Modeling the Health Delivery System and Policy Intervention Experiments

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Prof. Zhang has been engaged in hospital management teaching and research for 30 years, with the research direction of "evidence-based decision-making in health services". Prof. Zhang developed the laboratory research idea of "Research-Database-Modeling and Intervention Experiment-System and Theoretical Innovation", established the medical resource allocation database, and the theory of "two phases-three phases" of emergency medical rescue, which were widely recognized by international experts.

Prof. Zhang has presided over 30 national scientific research projects; won the second prize of the National Science and Technology Progress Award, the National Teaching Achievement Award, and the first and second prizes of the military or provincial science and technology progress/teaching achievement awards. Prof. Zhang has published more than 200 research articles, including 2 publications in The Lancet. Prof. Zhang has published more than 30 monographs as the chief editor and applied 45 patents.

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1 Introduction

Authors: Lulu Zhang, Wenya Yu

1.1 Study background

1.1.1 The public welfare nature of public hospitals

(1) According to the "Regulation on the Administration of Medical Institutions" and "Detailed Rules on Regulation on the Administration of Medical Institutions," medical institutions are those institutions that have registered and obtained the "Medical Institution Practice License." These can be classified as public and private medical and health institutions according to their registration category. "Public medical institutions" include state-owned and collective medical institutions, and "medical institutions" include hospitals, primary medical institutions, professional public health institutions, and other medical institutions. Therefore, the term "public hospitals" refers to state-owned and collective hospitals.

(2) As social organizational entities, public hospitals have social and natural attributes [1]. The social attribute of public hospitals is their public welfare nature, which is determined by their basic characteristics, social responsibility, and task characteristics. Public hospitals are responsible for healthcare, public health, medical assistance, research and teaching, disease prevention, and disaster relief, and should demonstrate fairness, accessibility, applicability, efficiency, and quality. These social responsibilities and characteristics determine the public welfare nature of public hospitals. On the other hand, as juridical persons and economic entities, public hospitals also have the natural attribute of operationality, which is restricted by market economic laws. The aim of carrying out business activities in the market economic system is to maintain self-operability and provide medical services. However, the operationality attribute of public hospitals differs from that of other economic entities, because it is based on the public welfare nature of public hospitals and has a non-profit aim. Profit is used for the overall operation of the hospital to provide medical services. Therefore, the social attribute of public hospitals is public welfare, and its natural attribute is operationality. Their public welfare nature is the basic attribute of public hospitals, and operationality should be based on the public welfare nature of public hospitals such as that related tasks can be better carried out through market economic activities.

(3) However, there is no unified concept of the public welfare nature of public hospitals. In China, the public welfare nature of public hospitals is conceptually defined from a multidisciplinary and multi-method perspective. Specifically, from a health economics perspective, the public welfare nature of public hospitals refers to the alignment of their behaviors and goals with the government's will in order to maximize social welfare. Furthermore, it should demonstrate fairness and accessibility, efficiency, and policy functions [2]. From a welfare economics perspective, the public welfare nature of public hospitals means that they are an extension of governmental functions and an important carrier of the public welfare healthcare industry [3]. The public welfare nature of public hospitals does not mean that operationality is avoided, but rather that the cost of the medical services provided to the patient is lower than the expected cost of a free-competition system [4]. The public welfare nature of public hospitals should meet the requirements of society as a whole or most of its members, should not be profit-oriented, and should fulfill national needs and serve society and the public [5]. From a public finance perspective, the public welfare nature of public hospitals must first reflect social fairness, which should also be evident in overall medical resource allocation efficiency and solving information asymmetry in the healthcare market. Furthermore, the public welfare nature of public hospitals is a relative concept intended to mitigate excessive pursuit of economic interests by hospitals [6]. From a public management perspective, the

public welfare nature of public hospitals refers to the positive externality from medical products and services [7]. From a health policy perspective, it ensures the provision of fair, accessible, and suitable medical services for the whole of society, and quality and efficiency of medical services, and satisfies the population's healthcare needs as much as possible [8]. Public hospitals emphasize the public welfare nature of the medical and health industry, promote the public welfare nature of public hospitals, establish an image of public interest and good public welfare, and promote people's health interests under the government's guidance to ultimately improve the health of all citizens and promote social harmony [9]. On the basis of a review of 29 papers, the meaning of the public welfare nature of public hospitals was summarized as fairness, suitability, feasibility, quality, and efficiency [10]. To summarize various studies, the public welfare nature of public hospitals was defined as non-profit oriented and intended to promote public welfare [11]. Their public welfare nature is the basic attribute of public medical institutions and is mainly presented as consisting of the accessibility, suitability, quality, and efficiency of basic healthcare services [12].

(4) Foreign scholars have also defined the public welfare nature of public hospitals. Hardin and Preker [13] provided a classic description of the public welfare nature of public hospitals, proposing that its core characteristics include (1) fairness and accessibility, (2) superior quality and low cost, and (3) a non-profit orientation. Specifically, fairness and accessibility mean that everyone can obtain medical services, particularly the poor and patients who are critically ill. The aim is to improve society's level of health and reduce health differences stemming from health resource allocation. Superior quality and low cost refer to medical services in which physicians increase quality but reduce price. A non-profit orientation means that public hospitals provide public goods and positive-externality products. Public goods include teaching and research, epidemiological monitoring, and patient and community health education. Positive-externality products include immunization plans, family planning, and treatment of infectious diseases. In addition, as Japan has undergone successful public hospital reform, some scholars have also provided a content definition of a public hospital's public welfare nature. Here, the public welfare nature means providing superior quality, being non-profit driven, and ensuring fair medical services and public goods [14]. Superior quality requires that public hospitals provide medical care at a high technical level; non-profitability requires that they do not excessively pursue economic benefits; fairness requires that they provide opportunities for equal medical services for poor populations and underdeveloped regions; and provision of public goods requires that they provide disaster relief and emergency services.

In summary, by combining the results of diverse academic disciplines in the literature from China and other countries, the public welfare nature of public hospitals can be defined as follows. Public hospitals should not excessively pursue economic benefits. Rather, the basic goal of public hospitals should be to demonstrate fairness, accessibility, suitability, efficiency, and the quality of medical services to all members of society.

1.1.2 Implementation of public welfare

Since 2009, when medical and health system reform (hereinafter referred to as "new medical reforms") was initiated, China's public hospitals have continuously developed. Now their importance has a direct impact on the success of the Chinese medical and health system reform. The former Minister of Health, Zhu Chen, pointed out that many conflicts and problems in the healthcare domain are concentrated in public hospitals; thus, the reform thereof is an important task in overall medical reform. In other words, public hospitals must be acknowledged as providing a platform for services to treat major diseases and refractory diseases, which are the main challenges to be addressed by medical reform.

In 2010, the Ministry of Health and another four ministries jointly released the "Guidelines on Pilot Reform of Public Hospitals," which emphasizes the public welfare nature of public hospitals and prioritizes the maintenance of people's health rights. It provides the direction of public hospitals in terms of their public welfare nature. In 2011, the General Office of the State Council released the "2011 Pilot Work Arrangements for Public Hospital Reform," which highlights the "separation of management, policies, medicine, profitability, and non-profitability" as key points of public hospital reform, and emphasizes the maintenance of the public welfare nature of medical services. In the same year, the General Secretary of the Communist Party, Hu Jintao, instructed that public hospital reform should be piloted, and the layout of public hospitals should be optimized, to ensure the public's access to affordable and high-quality medical consultation. In 2012, Premier Wen Jiabao further emphasized that public hospital reform should be carried forward, medical and pharmacy services should be separated, and regulation and operation of hospitals should be separated, thereby eliminating the mechanism of supplementing medical service income through drug prescription, fully mobilizing the enthusiasm of healthcare workers, and establishing harmonious doctor–patient relationships. Also in 2012, the General Office of the State Council released the "Notice on the Pilot Opinions of Integrated Reform for County-level Public Hospitals." In 2015, the General Office of the State Council released the "Implementation Opinions on Full Implementation of Integrated Reform for County-level Public Hospitals," marking the implementation phase of county-level public hospital reform. In 2015, the General Office of the State Council released the "Guiding Opinions on the Pilot Implementation of Integrated Reform for Municipal Public Hospitals," which calls for comprehensive pilot reforms for municipal public hospitals to be further expanded in 2015. In 2017, comprehensive pilot reforms for public hospitals were fully implemented. Furthermore, the General Office of the State Council released the "2017 Key Tasks for Deepening Medical System Reform," which explicitly advocates that comprehensive reform of public hospitals should be implemented by the end of September 2019, and reforms of the management system, medical costs, human resources and remuneration, drug distribution, and medical insurance payments should be coordinated and carried forward.

Overall, the "new medical reforms" deepened the application of public hospital reform policies in the construction and development of public hospitals, and continuous efforts resulted in many achievements. However, the implementation and success of the public welfare reform scheme of public hospitals still require considerable effort.

1.1.3 Research background of the public welfare

The tremendous conflict public hospitals face between their public welfare nature and operationality, and the severe absence of the public welfare nature of public hospitals are problems unique to China and have been widely studied in recent years by Chinese scholars.

(1) Causes of absence of the public welfare nature of public hospitals and ways to regain it

Most studies on public hospital reform focus on the causes of absence of their public welfare nature and ways to regain it. These studies mostly summarize the causes of the weakened public welfare nature of public hospitals by discussing the current situation and analyzing the problems. Three main causes have been highlighted. First, absence of governmental functions is considered the primary reason for the public welfare nature of public hospitals. Second, the profit-pursuing behavior of public hospitals is regarded as a key factor in explaining the absence of the public welfare nature. Third, a few scholars studied how the public welfare nature of public hospitals was regained from the perspective of influencing factors.

Studies on the causes of the weakened public welfare nature of public hospitals and ways to regain it summarized and discussed the causes of the weakened public welfare nature of public hospitals and corresponding improvement measures, thereby providing references for the formulation of plans to regain the public welfare nature. However, these studies are mostly qualitative and lack quantitative data on the magnitude of the various reasons' effects of the public welfare nature. Therefore, they lack scientific objectivity. Although they provide a reference for public welfare nature reform, a quantitative reference basis is lacking for the formulation of a scheme for the public welfare nature reform of public hospitals.

(2) Definitions of the public welfare nature of public hospitals and studies on definitions of connotation

Definitions of the public welfare nature of public hospitals and studies on definitions of connotation can be classified as those in health economics, welfare economics, public finance, public management, and health policy. From a health economics perspective, the public welfare nature of hospitals refers to aligning the behavioral goals of public hospitals with the government's will, so as to maximize social welfare as well as fairness, accessibility, efficiency, and policy functions [2]. From a welfare economics perspective, the core content of the public welfare nature of public hospitals is to reflect social welfare. From a public finance perspective, the public welfare nature of public hospitals is relative to the excessive pursuit of economic benefits and must represent social fairness, medical resource allocation efficiency, and solving information asymmetry in the healthcare market [6]. From a public relations management perspective, the public welfare nature of public hospitals refers to the positive externality from medical products and services [7]. Finally, from a health policy perspective, the public welfare nature should demonstrate fairness, accessibility, suitability, quality, and efficiency.

Studies on the connotations of the public hospitals' public welfare nature can be used to clarify their public welfare nature, thereby helping scholars, policy-makers, public hospital managers, and other relevant staff to understand its implications and importance; this is important in the accurate positioning of reform content and determining how to regain the public welfare nature. Although these studies have high theoretical value, they do not provide specific plans for reform, and their effects on the promotion thereof are not significant.

(3) Studies on public hospital system reform

Studies on public hospital system reform mainly examine the relationship between reform of the public welfare nature and the system, which comprises the operating mechanism, governance model, management system, compensation system, monitoring system, and performance appraisal system. Such studies are mainly based on management theories and theoretically investigate regaining the public welfare nature of public hospitals at the system level. From the perspective of operating mechanisms, the internal management of public hospitals can be strengthened through manpower, income, economic operation, and financial management systems [15]. From the perspective of the governance model, economic benefits should be detached, and the focus should be on effectiveness [16]. From the perspective of the management system, the public welfare nature can be protected by balancing and coordinating the market mechanism and the public welfare nature, strengthening market monitoring, and alleviating information asymmetry [17]. From a compensatory mechanism perspective, regaining the public welfare nature can be achieved by establishing compensatory mechanisms based on government procurement services, shouldering the wages of public hospital staff, strengthening regional health planning, and establishing a system for evaluating budget effectiveness [18]. From the perspective of monitoring mechanisms, separating medical and pharmacy services, auditing by certified accountants, chief accountant stationing, establishing a board of supervisors, information disclosure, and other supervision mechanisms can be implemented [19]. From the perspective of a performance appraisal system, a performance appraisal indicator system should be constructed to improve public hospitals' public welfare behavior [20].

Studies on the reform of public hospital systems have significant implications, particularly at the stage of implementation, because coordinated implementation of various aspects of systemic reforms will promote the recovery of public hospitals' public welfare nature. However, most current studies are in the theoretical phase and lack empirical evidence to support schemes of institutional mechanism reforms. Therefore, there are some limitations when the results of current studies are used to provide policy recommendations for institutional mechanism' reform.

(4) Awareness and evaluation research of the public welfare nature of public hospitals

There are relatively few studies on the awareness and evaluation of the public welfare nature of public hospitals. These studies can be placed into two categories. The first are those that focus on an awareness and evaluation analysis of the public welfare nature of public hospitals. These mostly employ questionnaires to collect data [21], which they statistically analyze. Other methods such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and literature reviews are seldom used [22]. The second category comprises studies on the construction of an evaluation system for public hospitals' public welfare nature, which primarily use the Delphi method, hierarchical analysis, and literature review [23].

Studies on the awareness and evaluation of the public welfare nature of public hospitals are theoretically significant in terms of reform. Questionnaire surveys are generally conducted, and statistical analysis methods are employed to evaluate the effects of different entities on the awareness and evaluation of public hospitals' public welfare nature. These reflect the current level of the public welfare nature of public hospitals and major problems more objectively and accurately. The Delphi method, hierarchical analysis, and literature review employed to formulate indicator systems for evaluation can be used to develop a comprehensive and multi-faceted evaluation system based on expert opinion and aid in promoting the recovery of public hospitals' public welfare nature. However, there are some limitations in existing studies, namely, a lack of representativeness, illogical evaluation indicators, one-sided evaluation subjects, and difficulty in comprehensively and objectively reflecting the current level of public hospitals' public welfare nature.

(5) Modeling studies on the public welfare reform of public hospitals

Few scholars have attempted to use game models and system dynamics modeling to analyze why the public welfare nature is weakened in public hospitals. By constructing causal relationship maps for system dynamics, the causes of the weakened public welfare nature of public hospitals can be analyzed through government subsidies, residents' medical consultation choice, and patient perceptions [24]. Furthermore, the construction of game models enables analysis of the weakened public welfare nature in asymmetric information conditions [25]. Game models on governmental financial compensation and the recovery of the public welfare nature of public hospitals can enable the maintenance of both hospital efficiency and public hospitals' public welfare nature [26].

Modeling techniques have significant methodological advantages in long-term policy problem studies and can achieve simulation analysis and results prediction regarding the public welfare reform policies of public hospitals. Through the short- and long-term simulation of policy outcomes, we can observe the effectiveness of different policy plans, which is important for formulating these policy plans. However, few modeling studies have been conducted, and most are exploratory. As such, only preliminary model frameworks have been constructed, and a complete model structure and study results are lacking, making it difficult to propose feasible recommendations for public welfare reform schemes of public hospitals.

Studies on public hospitals are ultimately the focus of experts, and there is room for improvement in terms of study content, methods, and depth and breadth.

1.2 Modeling and intervention experiment

1.2.1 Modeling

(1) System dynamics modeling

System dynamics modeling was developed by Jay W. Forrester from the Massachusetts Institute of Technology in 1956 and first used in the industrial domain to examine the dynamic characteristics of systems' behavior over time [27,28]. This method considers the feedback loop and effect or relationships of system behavior from the perspective of a system.

System dynamics modeling includes conceptual, causal loop diagram, and system dynamics models. Conceptual models are tools used to analyze the system and problems, and to describe the crucial factors and relationships of the entire system's problems. The causal loop diagram reveals the causes underlying the system and previous interaction relationships to establish a system-feedback framework. As such, it forms the basis of the modeling study. The system dynamics model, also referred to as the system dynamics flowchart, comprises variables such as state, rate, auxiliary, and initial variables, and connecting elements such as information and material flow.

(2) Agent-based modeling

Conceptually, the earliest agent-based model was Thomas Schelling's segregation model in 1971. This model presents the emerging results of agent interactions in the environment. Agent-based modeling is a method that employs overall system behavior to demonstrate the results of interactions among multiple individuals. This method is used to simulate multiple-individual behaviors and interactions to show and predict complex system problems. Agent-based model construction entails determining active entities (i.e., agents) to define their behavioral characteristics and rules, and establishing a model system network of multiple subject behavior by placing these entities in a dominant environment. The overall (system-level) behavior can be presented as the interaction result of the behaviors of multiple individuals in the system.

The modeling procedure includes system definition and description, individual agent division, individual agent modeling, construction of the multi-agent system (MAS) model, and computer simulation [29]. The system definition and description entail determining the problems studied; the boundaries of the system; and its characteristics, functions, structure, subject behaviors, and activities. Individual agent division should be based on the needs of the study problem. An entity in the system is abstracted as either a homogeneous or heterogeneous agent depending on its characteristics. System characteristics and needs are used to abstract the auxiliary or mobile agent. Individual agent modeling refers to the construction of computer models for every agent. The individual agent model contains three basic components, namely, perception, effects, and internal status. Macroscopic model construction employs the aforementioned individual agent models to construct an entire system model. The construction process requires determining the interaction rules and structure between individual agent models. Computer simulation uses a computer programming language and simulation platform to present the agent-based model through computer simulation software and employs the simulation platform to perform an intervention experiment of agent-based model simulation and policies.

(3) Discrete-event model

In 1961, IBM engineer Geoffrey Gordon invented GPSS software, the first discrete-event model software [30]. The process of discrete-event modeling considers the system as a process, or in other words, a series of entity operations. This network-based modeling method focuses on the processes and spaces needed for the simulation.

The discrete-event model construction process includes defining the model subjects, determining the basic attributes of the subjects, determining the discrete laws of event occurrence, and model realization. The main operations for discrete-event modeling include various time delays, resource services, branch selection, separation and assembly, and so on. This method is suitable for abstracting and simulating entities and resources. It focuses on processes and is commonly used for examining problems with queuing and delay characteristics. Discrete-event modeling is based on networks and focuses on spaces. As such, it can realize the simulation of entities' movements and resources emerging and involved in the physical space.

1.2.2 Simulation

(1) Simulation commissioning

The rationality, accuracy, and sensitivity of the model are verified based on the constructed model to achieve simulation commissioning. Specifically, the rationality of the model is commissioned by examining the model structure and boundaries and testing its parameters and dimensions. The purpose of examining these aspects is to ensure the accuracy of the model structure and logic, and test whether the relationship between them matches the actual system. Parameters and dimensions are tested to ensure the accuracy of all parameters and function relationships in the model, as well as consistency of parameters with dimensions before and after the function. Therefore, the parameters and dimensions must be tested to ensure the accuracy of model analysis. Model accuracy is tested through a fit analysis of the simulated and actual value, and by observing the goodness of fit between them. If goodness of fit ranges from -10% to 10%, the model is considered reliable, and accuracy is good. For the model sensitivity test, the model parameters are commissioned and changes in model output variables are observed. If a small adjustment of the parameter does not result in an obvious change in the output variable, the model is considered stable with good sensitivity.

