economic Impacts report indicates that global employment declines will range from 158 million to 242 million jobs in 2021. Global labor income will decrease from $1.2 trillion to $1.8 trillion. In addition, uncertainty about novel viral infections and treatment increases public anxiety and psychological burden, resulting in a mass panic(X. Li, Zhou, Wong, Wang, & Yuen, 2021). Misinformation and unverified information related to COVID-19 spread rapidly on social media and traditional media(Cinelli et al., 2020). These social issues also pose severe challenges to national and city emergency management(Lu, Ji, Zhang, Zheng, & Liang, 2021).

SRAS, H1N1, and Ebola have provided valuable experience in the emergency management of infectious diseases. Lin et al. summarized the experience of emergency management procedures in radiology departments during the SARS outbreak(Lin et al., 2005). Fraser, C. and Donnelly, C. A. assessed the severity of H1N1 and clarified the importance of developing effective health measures to deal with infectious diseases(Fraser et al., 2009). Brooks et al. considered the importance of establishing a functional incident management system (IMS) in response to the 2014-2016 Ebola virus disease outbreak in West Africa(Brooks et al., 2016). Chavez, Long, et al. highlight physicians' vital role in controlling emerging infectious diseases in cities(Chavez, Long, Koyfman, & Liang, 2021). In the early stages of an outbreak of a new infectious disease, it is essential to use the available reference guidelines and strictly follow the principles of infection control(Hewlett, Varkey, Smith, & Ribner, 2015). Zhang, YP and Zhou, RG encourage people to maintain social distance and take measures based on population characteristics after an outbreak of a new infectious disease(Y. Zhang & Zhou, 2021). Glass, R. J., and Glass, L. M tailored social distance for young people and children in the context of infectious diseases(Glass, Glass, Beyeler, & Min, 2006). In the event of a shortage of public health facilities and available medical resources, hospitals must allocate resources and materials equitably based on the best health outcomes under the guidance of local government or professional bodies(Tokalić, Viđak, Kaknjo, & Marušić, 2021). Measures taken at the societal level, such as social isolation, blockades, border closures, and human tracking, can be used to COVID-19 controlled transmission(Chinazzi et al., 2020; Rothan & Byrareddy, 2020; Van Bavel et al., 2020). However, previous studies have neglected the correlations and interactions between key events in the emergency management of emerging infectious diseases in cities. Scenarios are an effective way to study the interrelationships between events and their interactions. The scenario approach is a dynamic interaction model that can control the likelihood of multiple events occurring or not occurring to change the event's outcome. The scenario approach provides the tools that decision-makers need. Such tools enable the synthesis of specific trends and events into multiple alternatives that can be used for management. The scenario approach adds additional value to traditional management techniques(Victor A. Banuls & Turoff, 2011). Applying scenario methods to urban outbreaks of novel infectious diseases is very appropriate. However, previous studies have neglected the application of scenario methods to assess emergency management mechanisms in urban infectious disease outbreaks.

Based on this, this paper intends to explore the following two questions: what are the relationships between key events in urban outbreak infectious disease emergency management, and how do their interactions affect the effectiveness of urban infectious disease emergency management in different scenarios? How do we provide practical and effective suggestions for emergency management decision-makers in this process? To solve the above problems, this paper extracted key events in urban outbreaks of infectious diseases. It combines the CIA, ISM, and Delphi methods to establish a scenario-based assessment model for urban infectious disease emergency management. Then, we analyzed their interactions and simulated the urban emergency management with different scenarios to obtain the impact of emerging infectious diseases on economic loss, human casualties, controlled infectious diseases, and public trust, and finally evaluated the emergency management of Wuhan, China, in response to

COVID-19, an urban emerging infectious disease.

Compared with existing studies, the contributions of this paper are (1): Key events for emergency management of emerging urban infectious diseases are extracted, and the interrelationships among actual events related to urban infectious diseases are clarified (2). This paper combines the CIA, ISM, and Delphi methods to propose an integrated model for scenario analysis (3). The model can evaluate the effectiveness of urban infectious disease emergency management and, by conducting scenario analysis and extrapolation of the development of urban infectious diseases, propose some proven recommendations for decision-makers to improve urban infectious disease emergency management.

2 Literature Review

Research on emergency management of infectious diseases has focused on emergency preparedness, transmission models, and assessment of economic losses from infectious diseases, and social crises caused by infectious diseases. Brouqui, P et al. developed a draft infectious disease control for emergency management of infectious disease outbreaks(Brouqui et al., 2009). Wong, A. T. Y. et al. studied emergency preparedness for SARS and avian influenza in Hong Kong and developed new public health management measures(Wong et al., 2017). The CDC has taken steps to address the spread of EBOV, including monitoring travelers from Ebola-ravaged areas and grading hospital facilities(Van Beneden et al., 2016). The active cooperation of medical personnel and adequate medical resources play an essential role in emergency management. Therefore, in responding to infectious diseases at the global level, it is vital to provide a safe medical work environment, adequate food, rest, and family and psychological support for health care workers(Driggin et al., 2020). Lam et al. analyzed the difficulty in implementing the guidelines and their emergency management measures in an acute care setting(Lam, Kwong, Hung, & Pang, 2016). Huang et al. provided emergency management and infection control strategies in the radiology department, thus achieving a zero COVID-19 infection rate for all radiology staff(Huang et al., 2020).

In the development of the infectious disease transmission model, Kucharski, A. J. et al. used the transmission model of SARS-CoV-2 and the data of coronavirus disease (COVID-19) cases in Wuhan in 2019, it was concluded that regional closure would lead to a decrease in the transmission of infectious diseases. However, if the virus reaches a new region before the regional closure, it is likely to appear in the same state as in Wuhan(Kucharski et al., 2020). Wu, J. T., and Leung, K. used the number of cases exported internationally from Wuhan, a susceptible-exposed-infected-recovered metapopulation model was used to simulate the development of outbreaks in major cities in China, suggesting that worldwide outbreaks of the virus in major cities are inevitable(Wu, Leung, & Leung, 2020). Razavi-Shearer, D. et al. used a dynamic HBV transmission model to estimate the regional-level prevalence of HBV in the context of childhood vaccination(Razavi-Shearer et al., 2018). Chang, S et al. used a SEIR transmission model to simulate the spread of SARS-CoV-2 in ten major U.S. cities and concluded that mobility-related mechanisms lead to economic losses and increased infection rates(Chang et al., 2021). Musa, SS et al. used a dynamic model of COVID-

19 to simulate the rate of transmission, and the magnitude of mortality under different parameters and concluded that a two-pronged approach of maintaining social distance and vaccination could reduce the mortality caused by COVID-19 in South America(Musa, Tariq, Liu, Wei, & He, 2022).

Since COVID-19 is a significant threat to economic development, social systems, and human life, it has triggered fears of a possible coming economic crisis or recession. Kim and Loayza believe that, compared with high-income countries, the marginal benefit of governments in low-income countries not intervening in epidemic prevention and control measures is small(Altig et al., 2020). Maria and Zaid Alsafi then summarize the impact of COVID-19 on various aspects of the world economy(Nicola, Alsafi, et al., 2020a; Nicola, O'Neill, et al., 2020).

The series of social crises caused by infectious diseases should not be underestimated. Among them, panic is the most common psychological reaction that comes with new infectious diseases. How the government assesses public panic and the results can affect the operation of the emergency management mechanism for infectious diseases(Taylor, 2022). A mass rush for supplies by a panic-ridden public is highly likely, so maintaining an adequate supply during a significant public health event is also worthy of attention(Q. Li, Chen, Yang, & Cong, 2020; Rajkumar, 2021). Wang, CY et al. used the DASS-21 model to assess the psychological status of 1738 individuals in China and found that the response to COVID-19 should focus on the importance of escalating cases, promoting proper coping methods, and improving personal protection(Wang et al., 2020). Rumors arise from panic, and the widespread dissemination of inaccurate information creates obstacles to emergency management of infectious diseases(B. Chen et al., 2021). Hui, HW and Zhou, CC et al. developed a rumor propagation model based on the infectious disease model and proposed an effective strategy to suppress the spread of COVID-19 rumors(Hui, Zhou, Lu, & Li, 2020). By examining the spread of rumors in China during the first four months of the COVID-19 outbreak, Ning, PS et al. highlight the importance of authoritative official announcements to clarify rumors and reduce their impact(Ning et al., 2021). People want to mitigate losses and avoid catastrophic consequences through critical decisions(Deng & Peng, 2020).

Most studies have analyzed the impact of a single event or factor. However, emergency management measures and decisions for a single factor may be less effective when some other events or factors interact. For reliable and effective emergency management of urban outbreaks of COVID-19, cross-influences among multiple factors should be considered in management strategies. The scenario-based approach analyzes the interactions between critical events within a specified time frame(V. A. Banuls, Turoff, & Hiltz, 2013). This interaction analysis enhances managers' understanding of the factors involved in developing COVID-19 contingency plans and enhances the understanding of response measures by those involved in developing the plans. When combined with other predictive models, scenario models allow various flexible approaches to address uncertainty. This paper analyzes possible future trends in urban infectious disease outbreaks, identifies key factors, and makes optimal decisions.

3. Research Methodology

3.1 Basis of the scenario approach

The scenario-based emergency management model for urban outbreaks of infectious diseases is a combination of the Delphi method, the cross-influence approach (CIA), and the Interpretative Structural Model (ISM). The model aims to provide scenario analysis and interpretation of the development of urban outbreak infectious diseases. The Delphi method and the CIA allow the analysis of the relationships between the factors influencing urban outbreak infectious diseases. Specifically, CIA is a method that can find the path of a set of relationships between events that affect the outcome event and then enhance the stability of one or more identified events. However, using the CIA presupposes a series of interrelated events that may occur in the future must be presented. To identify these significant events, a team of experts is requested to perform a Delphi process to make predictions about the occurrence or nonoccurrence of the events based on inputs provided by the team of experts to assess cross-impacts jointly.

3.2 Event set creation

Observing and studying historical cases of infectious diseases was the basis for creating the COVID-19 event set. When responding to a significant health event, it is crucial to consider a wide range of technical and social factors and obtain input from experts with relevant experience, different research directions, and perspectives. Only in this way can we find as many critical factors and the relationships between them as possible, ensuring rationality, consistency of internal and causal relationships, and the usefulness of decisions. It is essential to obtain a comprehensive set of events, and in this work, 32 relevant events were selected, and we divided them into three categories according to their nature.

Initial events (IC_i): Initial events are those that have occurred or have not yet occurred before the occurrence of an infectious disease. When there is an infectious disease outbreak, the initial event can consist of crucial events that reflect the emergency management of an urban outbreak and would significantly impact the development of the infectious disease. When the expert group makes a subjective estimate, the probability of the initial event occurring or not occurring is 0.5—assuming that under the condition that an event with a probability less than 0.5 will occur, the expert is asked to re-estimate the probability of other events occurring.

IC_1: Infectious disease isolation and treatment capacity: The city can isolate and treat patients with infectious diseases.

IC_2: Infectious disease source detection capability: The city can quickly conduct rapid detection of the cause of the disease.

IC_3: Infectious disease infectivity assessment: The city can quickly assess the infectious characteristics or transmission routes of infectious diseases.

IC_4: Medical treatment.

IC_5: Government emergency response plan: The city has an excellent emergency response plan for infectious diseases.

IC_6: Government emergency response capability: The city has an infectious disease control agency, conducts frequent emergency drills, and has good response capability.

IC_7: Public self-protection ability: The public knows the general knowledge of infectious diseases and has good self-protection ability.

IC_8: Government communication capability: Have internal communication procedures and public communication plans and channels.

IC_9: Public trust: The public trusts the government and complies with government emergency instructions.

IC_{10}: Vaccine: There is no vaccine for infectious disease.

Dynamic events (DE_i): Dynamic events are events related to the epidemic after the occurrence, mainly including emergency management measures taken by the government in the face of the epidemic and events leading to secondary disasters. The probability of occurrence of these events is 0.5.

DE_1: Infectious disease patient treatment: Infectious disease patients are isolated and treated.

DE_2: Causal cause identification: The infectious disease causative agent (bacteria, virus) is rapidly identified.

DE_3: Infectious disease transmissibility assessment: The transmission route and transmissibility of infectious diseases are rapidly assessed.

DE_4: Decontamination action: Disinfect the patient's activity area after infection.

DE_5: Isolate the contacts: Isolate and observe people who are exposed to infectious diseases.

DE_6: Leaders do not agree to release information: Local heads do not agree to inform the public about the status of the infectious disease.

DE_7: Information leak: Social media leaks information about the infectious disease to the public.

DE_8: Emergency command center established: The government establishes an emergency command center and declares a state of emergency.

DE_9: Public panic: The public panics and either rushes to buy supplies or leaves the city by transportation if possible.

DE_{10}: Rumors spread: Various rumors appear on the Internet and social software.

DE_{11}: Spread of infectious diseases: Infectious diseases spread among the population.

DE_{12}: Restriction of movement of people: The government restricts the movement and gathering of people.

DE_{13}: Communicating infectious diseases: The government communicates about infectious diseases through the media and widely publicizes the hazards and protection. The government calls on and organizes businesses, non-profit organizations, and individuals for infectious disease prevention and control.

DE_{14}: Emergency medical supplies are distributed to organizations and people in need promptly.

DE_{15}: Some healthcare workers do not cooperate: Some healthcare workers or emergency managers refuse to work on infectious diseases because of a lack of protective materials or fear of being infected.

DE_{16}: Some members of the public do not cooperate: Some people do not comply with government measures for epidemic prevention.

DE_{17}: Area closure: Other cities restrict the entry of people from that city, and people from that city are not allowed to leave the city.

DE_{18}: Development of effective drugs/vaccines: Effective types of existing drugs are proposed, vaccines are developed, and mass production is carried out.

Outcome event (OE_i): An outcome event is a variety of consequences that may result from an infectious disease event, including casualties, property damage, Etc. The probability of an outcome event is accurate at the end of the period, and the initial probability is also set to 0.5.

OE_1: Economic loss: GDP loss caused by infectious diseases.

OE_2: Personnel Casualties: a certain number of infectious disease patients die.

OE_3: Infectious disease is controlled: The city's Infectious disease is controlled in a phased manner, and the number of sick people gradually decreases without spreading to other cities or regions.

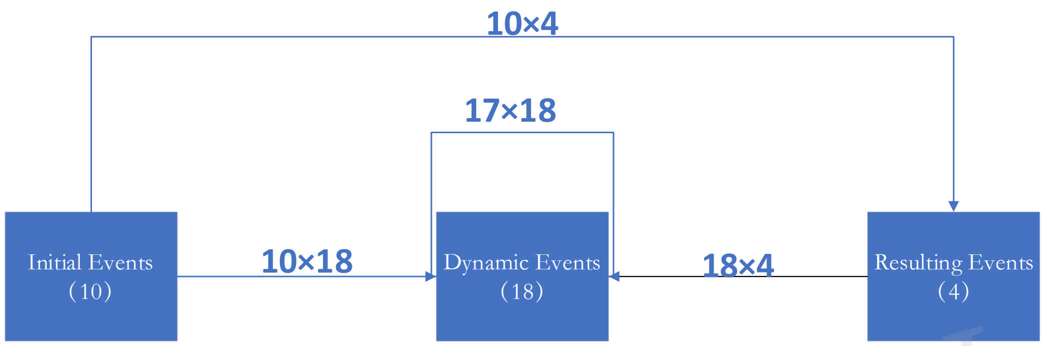
OE_4: Public trust: The public has a high level of trust in the local government after the epidemic and continues cooperating with the government in its actions.

Expert estimates of the relationship between the three-event sets (initial conditions, dynamic events, and outcome events) were sought.

3.3 Scenario analysis

A total of 18 experts in the field of emergency management and those involved in the frontline rescue were invited to the expert panel. The experts assessed, in turn, whether each of the three-event sets occurred and estimated the probability of the other events occurring. Because of the different nature of each event, the panel had to make 478 causality estimates, as shown in Fig 1.

Fig 1. Influence diagram of the number of three event sets and the number of estimates required



In an event set, there is an interconnection between events. However, in the Delphi method, the occurrence or nonoccurrence of an event does not affect the other events in the event set. So we merged the CIA in the ISM and used the CIA to obtain the three-event sets of COVID-19 as the input to the ISM. The most critical aspect of CIA-ISM is "structural modeling," The ISM approach has a solid mathematical basis for establishing a linear relationship between critical events and those that affect them. First, experts can initially estimate the relationships and probabilities between events. Then, a model is built that reflects the relationships between times in a complex situation, with the additional function of receiving feedback at different stages so that the expert can modify the input at any time.

Number	Explanation
0.99	Significant positive impact.
0.9	Apparent positive impact.
0.8	Great positive impact.
0.7	Modest positive impact.
0.6	Slight positive impact.
0.5	No impact.

0.4	Slight negative impact.
0.3	Modest negative impact.
0.2	Great negative impact.
0.1	Apparent negative impact.
0.01	Significant negative impact.

Table1.Rating Scale

The probability of event i occurring under the influence of event j depends on the following rule in Table 1, the scoring table. The factor metric between i and j is valid when at least two-thirds of the estimates of individual interactions are in an interval in the scoring table. The adjacency matrix obtained after this process can be used as an input to the CIA. The cells in the matrix represent the linear influence factor of event i on j, denoted by R_{ij}. The diagonal cells are the total probability. Based on this binary matrix, we can predict a scenario by making assumptions about the occurrence (or nonoccurrence) of event i.

3.4 Cross-Impact Analysis

As shown in Table 1, a mathematical "+" is used to indicate the facilitation of an event, while a mathematical "-" is used to indicate the suppression of an event; the "+" and "-" only indicate the direction of the mathematics of the impact and do not represent the magnitude. The equation (1)(2) represents the cross-influence factor and the probability of event occurrence.

$$C_{ij} = \frac{1}{1 - P_j}\left\{\left[\ln \frac{R_{ij}}{(1 - R_{ij})}\right] - \left[\ln \frac{P_i}{(1 - P_i)}\right]\right\} \tag{1}$$

$$P_i = \frac{1}{1 + \exp(-G_i - \sum_{k \neq i}^{N} C_{ik} P_k)} \tag{2}$$

where Gi is the sum of the effects of all possible external events on the event i that are not explicitly represented in the n events included in the model. To obtain a numerical estimate of the total variability in the matrix, we examined the following linear sum of the cross-impact factor $\Sigma|C_{ij}|$.

$|\text{internal event impact}|=\Sigma|C_{ij}|=683.8245761$

$|\text{initial event impact}|=\Sigma|C_{ij}|=293.4260838$

$|\text{Dynamic event impact}|=|\text{internal event impact}|-|\text{initial event impact}|=\Sigma|C_{ij}|-\Sigma|C_{ij}|=535.9788616$

$|\text{External unspecified event impact}|=\Sigma|C_{ij}|=186.593908$

$|\text{Total impact}|=|\text{internal event impact}|+|\text{external unspecified event impact}|=\Sigma|C_{ij}|+\Sigma|C_{ij}|=870.4184841$

Calculate the relative fraction or percentage of impact due to each type of event.