(2) Simulation optimization

The constructed model can be visualized using computer software for the system simulation. During the simulation process, different models and subsystems in the model are optimized. The computer modeling software uses the three-way test results of simulation commissioning to optimize the simulation interface, logic, and quantity relationships to better simulate the actual system and better fit the model and system in a more rational manner.

1.2.3 Intervention experiment

(1) Policy intervention “targets”

Combining the analysis of system problems with the literature review or expert consultations enables identification of key influencing factors that affect system efficiency and results as policy intervention “targets.” Policy intervention protocols can be designed based on these policy intervention targets to perform policy intervention experiments and determine the effects of different intervention “targets.”

(2) Policy intervention experiments

Policy intervention experiments are based on the computer model and use the previously selected policy intervention “targets” in model simulation experiments for different protocols by adjusting parameters or function relationships. This enables comparison of the results of different intervention experiments with the current model operation to determine the outcomes of implementing policy plans. Intervention experiments can be used to simulate the long- and short-term effects of policies on a computer to observe the quantitative effects of policy plans and their trends.

(3) Positive policy intervention experiment results

Through policy intervention experiments, the results of policy interventions can be obtained. On the basis of all experiment results, experiment protocols with significant effects on the system problems are screened out. The positive experiment results in these experiment protocols are used as a theoretical basis and quantitative reference for solving system problems. The positive results of the policy intervention experiment can be used to evaluate the effects of the policy plan and provide a quantitative reference to formulate the current policy plan, thereby improving its effectiveness.

1.2.4 Technical route

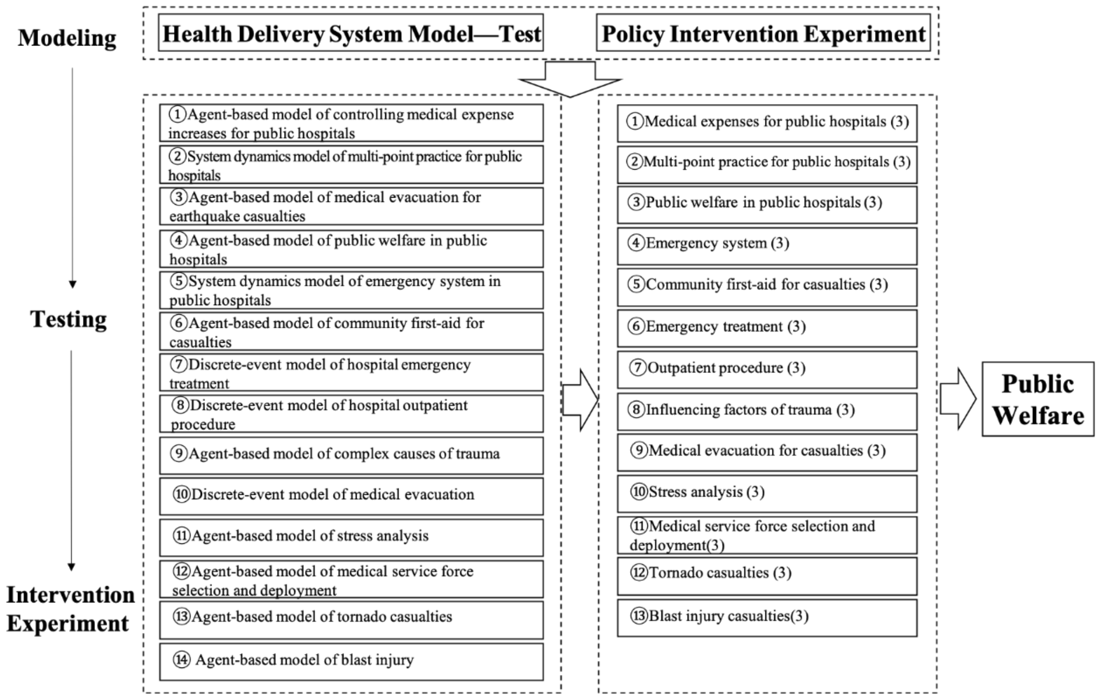

Figure 1-1. Study technical route.

1.3 Aims and significance

Our group has been committed to modeling research on the health service system and policies for more than 15 years and has extensive experience in this regard.

1.3.1 Aims

The aim of this study is to model the health service system and policy intervention experiment. The system dynamics, agent-based, and discrete-event models are used to construct 14 models (controlling medical expense increases, multi-site practice, medical evacuation for earthquake casualties, public welfare in public hospitals, emergency system in public hospitals, community first-aid for casualties, hospital emergency treatment, hospital outpatient procedure, complex causes of trauma, medical evacuation, stress analysis, medical service force selection and deployment, tornado casualties, and blast injury) from the two perspectives of health service system policy and the health service system. These 14 models are modeled, and policy intervention experiments are performed to deconstruct the model construction methods and techniques. This provides modeling ideas, methodology, and examples for studies on the health service systems and policy proposals, and short and long-term policy recommendations for improving the capabilities and efficiency of routine medical and health service systems.

1.3.2 Significance

In this book, the 14 constructed models were employed in policy intervention experiments on the medical and health services system. An in-depth quantitative analysis was carried out on different systems and key problems through modeling, simulation, and policy intervention experiments to increase the service capabilities and efficiency of the medical service system.

In this book, the constructed agent-based model of controlling medical expense increases for public hospitals, multi-point practice system dynamics model for public hospitals, agent-based model of medical evacuation for earthquake casualties, agent-based model of public welfare in public hospitals, system dynamics model of emergency system in public hospitals, agent-based model of community first-aid for casualties, discrete-event model of hospital emergency treatment, discrete-event model of hospital outpatient procedure, agent-based model of complex causes of trauma, discrete-event model of medical evacuation, agent-based model of stress analysis, agent-based model of medical force selection and deployment, agent-based model of tornado casualties, and agent-based model of blast injury were used for the modeling study on health service system problems. This provides novel study ideas and methods for improving system capabilities and for the effective and rational formulation of policy proposals.

Policy intervention experiments on controlling medical expense increases, multi-point practice, public welfare in public hospitals, emergency system, community first-aid for casualties, hospital emergency treatment, hospital outpatient procedure, complex causes of trauma, medical evacuation, stress analysis, medical force selection and deployment, tornado casualties, and blast injury were employed in simulated policy intervention experiments on 13 health service issues to examine key intervention "targets." This is important in discovering policy problems and improving policy efficiency.

2 Model of controlling medical expense increases and policy intervention experiment for public hospitals

Authors: Wenya Yu, Bo Wang, Lulu Zhang

2.1 Aims and significance

2.1.1 Aims

This study focused on the problem of recovering public welfare in public hospitals and controlling medical expenses in Shanghai; it aimed to construct a multi-agent model system model for controlling unreasonable increase in medical expenses in public hospitals and reveal the complex adaptive mechanisms and behavioral characteristics of multi-agent systems. Simulation and policy intervention experiments were used to examine critical behavioral characteristics and mechanisms that affect unreasonable increase in medical expenses and discover sources and policy intervention "targets" for controlling the increase in medical expenses and proposing policy recommendations for solving the continuous and rapid growth in medical expenses.

2.1.2 Significance

The model of controlling unreasonable medical expense increases in public hospitals constructed in this study was used to achieve simulation of medical expense variation trends, agent behavioral characteristics, and interaction environment, which enriched and expanded the healthcare system model. At the same time, the policy intervention experiments could provide a quantitative reference for screening feasible protocols to effectively control the increase in medical expenses. It as well, had important implications for solving the problem of "difficult and expensive medical services" and promoting reform of public welfare in public hospitals.

2.2 Methods

2.2.1 System definition and description

"The multi-agent model of controlling medical expense increases" mainly involves three agents: patients, physicians, and hospitals, and also involves the medical insurance system and government. This model uses different agent behavior characteristics and interactions to simulate the generation of medical expenses by starting at the stages of population disease occurrence and medical-seeking choice according to the actual situation. This process involves the behavioral choices of physicians and hospitals, and their behavioral characteristics will greatly affect the generation of medical expenses. This system model can be divided into two modules: the population disease occurrence and medical-seeking choice module and the medical expense generation module. Model construction is based on agent-based modeling as the core supplemented by system dynamics modeling.

Module 1: Population disease occurrence and medical-seeking choice module

(1) General population status: The total population and population ratio included in the model was set according to the current population size of Shanghai. Currently, Shanghai has a total population size of 24.15 million. In consideration of the running speed of the simulation, the population ratio can be set as 2000:1, that was, 1 agent in the model corresponds to 2000 of the actual population. In order to realistically simulate the actual environment, the map of Shanghai was included in the model, and agents in the model were randomly distributed into different administrative regions according to the ratio based on the population size and density of different administrative regions. General population status, that were, demographic

characteristics, included gender, age, occupation, marital status, income, and education level. These population characteristics were obtained from the National Health Statistical Yearbook, Shanghai Health Statistical Yearbook, and population census, which were used to confer various demographic characteristics randomly on the agents according to these ratios. Different demographic characteristics would determine agent behavior and directly affect the medical-seeking preferences of the agent. This model was based on the survey results of the group, and behavioral rules were conferred on medical-seeking preferences for different demographics. Computer software was used for automatic determination and generation of behavioral preferences for different agents.

(2) Disease occurrence: The disease categories in this model were classified according to the National Health Statistical Yearbook, which included infectious diseases, malignant tumors, benign tumors, endocrine, nutritional, metabolic disorders (diabetes), blood and hematopoietic diseases, mental illnesses, neurological diseases, eye and appendage diseases, ear and mastoid diseases, circulatory system diseases (heart disease, hypertension, cerebrovascular disease), respiratory system diseases (acute upper respiratory tract infection, pneumonia, chronic bronchitis), gastrointestinal tract diseases (acute gastritis, cirrhosis, and hepatobiliary disease), urinary tract and reproductive diseases, pregnancy, childbirth, and puerperal complications, skin and subcutaneous tissue disease, muscle, bone, and connective tissue diseases (rheumatoid arthritis), congenital deformities, injury and poisoning. The two-week morbidity rate for every disease category was used by the computer software to confer disease characteristics on different agents. The two-week morbidity rate data was obtained from the national health statistical yearbook.

(3) Medical institution characteristics: This model simplified public hospitals into tertiary hospitals, specialist hospitals, and district hospitals. However, as the protocol and policy directions for controlling irrational increase in medical expenses involved grassroots health institutions, this study included community health services centers in the model according to the actual situation of grassroots health institutions in Shanghai. Therefore, this mode included four types of medical institutions, and their quantity and geographical positions were accurately distributed in the model's map based on the actual situation of Shanghai at present. This model included 27 tertiary non-specialist hospitals, 22 specialist hospitals, 106 district hospitals, and 238 community health service centers. The geographical positions of all medical institutions were included in the model according to their actual latitude and longitude. The population's choices of medical institutions were determined by its demographic characteristics, disease characteristics, and socioeconomic status. After the type of medical institution was successfully determined, the specific hospital selected was determined by the distance from an individual to the hospital. However, when the type of medical institution cannot be determined based on the aforementioned factors, the medical institution nearest to the individual was selected. The distance from the individual to the medical institution was automatically calculated by the computer based on the actual distance in the embedded map.

(4) Health insurance institution: Different populations possessed different types of health insurance according to the actual situation. Official data from the National Health Services Survey, the China Health Statistical Yearbook, and the Shanghai population census were used to divide medical insurance into three types and ten grades, including basic health insurance for urban employees, basic health insurance for urban-rural residents, and non-health insurance. These people were divided by age and occupation according to the Shanghai health insurance reimbursement status: basic health insurance for urban employees was divided into retirees aged > 70 years and < 69 years, employed people aged > 45 and < 44 years; basic health insurance for urban-rural residents was divided into people aged > 70, 60–69 years, and 19–59 years, university students, secondary school students, and infants. Different populations possessed different types of health insurance, and different types and grades of health insurance

had different reimbursement ratios, which determined the medical-seeking preferences for different populations.

(5) Government departments: The effects of government on medical-seeking choice were mainly achieved through policies. At present, Shanghai is gradually implementing community first diagnosis and treatment system, a two-way referral system, and a family physician contract system, which would change the medical-seeking choices of different populations to some extent and might promote a benign of the medical-seeking model of “seeking medical services in community centers for minor illnesses and in hospitals for major illnesses,” thereby affecting the medical-seeking preferences of populations and ultimately affecting medical expenditure. The effects of government policies on various agent behaviors and the entire system model were examined and validated through simulation intervention experiments.

(6) Integration of population disease and medical-seeking choice module: The map of Shanghai was used as a basis while the actual population density and distribution status, actual number and geographical positions of medical institutions, and incidence of different diseases were used by the modeling software to automatically distribute populations and medical institutions; diseases were endowed to different individuals according to the incidence. The population’s medical institution preference after contracting disease was determined by the demographic characteristics, socioeconomic characteristics, disease characteristics of the population, and the geographical position of medical institutions. The specific selection behavior was generated automatically by the computer according to preset population medical-seeking rules.

Module 2: Medical expense generation module

(1) Disease treatment characteristics: Different diseases corresponded to different treatment regimens, specifically including outpatient or inpatient treatment, surgery, and examinations, which would correspondingly result in different medical expenses, surgery costs, examination costs, drug costs, and treatment costs.

(2) Patient medical-seeking behavior: After patients have selected the medical institution, different types of medical institutions would generate different costs for the same category, and health insurance reimbursement ratio would also differ. In addition, patients had their own behavioral choices during treatment, preferences for regimens, examinations, surgeries, and drugs, and prescription compliance rates. The medical-seeking behavior of patients was largely determined by the disease type. Patients suffering major or refractory diseases had more singular and objective behaviors and tended for better hospitals and complied with prescriptions. However, the behaviors of patients who suffered from common or minor illnesses were more subjective and diverse. Their preferences were affected by the financial capacities to a large extent, which were reflected by health insurance reimbursement levels and prescription compliance rates.

(3) Physicians’ practice behavior: The two greatest effects of physicians on medical expenses were the probability of over-prescriptions and the probability of receiving kickbacks. The probability of over-prescriptions would directly increase the medical expenses of patients by increasing treatment costs, examination costs, drug costs, and surgery costs. The receipt of kickbacks would increase the hidden expenditure of patients and critically affect the medical expenses as these cannot be reimbursed. These two unethical behaviors of physicians were affected by the physician’s socioeconomic status, disease characteristics, job satisfaction, and binding force of the medical institution and government. This was particularly so for the physician’s socioeconomic status, which was mainly presented as the gap between the actual and expected income. If the actual income was significantly lower than the expected income, physicians would tend to carry out more profit-driven and unethical behaviors. The financial investment of governments on medical institutions would also indirectly affect the probability of over-prescriptions. Excessive workload, dissatisfaction with the type of diseases, and low job satisfaction would cause physicians to carry out negative behavioral preferences and

continuously increase profit-driven behavior. In addition, the obvious differences in socioeconomic status of physicians, income levels, and job satisfaction among different medical institutions had significant effects on physicians' practice behavior.

(4) Medical institution: Differences in medical standards and treatment regimens in different types of medical institutions would result in large differences in medical expenses for the same type of disease. The choice of medical institution determined the starting level of the medical expenses, and subsequent medical expenses were mainly determined by the type of disease.

(5) Health insurance institution: The effects of health insurance institutions on medical expenses were mainly determined by the reimbursement ratio. Specifically, different populations have different types of health insurance, reimbursement scope and ratio for inpatient and outpatient treatment and different types of medical institutions have different reimbursement ratios. These differences in health insurance reimbursement rates would affect patients' prescription compliance rate, thereby influencing their medical expenses. In addition, health insurance institutions' restrictive and supervision effects on unethical behaviors in medical institutions and physicians would indirectly affect medical expenses.

(6) Government departments: The effects of government departments on medical expenses were mainly determined by the financial investment by the government on medical institutions. Insufficient government investment would cause medical institutions to over-pursue profits, which would encourage physicians to engage in unethical behavior such as over-prescriptions and receiving kickbacks, and ultimately significantly increased the medical expenses. Policies issued by the government for medical-seeking preferences would gradually change the medical-seeking behaviors of the population, and the adjustments to the health insurance reimbursement ratio could encourage patients to make rational medical-seeking choices from an economic perspective.

(7) Integration of medical expense generation module: Rules for generation of medical expenses were ultimately determined by combining the patients' medical-seeking behavior, physicians' practice behavior, medical institution behavior, restriction and supervision by the health insurance institution, and investment and guidance by the government. The patient's actual medical expenses were determined by basic outpatient or inpatient costs, actual costs for examinations, drugs, and surgeries, and the amount in kickbacks received by physicians. Patients' examination costs, drug costs, and surgery costs were simultaneously affected by the patients' prescription compliance rates, and these three costs were also influenced by physicians' over-prescription behaviors.

2.2.2 Agent division

The population disease occurrence and medical-seeking choice module was used to simulate and analyze the disease occurrence characteristics of Shanghai's population and medical-seeking preferences. Abstraction of this complex subsystem was carried out, and its agent can be divided into two heterogeneous agents, that were, population and medical institutions. In addition, the subsystem contained two supplementary agents, which were the government and health insurance institutions. These four agents constituted the population disease occurrence and medical-seeking choice system model with interrelations and interactions.

The medical expense generation sub-model was used to simulate and analyze the generation of medical expenses. According to the structure of the medical service system and medical-seeking process, the medical expense generation sub-model included two heterogeneous agents (population and physicians) and three supplementary agents (medical institutions, government, and health insurance institution). These five agents jointly constituted the medical expense generation subsystem model with interactions, restrictions and mutual influence.

2.2.3 Individual agent modeling

The individual agent model was the basis for constructing multi-agent model of a complex system. Every agent had its own internal status, and the agent would adjust its own internal structure and status according to the environmental characteristics and changes. Similarly, every agent can interact with and change the environment. The construction of the individual agent model was the process of constructing the internal status of the agent and achieving interactions between the agent and the environment.

(1) Model of population disease occurrence and medical-seeking choice sub-system

The construction of the population agent model was mainly based on the population's demographic and socioeconomic characteristics for its internal structure and status. Population demographic characteristics included gender, age, occupation, marital status, and education level. Socioeconomic characteristics included income level and type of medical insurance. The internal structure and status of the population agent model were constituted by the aforementioned characteristics, which determined the perception capabilities and response levels of the population agent toward the external environment and changes. The population distribution of this model was simplified and abstracted–according to the population density distribution of administrative regions in Shanghai, population mobility was not taken into consideration. The probability of disease occurrence in the population agent was affected by the incidences of different types of diseases. The choice of medical institution after the population agent developing disease was affected by two supplementary agents. Policies proposed by the government, including the community first diagnosis and treatment system, two-way referral system, and family physician contract system would affect the medical-seeking preference of the population through the degree of policy promotion, and the economic benefits and convenience produced. The responses of the population toward policies would in turn influence the policy-making process by the government. Health insurance institutions mainly affected the medical-seeking choice behavior of population agents through health insurance reimbursement levels. Health insurance reimbursement levels would affect the financial capacity of the population agent, thereby influencing their choice of medical institutions.