$|\text{Dynamic event impact}|/|\text{Total impact}|=0.615771461$

$|\text{initial event impact}|/|\text{total impact}|=0.337109206$

$|\text{External unspecified event impact}|/|\text{Total impact}|=0.21437264$

Therefore, 21.44% of the impact is due to unspecified events (external event impact). Dynamic events account for 61.58% of the impact. Furthermore, the initial conditions account for 33.71% of the impact. Essentially, 78.56% of the impact in the model is explained by the explicit events in the model. That implies that the event set is somewhat comprehensive and that the model is feasible.

Table2.Outcome events analysis.

Events	-OE1,-OE2 +OE3,+OE4	+OE1,+OE2 −OE3,−OE4

IC1:Infectious disease isolation and treatment	+	-
capacity.	+	-
IC2:Infectious disease source detection cap-ability.	+	-
IC3:Infectious disease infectivity assessment.	+	-
IC4:Medical treatment.	+	-
IC5:Government emergency response plan.	+	-
IC6:Government emergency response capability.	+	-
IC7:Public self-protection ability.	+	-
IC8:Government communication capability.	+	-
IC9:Public trust.	+	-
IC10:Vaccine.	+	-
DE1:Infectious disease patient treatment.	+	-
DE2:Causal cause identification.	+	-
DE3:Infectious disease transmissibility assessment.	+	-
DE4:Decontamination action	+	-
DE5:Isolate the contacts	-	+
DE6:Leaders do not agree to release information	-	+
DE7:Information leak	+	-
DE8:Emergency command center established	-	+
DE9:Public panic	-	+
DE10:Rumors spread	-	+
DE11:Spread of infectious diseases	+	-
DE12:Restriction of movement of people	+	-
DE13:Communicating infectious diseases	+	-
DE14:Emergency medical supplies are distributed to	-	+
organizations and people in need promptly.	-	+
DE15:Some healthcare workers do not cooperate	+	-
DE16:Some members of the public do not cooperate	+	-
DE17:Area closure	+	-
DE18:Development of effective drugs/vaccines		

After obtaining the cross-impact matrix, the structure of the strong relationships in the directed graph model is obtained by partitioning and extracting the matrix model. Applying the CIA-ISM method, we can represent the predicted scenario using a directed graph.

Table 2 summarizes each event's direct and indirect effects on the outcome events (cascade effects). The model predicts that the event DE_1 may have a positive impact on good outcomes or a negative impact on bad outcomes. IC_6, IC_8, and IC_9 have a direct negative effect on DE_{15}, which means that government emergency response capacity, emergency command center establishment, and public trust can almost certainly reduce the odds of partial health care worker non-cooperation. IC_2, IC_7, and DE_2 had a direct negative effect on DE_{16}, meaning that infectious disease source detection capabilities, information disclosure, and causation identification would undoubtedly reduce the chance of partial public non-cooperation.

Table3 OE1 ordered influences table

	Events	OE1
DE8	Emergency command center established.	3.4692
IC5	Government emergency response plan.	2.9
IC3	Infectious disease infectivity assessment.	2.7726
DE3	Infectious disease infectivity assessment.	2.3054
IC8	Government communication capability.	2.1972
DE12	Restriction of movement of people.	1.8889
DE17	Area closure.	1.8889
DE4	Decontamination action.	1.6002
DE5	Isolate the contacts.	1.3266
IC4	Medical treatment.	0.8946
DE2	Causal cause identification.	0.8946
IC1	Infectious disease isolation and treatment capacity.	0.8109
DE13	Communicating infectious diseases.	0.7279
IC6	Government emergency response capability.	0.5637
IC2	Infectious disease source detection capability.	0.4013
DE1	Infectious disease patient treatment.	0.3207
IC7	Public self-protection ability.	0.2403
DE14	Emergency medical supplies are distributed to organizations and people in need promptly.	0.2403
DE15	Some healthcare workers do not cooperate.	-0.16
DE11	Spread of infectious diseases.	-0.401
DE18	Development of effective drugs/vaccines.	-1.064
IC10	Vaccine.	-1.889
DE6	Leaders do not agree to release information.	-2.417
DE16	Some members of the public do not cooperate.	-2.9

Among all emergency response efforts, the establishment of an emergency command center (DE_8) has a direct and significant impact on reducing economic losses

(OE_1), controlling infectious diseases (OE_3), and increasing public trust (OE_4). Limiting the movement of people (DE_{12}) made a considerable contribution to increasing public trust (OE_4). Among all secondary-derived disasters, the spread of infectious diseases (DE_{11}) directly and significantly impacts human casualties (OE_2).

Table4.OE2 ordered influences table

	Events	OE2
DE8	An emergency command center was established.	2.4166
DE5	Isolate the contacts.	2.0919
IC8	Government communication capability.	1.7908
DE4	Decontamination action.	1.3266
IC3	Infectious disease infectivity assessment.	1.2381
IC4	Medical treatment.	1.2381
DE12	Restriction of movement of people.	1.2381
DE3	Infectious disease infectivity assessment.	1.1507
IC6	Government emergency response capability.	1.0644
IC2	Infectious disease source detection capability.	0.8109
DE14	Emergency medical supplies are distributed to organizations and people in need promptly.	0.5637
IC5	Government emergency response plan.	0.4013
DE13	Communicating infectious diseases.	0.4013
DE1	Infectious disease patient treatment.	0.3207
DE2	Causal cause identification.	0.2403
IC7	Public self-protection ability.	0.2403
IC1	Infectious disease isolation and treatment capacity.	0.1601
DE15	Some healthcare workers do not cooperate.	-0.16
DE11	Spread of infectious diseases.	-0.401
DE18	Development of effective drugs/vaccines.	-0.646
IC10	Vaccine.	-1.889
DE6	Leaders do not agree to release information.	-2.417
DE16	Some members of the public do not cooperate.	-2.9

Outcome event analysis can be complemented by the direct impact of initial conditions and dynamic events on this particular outcome (Tables 3,4,5 and 6). For example, Table 3 shows that the model predicts leadership disagreement to release information, and partial public non-cooperation is the most potent precursor to possible economic loss. In contrast, the establishment of an emergency command center, the assessment of infectious disease transmission capacity, and the existence of a government contingency plan significantly reduce the likelihood of this outcome.

Table5 OE3 ordered influences table

	Events	OE3
DE11	Spread of infectious diseases.	3.1713
IC10	Vaccine.	2.0919
DE16	Some members of the public do not cooperate.	1.5075
DE18	Development of effective drugs/vaccines.	1.3266
DE15	Some healthcare workers do not cooperate.	1.1507
DE10	Rumors spread.	1.0644
DE6	Leaders do not agree to release information.	0.8109
DE7	Information leak.	0.8109
IC1	Infectious disease isolation and treatment capacity.	-0.16
IC2	Infectious disease source detection capability.	-0.321
IC4	Medical treatment.	-0.482
DE3	Infectious disease infectivity assessment.	-0.482
IC6	Government emergency response capability.	-0.564
DE17	Area closure.	-0.564
IC5	Government emergency response plan.	-1.064
IC8	Government communication capability.	-1.889
DE14	Emergency medical supplies are distributed to organizations and people in need promptly.	-1.989
IC9	Public trust.	-2.092
DE13	Communicating infectious diseases.	-2.305
IC3	Infectious disease infectivity assessment.	-2.417
DE2	Causal cause identification.	-2.417
DE1	Infectious disease patient treatment.	-2.65
DE5	Isolate the contacts.	-2.65
IC7	Public self-protection ability.	-2.773
DE4	Decontamination action.	-2.773
DE12	Restriction of movement of people.	-2.773
DE8	An emergency command center was established.	-3.631

We list the events that have a direct positive or direct negative impact on the outcome event. On the other hand, the factors that had the most significant impact on the infectious disease being contained and public trust were the establishment of an emergency command center, identification of the causative agent, and restriction of movement of people (Tables 5 and 6), whereas the factors that made these desired outcomes least likely were the spread of the infection, public panic, and the absence of a vaccine.

Table 6 OE4 ordered influences table

	Events	OE4
DE9	Public panic.	3.0327
DE11	Spread of infectious diseases.	2.7726
DE18	Development of effective drugs/vaccines.	2.7726
DE10	Rumors spread.	1.4164
DE6	Leaders do not agree to release information.	0.2403
IC8	Government communication capability.	-0.16
IC6	Government emergency response capability.	-0.24
IC4	Medical treatment.	-0.321
DE14	Emergency medical supplies are distributed to organizations and people in need promptly.	-0.728
IC9	Public trust.	-1.508
DE12	Restriction of movement of people.	-1.6
IC5	Government emergency response plan.	-1.889
DE13	Communicating infectious diseases.	-1.989
IC3	Infectious disease infectivity assessment.	-2.092
IC1	Infectious disease isolation and treatment capacity.	-2.305
DE7	Information leak.	-2.417
DE3	Infectious disease infectivity assessment.	-2.531
IC2	Infectious disease source detection capability.	-2.65
DE2	Causal cause identification.	-3.171
DE8	An emergency command center was established.	-4.181

Four Tables 3 through 6 show the most important events leading to the occurrence or nonoccurrence of each of the four outcomes. The scores in Table 7 are obtained by summing the absolute values of the positive impact of C_{ij} on the events. For adverse event outcomes, the most meaningful events are shown in Table 8. The weights shown represent the total adverse impact and are expressed as the sum of the absolute values of the negative impact of C_{ij} on the events.