The medical institution agent model was abstracted as the type, quantity, and geographical position of medical institutions. These medical institutions were distributed throughout the entire system according to the actual geographical positions. There were four categories of medical institution agents, namely, tertiary non-specialist hospitals, specialist hospitals, district hospitals, and community health service centers, with the number of 27, 22, 106, and 238, respectively. The distribution of the medical institutions in the system was based on the latitude and longitude of the actual geographical locations. This constituted the internal structure and state of the medical institution agents. The interactions of the medical institution agent and the environment–were not considered in this subsystem while it was presented in the medical expense generation subsystem.

(2) Model of medical expense generation sub-system

In this sub-system, the internal structure and status of the population agent were mainly affected by reimbursement levels and kickbacks receipt by physicians. The main external environments were health insurance institutions and medical institutions, and their interactions with the environment determined the behavior of the population agent. The execution rate of the physicians' resuscitation regimen, which was mainly presented as patients' prescription compliance rate, would affect the medical expenses. The social environment interactions between the population agent and the kickback receipt behavior of physicians determined whether population agents would give out kickbacks and the amount of money. In addition, the internal structure and status of the population agent in this sub-system were consistent with the demographic characteristics and socioeconomic characteristics of the population agent in the aforementioned model. These basic internal structures and statuses would still affect the population agent model in this sub-system.

The internal structure and status of the physician agent model were mainly presented as their professional title, workload, actual and expected income, over-prescription behavior, and kickback receipt behavior. The professional title of a physician agent was intimately associated with the actual and expected income. Excessive workload and a large gap between actual and expected income would encourage physicians to carry out more unethical behaviors. The aforementioned internal status of the physician agent was very sensitive to environmental changes and would significantly change with the actual work environment and income. In addition, the behavior of the physician agent was affected by two supplementary agents (medical institutions and the government). The social responsibilities undertaken by medical institutions would result in the formation of a public welfare environment in medical service system, which would encourage the physician agent to carry out more public welfare behaviors with the environmental changes. The increase in financial investment by the government would increase self-construction, maintenance, and development costs in medical institutions, which would decrease the probabilities of pursuing profits of medical institutions. It would also indirectly increase the reasonable income of physician agents and weaken their unethical behaviors of over-prescriptions and receiving kickbacks. Changes in the internal structure and status of physician agents would directly affect the medical expense generation process.

2.2.4 Multi-agent system model

The construction of the multi-agent system model was an integration of the aforementioned individual agent models and involved interactions and coordination mechanisms among agents. The population agent model was the core of the multi-agent system model as the population agent activated the entire system through disease occurrence. After a disease has occurred, the medical-seeking behavior of population agents interacted with the medical institution agent. The geographical location of the medical institution agent was one of the factors affecting medical-seeking behavior in population agents. This medical-seeking behavior was simultaneously affected by policy directions and the reimbursement system of the government agent and health insurance institution agent. After medical-seeking choice was made, the system model entered the second stage, that was, the medical expense generation process. After the population agent has selected the medical institution, it would accept different treatment regimens and modalities according to disease characteristics. During this process, the population agent would be affected by the reimbursement system of the health insurance institution agent, while the latter would affect medical expenses by interacting with the prescription compliance rate in the population agent. At the same time, the behavior of the physician agent was key to the generation of medical expenses. The physician agent was affected by the medical institution agent and government agent through financial subsidy and social responsibilities, which would lead the physician agent to make judgments and changes to the environment. The workload and income of physician agents were intimately associated with their behaviors and would directly affect medical expenses.

The model of controlling medical expense increases of public hospitals can be established by AnyLogic software. The following figure showed the structure of the model (Figure 2-1). According to different agents and model functions, the computer simulation interface was divided into the Area, Disease, Hospital, Main, Pcost, Person, Preference HT, Option List, and Simulation modules. These modules were used for simulation of the characteristics, behaviors, mechanisms, and simulation functions of the aforementioned agents.

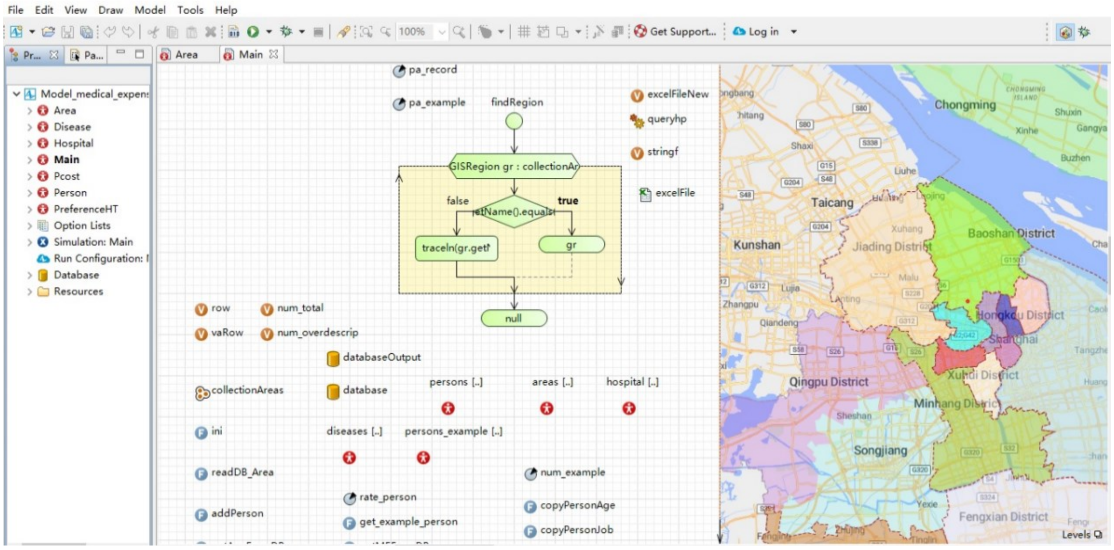

Figure 2-1. Model of controlling unreasonable medical expense increase for public hospitals.

2.3 Model simulation

2.3.1 Simulation commissioning

The simulation duration of the model was set as three years (36 months), the model output unit was one month, and the mean outpatient and inpatient medical expenses were observed. The simulation experimental results showed that the mean outpatient and inpatient medical expenses all increase with time without interventions. However, the increasing trend was relatively stable, and there was no drastic change. This result was consistent with the actual situation, showing that the model had good reliability.

2.3.2 Model summary

In this study, the model of controlling unreasonable medical expense increase for public hospitals was constructed from the perspectives of five agents (population, physicians, medical institutions, health insurance institutions, and government) through the simulation of the characteristics, behavioral rules, and interactions of different agents. This model covered two modules (population disease occurrence and medical-seeking choice, and medical expense generation) and was used to simulate population disease occurrence characteristics, medical-seeking choice behavior, and medical expense generation, thereby achieving the simulation analysis of medical expenses for public hospitals. This model simulated behaviors and interaction mechanisms among different agents, and from the perspective of agent behaviors, policy interventions could be used to change behavioral rules to achieve a simulated analysis of changes in medical expenses.

The policies proposed in the “New Healthcare Reform” on public hospitals were directional policies for the behaviors of physicians, patients, and regulatory authorities. The aim of this reform was to rationalize the medical-seeking behavior of patients, control profit-pursing behavior of physicians, and strengthen the restrictive behaviors of regulatory authorities to control the reasonable growth of medical expenses. Therefore, the model constructed in this study can simulate these policies and examine the short-term and long-term effects rapidly and reliably, thus providing a theoretical basis for further quantitative guidance for policies.

2.4 Policy intervention experiment

2.4.1 Intervention experiment 1: Intervention experiment of patient behaviors

(1) Intervention experiment of patient behaviors

Patient behavioral intervention experiment: The behavioral intervention experiment protocol for patient behavior changed patients' medical-seeking preferences through the promotion and application of the community-first consultation system, thereby observing the effects of this behavioral change on medical expenses. Three intervention experiments were designed to compare the simulation experiment results and baseline results. The protocol for the three intervention experiments was as follows.

Experiment 1: The promotion and application of the community-first consultation system were decreased by 50%, and patients prefer tertiary general hospitals.

Experiment 2: The promotion and application of the community-first consultation system were increased by 50%, and patient preferences were rational.

Experiment 3: The promotion and application of the community-first consultation system were increased by 100%, and patient preferences were rational.

(2) Patient behavioral intervention experiment results

(a) Outpatient medical expenses

Adjustments to the level of promotion and application of the community-first consultation system did not affect the 3-year variation trends in total outpatient medical expenses, drug expenses, examination expenses, proportion of drug expenses, and proportion of examination expenses. Expanding the promotion and application of the community-first consultation system could significantly decrease total outpatient expenses, drug expenses, examination expenses, and proportion of examination expenses. However, this intervention had no effect on regulating the proportion of outpatient drug expenses because it showed a slight increase. In addition, with the expansion of the level of promotion and application of the community-first consultation system, the regulatory effects on outpatient medical expenses could be achieved.

Table 2-1. Changes in outpatient medical expenses (patient behavioral intervention experiment).

Time	Group	Total outpatient medical expenses (CNY*)	Outpatient drug expenses (CNY*)	Outpatient examination expenses (CNY*)	Proportion of outpatient drug expenses	Proportion of outpatient examination expenses
Year 1	Baseline	241.7	120.1	43.1	48.7%	18.2%
	Experiment 1	265.3	135.6	46.8	49.9%	18.2%
	Experiment 2	205.7	105.9	28.4	50.4%	14.2%
	Experiment 3	201.1	103.8	26.5	50.6%	13.9%
Year 2	Baseline	248.6	122.2	44.3	48.1%	18.2%
	Experiment 1	273.1	138.0	48.1	49.3%	18.3%
	Experiment 2	209.7	106.8	28.9	49.9%	14.3%
	Experiment 3	204.7	104.6	27.0	50.0%	13.9%
Year 3	Baseline	255.8	124.1	45.6	47.5%	18.3%
	Experiment 1	280.6	139.8	49.4	48.7%	18.3%
	Experiment 2	212.8	107.0	29.6	49.3%	14.3%
	Experiment 3	207.3	104.6	27.5	49.4%	14.0%

*CNY: Chinese Yuan (currency unit)

(b) Inpatient medical expenses

Adjustments to the level of promotion and application of the community-first consultation system did not affect the 3-year variation trends in total inpatient medical expenses, drug expenses, examination expenses, proportion of drug expenses, and proportion of examination expenses. Expanding the level of promotion and application of the community-first consultation system could significantly decrease total inpatient medical expenses, drug expenses, examination expenses, the proportion of drug expenses and examination expenses. However, when the level of promotion and application of the community-first consultation system was 1.5 times the current level, the regulatory effects on inpatient drug expenses of continued expansion would significantly decrease and showed negative regulation effect, and the regulatory effects on total inpatient medical expenses, drug expenses, examination expenses, and proportion of examination expenses would be significantly weakened. This suggested that adjustments to the level of promotion and application of the community-first consultation system should be moderate. Within the threshold range, the greater the level of promotion and application of the community-first consultation system, the more significant the regulatory effects on inpatient medical expenses.

Table 2-2. Changes in inpatient medical expenses (patient behavioral intervention experiment).

Time	Group	Total inpatient medical expenses (CNY)	Inpatient drug expenses (CNY)	Inpatient examination expenses (CNY)	Proportion of inpatient drug expenses	Proportion of inpatient examination expenses
Year 1	Baseline	9676.0	3523.8	728.8	37.0%	8.3%
	Experiment 1	11944.9	4482.9	1010.4	37.8%	9.7%
	Experiment 2	5388.8	2001.9	286.3	37.7%	5.4%
	Experiment 3	4590.1	1698.5	183.5	37.9%	4.9%
Year 2	Baseline	9694.1	3438.3	739.1	36.0%	8.3%
	Experiment 1	11976.0	4375.9	1028.1	36.8%	9.7%
	Experiment 2	5381.1	1944.2	281.6	36.7%	5.2%
	Experiment 3	4568.1	1644.3	177.0	36.9%	4.7%
Year 3	Baseline	9731.6	3344.8	745.8	34.9%	8.2%
	Experiment 1	12017.5	4248.1	1034.0	35.6%	9.6%
	Experiment 2	5338.7	1866.4	269.8	35.6%	4.9%
	Experiment 3	4517.0	1572.5	162.9	35.7%	4.3%

(c) Patient medical-seeking choice preferences

Adjustments to the level of promotion and application of the community-first consultation system would significantly change the medical-seeking choice preferences of patients. Expanding the level of promotion and application of the community-first consultation system significantly led patients to choose community health service centers and specialist hospitals for the first consultation. On the other hand, weakening the level of promotion and application of the community-first consultation system would cause more patients to seek medical services first in tertiary general hospitals. However, when the level of promotion and application of the community-first consultation system was 1.5 times the current level, the effects of continued expansion on patient medical-seeking choice preference would significantly decrease, suggesting that adjustments to the level of promotion and application of the community-first consultation system should be moderate.

Table 2-3. Changes in patient medical-seeking choice preferences (patient behavioral intervention experiment).

Time	Group	Proportion of patients who seek medical services first in tertiary general hospitals	Proportion of patients who seek medical services first in specialist hospitals	Proportion of patients who seek medical services first in district hospitals	Proportion of patients who seek medical services first in community health service centers
Year 1	Baseline	40.2%	1.9%	44.0%	13.8%
	Experiment 1	68.1%	1.3%	30.0%	0.7%
	Experiment 2	4.7%	2.6%	4.1%	88.6%
	Experiment 3	< 0.1%	0.3%	3.2%	96.4%
Year 2	Baseline	40.2%	2.0%	43.9%	13.9%
	Experiment 1	68.0%	1.2%	30.1%	0.6%
	Experiment 2	4.9%	2.6%	4.2%	88.4%
	Experiment 3	< 0.1%	0.3%	3.4%	96.3%

Year 3	Baseline	40.2%	1.9%	44.0%	14.0%
	Experiment 1	68.1%	1.1%	30.0%	0.7%
	Experiment 2	4.9%	2.6%	4.1%	88.4%
	Experiment 3	< 0.1%	0.3%	3.2%	96.4%

2.4.2 Intervention experiment 2: Intervention experiment of physician behaviors

(1) Intervention experiment of physician behaviors

Physician behavioral intervention experiment: The behavioral intervention experiment protocol for physician behavior mainly adjusted the actual income and workload of physicians to change their practice behaviors, thereby observing the effects on medical expenses. Three intervention experiments were designed for physician behaviors for comparison of simulation experiment results and baseline results. The protocol for the three intervention experiments was as follows.

Experiment 1: Physician income was decreased by 50%, income increment rate was decreased by 50%, weekly working hours were maximized (60 hours), and increment rate for weekly working hours was increased by 50%.

Experiment 2: Physician income was increased by 100%, income increment rate was decreased by 50%, weekly working hours were decreased by 25%, and increment rate for weekly working hours was decreased by 50%.

Experiment 3: Physician income was increased by 200%, income increment rate was increased by 100%, weekly working hours were decreased by 50%, and increment rate for weekly working hours was decreased by 80%.

(2) Physician behavioral intervention experiment results

(a) Outpatient medical expenses

Adjustments to physician income and workload did not affect the 3-year variation trends in total outpatient medical expenses, drug expenses, examination expenses, proportion of drug expenses, and proportion of examination expenses. Increasing physician income and reducing physician workload could reduce outpatient medical expenses, but these effects were general. In addition, after increasing physician income to twice the current level and reducing working hours by 75% of the current level, the continued increase in income and reduction in workload did not show significantly extra regulatory effects on outpatient medical expenses but show negative regulation, suggesting that adjustments to physician income and physician workload should be moderate.

Table 2-4. Changes in outpatient medical expenses (physician behavioral intervention experiment).

Time	Group	Total outpatient medical expenses (CNY)	Outpatient drug expenses (CNY)	Outpatient examination expenses (CNY)	Proportion of outpatient drug expenses	Proportion of outpatient examination expenses
Year 1	Baseline	241.7	120.1	43.1	48.7%	18.2%
	Experiment 1	251.5	129.8	44.9	50.4%	18.2%
	Experiment 2	237.1	115.6	42.3	47.8%	18.2%
	Experiment 3	237.2	115.7	42.4	47.8%	18.2%
Year 2	Baseline	248.6	122.2	44.3	48.1%	18.2%
	Experiment 1	256.7	130.2	45.7	49.5%	18.2%
	Experiment 2	244.2	117.8	43.5	47.2%	18.2%
	Experiment 3	244.4	118.0	43.5	47.3%	18.2%
Year 3	Baseline	255.8	124.1	45.6	47.5%	18.3%
	Experiment 1	262.8	131.1	46.9	48.8%	18.3%
	Experiment 2	251.9	120.2	44.9	46.7%	18.3%
	Experiment 3	252.1	120.4	44.9	46.8%	18.3%

(b) Inpatient medical expenses

Adjustments to physician income and workload did not affect the 3-year variation trends in total inpatient medical expenses, drug expenses, examination expenses, proportion of drug expenses, and proportion of examination expenses. Increasing physician income and reducing physician workload could reduce inpatient medical expenses, but these effects were general. In addition, after increasing physician income to twice the current level and reducing working hours by 75% of the current level, the continued increase in income and reduction in workload did not show significantly extra regulatory effects on inpatient medical expenses but show negative regulation, suggesting that adjustments to physician income and physician workload should be moderate.

Table 2-5. Changes in inpatient medical expenses (physician behavioral intervention experiment).

Time	Group	Total inpatient medical expenses (CNY)	Inpatient drug expenses (CNY)	Inpatient examination expenses (CNY)	Proportion of inpatient drug expenses	Proportion of inpatient examination expenses
Year 1	Baseline	9676.0	3523.8	728.8	37.0%	8.3%
	Experiment 1	9968.7	3781.5	852.0	38.3%	9.2%
	Experiment 2	9539.2	3403.1	669.7	36.3%	7.8%
	Experiment 3	9545.7	3408.6	672.7	36.3%	7.8%
Year 2	Baseline	9694.1	3438.3	739.1	36.0%	8.3%
	Experiment 1	9924.2	3643.6	841.2	37.1%	9.0%
	Experiment 2	9564.9	3323.8	681.0	35.3%	7.8%
	Experiment 3	9572.3	3330.0	684.5	35.4%	7.8%
Year 3	Baseline	9731.6	3344.8	745.8	34.9%	8.2%
	Experiment 1	9922.9	3517.9	835.1	35.9%	8.8%
	Experiment 2	9624.2	3247.5	694.8	34.3%	7.8%
	Experiment 3	9631.8	3253.9	698.5	34.3%	7.8%

(c) Physicians' public welfare behavior

Reducing the income and increasing the workload of physicians did not significantly affect the over-prescription and receipt of kickback behaviors of physicians. This suggested that current physician income and workload were poor, and manifestation of public welfare behavior has reached its bottom line. Increasing physician income and reducing workload could significantly reduce the probability of over-prescriptions and receipt of kickback, and the amount of kickback received. In addition, the higher the income and the less the workload, the more significant the effects were. However, after increasing physician income to twice the current level and reducing working hours by 75% of the current level, continued increase in income and reduction in workload did not have significant regulatory effects on drug and examination expenses caused by over-prescriptions but caused negative regulation, suggesting that adjustments to physician income and physician workload should be moderate.

Table 2-6. Physicians' public welfare behavior (physician behavioral intervention experiment).

Time	Group	Probability of over-prescription by physicians	Increment in drug expenses caused by over-prescription (CNY)	Increment in examination expenses caused by over-prescription (CNY)	Probability of receipt of kickback by physicians	Amount of kickback accepted by physicians (CNY)
Year 1	Baseline	50.0%	55.9	61.9	33.5%	1557.6
	Experiment 1	50.0%	199.7	262.6	33.5%	2423.0
	Experiment 2	26.5%	1.6	1.6	13.5%	139.1
	Experiment 3	10.0%	3.9	4.1	0.0%	0.0

Year 2	Baseline	50.2%	53.0	60.8	33.6%	1704.1
	Experiment 1	50.2%	166.8	221.6	33.6%	2368.8
	Experiment 2	19.2%	1.3	1.4	7.2%	124.5
	Experiment 3	9.9%	3.9	4.3	0.0%	0.0
Year 3	Baseline	50.0%	45.8	53.6	33.6%	1670.2
	Experiment 1	50.0%	140.7	189.2	33.6%	2304.3
	Experiment 2	12.5%	1.2	1.3	1.9%	121.4
	Experiment 3	10.0%	3.9	4.4	0.0%	0.0

2.4.3 Intervention experiment 3: Intervention experiment of government behaviors

(1) Intervention experiment of government behaviors

Government behavioral intervention experiment: The government behavioral intervention experiment protocol mainly adjusted the government's financial subsidy and investment in four types of public medical institutions to change the public welfare responsibilities undertaken by public medical institutions, thereby observing the effects of these behavioral changes on medical expenses. Three intervention experiments were designed for government behavior for comparison of simulation experiment results and baseline results. The protocol for the three intervention experiments was as follows.

Experiment 1: Reduction in financial subsidy investment and annual growth rate of financial subsidy investment for four public medical institutions by 50%.

Experiment 2: Increase in financial subsidy investment for four types of public medical institutions by 100%, increase in annual growth rate of financial subsidy investment for tertiary general hospitals, specialist hospitals, and district hospitals by 100%, and increase in annual growth rate of financial subsidy investment by 75% for community health service centers.

Experiment 3: Increase in financial subsidy investment for four types of public medical institutions by 200%, increase in annual growth rate of financial subsidy investment for tertiary general hospitals, specialist hospitals, and district hospitals by 200%, and increase in annual growth rate of financial subsidy investment by 100% for community health service centers.

(2) Government behavioral intervention experiment results

(a) Outpatient medical expenses

Adjustments to the financial subsidy investment by government on four types of public medical institutions did not affect the 3-year variation trends in total outpatient medical expenses, drug expenses, examination expenses, proportion of drug expenses, and proportion of examination expenses. Increasing the financial subsidy investment by government on public medical institutions could effectively decrease total outpatient medical expenses, drug expenses, examination expenses, proportion of drug expenses, and proportion of examination expenses. However, increasing the financial subsidy investment by government would instead increase the proportion of outpatient examination expenses. This result showed that the proportion of outpatient examination costs was not regulated by financial subsidy investment by the government. In addition, the greater the proportion of financial subsidy investment by government over the total income of the medical institution, the more significant the effects on outpatient medical expenses.

Table 2-7. Changes in outpatient medical expenses (government behavioral intervention experiment).

Time	Group	Total outpatient expenses (CNY)	Outpatient drug expenses (CNY)	Outpatient examination expenses (CNY)	Proportion of outpatient drug expenses	Proportion of outpatient examination expenses
Year 1	Baseline	241.7	120.1	43.1	48.7%	18.2%
	Experiment 1	262.0	131.0	45.2	49.0%	17.7%
	Experiment 2	223.0	110.1	41.2	48.4%	18.7%
	Experiment 3	198.2	96.9	38.2	47.9%	19.5%

Year 2	Baseline	248.6	122.2	44.3	48.1%	18.2%
	Experiment 1	269.8	133.4	46.4	48.4%	17.8%
	Experiment 2	229.6	112.1	42.3	47.8%	18.7%
	Experiment 3	203.9	98.7	39.2	47.4%	19.5%
Year 3	Baseline	255.8	124.1	45.6	47.5%	18.3%
	Experiment 1	277.7	135.6	47.8	47.8%	17.8%
	Experiment 2	236.6	114.1	43.5	47.2%	18.7%
	Experiment 3	209.9	100.3	40.4	46.8%	19.6%

(b) Inpatient medical expenses

Adjustments to the financial subsidy investment by government on four types of public medical institutions did not affect the 3-year variation in total inpatient medical expenses, drug expenses, examination expenses, proportion of drug expenses, and proportion of examination expenses. However, increasing the financial subsidy investment by government on public medical institutions could effectively decrease total inpatient medical expenses, drug expenses, examination expenses, the proportion of inpatient drug expenses and proportion of inpatient examination expenses. The greater the proportion of financial subsidy investment by government over the total income of the medical institutions, the more significant the reduction of medical expenses, and rationalization of the proportion of drug expenses and proportion of examination expenses.

Table 2-8. Changes in inpatient medical expenses (government behavioral intervention experiment).

Time	Group	Total inpatient medical expenses (CNY)	Inpatient drug expenses (CNY)	Inpatient examination expenses (CNY)	Proportion of inpatient drug expenses	Proportion of inpatient examination expenses
Year 1	Baseline	9676.0	3523.8	728.8	37.0%	8.3%
	Experiment 1	10771.4	4008.3	938.1	37.7%	9.8%
	Experiment 2	8646.2	3070.3	597.2	36.2%	7.1%
	Experiment 3	7073.3	2390.2	398.0	35.1%	5.1%
Year 2	Baseline	9694.1	3438.3	739.1	36.0%	8.3%
	Experiment 1	10799.8	3910.6	950.8	36.7%	9.8%
	Experiment 2	8656.3	2997.6	606.0	35.3%	7.1%
	Experiment 3	7054.2	2329.5	401.7	34.2%	5.1%
Year 3	Baseline	9731.6	3344.8	745.8	34.9%	8.2%
	Experiment 1	10854.8	3805.9	959.5	35.5%	9.8%
	Experiment 2	8684.0	2918.8	612.6	34.2%	7.1%
	Experiment 3	7049.9	2265.8	405.3	33.3%	5.1%

(c) Undertaking public welfare responsibilities

Adjusting the financial subsidy investment of the government toward various public medical institutions did not affect the simulated 3-year variation trend of the rate of shouldering the public welfare responsibilities. Increasing financial subsidy investment by the government, however, could significantly increase the rate of undertaking public welfare by various public medical institutions. In addition, the greater the proportion of financial subsidy investment by the government over total income, the greater the rate of undertaking public welfare responsibilities. When the financial subsidy investment by the government toward the community health service centers was increased by 175% compared with the current level, however, the undertaking rate of the public welfare responsibilities by community health service centers reached 100%, showing that financial subsidy investment by the government toward community health service centers should not exceed this level.

Table 2-9. Changes in undertaking rate of public welfare responsibilities (government behavioral intervention experiment).

Time	Group	Undertaking rate of public welfare responsibilities by tertiary general hospitals	Undertaking rate of public welfare responsibilities by specialist hospitals	Undertaking rate of public welfare responsibilities by district hospitals	Undertaking rate of public welfare responsibilities by community health service centers
Year 1	Baseline	29.6%	44.4%	46.1%	73.8%
	Experiment 1	14.9%	22.3%	23.3%	37.9%
	Experiment 2	44.1%	66.2%	68.0%	99.8%
	Experiment 3	72.4%	99.8%	100.0%	99.9%
Year 2	Baseline	29.3%	43.2%	45.7%	75.6%
	Experiment 1	14.7%	21.8%	23.1%	38.2%
	Experiment 2	43.9%	65.9%	67.6%	100.0%
	Experiment 3	72.4%	100.0%	100.0%	100.0%
Year 3	Baseline	28.9%	42.1%	45.5%	78.3%
	Experiment 1	14.6%	21.4%	22.9%	38.8%
	Experiment 2	43.7%	66.5%	67.3%	100.0%
	Experiment 3	72.3%	100.0%	100.0%	100.0%

2.5 Model and policy recommendations

With regard to controlling the unreasonable medical expense increase in public hospitals, intervention must be carried out through medical service suppliers, providers, and the government to optimize current medical-seeking pattern and guide the public welfare behavior of different agents in order to effectively promote the control effect.

(1) The unreasonable medical expenses for public hospitals are significant at present and public welfare in public hospitals is to be enhanced

At the baseline, the simulated 3-year results suggested that medical expenses were at a high level and showed a slightly increasing trend. The proportions of drug expenses and examination expenses were unreasonably high. The government's financial subsidies toward medical institutions were severely lacking. Patients' medical-seeking preferences were far away from the target of rational graded diagnosis and treatment in different levels of medical institutions. Physicians' public welfare behaviors were relatively weak and preferred to over-prescribe and receive kickbacks.

(2) Expanding the promotion and application of the community-first consultation system can optimize patients' medical-seeking preferences and effectively control unreasonable increase in medical expenses

Expanding the level of promotion and application of the community-first consultation system can rationalize the medical-seeking preferences of patients, which can guide them to seek medical services in community health service centers. Thereby, rational streaming can be achieved and outpatient and inpatient medical expenses can be reduced in terms of medical-seeking preferences rationalization. However, it should be noted that the level of promotion and application of the community-first consultation system should be moderate and adjustments should not exceed the threshold value of 1.5 times the current level, because overexpansion has no significant effects in controlling medical expenses. In addition, the effects of this system on the proportion of outpatient drug expenses are not significant.

(3) Increasing physician income and reducing workload can drive public welfare behaviors in physicians and control the unreasonable increase of medical expenses

Increasing physician income and reducing workload can significantly restrict physicians from over-prescribing and receiving kickbacks. Decreasing over-prescriptions will reduce additional drug and examination expenses, which will reduce outpatient and inpatient medical expenses, but the effects of this mechanism are fair. It is worth noting that the excessive increase in physician income and reduction in workload should not be carried out. When income is increased to twice the current level and working hours reduced to 75% of the current level, the threshold value of this policy intervention will be reached, and further adjustments will not effectively decrease medical expenses. In addition, although implementation of policy intervention on physician income and workload alone can control unreasonable increase in medical expenses, the effects are fair.

(4) Increasing the government's financial subsidies toward public medical institutions can effectively control unreasonable increase in medical expenses

Increasing the government's financial subsidies toward public medical institutions can guide public hospitals to increase their public welfare responsibilities, which can thereby effectively decrease inpatient and outpatient medical expenses. The greater the proportion of financial subsidies over the total income of a medical institution, the more significant the reduction of medical expenses and, rationalization of the proportion of drug and examination expenses. No significant threshold values were seen and a continuous increase in government's financial subsidies can continuously rationalize medical expenses and promote the realization of public welfare in public medical institutions. This suggests a severe lack of financial subsidies by the government toward public medical institutions currently, and financial subsidies should be increased urgently. Furthermore, financial subsidies by the government have no significant effects on the proportion of outpatient examination expenses.

3 Multi-point practice model and policy intervention experiment for public hospitals

Authors: Junqiang Dong, Zhixin Dai, Lulu Zhang

3.1 Aims and significance

3.1.1 Aims

Multi-point practice refers to employment of qualified physicians who registered by the health administrative department in two or more medical institutions. [31]. In 2009, the former Ministry of Health promoted reasonable flow of medical staff and horizontal and vertical exchange of talents between different medical institutions and examined the requirements for "multi-point practice" for registered physicians based on the "Stable Promotion of Rational Exchange of Medical Staff" in the "Opinions of the CPC Central Committee and the State Council on Deepening the Reform of the Medical and Health Care System" by the State Council of the People's Republic of China, published in the "Notification on Problems in Physician multi-point Practice;" and pilot sites were set up in some regions. In 2011, a notice on expanding the scope of multi-point practice for physicians was released to encourage medical staff to practice in grassroots and rural regions. In January 2015, after summarizing the experiences of various test sites, the former National Health and Family Planning Commission published a notice concerning the registration management, manpower management, and qualification conditions for multi-point practice by physicians. This means that the exploration and pilot testing for multi-point practice by physicians in China has been completed and has gradually expanded to full implementation. Physician multi-point practice can aid in driving the reasonable flow of medical staff, promoting the horizontal and vertical flow of talent from different medical institution, optimizing the rational allocation of superior medical staff, and alleviating the current status of unequal regional distribution of manpower resources. Most local and overseas studies on physician multi-point practice in public hospitals were qualitative, and there were few studies examining physician multi-point practice activities from a systematic and scientific perspective or employing quantitative methods. From a systematic and scientific perspective, physician multi-point practice in public hospitals was a complex and large system. On one hand, the various elements in the system continuously evolved with time. On the other hand, the various elements in the system interacted with each other [32]. Therefore, system dynamics model was used to construct the public hospital physician multi-point practice model and quantitative methods were used to analyze the current status of physician multi-point practice in public hospitals and predict development trends in the future according to systematic and scientific theories.

3.1.2 Significance

Multi-point practice refers to physicians carrying out clinical activities in two or more medical institutions and does not include consultation in other institutions. In China, there are three main types of physician multi-point practice: (1) the government-directed type. physicians approve government-directed tasks at the medical institutions employing them, such as rural health support, supporting community and emergency treatment centers (stations), and medical institution partner assistance, etc.; (2) The medical cooperative type. Multiple hospitals carry out horizontal or vertical medical cooperation through integration of medical resources, thereby facilitating patient medical-seeking, and improving medical techniques by signing agreements; (3) The active physician employment type. Physicians who are employed in two or more medical institutions should apply to the Ministry of Health for an increase in the number of registered practice sites. In this case, physician multi-point practice mainly refers to the third type, that is, the active physician employment [31-33]. System dynamics set off from the microstructure of the system and use the causal loop diagram and stock–flow diagram to describe the logical relationships between various factors and table functions to describe the quantitative relationships between various elements. System behavior is mainly determined by its structural relationships, and numerical requirements are not as precise as the requirements of other statistical models [34]. Scenario simulation was used to simulate the model conditions to increase the reliability and precision of the model [35]. System dynamics emphasize the causal mechanisms between various factors during the study of problems in physician multi-point practice in public hospitals and can reflect the operation mechanism between various factors of the system in detail, and realistically and objectively reflect the system structure and its operation rules [36]. Implementation of physician multi-point practice has important practical significance as it can promote the flow of high-quality medical resources, benefit more patients, alleviate unequal medical manpower resource structures, and change the current status of extremely insufficient high-quality medical resources. System dynamics methods were employed to study the awareness, requirements, and influencing factors impeding the successful implementation of this policy of multi-point practice policies in physicians from large public hospitals against the background of the national implementation of multi-point practice in physicians in order to solve this problem gradually and contrapuntally.

3.2 Methods

3.2.1 Model description

This model included physicians, the government, public hospitals, and private and grassroots medical institutions. This model mainly simulated the approval of multi-point practice by physicians and the number of hospitals in which they were willing to practice in the multi-point practice policy under the effects of public hospitals, the government, and private and grassroots medical institutions. The input variables of the model were mainly quantified influencing factors of these institutions. The final result was the approval of multi-point practice by physicians and the number of hospitals in which they were willing to practice.

The system dynamics model description of physician multi-point practice in public hospitals involved four agents (government, public hospitals, private and grassroots medical institutions and physicians). The government mainly formulated policies and laws to restrict physicians and multi-point practice in various grades of medical institutions. Public hospitals and private and grassroots medical institutions mainly employed manpower systems, compensation systems, and wage allocation systems to affect multi-point practice behavior in physicians. The gender, job title, and quantum of physicians' free time determined the acceptability of physicians for multi-point practice. The four agents are mutually connected and interact with each other to jointly affect physician multi-point practice behavior in public hospitals.

3.2.2 Causal loop diagram

As public hospitals possessed more medical resources, they were best placed to attract physicians, which resulted in lower acceptability by physicians to participate in multi-point practice, and thus the number of physicians participating in multi-point practice was reduced. Grassroots hospitals had fewer resources and were insufficient to attract physicians from public hospitals. This resulted in an insufficient number of physicians participating in multi-point practice and empty beds and equipment, which further reduced the resources allocated to grassroots medical institutions. Analysis of the operational mechanisms in many public hospitals showed that the increase in total investment in hospitals increased the number of medical staff, and there were faster upgrading of medical equipment and improvements in hospital facilities and the environment, thereby resulting in reducing the desire of physicians to participate in multi-point practice and a large increase in medical technology levels. This ultimately caused an increase in hospital operational income and more resources to invest in hospital development and construction. On the other hand, an increase in hospital medical technology levels also led to an increase in the number of physicians participating in multi-point practice and further decrease in physicians' free time. This caused medical staff to spend less time on scientific research and limited the development of medical technology.

Analysis of the operational mechanisms of grassroots hospitals showed that the total investment in grassroots hospitals was insufficient and the total income of medical staff was low, which made it difficult to attract physicians from public hospitals in terms of income. In addition, equipment and environmental facilities were upgraded at a slower pace, and the medical levels of medical staff decreased, resulting in less approval of multi-point practice by physicians, a reduction in the number of physicians participating in multi-point practice, and a vicious cycle in approval development. Increasing the medical level of grassroots hospitals and the income of medical staff could attract more public hospital physicians to participate in multi-point practice. In the multi-point practice system, public hospitals and grassroots hospitals were major carriers of resource flow, physician flow, and information flow in the system and were centers for system behavior and functional implementation. Under common external conditions, the sharing of the same healthcare service market and medical resources, particularly physician manpower resources, caused various grades of hospitals to show different developmental trends.

3.2.3 System dynamics model

The causal relationships of physician multi-point practice in public hospitals were complex and involved many factors. In addition, there were many types of medical institutions, which made it difficult to descriptively analyze the system. This study was a simplified study that only studied physician multi-point practice between large public hospitals and grassroots medical institutions. Other types of medical institutions were not within the scope of this study. On the basis of previous studies, system functional observation markers were divided into two parts, of which one was the public hospital output marker which included the number of physicians participating in multi-point practice, and the economic benefits of the hospital; the other part was the system structural marker which included the manpower resource ratios of various grades of hospitals. According to the systemic analysis of factors affecting multi-point practice in physicians, the factors that affected the system mainly included investment of medical resources, government's multi-point practice policies, and budgeted investment. Adjustments to the aforementioned variables were used to achieve intervention in the system.

The model variables could be classified as flow variables, flow rate variables, auxiliary variables, initial variables, and observation variables. (1) Flow variables included the total number of physicians, total public hospital capital, and total number of public hospital physicians; total grassroots hospital capital, and total number of grassroots hospital physicians. (2) Flow rate variables included the number of new physicians, physician turnover, amount of increase in public hospital capital, amount of public hospital capital consumed, increase in public hospital physicians, public hospital physician turnover, amount of increase in grassroots hospital capital, amount of grassroots hospital capital consumed, increase in grassroots hospital physicians, and grassroots hospital physician turnover. (3) Auxiliary variables included medical service demand, medical service demand in public hospitals and grassroots hospitals, medical revenue, mean hospital physician income, total hospital cost, hospital output capabilities, and medical service prices. (4) Initial variables included the number of physicians in public hospitals and grassroots hospitals, physician acceptability to participate in multi-point practice, income per capita in the hospital, and initial value of government budgeted investment. (5) Observation variables included the percentage of capital in various grades of hospitals, percentage of physicians, and medical service efficiency.

The major function relationships included (1) Hospital investment output function relationship: The classical Cobb–Douglas production function was used to define variables as follows: Y was the hospital service output variable expressed by the total number of patients undergoing consultation at the medical institution; K is the total capital invested expressed by the hospital capital; L was the total manpower in the medical service institution expressed by the total number of physicians; A was the technology coefficient, and α and β were the output elasticity coefficients for capital K and labor force L, respectively, which were to be determined. (2) Physician number function relationship: By combining literature review and expert consultation, we confirmed that changes in the total number of physicians were mainly affected by the increment rate and turnover rate in physicians. The total number of physicians was confirmed to be a variable of integration according to the theoretical method for system dynamics modeling to construct the physician variable function. (3) Determination of table function: During modeling, table function was used according to the theory of system dynamics modeling to describe the variation trends of variables that could not be expressed by specific numerical functions.