Table7 Total impact on positive events

	Events	OE3,OE4
DE8	An emergency command center was established.	7.812062127
DE11	Spread of infectious diseases.	5.94384325
DE2	Causal cause identification.	5.587876939

IC3	Infectious disease infectivity assessment.	4.508559522
DE12	Restriction of movement of people.	4.372827322
DE13	Communicating infectious diseases.	4.29460417
DE18	Development of effective drugs/vaccines.	4.099177157
IC9	Public trust.	3.599480715
DE7	Information leak.	3.227552628
DE9	Public panic.	3.032694979
DE3	Infectious disease infectivity assessment.	3.01365686
IC2	Infectious disease source detection capability.	2.97053613
IC5	Government emergency response plan.	2.953356845
IC7	Public self-protection ability.	2.772588722
DE4	Decontamination action.	2.772588722
DE14	Emergency medical supplies are distributed to organizations and people in need promptly.	2.717175905
DE1	Infectious disease patient treatment.	2.649850829
DE5	Isolate the contacts.	2.649850829
DE10	Rumors spread.	2.480803743
IC1	Infectious disease isolation and treatment capacity.	2.465444435
IC10	Vaccine.	2.09193711
IC8	Government communication capability.	2.049008633
DE16	Some members of the public do not cooperate.	1.507543605
DE15	Some healthcare workers do not cooperate.	1.15072829
DE6	Leaders do not agree to release information.	1.05121884
IC6	Government emergency response capability.	0.803990928
IC4	Medical treatment.	0.803009414
DE17	Area closure.	0.563702304

Table8 Total impact on negative events

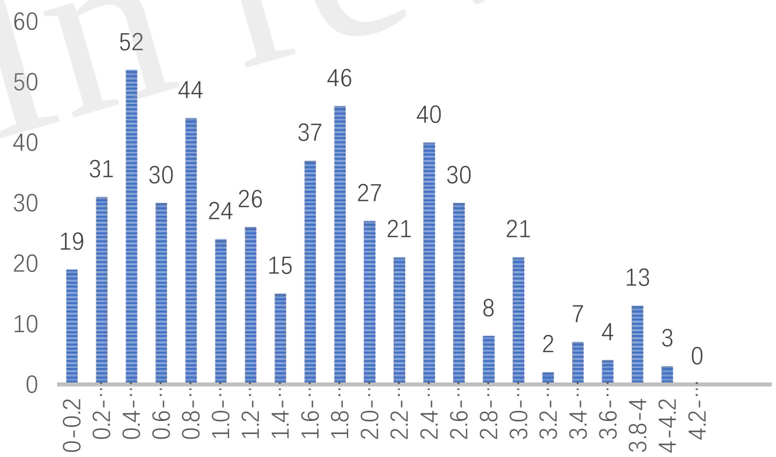
	Events	OE1,OE2
DE8	An emergency command center was established.	5.885824523
DE11	Spread of infectious diseases.	4.795790546
IC10	Vaccine.	4.30554563
IC3	Infectious disease infectivity assessment.	4.010667139
IC8	Government communication capability.	3.987992671
DE6	Leaders do not agree to release information.	3.481056039
DE3	Infectious disease infectivity assessment.	3.45608731
DE5	Isolate the contacts.	3.418525545
IC5	Government emergency response plan.	3.301361742
DE12	Restriction of movement of people.	3.127001634
DE4	Decontamination action.	2.926827035
DE16	Some members of the public do not cooperate.	2.900020351
IC7	Public self-protection ability.	2.545647644
IC4	Medical treatment.	2.132702853
DE17	Area closure.	1.888923218
DE18	Development of effective drugs/vaccines.	1.709980412

IC6	Government emergency response capability.	1.628135932
IC2	Infectious disease source detection capability.	1.212271607
DE2	Causal cause identification.	1.13491306
DE13	Communicating infectious diseases.	1.129272145
IC1	Infectious disease isolation and treatment capacity.	0.971015632
DE14	Emergency medical supplies are distributed to organizations and people in need promptly.	0.803990928
DE1	Infectious disease patient treatment.	0.480770715
DE15	Some healthcare workers do not cooperate.	0.400374039

4.1 Incremental analysis

We perform an incremental analysis of the predicted scenarios to understand the links between the different events. The primary method is to analyze the distribution of $|C_{ij}|$. Non-zero $|C_{ij}|$ values are taken, and a histogram from zero to the maximum absolute value is plotted based on their number, as shown in Fig 2.

Fig 2. histogram of $|C_{ij}|$



Next, we determine the value of $|C_{ij}|$ that represents the highest k% of the distribution as the cut point of the directed graph. For example, if we take 90% and 85% as the cut points, the directed graph contains the highest impact of 10% and 15%, as shown in Figs 3 and 4. The line between two events of the same color represents the positive impact, while the line between two events of different colors is the negative impact.

Fig 3. Digraph for the limit value |Cij| = 2.93 – with 15%.

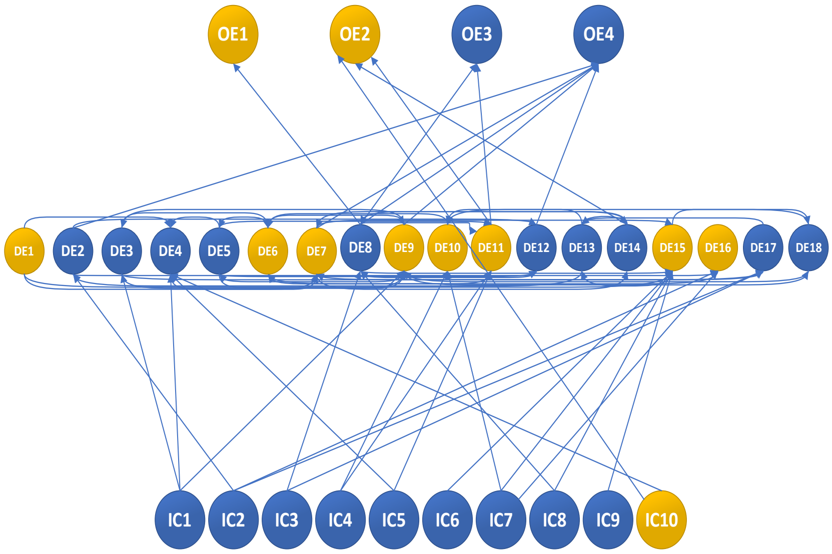
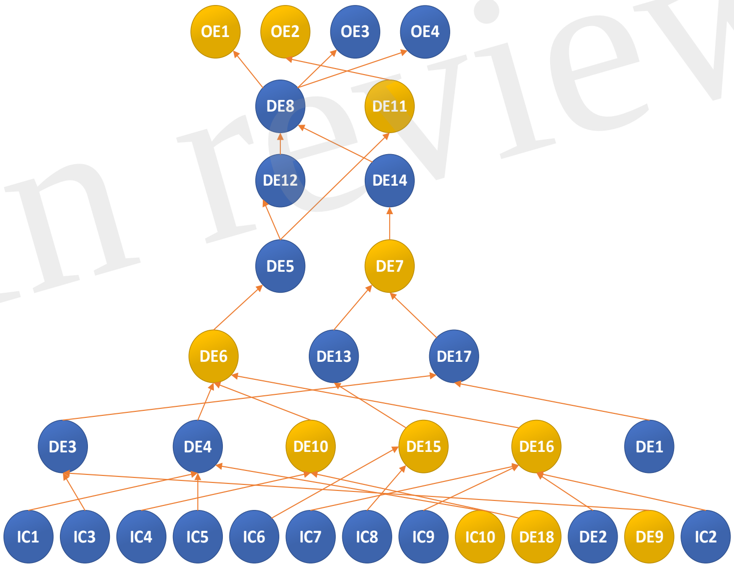
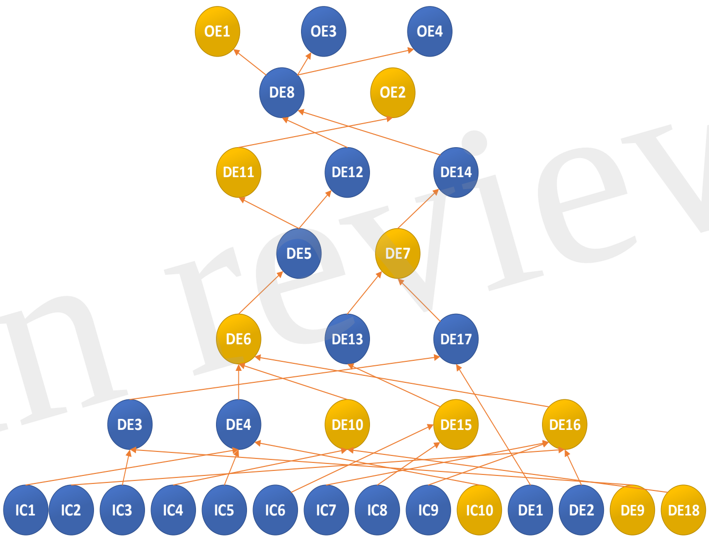


Fig 4. Digraph for the limit value $|C_{ij}|$ = 3.42 – with 5%.