3.3 Model simulation

3.3.1 Simulation commissioning

Model input variables: SEP: public hospital service efficiency; PPGR: public hospital physician growth rate; SEB: grassroots hospital service efficiency; PBGR: grassroots hospital growth rate. X2: mean length of hospitalization in public hospitals; X3: number of multi-point practices in public hospital; X4: public hospital equipment value; X5: mean age; X6: job title; X7: mean length of hospitalization in grassroots hospitals; X8: degree of policy support; X9: grassroots hospital equipment value.

Model output variables: MI: multi-point practice acceptability; MPTPR: number of public multi-point practice physicians; MPTBR: number of grassroots multi-point practice physicians.

3.3.2 Model summary

The basic idea of multi-point practice by public hospital physicians was that qualified physicians registered by the health administrative departments s could be employed in two or more medical institutions. This model was based on two assumptions: first, multi-point practice physicians were from public hospitals, and the second or third practice sites were grassroots medical institutions. Second, the model simplified the effects of government agencies as much as possible. The system dynamics model for physician multi-point practice in public hospitals involved four agents (government, public hospitals, physicians, and grassroots medical institutions). Description of multi-point practice system for public hospital physicians: public hospital physicians approved by the health administrative departments could choose to practice in grassroots medical institutions (one or more). To alleviate the usage of medical talents, the government encouraged physicians to participate in multi-point practice and the relevant policies were promulgated. Physician multi-point practice would affect the benefits of public hospitals, result in patient triage and reduce earnings. Physician multi-point practice could increase grassroots medical service capabilities and increase earnings. For individual physicians, participating in multi-point practice would increase workload and reduce free time, but would increase income and self-achievement.

System dynamics methods were employed to study the awareness, requirements, and influencing factors impeding the successful implementation of this policy of multi-point practice policies in physicians from large public hospitals against the background of national implementation of multi-point practice by physicians in order to solve this problem gradually and contrapuntally.

3.4 Policy intervention experiment

3.4.1 Intervention experiment 1: Effects of governmental support on multi-point practice of physicians in public hospitals

(1) Intervention experiment protocol in which level of government support affects multi-point practice by public hospital physicians

The intervention experiment protocol for level of government support mainly quantified the policies supporting multi-point practice by public hospital physicians and quantified the authority of various government departments and policies. The level of government support was continuously adjusted within a range of 0–1. The approval of multi-point practice in public hospital physicians and the number of physicians participating in multi-point practice were observed.

(2) Intervention experiment result on how government support affected multi-point practice by public hospital physicians

The level of government support for multi-point practice by public hospital physicians had significant effects on the acceptability of multi-point practice by public hospital physicians and the number of public hospital physicians who participated in multi-point practice. When the level of policy support reached a certain threshold (more than 40%), the approval of multi-point practice by public hospital physicians and the number of public hospital physicians who participated in it would significantly increase. This meant that subjects were the most concerned with hospital support, and this was related to the administrative system of China as physicians were not “society’s people” but “individual people.” This was also the most challenging aspect for medical reform and affected many stakeholders. However, simultaneously, this was also an aspect that should be thoroughly changed. As long as physicians’ identity as “individual people” remained unchanged, many reforms were only superficial and could not eradicate the core problem.

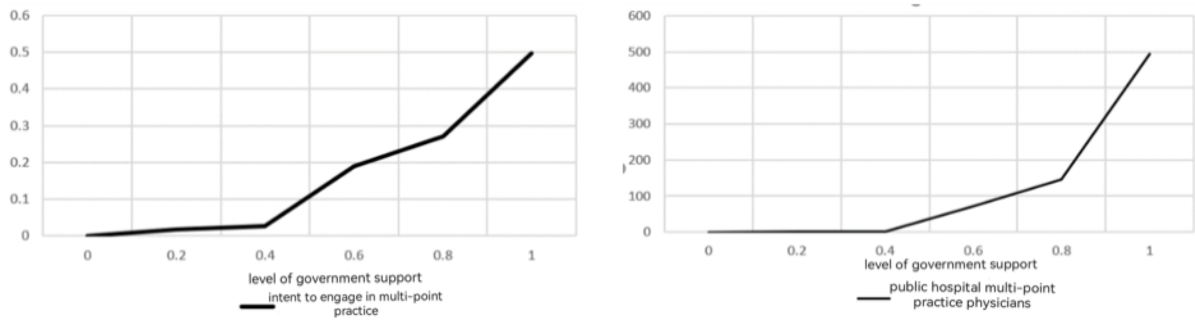

Figure 3-1. Intervention experiment results on how government policies affected multi-point practice in public hospital physicians and number of physicians.

3.4.2 Intervention experiment 2: effects of the number of multi-point practice hospitals on the acceptability and number of multi-point practices among physicians

(1) Intervention experiment protocol on the effects of the number of multi-point practice hospitals on the approval and number of multi-point practices among physicians

The intervention experiment on the effects of the number of multi-point practice hospitals on approval of multi-point practice in physicians and the number of multi-point practice physicians mainly regulated the number of multi-point practice hospitals. Assuming that the minimum number of hospitals in which physicians could conduct multi-point practice was zero (i.e., no hospitals carried out multi-point practice), and the maximum number was three (as currently many local governments stipulated that physicians could carry out multi-point practice activities in three hospitals at most). The number of hospitals was adjusted to observe the approval for multi-point practice and the number of multi-point practice physicians.

(2) Intervention experiment result on the effects of the multi-point practice hospitals on the approval and number of multi-point practices among physicians

The intervention experiment showed that 10.88% of subjects selected "0, that was, not willing to participate in multi-point practice, 25.69% of subjects selected multi-point practice in one site, 50.33% of subjects selected multi-point practice in two sites, and 13.10% of subjects selected multi-point practice in three sites. In addition to their own original practicing hospitals, one-quarter of subjects chose one medical institution for practice, and half of the subjects chose two medical institutions for practice. However, the number of subjects who selected three medical institutions was significantly decreased, showing that the subjects did not think it was better to practice in more medical institutions.

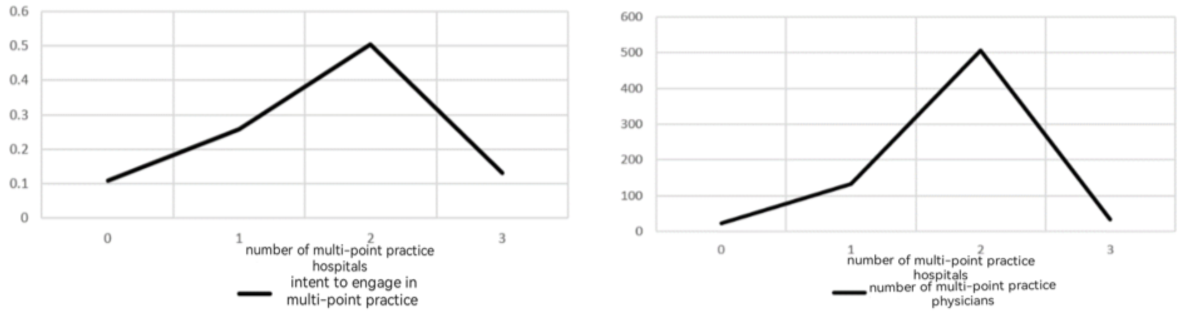

Figure 3-2. Intervention experiment results on the effects of multi-point practice hospitals on the intent to engage in multi-point practice and the number of multi-point practices among physicians.

3.4.3 Intervention experiment 3: effects of level of public hospitals on the acceptability and number of multi-point practice among physicians

(1) Intervention experiment protocol on the effects of physicians' job title on the intent to engage in multi-point practices and the number of multi-point practices among physicians

The effects of physician job title on the intent to engage in multi-point practices and number of multi-point practices among physicians mainly adjust physician job title to observe the intent to engage in multi-point practices and number of practicing physicians. Job titles were numbered as 1, 2, 3, and 4, for junior, middle, deputy senior, and senior titles. The job title categories were adjusted, and observations were conducted.

(2) Intervention experiment result on the effects of physicians' job title on the intent to engage in multi-point practices and number of multi-point practices among physicians

Results showed that different job titles greatly affected hopes regarding whether hospitals would promote multi-point practice in physicians. Compared with junior physicians, more middle job title physicians hoped that hospitals would promote this policy. Compared with physicians with middle job titles, more deputy senior job title physicians hoped that hospitals would promote this policy. Junior staff who had just entered the workforce had limited capabilities and experience and many areas to learn about, and did not have enough energy for multi-point practice. This matched the new job title stipulations for multi-point practice physicians promulgated by the National Health and Family Planning Commission in January 2015. The original regulations only stipulated that deputy senior and senior physicians could participate in multi-point practice while the new regulations had been relaxed to allow attending physicians and above to participate.

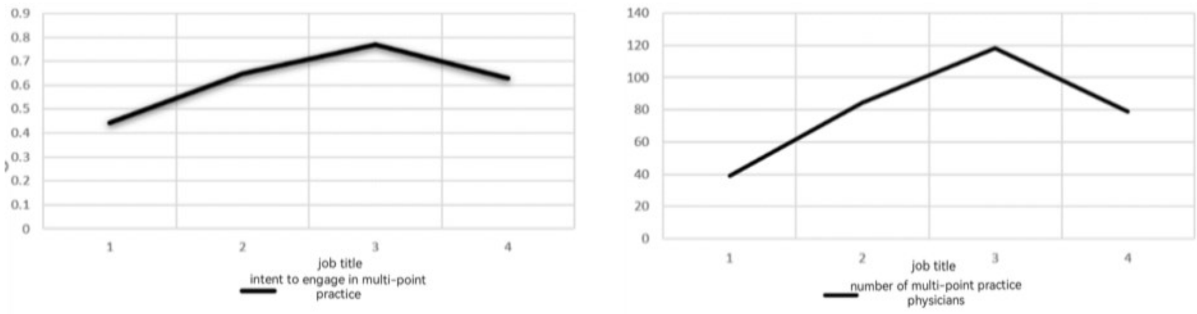

Figure 3-3. Intervention experiment results on how job title affected multi-point practice in public hospital physicians and number of physicians.

3.5 Model and policy recommendations

(1) Perfecting the legal system and strict law enforcement

(a) Accelerating relevant legislation and revisions for physician multi-point practice

The effects of law are greater than departmental regulations. In order to implement physician multi-point practice, legal problems must be solved first. On the one hand, revisions in the “Law on Practicing Doctors” should be accelerated and the rights, obligations, and responsibilities of physicians in multi-point practice should be confirmed. On the other hand, management measures and implementation rules regarding physician multi-point practice should be continuously promulgated and clear and detailed regulations for application criteria, implementation process, monitoring methods, and responsibility sharing for physician multi-point practice should be specified.

(b) Guidance for formulating multi-point practice contract industry

The contract between physicians and practicing hospitals must include the following basic content: working hours, service scope, service quality standards of physicians, remuneration standards and payment times of the hospital, and infringed responsibility sharing for breach of contract. Health administrative departments can reference measures used by other industries to set the contract format for physicians and hospitals, require them to sign an agreement according to stipulated content, and include this as one of the conditions.

(c) Strengthening legal monitoring for physician multi-point practice

(I) Strict entry. Physicians applying for multi-point practice must fulfill certain criteria, including job title, skills, educational level, physical health, and medical ethics criteria to ensure healthcare quality and safety during multi-point practice. (II) Strict monitoring. Various grades of health administrative departments should strictly strengthen the monitoring of multi-point practice activities to prevent disorderly movement of medical talents. (III) Transparent renumeration. The income received by physicians for multi-point practice should be accessible to the society and included in monitoring by the tax department.

(2) Deepening reform and strengthening management

(a) Promoting the management system and manpower system reform for medical institutions

Implementation of multi-point practice will inevitably unblock the originally closed administrative management system and manpower system of hospitals, thereby transforming physicians from “individual people” to “society’s people.” Therefore, we must continuously drive the reform of the management system and manpower system in medical institutions, remove obstacles impeding the free movement of medical staff, and enable physicians to gradually transform from “individual people” to “society’s people” in order to truly implement multi-point practice in physicians.

(b) Construction of a sound medical liability insurance system

Encouraging or even making it mandatory for practicing physicians to participate in medical liability insurance can solve worries of hospitals and physicians and also enable patients' legal rights to be sufficiently exercised in a timely manner. A summary of international methods has found that there are usually two methods: The first is the collective purchase of medical liability insurance for physicians in various practicing hospitals. The second method is physicians' individual purchase of medical liability insurance so that the insurance agency is responsible for management of the aftermath of medical malpractice.

(c) The regulatory authorities should actively explore the supervision and management of multi-point practice physicians

The registration department for multi-point practice physicians should report illegal behavior, rule violations, disciplinary actions, and management of the physician in the region of jurisdiction. A physician consultation file information system should be constructed to gradually release physician's practice information to the society. As the ratio of surgeons participating in multi-point practice in this city is high and surgery is the main practice characteristic, focused monitoring of multi-point practice in such physicians and strengthened supervision should be carried out to ensure medical quality and safety. A system for the restraint of trade among physicians should be established. This is to strictly ensure the commercial secrets of the employers and continuously strengthen the medical ethics training of physicians at the same time to continuously improve the level of medical ethics and personal development of physicians.

(3) Improving protection and creating an environment

(a) Expanding channels for external practice by physicians

The health administrative departments can promulgate external practice policies to expand multi-point practice routes for physicians. As an example, a policy that vertically integrates medical resources will include more grassroots and private medical institutions in the system, thereby solving the problem of physician movements simultaneously. This will increase the support of tertiary hospitals toward grassroots medical institutions. In addition, talent output should be considered as a performance indicator to promote the orderly and reasonable movement of physicians. A series of measures can also be introduced to establish a compensatory mechanism of talent cultivation and patient triage in public hospitals to ensure the healthy, continuous, and orderly development of multi-point practice.

(b) Improving government governance and authorizing organizations in the healthcare industry

According to international norms, physicians should undertake industrial autonomy. The function of physician associations should be fully utilized as these are highly professional organizations that have the ability to shoulder physician training, assessment, examination, review, and accreditation. The government should confer management rights to industrial organizations and standardize the practice behavior of physicians. The internal culture of physician practice groups and peer pressure will also help to improve the behavior of public physicians. For example, pharmaceutical organizations strictly limit illegal or unconventional retail behavior, which promotes and maintains industry standards.

(c) Cultivating a practice environment

A corresponding practice environment should be cultivated to encourage physicians from tertiary general medical institutions to participate in in-depth grassroots multi-point practice. The health authorities must increase the investment to provide essential medical devices and facilities to these institutions. At the same time, training grassroots talents combined with multi-point practice should be carried out so that grassroots practice assurance measures are further improved and updated in time. This will reduce the risk of medical malpractice and ensure medical service quality.

4 Agent-based model of medical evacuation for earthquake casualties

Authors: Xu Liu, Xinyu Fan, Lulu Zhang

4.1 Background

4.1.1 Existing studies in China and other countries

1 Existing studies in other countries

(1) Patient flow is widely used in resource allocation and capacity planning in routine healthcare service systems.

Patient flow is internationally recognized as one of the most important principles in increasing the efficiency of health service systems. The patient flow theory has opened up new pathways for the application of operations research and systems engineering in emergency medicine. The application of prediction and queuing models and other quantitative tools for simulation of patient flow can help decision-makers in decision-making and evaluation of health services. U.S. researcher Côté believed that because patient flow is the same as health service requirements, medical services must carry out effective resource allocation and capacity planning based on patient flow. Jeffrey from the University of Alberta Hospital in Canada conducted a study, which found that computer modeling can effectively assess minor changes in the structure of medical service systems, such as the effects of adding internal medicine physicians or expanding nursing regions on the entire patient flow. Au-Yeung from Imperial College London developed a multiclass Markovian queuing network model for patient flow and employed discrete event simulation to solve the time point and probability density function for patient response time to compare the effects of different patient triage protocols on patient flow. Patient flow has become a new hotspot in emergency medicine research. At present, patient flow is mainly used in resource allocation and capacity planning in health service systems, and there has been no paper so far that reports its application in disaster medicine.

(2) Disaster patient studies mostly focus on injuries and triage and there is a lack of complex system pattern research on patient flow.

At present, local and overseas studies on disaster patient flow mostly focus on the condition and triaging of patients and are studies on influencing factors of patient flow. Such studies only focus on certain "points" during patient flow and there is a lack of systematic thinking and research on the entire patient flow process. Injury classification is divided into pre-hospital and intra-hospital groups. The former is concerned with the evacuation option and on-site management of casualties while the latter is concerned with evaluating the prognosis of casualties. The aim of pre-hospital scoring is to identify injury severity and screen for severely injured casualties for evacuation to a trauma center or major hospitals in a timely manner. Commonly used methods include the Trauma Index (TI), Illness-Injury Severity Index (IISI), Trauma Score (TS), CRAMS, and Prehospital Index (PHI). The aim of intra-hospital scoring is to quantitatively determine trauma severity and estimate its prognosis; it mainly includes the Abbreviated Injury Scale (AIS) and the Injury Severity Score (ISS) that is calculated by using the former. In addition, there are also triage methods that focus on casualties, which determine the priority for treating patients based on the severity of injury in situations where there are insufficient medical resources so that more casualties can obtain timely and effective treatment. The main aim of such methods is to determine the priority of casualties' treatment to reduce injuries and deaths to the minimum. Such methods include: START, Triage Sieve, Care Flight Triage, Triage sort, Baker, and WMA (World Medical Association) recommended methods (Table 4-1).

Table 4-1. Disaster triage studies.

Triage method	Grade	Basis for classification	Major characteristics	Application status
Simple triage and rapid treatment (START) 1983	Immediate: treatment must be started within 1 hour; delayed: unable to walk, transported to hospitals within 2 hours; minor: able to walk by himself/herself; death: death declaration by qualified medical staff or accompanying medical staff.	Autonomous breathing, pulse, and level of consciousness	Can be carried out by non-professional staff or emergency workers after simple training. Simple but high over triage rate.	Many US hospitals employed START as a tool for pre-hospital triage. This method was used in the 1989 Northridge earthquake.
Jump START 2002	Identical to START	Similar to START but emphasizes more on autonomous breathing Establishing artificial ventilation in pediatric casualties who cannot breathe autonomously	Combined with START. Suitable for pediatric casualties aged 1–8 years.	No reports on its application in disaster sites so far.
Triage Sieve 1995	Priority 1 (immediate) Priority 2 (urgent) Priority 3 (delayed) Priority 4 (deceased)	Autonomous mobility, open airway, respiratory frequency, pulse	Physiological threshold value is different from START: a respiratory rate of l < 10 times/min or > 30 times/min is considered as immediate.	Accepted by some pre-hospital medical staff in the United Kingdom and Australia. The literature reported that this method is used in railway and traffic accidents.
Pediatric Triage Tape (PPT) 1998	Identical to Triage Sieve	Similar to Triage Sieve but uses different physiological parameters such as age, height, and weight.	Triaging of pediatric casualties	No reports on its application in disaster sites so far.
Care Flight Triage 2001	Immediate Immediate Urgent Delayed Unsalvageable	Observe systemic status and vital signs, assess level of consciousness, respiration, and pulse	First, level of consciousness is assessed but respiration and pulse are not. Applicable for adults and children.	The literature reported that this method is used in explosions.
Sacco Triage Method (STM) 2005	Identical to START	Survival probability, possibility of worsening, usable resources. Respiratory rate, pulse, and motor function are used to evaluate survival probability and expert opinion is used to assess possibility of worsening.	This method is a 3-parameter mathematical model in which available resources are used to determine the treatment and evacuation of casualties. Computer software and hardware are required for support. It is not suitable for economically backward regions.	This method is only used in empirical studies and there are no reports of its application in disaster sites currently.

(3) Disaster simulation uses mainly qualitative models while patient flow simulation mainly uses microscopic models.

Simulation techniques can provide references for scientific predictions and warnings of disaster occurrence patterns and are particularly suited for the analysis, research, design, evaluation, decision-making, and training for disasters and rescue, and other complex systems. Overseas natural disaster simulation studies mainly focus on model construction. For example, earthquake simulation mainly focuses on building earthquake damage simulations, lifeline system earthquake damage simulations, and secondary damaged simulations. With the development of information technology and computerized techniques, existing disaster simulation studies have focused on visualization methods and virtual reality. Mechanistic simulation and realistic rendering are used to improve the realism of disaster simulation to study its laws of evolution. In disaster evolution research, the focus is on construction of various evolution models, which mainly include Turner's disaster stage model and pre-disaster stage model, Ibrahim-Razi's model, the system failure cultural readjustment model, industrial crisis model, emergency evolution model, and emergency stage model. However, these models are mostly qualitative analysis models and lack quantitative tools. Takeuchi et al. developed an Integrated Earthquake Disaster Simulation System (IDSS) to achieve a preliminary simulation of the earthquake site. Patient flow simulation has great significance in military security support during war. The scope and methods used in overseas patient-flow modeling studies during war are also broader. For example, Walker studied marine casualties and a non-combat attrition patient flow model; Coellit, Chaussalet, and Chazard employed computer simulation of discrete events, queuing theory, and graphical solutions to carry out casualty flow studies on resuscitation and health insurance.

2 Existing studies of China

(1) Most patient flow studies are qualitative analyses and there is a lack of quantitative studies on specific factors and performance markers

In China, patient flow studies mainly used patient flow theory as a basis for research on army combat and health attrition. This theory was based on the compilation and analysis of the data of several million casualties around the world. In this theory, the flow of casualties caused by battlefield injuries is termed casualty flow, and the medical evacuation experiences of other national organizations are used as a reference to summarize the flow direction, state, volume, sequence, wave, time, barrier, distance, and type. Casualty flow is a macroscopic phenomenon in which large numbers of casualties are evacuated from the frontline to the rear. The first casualty who left the frontline is the start of casualty flow while the admission of the last casualty into hospital is the end of casualty flow. Military and medical resuscitation requirements are the driving force of casualty flow. "Casualty flow" in the system refers to the combined flow of casualty flow and the flow of materials and information along with casualty flow. Information is another driving force of casualty flow, and optimization of resources and information are the basis and prerequisite for optimization of casualty flow. These studies are mostly trapped by the qualitative analysis as they lack a quantitative analysis of patient flow factors and performance markers.

(2) Disaster emergency medicine exhibits "two phase and three stage" characteristics and in-depth examination of patient flow evolution patterns is required

The leader of the group in which the applicant is based, Lulu Zhang successively carried out empirical analysis and external evaluation of emergency medicine in the Wenchuan and Yushu earthquakes. Earthquake patient flow time and flow patterns were used as main lines to propose the "two phase and three stage" characteristics for earthquake emergency medicine, that is, "growth phase" and "stability phase" for casualties, and "emergency stage," "effective stage," and "maintenance stage" for rescue operations. The time curves for post-earthquake patient flow show an obvious inflection point. The continuous growth period before the inflection point is the "growth phase" and the stable period after the inflection point is the “stability phase.” The time point of the inflection point’s appearance is associated with the scale of the earthquake and is simultaneously associated with rescue efficiency. Therefore, the organizational leadership, force usage, and task transfer in emergency medicine use patient flow for needs prediction, which simultaneously affects the subsequent evolution of patient flow. This study is based on our group’s previous “two phase and three stage” emergency medicine pattern to conduct an in-depth study of complex laws and refined procedures of patient flow direction, sequence, wave, and rate. This will provide a scientific decision-making basis for increasing the emergency medicine rescue efficiency for major disasters.

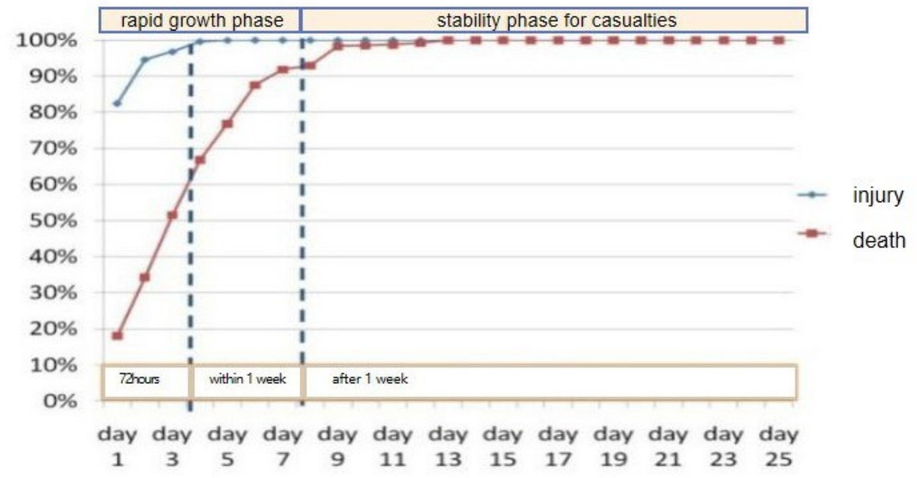

Figure 4-1. “Two phase” temporal pattern for patient flow in the Yushu earthquake.

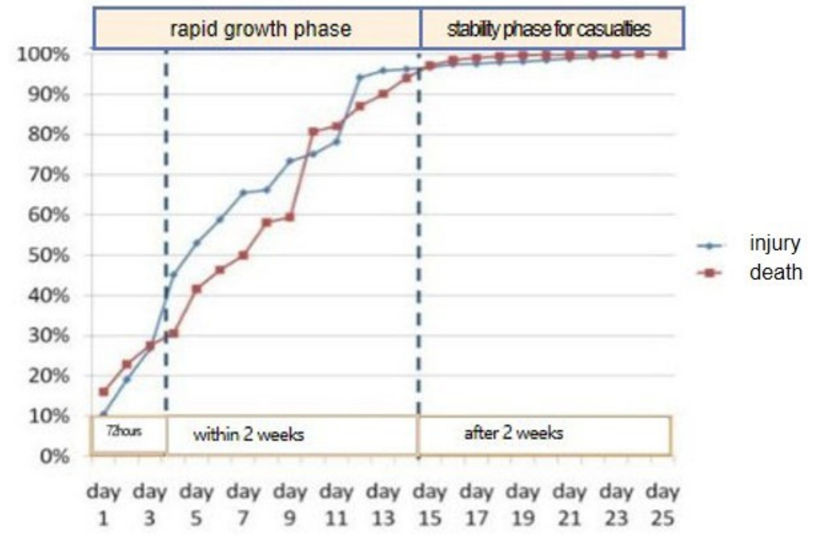

Figure 4-2. “Two phase” temporal pattern for patient flow in the Wenchuan earthquake.

(3) Model construction is based mainly on linear methods and microscopic models, and there is a lack of systemic model construction on patient flow complexity

In China, researchers have conducted simulation studies on disaster management systems to obtain an understanding of the characteristics of disaster management systems and their operation and evolution laws at the disaster prevention and mitigation aspects, thereby identifying core factors that affect the disaster management evolution process, which are used for designing disaster management systems. Some researchers have carried out post-earthquake rescue simulation studies based on the Swarm platform, employed the Swarm platform to simulate the process mechanism of post-earthquake rescue, established a rescue process model under the simplest conditions, used this for rescue process simulation and analysis, and compared it with the rescue process and results. With regard to the combat health logistics attrition model for patient flow, the Dupuy model was mostly used. This is a linear method that puts more focus on the number of casualties. The type and severity of injuries studied are relatively simple and there are still insufficient non-linear studies on casualties under complex situations. There is still no integrated prediction patient flow model that includes quantity, structure, and distribution, which affects the understanding of patient flow complexity during disaster rescue. Some studies also use the MatLab neural network toolbox for patient flow prediction. These patient flow simulation models mostly use a certain level of medical rescue institutions as nodes to study the movement of casualty patients through individual medical rescue institutions, evacuation behaviors, and policies. However, these models do not consider the movement of different casualties at medical rescue institutions of different levels and with different attributes as a dynamic and continuously changing process, which disrupts the integrity of patient flow.

Overall, patient flow researches on routine medical service resource allocation, performance evaluation, and combat health attrition prediction are more mature. However, there is a lack of studies on emergency medicine rescue, particularly patient flow factors during major disasters, quantitative description of characteristics, and macroscopic model construction and simulation. In-depth studies on patient flow evolution patterns will greatly increase the precision and scientificity of emergency medical rescue decision-making in major disasters.

4.1.2 Aims and significance

The earthquake casualty evacuation agent-based model is a multi-agent behavioral interaction computer model constructed by combining GIS maps and AnyLogic software-based platform that uses casualties, evacuation tools, evacuation medical resources, and rear hospital resources as intelligent agents.

This study focuses on casualty evacuation efficiency, and is based on the (1+n) health service system (HDS) complex model system that was previously constructed by the author, empirical studies on emergency medical rescue in the Wenchuan and Yushu earthquakes, and the aforementioned “two phase and three stage” disaster emergency medical rescue pattern, literature review, and comparative analysis. It employs characteristic analysis to obtain patient flow factors, composition, performance indicators, and other detailed descriptions. Earthquake casualty evacuation models constructed by using queuing network theory and multi-agent modeling are used and empirical study data from the Yushu earthquake are used for patient flow simulation to reveal the evolution patterns of the earthquake patient evacuation system, screen for patient flow performance (emergency medical rescue efficiency), convert “inflection points” to policy intervention targets for multiple intervention experiments on patient flow, rate, stage, time, and sequence to form an optimization strategy protocol for emergency medical rescue.

The earthquake casualty evacuation agent-based model obtained in this study can provide a simulation and intervention experiment tool for earthquake casualty evacuation and a quantitative basis for improving the scientificity and precision of earthquake emergency medical rescue decisions.

4.2 Agent-based model simulation

4.2.1 System definition and description

Earthquake patient flow is the basis of the existence of the entire earthquake medical evacuation system. “Flow” specifically refers to the flow of materials, talents, information, and culture between individuals and between individuals and the environment in the system. Patient flow refers to the phenomenon in which earthquake casualties move toward rear resuscitation institutions and include flow direction, status, volume, sequence, wave, speed, time, barrier, distance, and type. Flow status is the status of patient flow and an overall model of patient flow. Flow volume is the volume of patient flow and is based on the total number of casualties. Flow speed refers to the time taken for the casualty to be evacuated from the occurrence of injury to various resuscitation institutions. Flow wave refers to the waveform of patient flow and there are differences in the shape, wavelength, and increment speed in patient flows from different resuscitation organizations. Flow type refers to the shape of patient flow. In the past, a triangular shape appeared before battlefield casualties reached the divisional treatment site (or early resuscitation institutions). Following that, a knot shape, fan shape, gourd shape, and radial shape may appear. Flow time is the number of days it takes to reach the final treatment institution from the first casualty to the last. Flow distance refers to the distance from the casualty site to various levels of resuscitation institutions. In principle, the shorter the flow distance, the better, that is, medical institutions should be closer to the site, which will shorten treatment time. Flow direction refers to the direction of patient flow and includes forward, reverse, and horizontal flow. Flow sequence refers to the sequence of patient flow. In medical rescue during non-combat military operations, particularly during earthquake medical rescue, the casualty rescue stage is simplified, flow speed accelerated, and the process shortened so that casualty evacuation to early treatment or confirmatory treatment institutions can be carried out as soon as possible. Flow barriers: Casualty evacuation is often impeded due to destruction of roads and bridges, weather, environmental factors and the inability to carry out evacuation work in a timely manner; this is termed flow barrier. When flow barriers occur, they should be repaired or rectified as soon as possible so that normal patient flow can be restored.

The goal of earthquake casualty evacuation systems is usually the restoration of health in earthquake casualties, with the earthquake medical rescue environment as the space, support force flow as an essential basis, patient flow as the core, and information flow as the operation system to support the joint effects of force flow and information flow on patient flow to output system “products,” that is, casualty health Figure (4-3).

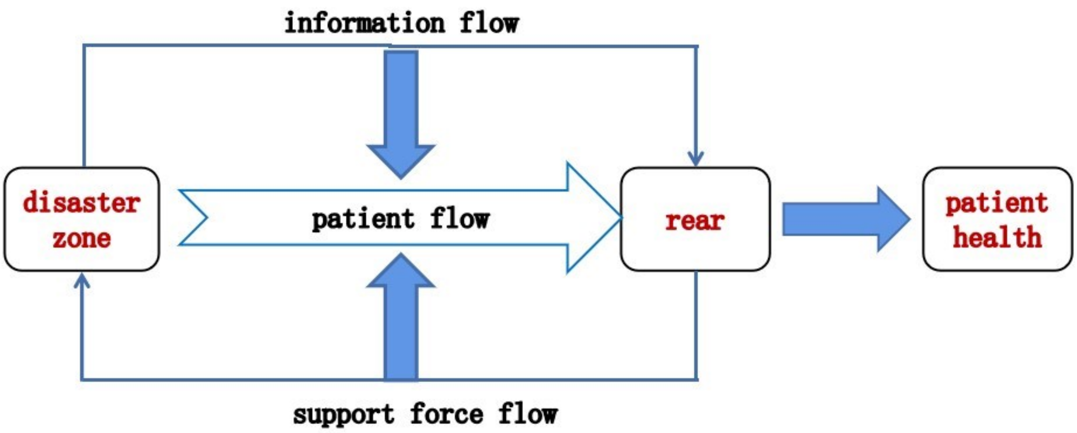

Figure 4-3. Earthquake casualty evacuation system flow analysis.

4.2.2 Individual Agent division

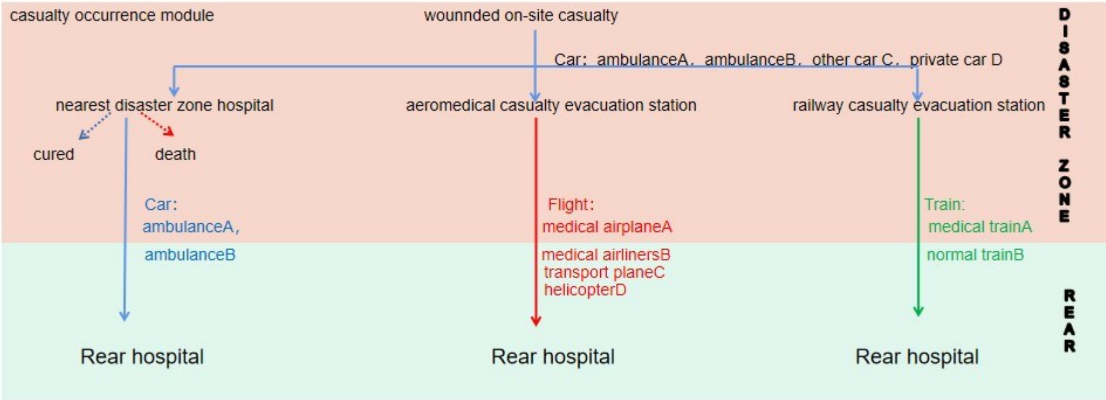

Figure 4-4. Earthquake casualty evacuation casual loop model.

(1) Casualties at the earthquake site are evacuated through ambulance A (disaster zone ambulance), ambulance B (supporting ambulance), other vehicles (such as large trucks), and private-hire vehicles (such as five minibuses).

Determination criteria for evacuation capacity

Ambulances: Four casualty places, of which moderate and mild casualties occupy one place, severe casualties occupy three places, and critical casualties occupy four places.

Private-hire vehicles: Three casualty places, of which moderate and mild casualties occupy one place, and severe casualties occupy three places.

Other vehicles: Twenty places on average, of which moderate and mild casualties occupy one place, and severe casualties occupy three places.

Ambulance A had an initial value of 20.

Ambulance B had an initial value of 0. These values change to 10, 20, and 40 after 4h, 8h, and 24h, respectively.

Other vehicles had an initial value of 4.

Private-hire vehicles had an initial value of 10.

(2) For disaster zone hospital casualties, those with mild and moderate injuries remain for treatment. Except for dead casualties, severe and critical casualties continue to be evacuated.

At this point, ambulance A has an initial value of 2.

Ambulance B had an initial value of 2. If many casualties require evacuation, this value gradually increases after an application is made.

(3) In the aeromedical casualty evacuation station, those with mild and moderate injuries remain for treatment. Except for dead casualties, severe and critical casualties continue to be evacuated.

Severe casualties occupy three places, and critical casualties occupy four places. Moderate and mild casualties occupy two places (critical casualties can be transported if the places are not filled).

Medical airplane A: 80 places were preset.

Modified airline B: 40 places were preset.

Modified transport plane C: 60 places were preset.

Helicopter D: Six places were preset.

(4) In the railway casualty evacuation station, those with mild and moderate injuries remain for treatment. Except for dead casualties, severe and critical casualties continue to be evacuated.

Severe casualties occupy three places, and critical casualties occupy four places. Moderate and mild casualties occupy two places (critical casualties can be transported if the places are not filled).

Medical trains, 80 places per carriage, three carriages.

Ordinary trains, 80 places per carriage, two carriages.

(5) Special settings.

The default setting for ambulances, medical planes, and medical trains is that these contain medical equipment and medical staff.

If airliners, transport planes, helicopters, and ordinary trains are not equipped with medical equipment or medical staff, the severe casualty capacity is reduced by 50% and critical casualty capacity is reduced by 80%.

Ambulances had an initial speed of 40 km/h.

4.2.3 Individual agent model

(1) Aeromedical evacuation-tool agent

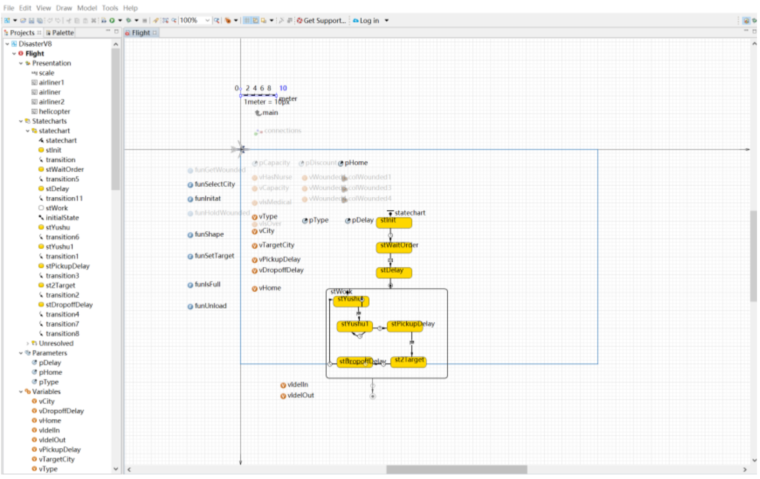

Figure 4-5. Aeromedical evacuation-tool agent model.