The graph is directed with the highest 85% of the distribution value. At this level of analysis, although all events are included, the logical order of events occurring is not sorted out. It was then necessary to incorporate more $|C_{ij}|$ factors in this process and examine all $|C_{ij}|$ greater than (or equal to) this absolute value to form the final model. At this point, the $|C_{ij}|$ value of event i is used as the prior or after the occurrence and nonoccurrence of event j. The histogram of cross-influencing factors shows that the limit value is $|C_{ij}|$ = 3.42 when the most significant influence of the top 5% needs to be extracted. At this point, the CIA-ISM output is shown in Fig 4, and its adversarial plot is shown in Fig 5. If the value of $|C_{ij}|$ is greater than or equal to the limit value, there is a direct connection from node j to node i. Extracting the most critical event in the event set by the limit value helps to understand the underlying logic of the particular influence path and scenario leading to that outcome. In addition, it helps to understand the sequence of events and the potential impact.

Fig 5. Digraph for the limit value $|C_{ij}|= 3.42$ – with 5%.



The Fig shows that vaccines (IC_{10}), infectious disease isolation and treatment capacity (IC_1), medical resource reserves (IC_4), government contingency plans (IC_5), public trust (IC_9), government emergency response capacity (IC_6), government communication capacity (IC_8), public self-protection capacity (IC_7), infectious disease source detection capacity (IC_2), and infectious disease transmission capacity assessment (IC_3) A series of dynamic events (DE_4, DE_9, DE_{14}, DE_8, DE_{15}, DE_{13}, DE_7, DE_6, DE_{16}, DE_5, DE_{11}) will be triggered, which will reduce the probability of death (OE_2) and increase the probability of infectious disease control (OE_3) and public trust (OE_4). Timely treatment of infected patients (DE_1) has a direct positive impact on limiting the movement of people (DE_{17}), the lack of vaccines (IC_{10}) has a direct negative impact on decontamination actions (DE_4), and active development of effective vaccines should be included in decontamination actions (DE_4).

Increased capacity for isolation and treatment of infectious diseases (IC_1), development of government contingency plans (IC_5), and development of an effective vaccine against novel viruses (IC_{10}) will mean excellent results for decontamination operations (DE_4). Inadequate medical resource reserves (IC_4) and the absence of an effective vaccine against novel viruses (DE_{18}) will lead to the spread of rumors (DE_{10}). Reduced public panic (DE_9) and low infectious disease transmission capacity (IC_3) would significantly enhance the infectious disease transmission capacity assessment (DE_3). Good public trust (IC_9), a high level of infectious disease source detection capability (IC_2), strong causative agent identification (DE_2) capability, and improved public self-protection (IC_7) will significantly reduce the likelihood of partial public non-cooperation (DE_{16}). A high level of Government emergency response capability (IC_6) and strong Government communication capability (IC_8) will effectively curb the non-cooperation of some health care workers (DE_{15}). Inefficient decontamination operations (DE_4), partial public cooperation (DE_{16}), and rumor spreading (DE_{10}) have a direct positive effect on leaders' nonconsent to release information (DE_6), implying that high efficiency of decontamination operations (DE_4), reduced rumor spreading (DE_{10}), and partial public non-cooperation (DE_{16}) will almost certainly avoid leader nonconsent to release information (DE_6). Infectious disease transmission capacity assessment (DE_3) and infectious disease patient treatment (DE_1) had a direct positive effect on regional closure (DE_{17}). In contrast, partial health care worker non-cooperation (DE_{15}) had a direct positive effect on infectious disease communication (DE_{13}). Leadership disagreement to release information (DE_6) will directly lead to the unfavorable implementation of contact isolation (DE_5). Area closure (DE_{17}) and communicable disease communication (DE_{13}) will directly reduce the probability of information leakage (DE_7). Information leakage (DE_7) significantly negatively impacts the timely distribution of emergency medical supplies to organizations and people in need (DE_{14}). Contact isolation (DE_5) not only contributes directly to restricting the movement of people (DE_{12}) but also acts as an excellent deterrent to the spread of infectious diseases (DE_{11}). Restricting the movement of people (DE_{12}) and the timely distribution of emergency medical supplies to organizations and people in need (DE_{14}) facilitated the establishment of the emergency command center (DE_8). The establishment of an EOC (DE_8) directly increases the probability of infectious disease control (OE_3) and public trust (OE_4) and reduces economic losses (OE_1). The weakening effect of contact isolation (DE_5) on the spread of infectious disease (DE_{11}) will directly reduce the probability of Personnel Casualties (OE_2).

4.2 Sensitivity analysis

This paper aims to model the emergency management of urban infectious disease outbreaks, so the associated events are selected for sensitivity analysis. The impact of critical factors is tested by varying the initial probabilities.

4.2.1 Initial conditions analysis

In the previous analysis, it can be concluded that $IC_{4,\ 5,\ 6,\ 8}$ are events related to emergency management. Sensitivity analysis analyzes the results of other events, especially outcome events, by changing the initial probabilities of these four events. We set up six scenarios to predict that all four key events occur, all do not occur, and only one occurs. The probability of other initial events is 0.5. According to the formula (1)(2), the probability of occurrence of other events under the six scenarios is derived as shown in Table 9. The economic loss (OE_1) is affected by the initial events in descending order of IC_6, IC_5, IC_8, and IC_4. Government emergency response capability (IC_6) is vital to reduce economic loss.

Table 9 Prediction probabilities of the other events in initial conditions analysis

	S0	S1	S2	S3	S4	S5
IC1	0.5	0.5	0.5	0.5	0.5	0
IC2	0.5	0.5	0.5	0.5	0.5	0.5
IC3	0.5	0.5	0.5	0.5	0.5	0.5
IC4	0	1	0	0	0	1
IC5	0	0	1	0	0	1
IC6	0	0	0	1	0	1
IC7	0.5	0.5	0.5	0.5	0.5	0.5
IC8	0	0	0	0	1	1
IC9	0.5	0.5	0.5	0.5	0.5	0.5
IC10	0.5	0.5	0.5	0.5	0.5	0.5
DE1	0.0012	0.2243	0.5124	0.7823	0.4124	0.9968
DE2	0.0015	0.3154	0.5239	0.7577	0.4239	0.9868
DE3	0.0017	0.2019	0.5287	0.8424	0.4287	0.9749
DE4	0.002	0.2534	0.5183	0.7676	0.4183	0.9821
DE5	0.0024	0.2314	0.5435	0.7733	0.4435	0.9677
DE6	0.8968	0.7754	0.4322	0.4134	0.6322	0.0012
DE7	0.8868	0.7655	0.4423	0.4234	0.6423	0.0015
DE8	0.0026	0.2412	0.5634	0.7324	0.3398	0.9135
DE9	0.9923	0.7123	0.4512	0.2243	0.6923	0.0012
DE10	0.8725	0.7612	0.4678	0.3154	0.6725	0.0015
DE11	0.9736	0.7832	0.4768	0.2019	0.6736	0.0017
DE12	0.0035	0.3513	0.5723	0.7412	0.4513	0.8923
DE13	0.0042	0.2678	0.5898	0.7325	0.4678	0.8725
DE14	0.0039	0.3189	0.5943	0.8297	0.4189	0.9736
DE15	0.9749	0.7517	0.4124	0.3158	0.4724	0.0073
DE16	0.9821	0.7849	0.4239	0.2819	0.4639	0.0081

DE17	0.0056	0.3398	0.5523	0.7139	0.4124	0.9651
DE18	0.0062	0.2588	0.5845	0.8098	0.4239	0.9723
OE1	0.8825	0.7612	0.4287	0.3398	0.6925	0.0056
OE2	0.9543	0.1919	0.5183	0.3588	0.6536	0.0062
OE3	0.0073	0.3158	0.6135	0.7678	0.4322	0.9279
OE4	0.0081	0.2819	0.6243	0.7821	0.4423	0.9153

The government should regularly update the government contingency plan for urban infectious disease outbreaks (IC_5), check the medical resource reserve (IC_4), and develop public awareness of epidemic resistance. Compared with the other three critical events, IC_4 significantly reduces casualties (OE_2). Therefore, it is essential for priority hospitals and treatment facilities to have adequate medical resource reserves (IC_4) and a higher level of government emergency response capacity (IC_6). A sound Government emergency response plan (IC_5) is critical in stabilizing public confidence and enhancing public trust (OE_3). Together, the four initial conditions can go a long way toward reducing losses, which means that proper emergency preparedness is needed to deal with the human fatalities and economic losses associated with COVID-19.

Table10-1. Prediction probabilities of the other events in dynamic events analysis.

	S0	S1	S2	S3	S4	S5
DE1	0.0017	0.8124	0.6123	0.5823	0.5243	0.5124
DE2	0.0019	0.7239	0.6577	0.5977	0.5554	0.5239
DE3	0.0027	0.8287	0.6424	0.5824	0.5619	0.5287
DE4	0.0030	0.8183	0.6376	0.5676	0.5434	0.5183
DE5	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
DE6	0.9883	0.1553	0.2253	0.2587	0.2957	0.3387
DE7	0.9875	0.1475	0.2175	0.2683	0.3093	0.3483
DE8	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
DE9	0.9923	0.1653	0.2353	0.2787	0.3157	0.3487
DE10	0.9725	0.1575	0.2275	0.2583	0.3093	0.3583
DE11	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
DE12	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
DE13	0.0044	0.7435	0.6233	0.5733	0.5614	0.5435
DE14	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000

DE15	0.8825	0.1843	0.2493	0.2686	0.2965	0.3479
DE16	0.9543	0.1585	0.2379	0.2673	0.3001	0.3215
DE17	0.9736	0.1375	0.2395	0.2780	0.3126	0.3562
DE18	0.0000	0.8087	0.6224	0.5624	0.5419	0.5087
OE1	0.9749	0.1234	0.2179	0.2987	0.3056	0.3341
OE2	0.9821	0.1219	0.2469	0.2587	0.2934	0.3490
OE3	0.0012	0.8383	0.6576	0.5876	0.5634	0.5383
OE4	0.0015	0.7439	0.6777	0.6177	0.5754	0.5439

4.2.2 Analysis of dynamic events

The analysis above shows that the dynamic events related to emergency management are $DE_{5,8,11,12,14}$. The impact of these key events can be tested similarly, as shown in Table 10-1 and Table 10-2. Emergency command center establishment (DE_8) had a significant effect on reducing economic losses (OE_1). Exposure to personnel isolation (DE_5) could reduce economic loss (OE_2). While any of these six dynamic events alone do not critically impact the four outcome events, their combination can significantly impact them. Therefore, we considered several scenarios (S6, 7, 8, and 9).