(2) Land evacuation-tool agent

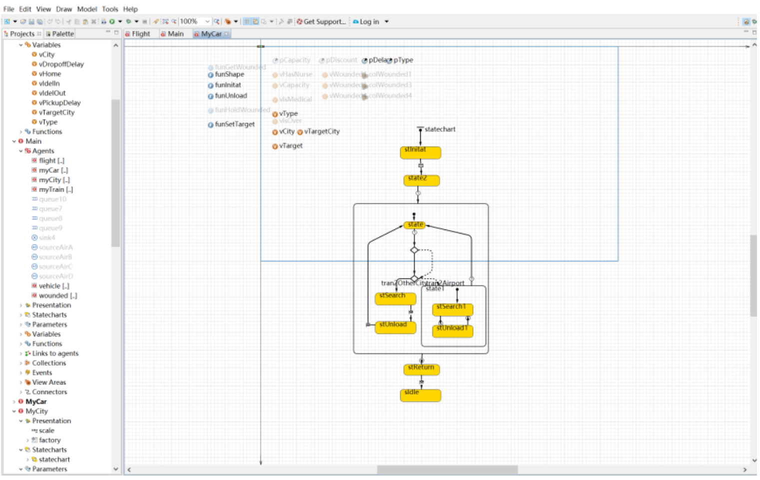

Figure 4-6. Land evacuation-tool agent model.

(3) Evacuation target city agent

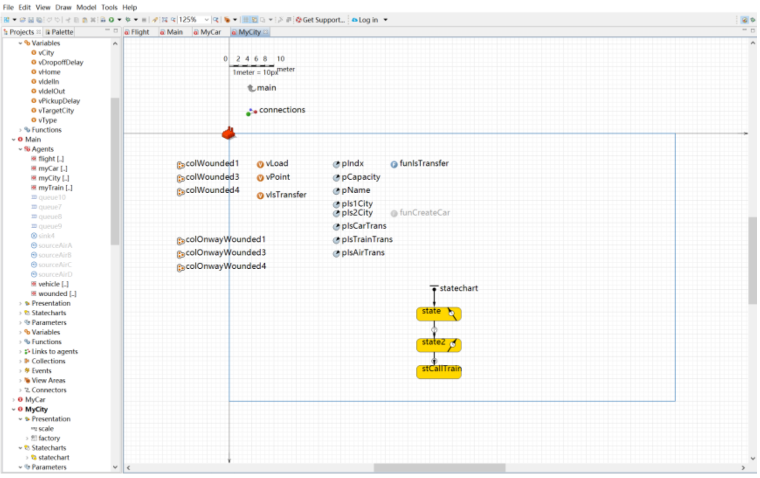

Figure 4-7. Evacuation target city agent model.

(4) Railway evacuation-tool agent

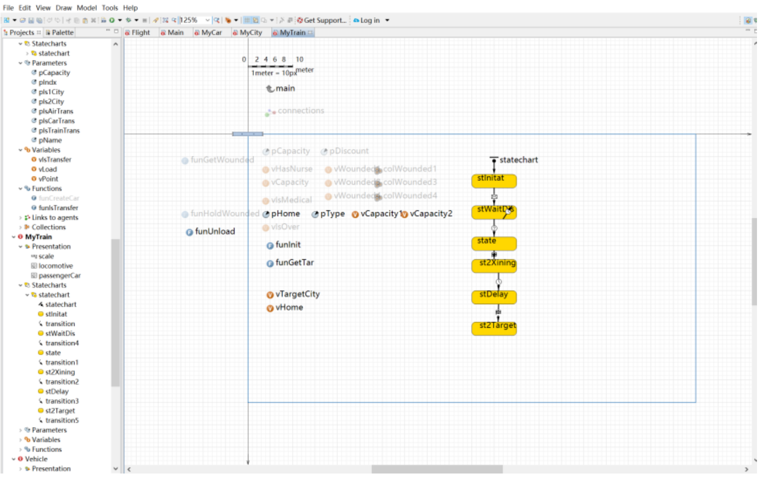

Figure 4-8. Railway evacuation-tool agent model.

(5) Disaster casualty agent

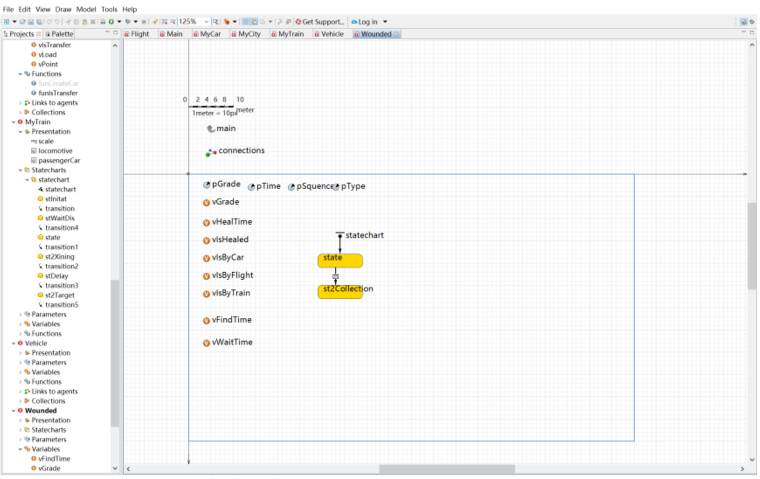

Figure 4-9. Disaster casualty agent model.

4.2.4 Macroscopic multi-agent system model

Model operation GIS interface can be seen from Figure 4-10.

Figure 4-10. Model operation GIS interface.

4.3 Model and policy recommendations

4.3.1 Early evacuation of casualties after disaster can shorten the time from injury to specialist treatment and improve casualty resuscitation outcomes

A certain magnitude of earthquake usually destroys medical service institutions in the disaster zone and cannot satisfy the specialist, surgery, rehabilitation, and psychological support requirements of mass earthquake casualties. Therefore, casualty evacuation to rear hospitals for specialist treatment is an important aspect of disaster emergency medical rescue. Internationally, early evacuation, early specialist treatment, and early rehabilitation are new trends in emergency medical rescue during mass casualty events. On Day 6 of the Wenchuan earthquake, the earthquake relief headquarters activated cross-provincial casualty evacuation, and 10,015 earthquake casualties were successfully evacuated. During the Yushu earthquake relief efforts, severe casualties were evacuated on the day of the earthquake, and the evacuation of all severe casualties was completed by Day 3. The mortality rate of all evacuated casualties was only 0.10%, which sets a new world record in safe evacuation of casualties on a plateau.

4.3.2 Determining a suitable casualty evacuation ratio is key to improving medical evacuation system resource utilization rate and effective implementation of triaging

With the developmental trend of simplifying disaster relief medical evacuation stages and early evacuation, the organization of emergency medical rescue can be divided into two methods. The first method is to transport a large number of elite medical forces to the frontline in the early stage for on-site first aid. The second is the timely and safe evacuation of casualties to rear hospitals for treatment. The destruction area of the earthquake, available medical forces in the disaster zone, evacuation tool-carrying capacity, and evaluation of casualties' resuscitation needs are key to determining a suitable casualty evacuation ratio to improve medical evacuation system resource-allocation efficiency and effective implementation of triaging. Ignoring available medical resources in the disaster zone and low casualty evacuation ratios will result in on-site treatment needs exceeding the supply, causing a lower effective treatment rate for casualties. On the other hand, overlooking the carrying capacity of evacuation tools and the high casualty evacuation ratio will result in long casualty evacuation duration and will delay the evacuation time, thus delaying the time in which casualties receive specialist treatment. In addition, it is extremely important to formulate evacuation criteria based on scientific and professional triaging given limited medical resources after an earthquake. During the Wenchuan earthquake, unclear evacuation criteria resulted in 30% of the casualties evacuated by helicopter being mild casualties. Similarly, improper triaging and unclear evacuation criteria resulted in wastage and insufficient medical evacuation resources. Strict enforcement of evacuation criteria according to the distribution of medical evacuation resources and real-time adjustment of casualty evacuation ratio can enable casualty evacuation to be orderly and rational, and result in more effective resource utilization.

4.3.3 Rational allocation of disaster zone medical forces and rear hospital resources is the key to increase the earthquake relief MES system efficiency

Timely adjustment of disaster zone medical forces can drastically decrease low efficiency in medical forces in the disaster zone after 72 hours. In on-site studies of the two earthquakes, both the medical relief command and medical team found that 24 hours after the earthquake is a critical period for medical rescue and the first eight hours is a "golden period" for rescue. Specialist medical rescue staff play the most important role within 72 hours after an earthquake and can be withdrawn after this time; medical rescue force remaining at the disaster zone must tour the site as soon as possible. Specialist forces can work in shifts to supplement the medical force. During the Yushu earthquake relief, medical forces started to withdraw nine days after the earthquake. On Day 17 of the earthquake (30 April), support forces from other provinces (excluding military field cabin hospitals) all withdrew. On Day 30 of the earthquake, regional (mainly within the province) support force did the same. Field cabin hospitals are mainly used as hospital substitutes during disaster zone recovery and reconstruction and do not belong to the earthquake relief evacuation system. In contrast with medical logistic forces in the Wenchuan earthquake that returned after 70 days, the deployment of the Yushu earthquake relief medical force was more scientific and fit the pattern of casualty occurrence. The continuous medical needs of evacuated casualties must be considered in the selection of rear hospitals. During research and literature review, it was found that casualty admission reached its peak within a week, and this peak was usually maintained for around two weeks. In addition, the mean length of hospitalization is longer for earthquake casualties, which may be associated with non-medical reasons such as subsequent arrangements of casualties. Therefore, the commanding institution must fully evaluate the carrying capacity for a period of time when selecting rear hospitals. Rear hospitals should strengthen emergency management, properly arrange casualty treatment, and fully consider their rehabilitation treatment and psychological intervention needs.

5 Policy intervention experiment of public welfare in public hospitals

Authors: Meina Li, Wenya Yu, Kang Tang, Lulu Zhang

5.1 Model simulation

Public hospital reform related to the focus of social contradictions and involves competition between multiple interests. The core of public hospital reform is whether the return of public welfare can be achieved. And the reform is mainly based on medical-seeking choices of patients. In this study, multi-agent modeling theory was used for deep analysis of public welfare in public hospitals' agency and its behavioral rules for constructing a public hospital welfare agent model; it was also used for dynamically simulating patient (social) choices and role expectations within the behavioral interactions of public hospital agents to reveal the complex adaptive mechanism and evolution laws of patients' choices in public hospitals, and to propose theory, methods, and policy systems of public welfare in public hospitals.

5.1.1 Model introduction

(1) Study significance of public hospital welfare model

(a) Theoretical significance: Expanding the theoretical methods for public hospital research and driving the application of complex adaptive systems in healthcare

Most public hospital studies remain at the (static) research stage in which the structure remains unchanged, and more advanced theoretical studies have examined structural evolution. However, very few studies involve the interactions between structure and agent behavior. Exploring complex behaviors is a goal that international and Chinese researchers continuously pursue. Only by exploring complex behavioral characteristics and identifying policy intervention targets for simulation and intervention can complex problems be solved fundamentally while also treating the consequences. Complex adaptive systems (CAS) provide a good method. Overseas studies on CAS are more in depth, are conducted in CAS laboratories with influence (such as Santa Fe), and are directly used in national assistance decisions in macroeconomics and business management [37,38]. Holland [39] collaborated to develop a computer program to simulate the stock market and successfully explained the stock market bubble and crash. In China, studies on CAS theory and methods are at the infancy stage and mainly involve concept introduction, CAS theoretical analysis, and modeling studies on some questions; there is a lack of influential CAS laboratories. Interest on the application of CAS in healthcare has been burgeoning [40,41]. In the annual meeting of the National Academy of Engineering (NAE), the foreign researcher, William B. Rouse, proposed the design and framework for CAS for healthcare services. Syamala et al. constructed a multi-agent model for healthcare systems. Sobole et al. [42] carried out modeling studies on patient flow in hospitals. Deiekmann et al. constructed a CAS model for social epidemics and applied this in guiding healthy behavior and drug use.

Studies and examination of agent self-adaptive structure and deficiencies have greatly promoted the application of CS in healthcare. However, this does not explain these systems very well as we are presently unable to fully simulate healthcare CAS. Studies on interpreting healthcare agent supply-demand equilibrium and the system structure energy level are still not deep enough. Attentions to game relationships between agents and behavioral characteristics are still insufficient, and integrations of complexity analysis models revolving around adaptivity are still insufficient. It can be seen that studies on multi-model integration, simulation, and modeling are difficulties and bottlenecks in the expansion of CAS in healthcare, and further relevant studies are required. In this study, complex system theory was employed to construct a public hospital welfare agent model to expand the application of CAS theory in healthcare.

(b) Practical significance: Revealing the critical policy points for public hospital welfare and providing a basis for deepening healthcare system reform

Public hospitals are a domain where many contradictions and problems are concentrated and public hospital reform is an important task that concerns entire medical reforms, that is, public hospital must provide a platform for services in treating major diseases, serious diseases and refractory diseases, which are the main challenges in medical reform. Compared with public hospital reform, medical reforms in other domains and policy adjustments show significant results. The national health insurance system in China has initially taken shape, and the national basic medicine systems have achieved complete coverage under government-run grassroots medical institutions. The medical and health service system has basically been completed in grassroots medical institutions, and new progress has been made in the equalization of basic public health services. However, it is not possible for public hospital reform to show immediate results. Evidence has shown that it is difficult to carry out public hospital management system with public welfare as a target.

First, the work of public hospitals has high complexity and low measurability. Measurability is a concept that foreign researchers created especially for medical services. The reason of low measurability is that public hospitals are complex systems with strong knowledge concentrations, high scientific technology, and broad service content, which includes medicine, prevention, pre-hospital first aid, and healthcare. At the same time, strong timeliness, simultaneous regulation and randomness, complex resource allocation requirements, and strong overall collaboration make it difficult to measure the quality, quantity, and suitability of medical services. The direct consequence of low measurability is asymmetric information, as there is severe information asymmetry between medical service provider and regulators, regulatory lapses frequently occur, and government regulation is difficult in immediate effects.

Second, system problems are most likely to involve adjustments to the interest of different parties, and it is difficult to balance the interests of the government, hospitals, and patients. First, the government can be horizontally divided into the central government and local governments and vertically divided into the Ministry of Health, Ministry of Finance, health insurance organizations, and several sub-organizations. The value preferences of these sub-organizations are not completely identical during reform. In addition, it is difficult to coordinate multiple targets, and reform complexity increases. Second, there are many healthcare-related interest groups, including hospitals, drugs, device manufacturers and dealers, and even advertising companies. Hospitals can be divided into large hospitals and small hospitals, public hospitals and private hospitals. Staff can be divided into hospital deans, administrative staff, medical technologists, etc. The various sub-groups can form interest groups, and almost every reform encounters resistance from these groups, which forms a major obstacle that makes it difficult to drive reform. Third, from the public' perspective, on one hand, socioeconomic development has caused the greater quality of life, and health requirements and demands for medical service quality have increased; on the other hand, the public urgently demands a reduction in medical expenses. The contradiction between high-quality medical services and low-cost medical expenses has further increased difficulties in reforming.

Finally, system problems cannot be modified independently from the government's management system. The core of management system problems is right allocation, including right allocation between the government and public hospitals, between various government agencies, and between various levels of government. The difficulty in managing right allocation has resulted in specific problems such as (I) lack of governance of owners. At present, the ownership, property rights, management rights, and decision-making power of public hospitals are not clearly delineated, and these rights are even mixed together; (II) lack of effective governance structure. There is no clear decision-making, implementation, incentives, and supervision structure; (III) industrial regulations do not match each other. Reforms in healthcare system-related economic system, allocation system, and finance, material prices, and manpower resources systems are not synchronous and do not match; (IV) benefits: agent incentives are incompatible. The targets of various welfare agents in public hospitals are separated and result in behavioral conflicts; (V) weakly integrated governance of important stakeholders.

These problems severely restrict public welfare reform in public hospitals. In-depth research is required to understand which factors are key nodes restricting public welfare in public hospitals in the relationship between public welfare and interests. CAS theory was employed in this study, and a multi-agent technique was used to construct a public hospital welfare agent model to reveal key policy points of public hospital welfare and provide a basis for deepening reform in the healthcare system.

(2) Definition of public hospital welfare model

The agent of the public hospital welfare model was defined as public hospitals and modeling content was limited to benefits, that was, the relationship between public welfare and profit in public hospitals.

(a) Public welfare hospitals

The meaning of public is "government-built and maintained;" it emphasizes that the aim of government construction is public availability and public welfare [43]. The aim of constructing public hospitals by the government is to maintain the quality of life of residents, reduce poverty, and promote social cohesion through social welfare, social insurance, and social assistance [44]. Public hospitals are built by using government capital in the socialist market economy and can be defined as public welfare hospitals that provide basic medical services that are not profit-driven, with a clear ownership relationship and modern governance structure. This does not mean that these hospitals are state-run, but rather they are built for the public [45]. Public hospitals are responsible for basic medical services, emergency treatment in major events, medical assistance, and regulating healthcare behavior. These are important social functions of public hospitals and demonstrate non-profit and public welfare social functions [46].

(b) Benefits-public welfare

The aim of public welfare is to obtain benefits for the public [47]. Public welfare of social organizations refers to the behavioral characteristics of certain social organizations that provide society with a product or service that can satisfy society's basic needs in a non-profit manner through purposeful activities. Currently, there is no unified definition of public welfare in public hospitals. Nicholson et al. [48] believed that the public welfare of public hospitals was a service enjoyed by individuals, and it would not decrease the absolute value of that service when simultaneously enjoyed by others. Sandrick [49] believed that public welfare was treatment or health-promoting and rehabilitation plan or activities required by the public but not the market. The Chinese academic world has interpreted its connotations from the perspective of health economics [50], welfare economics [51], and public finance [52] and pointed out that public welfare benefits the public and emphasizes solving the fairness, suitability [53], and feasibility problems in medical services to ensure their quality and efficiency.

Public welfare is the fundamental target and basic characteristic of public hospitals. The public welfare of public hospitals should be a consensus between hospital targets and government policies, thereby matching social welfare targets. The public hospital's public welfare is a behavioral characteristic that must have undergone benefit activities between multiple agents (government, hospitals, patients) and matched the expected social roles of demand and supply. Social expectation refers to the wishes or needs of the society or groups according to an individual's social position or social role; it reflects socially acceptable value standards or a code of conduct.