Table10-2. Prediction probabilities of the other events in dynamic events analysis.

	S6	S7	S8	S9	S10
DE1	0.8823	0.7824	0.9543	0.9823	0.8249
DE2	0.8577	0.7639	0.9554	0.9977	0.8039
DE3	0.8424	0.7787	0.9419	0.9984	0.8187
DE4	0.8676	0.7883	0.9434	0.9776	0.8383
DE5	0.0000	0.0000	1.0000	1.0000	1.0000
DE6	0.0187	0.0953	0.0087	0.0017	0.0553
DE7	0.0283	0.0975	0.0083	0.0013	0.0575
DE8	1.0000	0.0000	0.0000	1.0000	0.0000
DE9	0.0387	0.1053	0.0092	0.0016	0.0753
DE10	0.0249	0.1089	0.0073	0.0011	0.0675
DE11	0.0000	1.0000	1.0000	1.0000	1.0000
DE12	1.0000	0.0000	0.0000	1.0000	0.0000
DE13	0.8733	0.7635	0.9314	0.9733	0.8235
DE14	0.0000	1.0000	1.0000	1.0000	0.0000
DE15	0.0190	0.0903	0.0086	0.0019	0.0513
DE16	0.0173	0.0915	0.0081	0.0011	0.0589

DE17	0.0274	0.1134	0.0079	0.0021	0.0502
DE18	0.8224	0.7587	0.9219	0.9784	0.7987
OE1	0.0356	0.1289	0.0072	0.0046	0.0563
OE2	0.0279	0.1178	0.0081	0.0058	0.0597
OE3	0.8868	0.8045	0.9475	0.9712	0.8541
OE4	0.8723	0.7859	0.9598	0.9942	0.8241

In S6, the dynamic event $DE_{12} = DE_8 = 1$, $DE_5 = DE_{14} = DE_{11} = 0$ scenario is used. It represents the scenario where the movement of personnel is restricted, and the emergency command center is established. In this case, casualties (OE_2) can be significantly reduced, and economic losses (OE_1) can be reduced to some extent. That means that effective rescue efforts and limiting the movement of people in the COVID-19 ravaged area of Wuhan are the key to reducing casualties and economic losses and enhancing public trust (OE_4). The government's effective measures in guiding public opinion and informing about the infectious disease situation through the media and widely publicizing the hazards and protection, and organizing enterprises, non-profit organizations, and individuals for infectious disease prevention and control have a more significant impact on alleviating social panic (OE_4) than other events. It can be seen that under S7, the economic loss (OE_1) is significantly reduced, but the reduction in casualties (OE_1) is not significant and has little effect on enhancing public trust (OE_3). In S8, $DE_{12} = DE_8 = 0$, $DE_5 = DE_{11} = DE_{14} = 1$, there is a significant decrease in economic loss (OE_1) and a significant increase in public trust (OE_4), as well as a significant decrease in casualties (OE_2).

5. Applications and Discussion

5.1.1 Scenario reasoning for emergency management of COVID-19 in Wuhan, China

Based on the actual situation of the epidemic and its spread, the timeline of critical anti-epidemic events following the COVID-19 outbreak in Wuhan can be obtained, as shown in Table 12. Wuhan Jinyintan Hospital did not prepare sufficient resources for infectious disease control, such as protective equipment, medical gowns, medical protective masks, and goggles, at the beginning of the COVID-19 outbreak(Lippi & Plebani, 2020). In December 2019, pneumonia caused by coronavirus was reported in Wuhan, China, with clinical symptoms different from the Severe Acute Respiratory Syndrome (SARS) outbreak in 2003. It was hypothesized that the virus might be a new variant of coronavirus(Chan et al., 2020). Therefore, $IC_1 = IC_2 = IC_3 = 1$ and $IC_4 = 0$. Although Wuhan hospitals have made significant progress in their ability to control infectious diseases, their robust routine infection prevention and control initiatives are inadequate to deal with unknown viruses(Bahl et al., 2022). Outbreak emergency drills to deal with common infectious diseases are frequent in Wuhan, but they are inadequate to deal with a highly transmissible virus and therefore do not have excellent response capabilities. Public self-protection capabilities are relatively poor in the immediate outbreak and are not given sufficient attention or access to relevant knowledge is confusing(H. Q. Chen et al., 2021; Teslya et al., 2020). Local governments have weak communication capabilities with the public. Although they have procedures for internal communication with the central government, they lack plans and ways to communicate with the public. Despite this, the public can trust the government and comply with its emergency instructions. Since novel coronavirus is a new infectious disease, there is no vaccine for this infection at the initial stage of its onset(H. Zhang, Li, Dolan, & Song, 2021). In summary we can obtain the probability of initial event $IC_5 = IC_6 = IC_7 = IC_8 = IC_{10} = 0$ and $IC_9 = 1$.

In this paper, once they occur, dynamic events have a probability of 1. Many cases were seen in and outside Hubei Province at the beginning of the COVID-19 outbreak, and cases began to appear in other countries. That made the population panic to some extent(Khan, Li, Liu, & Li, 2021). Various rumors appeared on the Internet and social software. Social media leaked information about infectious diseases to the public, and the main field of proliferation was WeChat and Weibo(Zhu, Zheng, Liu, Li, & Wang, 2020). Routine emergency medical supplies were promptly distributed to the organizations and people in need, and a shortage of supplies soon emerged(Zhou et al., 2020). Meanwhile, the outbreak spread rapidly, spreading to other provinces and cities in China(Hua & Shaw, 2020). In order to control the spread of COVID-19, China imposed traffic control on Wuhan city on January 23, 2020 Therefore, $DE_7 = DE_9 = DE_{10} = DE_{17} = DE_6 = 1$, $DE_{18} = 0$. Mass production of the vaccine cannot be achieved in the short term(F. C. Zhu et al., 2020), and there are occasional cases where local heads do not agree to inform the public about the status of the epidemic(Shangguan, Wang, & Sun, 2020).

Table 11. Prediction probabilities of the other events under each scenario

	S0	S1	S2	S3	S4	S5
IC1	1	1	1	1	1	1
IC2	1	1	1	1	1	1
IC3	1	1	1	1	1	1
IC4	0	0	0	0	0	0
IC5	0	0	0	0	0	0
IC6	0	0	0	0	0	0
IC7	0	0	0	0	0	0
IC8	0	0	0	0	0	0

IC9	1	1	1	1	1	1
IC10	0	0	0	0	0	0
DE1	0.788	0.7655	0.8212	0.8542	0.8679	0.9013
DE2	0.878	0.8524	0.8449	0.8721	0.9266	0.9657
DE3	0.614	0.5679	0.6241	0.6412	0.7987	0.8977
DE4	0.624	0.5972	0.6897	0.7825	0.8554	0.9019
DE5	0.554	0.5143	0.6045	0.8522	0.8769	0.9212
DE6	0.998	1	1	1	1	1
DE7	0.969	1	1	1	1	1
DE8	0.875	0.8539	1	1	1	1
DE9	0.97	1	1	1	1	1
DE10	0.991	1	1	1	1	1
DE11	0.977	1	1	1	1	1
DE12	0.771	0.7312	0.7613	1	1	1
DE13	0.582	0.5598	0.6712	0.7012	1	1
DE14	0.739	0.7111	0.7688	0.8099	1	1
DE15	0.767	0.7933	0.6012	0.5691	0.4115	0.3011
DE16	0.869	0.8721	0.6012	0.5576	0.3862	0.2512
DE17	0.713	0.6982	0.8211	0.8622	0.8723	1
DE18	0.892	0	0	0	0	0
OE1	0.987	0.9921	0.9666	0.9489	0.9415	0.9233
OE2	0.979	0.9867	0.8791	0.8344	0.7562	0.6725
OE3	0.841	0.8213	0.8612	0.8879	0.9012	0.9588
OE4	0.152	0.1091	0.7729	0.7811	0.8466	0.9065

Table12 Timeline of major rescue events after COVID-19 in Wuhan

Time	Events
Dec 27, 2019	The hospital reported a case of unexplained pneumonia to the Jianghan District CDC.
Dec 30	The National Health and Wellness Commission was informed of this and immediately organized research and prompt action.
Dec 31	27 cases were found, prompting the public to avoid public places and crowded places, and to wear masks when going out.
Jan 1, 2020	An outbreak response leadership team is established. CDC and Chinese Academy of Medical Sciences receive cases and immediately carry out pathogen identification.
Jan 3	Further pathogen identification China regularly and proactively informs the World Health Organization of outbreak information.
Jan 4	Develop a workbook for medical treatment of viral pneumonia of known cause and reach a consensus with the CDC for close liaison.
Jan 5	The World Health Organization informs about the cases of unexplained pneumonia in Wuhan.
Jan 7	Successful isolation of a novel coronavirus strain by the Chinese CDC.
Jan 9	The pathogen was initially determined to be a novel coronavirus.
Jan 10	The National Health and Wellness Commission shares information on the genome sequence of the new coronavirus with the World Health Organization.

Jan 15	Released the first version of the treatment, prevention and control protocol for pneumonia with novel coronavirus infection.
Jan 17	The National Health and Wellness Commission sent seven supervisory teams to localities to guide the prevention and control of the epidemic.
Jan 18	Release the second version of the treatment protocol for pneumonia with novel coronavirus infection.
Jan 19	Organized a high-level expert group on prevention and control to rush to Wuhan City for a field study on the prevention and control of the outbreak. Clarify that human-to-human transmission of the new coronavirus is occurring.
Jan 23	Airports and train stations are temporarily closed for departures from Wuhan. Provinces across the country activate provincial-level emergency response for major public health emergencies one after another.
Jan 24	National medical teams and public health personnel are mobilized from various regions and the military to assist Hubei Province and Wuhan City.
Jan 25	Sent steering teams to Wuhan and other areas with serious outbreaks to promote strengthening of front-line prevention and control efforts.
Jan 26	Extend the 2020 Spring Festival holiday and postpone the opening of colleges, universities, primary and secondary schools, and kindergartens around the country.
Jan 27	The central steering team is stationed in Wuhan to comprehensively strengthen guidance and supervision of the frontline prevention and control of the epidemic.

5.1.2 Results of cross-impact analysis

Based on the previous formula, the probabilities of the events in the six scenarios are presented in Table 11. Based on the temporal order of key events, $DE_8 = DE_{12} = DE_5 = DE_{14} = DE_{11} = 1$ was set, as shown in Table 13. Based on the timeline in Table 12, we used seven steps to infer the scenario of the spread of the epidemic after the COVID-19 outbreak in Wuhan(Roosa et al., 2020). As shown in Table 13.

Table13.Wuhan COVID-19 situational rehearsal setup.

Step	Scenario
Step0	IC1 = IC2 = IC3 = IC9 =1 IC4 =IC5 = IC6 = IC7 = IC8 = IC10 = 0，
Step1	DE7 = DE9 = DE10 = DE11 = DE6 = 1, DE18 = 0
Step2	DE13 = 1
Step3	DE8 = DE14 = 1
Step4	DE12 = 1
Step5	DE17 = 1

To verify the model's suitability, the predicted results were compared with the actual situation of COVID-19 in Wuhan, where, as of 24:00 March 10, 2020, a cumulative total of 67,773 confirmed cases, 49,056 cured discharges, and 3,046 cumulative deaths were reported in Hubei Province. Shortly after the onset of COVID-19, there was a significant increase in mortality and daily additions, and The cure rate was poor, as shown in Figs 6-8.

Fig 6. Cumulative deaths due to COVID-19 on January 30

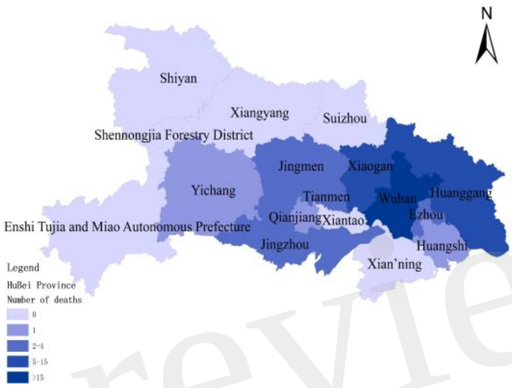


Fig 7. Number of new confirmed COVID-19 diagnoses on January 30

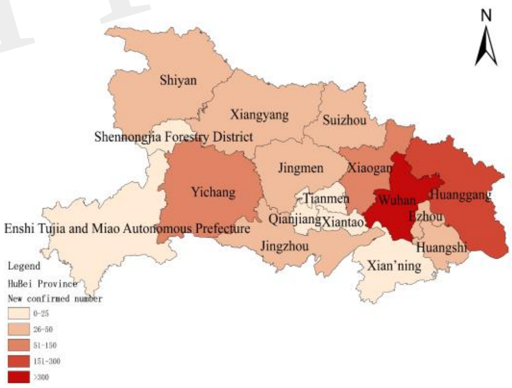


Fig 8. Number of people cured after having COVID-19 on January 30

The probability of human casualty (OE_2) increased from 1.163% to nearly 9%, as shown in Fig 12. With the development of the Chikyu Wuhan anti-epidemic work, the mortality rate of COVID-19 rapidly decreased from 9.026% on January 27 to 5.346% on January 28. The number of new cases in Wuhan showed the first decreasing trend of 2.14, and the cumulative number of deaths began to slow down, while the number of cured cases continued to go up, as shown in Figs 9-11.

Fig 9. Cumulative deaths due to COVID-19 on February 14

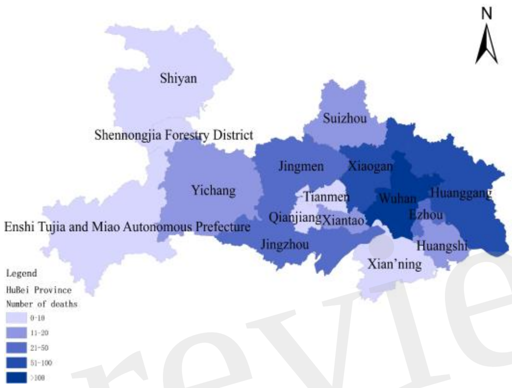


Fig 10. Number of new confirmed COVID-19 diagnoses on February 14

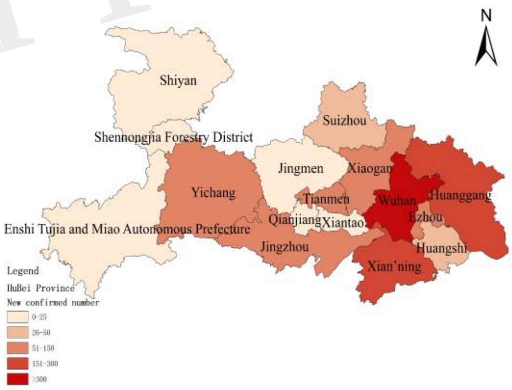
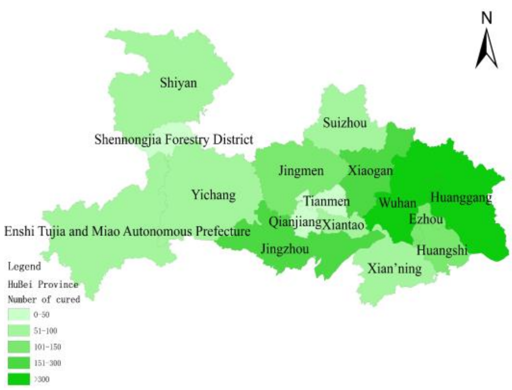
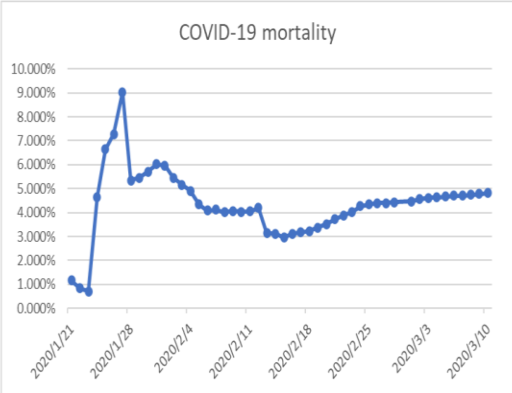


Fig 11. Number of people cured after having COVID-19 on February 14



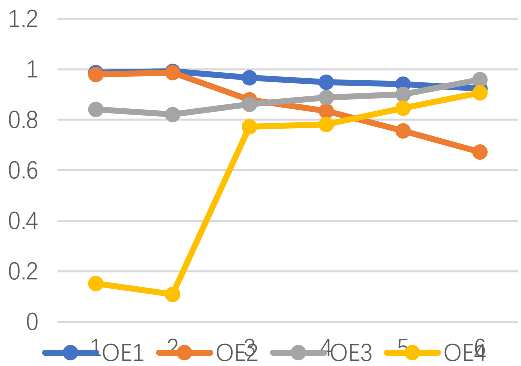
Subsequent mortality rates continued to decline and stabilized below 5%, and the epidemic was largely under control by early March, as shown in the attached video. The predicted trend is consistent with the actual situation described in the statistical report.

Fig12. COVID-19 mortality rate



COVID-19 caused at least \$1.1 trillion in damages. Although the government has raised significant amounts of donations and supplies, it has had little effect in the making up for the enormous losses. The probability of economic loss (OE_1) remained close to 100% with minimal fluctuations, consistent with the actual situation. Emergency response measures after the COVID-19 outbreak had little impact on preventing economic losses, but the greater emphasis should be placed on emergency preparedness. The Chinese government is highly commended for its emergency response following the COVID-19 outbreak. The central government responded quickly, dispatching medical personnel to the affected areas within four days of the outbreak. Various departments actively collected and approved valuable data and information, and the National Health and Wellness Commission promptly released the latest situation to the community. The timely release of authoritative information eased public panic and anxiety to a certain extent and was highly evaluated at home and abroad. As for the public trust (OE_4), after COVID-19, this possibility was reduced to nearly 10%, which is in line with the actual situation. Public trust tended to rise sharply after the government's immediate relief efforts. The government effectively guided public opinion and promptly announced information about the outbreak, which significantly eased social panic and further increased public trust. The probability of public trust occurring was highest when rescue teams and supplies arrived in Wuhan, and emergency medical supplies were promptly distributed to the organizations and people in need. The results indicate that the government played an active role in calming public panic and gaining public trust, and establishing the emergency command center was a key factor. However, in the initial scenario (step0), the probabilities of the two outcome events reach very high values, indicating that the lack of emergency preparedness significantly impacts the two outcomes that produce severe losses. The simulation results match the actual situation better, as shown in Fig. 13.

Fig13. The trend of the prediction probabilities of four outcome events



The emergency response to the COVID-19 outbreak in Wuhan was rapid and effective. If the emergency preparedness is weak, the ravages of COVID-19 may still cause significant casualties and huge economic losses. Our simulation aims to generate dynamic scenarios for possible urban infectious disease outbreaks. Simulating scenario-based contingency plans for possible urban infectious disease outbreaks can help decision-makers analyze potential scenarios during COVID-19 and predict the impact and consequences of different actions that decision-makers may take. The simulation contains four scenarios: $IC_4 = 1$, $IC_5 = IC_7 = 0$; $IC_5 = 1$, $IC_4 = IC_7 = 0$; $IC_7 = 1$, $IC_4 = IC_5 = 0$; $IC_4 = IC_7 = IC_5 = 1$. The others are the same as in the Wuhan COVID-19 outbreak.

Fig 14. Economic loss

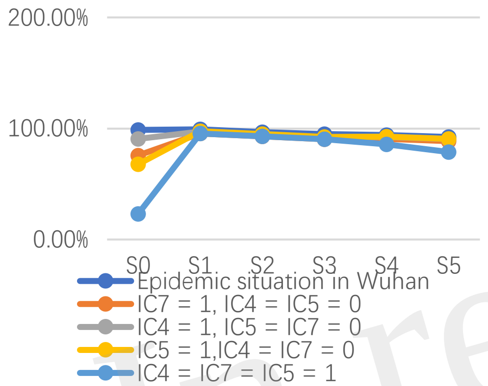


Fig 15. Personnel death

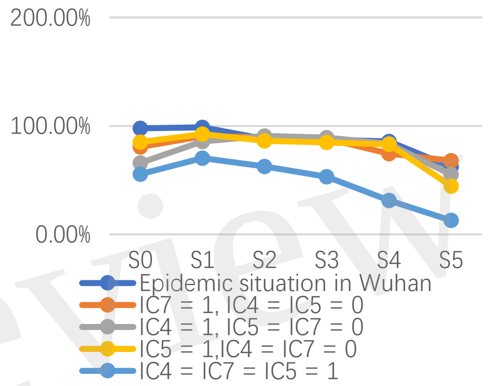


Fig 16 Infectious diseases are under control

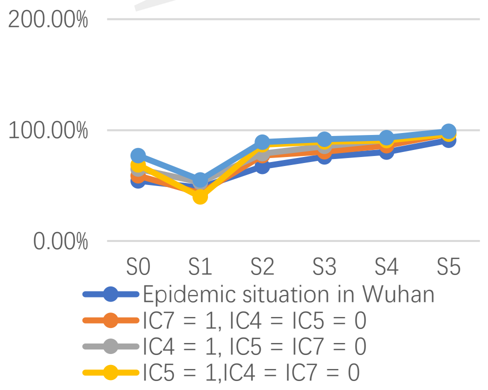
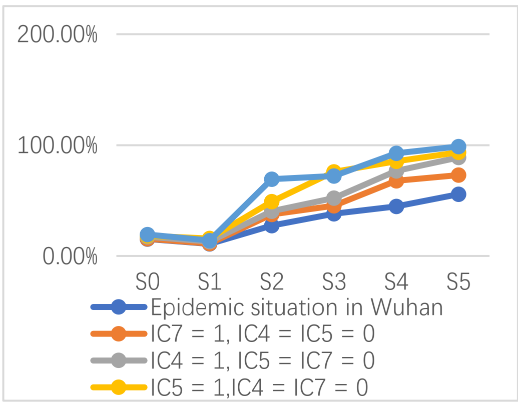


Fig 17 Public trust



The probabilities of the four outcome events of human casualties, economic losses, the infectious disease controlled, and public trust under different scenarios are shown in Figs 14-17, respectively. In Fig. 15, government communication capacity (IC_8) positively reduces economic losses.

However, recovering once COVID-19 has caused significant economic losses is difficult. In Fig 15, medical resource reserves (IC_4) and public self-protection capabilities (IC_7) play a critical role in reducing human casualties. Government contingency plans (IC_5) have the same positive effect. Public panic (DE_9), rumor spreading (DE_{10}), the spread of infectious diseases (DE_{11}), leadership disagreement to release information (DE_6), and information leakage (DE_7) significantly increased the likelihood of human casualties (Step2). In contrast, Fig 16 shows that adequate government contingency plans (IC_5) and medical resource reserves (IC_4) can help control infectious diseases more quickly. However, spreading infectious diseases would significantly increase the likelihood of social panic (Step2).

Nevertheless, proper emergency preparedness and robust government contingency plans quickly control public panic and establish public trust, as shown in Fig 17. Therefore, some recommendations can be made, as emergency preparedness plays a crucial role in guiding the government and the public to respond positively to COVID-19. At the same time, it is essential to consider minimizing the risks and losses associated with COVID-19 to the greatest extent possible. The ease of access to transportation facilities may increase the spread of infectious diseases, thereby causing casualties and economic losses, so contact isolation of people in transit should likewise be considered in managing urban infectious disease outbreak emergencies. In addition, the government should pay more attention to rumor spreading and information leakage. In this scenario, it is necessary to develop adequate emergency response measures and extensive public education. The rescue efforts of frontline medical personnel and the related medical resources are vital in saving lives. In this regard, sound emergency management makes the fight against an epidemic easier while ensuring adequate rescue supplies and enabling the active deployment of medical resources. The economic damage caused by an urban infectious disease outbreak is challenging to recover from, so the performance of hospitals' medical facilities and the rescue efforts of local hospitals are particularly critical. Finally, in terms of reducing social panic and enhancing public trust, active public opinion guidance and timely and effective publication of epidemic-related information play an irreplaceable role.

6. Discussion

In this paper, based on cases of infectious diseases (H_1N_1 and SARS, Etc.)(Lin et al., 2005), experts in the field of emergency management and Wuhan COVID-19 frontline responders are invited to form an expert panel. The panel of experts then provided the broadest possible range of critical events related to emergency management decisions. A consistent causality estimation matrix between the events was given using the Delphi method. After building the cross-impact matrix, the most significant impacts in the top 5% and 15% were extracted and represented graphically. First, the model can be used for multiple scenario analysis to identify critical contingencies. Then, correlations between actual events can be identified to explore the trends of outcome events resulting from different courses of action. Emergency management efforts that positively impact each other form a micro-set, or they can be separated to clarify the impact of different emergency management measures on human casualties and economic losses. Scenario simulations constructed from different emergency management measures are more scientific than single-factor emergency management(Van Beneden et al., 2016).

Emergency medical supplies delivered to the organizations and people who need them directly impact casualties. This is in agreement with the study of Tokalić R and Viđak M(Tokalić et al., 2021). In emergency preparedness, the stockpiling of medical resources and establishing an emergency command center are top priorities in avoiding mass casualties. At the same time, this study confirms that the spread of rumors and leakage of information have a significant negative impact on the containment of infectious diseases(B. Chen et al., 2021). Limiting the movement of people can have a significant effect on the reduction of casualties. In terms of economic losses, the rapid depletion of medical supplies and the shutdown of economic activities across the country due to the restriction of movement of people were significant contributors to the enormous economic losses. Although it is difficult to recover from the substantial economic losses caused by infectious diseases in a short period, there are no emergency measures that can quickly recover from economic losses. A well-developed emergency plan is vital in stabilizing public confidence and enhancing public trust. Awareness of effective anti-epidemic measures and improved public self-protection can help the public cope with infectious diseases quickly. However, many casualties, information leaks, and rumors can intensify the public panic. At this time, active guidance such as vital rescue and treatment by medical personnel and authoritative publication of information on infectious diseases by the government can significantly alleviate panic. The results show that emergency preparedness is necessary to avoid severe economic losses, casualties, and adverse social impacts caused by infectious diseases. In the primary stage of emergency rescue, all rescue measures must cooperate to achieve the expected effective results. The simulation results show that when several emergency management measures are effectively implemented, the probability of damage caused by an infectious disease will be significantly reduced.

Relative to Brooks et al.'s study, this paper considers the dynamic interaction between the three event sets and constructs a scenario model that can be used to analyze and evaluate the emergency management of COVID-19 in Wuhan(Brooks et al., 2016). Therefore, this paper presents a hypothetical urban outbreak infectious disease emergency response scenario based on the actual occurrence of COVID-19 in Wuhan, China, and analyzes the strong impact of critical events on dynamic events, especially on the four outcome events. Also, the relationship between events is represented figuratively using directed graphs to show the disruptive effects of rumor spreading, information leakage, and other events. The leaders' disagreement to release information and the lack of cooperation of some health care workers are the reasons for the occurrence of other dynamic events, which clarify the compass role of emergency preparedness for the work of fighting the epidemic. The analysis results in this paper indicate that establishing the emergency command center was one of the essential vital factors and that the government played an active role in alleviating public fear and gaining public trust. Isolation and observation of people exposed to infectious diseases is the top priority of emergency management, which can effectively reduce the spread of infectious diseases and reduce casualties and economic losses.

Based on the real epidemic and scenario simulation results, it is possible to assess the while effectiveness of crucial measures taken in emergency management, identify critical events in subsequent efforts to combat the epidemic, and suggest several specific recommendations for reducing epidemic-related losses to improve future emergency management.

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