(3) Multi-agent system

(a) Agent

An agent originally referred to the party authorized to represent the client in commercial activities. Subsequently, the term “agent” was used in artificial intelligence and computer science to describe the intelligent behavior of computer software. The concept of agent was first proposed by one of the cofounders of computer science and artificial intelligence in Massachusetts Institute of Technology, Professor Marvin Minsky in the book “*Society of Mind*.” This term is used to describe a self-adaptive and autonomous hardware, software, or other entities to recognize and simulate intelligent behavior in humans. Agents are defined as physical or logical subjects that possess intelligent or semi-intelligent functions and are able to independently operate in specific environments, employ functions to promote structural changes, and possess autonomous, reactive, and self-adaptive characteristics. Agents can be considered to be computing entities with a specific life cycle that acts on a certain environment. From a practical application perspective, agents are essentially decentralized and individual-centric (in contrast to the system layer) models. If active entities, that is, agents (may be humans, companies, projects, cities, products, etc.) are determined, their behaviors are defined (main driving force, reaction, memory, status), and they are placed in a central environment or connections are established, then overall behavior (the system layer) can be considered to be the results of interactions between multi-agent behaviors. These agents have their own characteristics, are able to sense the surrounding environment, can operate autonomously, and affect and change the environment. An agent includes three basic states, that is, belief, desire, and intention, which represent the knowledge, capabilities, and goals of the agent, respectively. Therefore, the BDI model can be used to describe the basic characteristics of agents [54]. All autonomous behaviors of agents are based on their three basic mental states and are achieved through interactions between environments and between agents. A physical or virtual entity that can perceive the environment and act on the environment can be considered an agent, and the computer system formed from the interactions between multiple agents to achieve a specific objective is a multi-agent system.

(b) Multiple agents

Multiple agents usually refer to Multi-Agent System (MAS) or Multi-Agent Technology (MAT). MAS is an important branch in distributed artificial intelligence (DAI) and is a computerized system composed of multiple interacting agents in the environment. MAS can be used to solve problems that are difficult or cannot be solved by single agents or single systems.

MAS is an integration of multiple agents, and its objective is to use large and complex systems to construct small and easily managed systems that can mutually communicate and be coordinated. The individuals or organizations of real-world events and objects can be considered as a MAS. The MAS is an open system, in which agents are autonomous and can freely join or leave. Every agent is endowed with behavioral rules according to their inherent attributes. In an agent’s activity space, the agent will behave according to its own rules, work together, and coordinate their abilities and objectives with others to solve problems that cannot be solved by a single agent. Finally, as time changes, the system will generate different scenarios that can be used to assist people in judging and analyzing complex phenomena that cannot be directly observed by people in the real world.

(c) Agent characteristics

The MAS is an organic whole composed by multiple agents. An agent usually has five basic characteristics, namely, autonomy, reactivity, proactivity, sociability, and evolvability. These characteristics are mainly present in its intelligence and agent capabilities. Intelligence refers to the ability to use the system to employ deduction, learning, and other techniques to analyze and understand various forms of information and knowledge that it encounters or has been given. Agent capabilities refer to an agent’s abilities to perceive external information and react automatically according to its own knowledge.

(I) Autonomy: An agent can automatically adjust its behavior and state according to changes of the external environment; it not only passively receives external stimuli but also possesses self-management and self-adjustment capabilities.

(II) Reactivity: The ability to react to external stimulation.

(III) Proactivity: The agent possesses the ability to proactively react according to changes of the external environment.

(IV) Sociability: The agent possesses the ability to cooperate with other agents or people. Different agents can interact with other agents according to their own intentions to solve problems.

(V) Evolvability: The agent can accumulate or acquire experience and knowledge and modify its behavior to adapt to a new environment.

(4) Construction of public hospital benefits agent—the AnyLogic model

(a) Principle of multi-agent system modeling

Multi-agent modeling is an effective method in solving a problem in which various factor agents compete and cooperate with each other in a complex system. In a MAS, there are many independent and mutually cooperative agents that represent different entities, play different roles, and carry out function of behavior entities. Agents with independent behaviors all comply with a collaborative mechanism and exchange data with the external environment in real-time through certain pathways so that various internal and external resources in the system can be fully utilized to achieve the system's overall target and function [55]. The MAS is a bottom-up or process-based modeling study method that uses simulation to reproduce complex phenomenon in the real world. This is mainly presented in the following aspects: The agent is a proactive and living entity; the mutual effects and interactions (i.e., adaptivity) between the agents and between agents and the environment are the main driving force for system evolution; macroscopic and microscopic aspects are linked in an organic manner; and introduction of random factors' effects can result in more powerful description and expression.

The following factors must be considered in MAS modeling. Individual agents must be inferred, tasks must be decomposed and allocated, multiple agents must be planned, the consistency of the goals and behaviors of various member agents must be coordinated, conflict must be recognized and eliminated, and other agent models must be constructed in which communication management, resource management, adaptive learning, movement and system security, and load balancing must be taken into account.

(b) Multi-agent modeling software tools

There are many types of multi-agent simulation software and influential software, including Swarm, RePast, NetLogo, ASCAPE, and AnyLogic. Swarm was developed by the Santa Fe Institute in the United States and is a multi-agent software platform used in CAS simulation. In the Swarm system, the basic simulation unit is the "swarm," which is a collection of agents that carry out action plans. Swarm supports stratified modeling and agents can be composed of other agents' programs in a nested structure. Swarm provides an object-oriented reusable component library that is used for modeling and analysis, and experiments that demonstrate and control these models. NetLogo was developed by the Center for Connected Learning and Computer-Based Modeling at Northwestern University, United States, and its predecessor is StarLogo. NetLogo is an agent-based programming language and integrated modeling environment. Ascape is an innovative tool based on universal agent models that was developed and examined by Miles T. Parker from the Brookings Institution in the United States. It was designed to be flexible and powerful and provided broad modeling and visualization tools. AnyLogic supports agent-based modeling and can support commercial software for multi-agent simulation. At the same time, AnyLogic supports simulation based on agents, discrete events, system dynamics, Petri nets, pedestrians, and traffic, and can carry out simulations with any combination. AnyLogic was developed completely based on Java and its modeling environment is based on the popular software development tool, Eclipse. AnyLogic supports almost all Java applications and can use abundant Java resources. The model can be exported and be operated on the Internet away from the software environment or be integrated into other programs. Users can make their own user control library through secondary development. AnyLogic has a friendly visualizable development environment that can be conveniently used for constructing model and related statistical graphs, two- and three-dimensional animations, and it provides interactive controls for model operating, such as buttons, sliders, edit boxes, radio buttons, and check boxes. Multiple models can be simultaneously opened and edited, and modeling elements can be copied within various models. AnyLogic makes it convenient for joint team development and supports control version software.

(c) Public hospital benefits agent model content

The public hospital benefits agent model system is divided into the conceptual model, "stimulation-response" agent model, and multi-agent adaptive-behavior echo model.

I. Construction of the public welfare conceptual model: Confirming the core agent, management agent, and information agent in the public welfare of public hospitals' agent model system, defining the input and output variable library for agent behavior, establishing a value rules' library for information and resource flow between various agents, and achieving evolution of agent behavioral value rules.

II. "Stimulation-response" agent model: Including a universal formula for public welfare calculations, confirming major function relationships in the model, achieving modeling of competition rules and evolution rules, digitalization of random behavior, and estimation of related parameters.

III. Multi-agent adaptive-behavior echo model: A "stimulation-response" model that integrates patients, health insurance institutions, hospitals, and the government, defining the external environment in which agents conduct activities, confirming extrinsic variable value and the initial value of some intrinsic variables, and achieving multi-agent adaptive digitalization.

(d) Public hospital benefits agent model procedure

I. Identifying agents in the system, conferring agent attributes, and constructing a conceptual model for various agents;

II. Employing genetic and parallel algorithms to simulate the learning and evolution processes of three agents in the system and employing "machine learning" to optimize the self-adaptive behaviors of various agents;

III. Employing object-oriented simulation technique (Object-C) to construct a "stimulation-response" model between agents and between agents and the environment;

IV. Employing computer simulation techniques, using the SWARM2.2 software platform, constructing various agent models, and integrating CAS system agent models.

(e) Public hospital benefits agent—the AnyLogic model

The "public hospital benefits agent AnyLogic model" includes three major agents, namely, patients, physicians, and hospitals. In addition, the model also involves two other agents, namely, the health insurance system and government. This model uses different agent behavior characteristics and interactions to simulate the generation of medical expenses by starting at the stage of population disease occurrence and consultation choice according to the actual situation. This process involves the behavioral choices of physicians and hospitals; their behavioral characteristics will greatly affect the generation of medical expenses. This system model could be divided into two modules: the population disease occurrence and medical-seeking choice module and the medical expense generation module. Module 1 was mostly constructed based on agents. Module 2 was constructed mainly according to system dynamics.

In this study, computer integration of the "Public hospital benefits agent AnyLogic model" was achieved through the AnyLogic software. This software can simultaneously achieve the construction and combination of agent models and SD models. The computer integration interface of the multi-agent model includes the main model interface, basic model construction module, dynamic simulation module, data output, and other modules. To ensure the realism and reliability of the model, the actual map of Shanghai was input into the model. The main function of this map was to confirm population distribution, the actual geographical positions of hospitals, and actual distances between populations and hospitals.

5.1.2 Simulation commissioning

The public hospital benefits agents include multiple agents such as hospitals, physicians, and ~~patients~~ which are mainly presented in the consultation process of patients, and patients' medical-seeking choice behavior is used as the dominant factor. Medical-seeking choice behavior is inherently the result of cooperation and competition in a multi-agent system. Many opportunities and challenges like the diversity of patients' medical-seeking needs, the difference of physicians' skill levels, the diversity of medical services, the dynamic changes in the socioeconomic environment, the multiple levels of government regulatory functions, the abundant monitoring measures by industry associations, the coverage of health insurance systems, the complexity of news and media coverage and so on cause complexity and variability in the patient medical-seeking choice multi-agent system.

The patients' medical-seeking choice model is inherently an organized system in which multiple agents operate together in a benign manner. The complexity of patients' medical-seeking needs, different layers of optional medical services, physical skill levels, a dynamic socioeconomic environment, and levels of government regulation cause more intricacies and complexity in the patients' medical-seeking choice multi-agent system.

The patients' medical-seeking choice multi-agent system revolves around patients' medical-seeking choices while the government, health insurance organizations, industry associations, hospitals, physicians, media, and third-party service organizations are integrated into a MAS through cooperative mechanisms. The system is used to achieve modification in service processes, guide the direction of medical-seeking, share information resources, optimize allocation of health resources, and evaluate medical services to provide fast, economic, and personalized medical services for patients. It is shown in Figure 5-1.

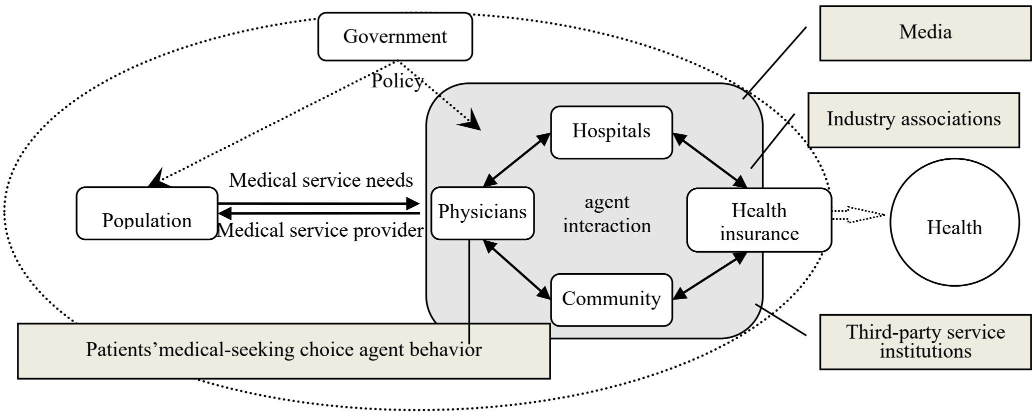

Figure 5-1. The structure of Patients' medical-seeking choice agent.

5.2 Policy intervention experiment

5.2.1 Intervention experiment 1: modeling experiment on outpatient and inpatient medical expenses

(1) Outpatient and inpatient medical expenses simulation experimental protocol

The simulated operation time for the model was set as three years (36 months), and the model would provide results every month, which were used for observation of the mean outpatient and inpatient medical expenses.

(2) Outpatient and inpatient medical expenses simulation experimental results

The simulation's experimental results showed that when no intervention was involved, the mean outpatient and inpatient medical expenses all increased as time progressed. However, the increasing trend was relatively stable, and there were no drastic changes. This result is consistent with the actual situation, showing that the model has good reliability.

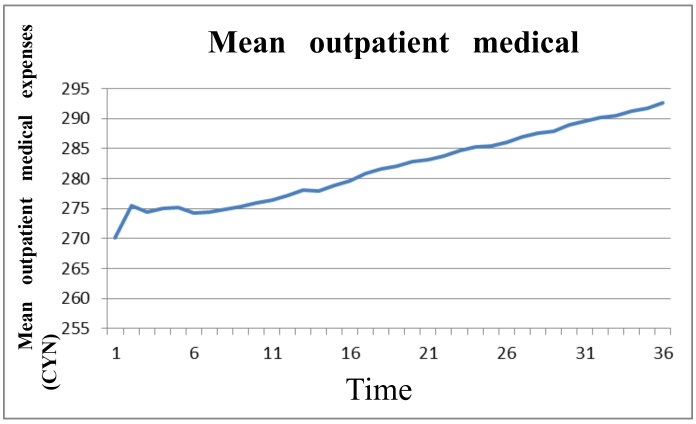

Figure 5-2. Mean outpatient medical expenses.

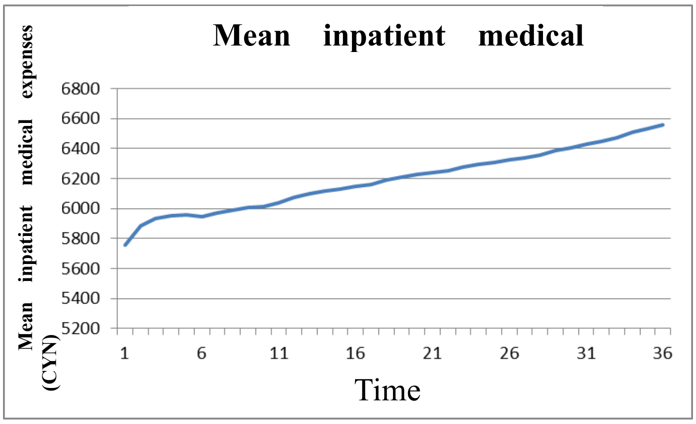

Figure 5-3. Mean inpatient medical expenses.

5.2.2 Intervention experiment 2: effects of community-first consultation system on outpatient and inpatient medical expenses

(1) Simulation intervention experiment protocol for promotion of a community-first consultation system

Baseline: Current status

Experiment 1: 50% promotion of the community-first consultation system

Experiment 2: 100% promotion of the community-first consultation system

(2) Simulation intervention experiment results for promotion of a community-first consultation system

The simulation intervention experiment results showed that as the level of promoting the community-first consultation system increased, mean outpatient and inpatient medical expenses would significantly decrease. The simulation intervention experiment results for the community-first consultation system showed that one of the main reasons for high medical expenses currently was unreasonable patients' medical-seeking choices. The level of promoting the community-first consultation system was inversely proportional to outpatient and inpatient medical expenses. Promotion of the community-first consultation system could effectively decrease high medical expenses generated because of the wrong choices. The better the implementation of the community-first consultation system, the more patients would firstly seek medical attention in community health centers. As there was a large difference in the medical expenses between community health centers and major hospitals, this would control the unreasonable increase of medical expenses. This result is consistent with the community-first consultation system that the Chinese government is currently promoting and will decrease medical expenses.

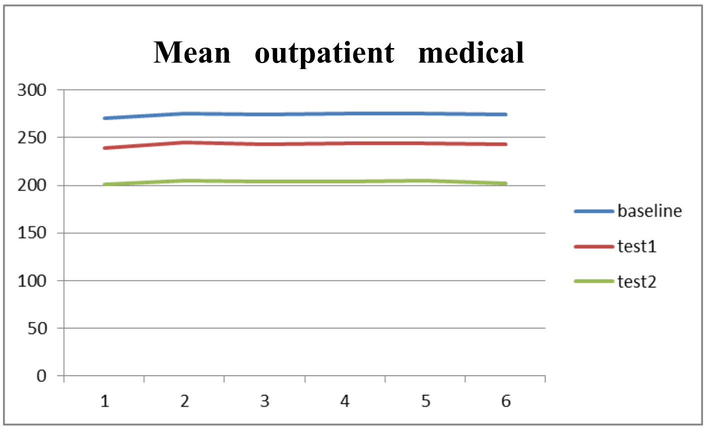

Figure 5-4. Experimental result 1.

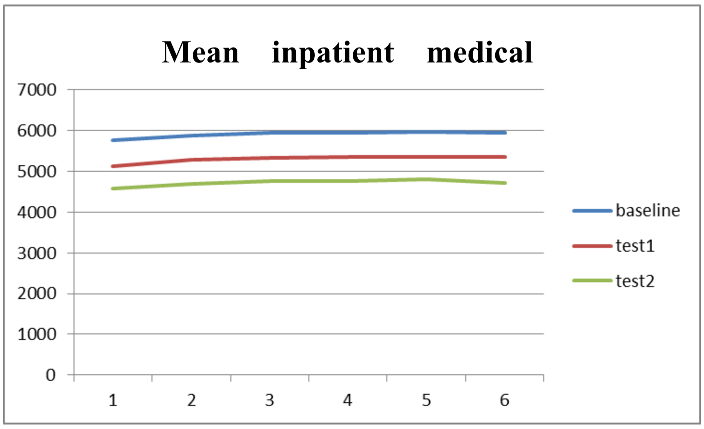

Figure 5-5. Experimental result 2.

5.2.3 Intervention experiment 3: effects of physicians' public welfare behavior on outpatient and inpatient medical expenses

(1) Simulation intervention experiment protocol for physicians' public welfare behavior monitoring

Baseline: Current status

Experiment 1: The probability of physicians issuing large prescriptions was decreased by 50% and the probability of receiving kickbacks was decreased by 50%.

Experiment 2: The probability of physicians issuing large prescriptions was decreased by 100% and the probability of receiving kickbacks was decreased by 100%.

(2) Simulation intervention experiment results for physicians' public welfare behavior monitoring

The simulation intervention experiment results on the effects of physicians' public welfare behavior on outpatient and inpatient medical expenses showed that as the probability of issuing large prescriptions and receiving kickbacks decreased in physicians, outpatient and inpatient medical expenses showed a decreasing trend. These results suggest that strengthening the monitoring of physicians' public welfare behavior can effectively curb their issuing large prescriptions and their receipt of kickbacks. The weakening of non-public welfare behavior in physicians will increase the public welfare of public hospitals and objectively decrease medical expenses in patients, which facilitates the demonstration of public welfare in public hospitals. This is consistent with the government's policies of strengthening physician behavior monitoring and hospital behavior.

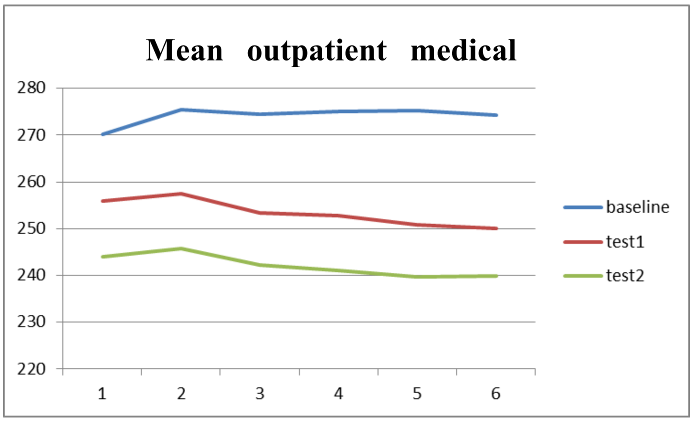

Figure 5-6. Experimental result 1.

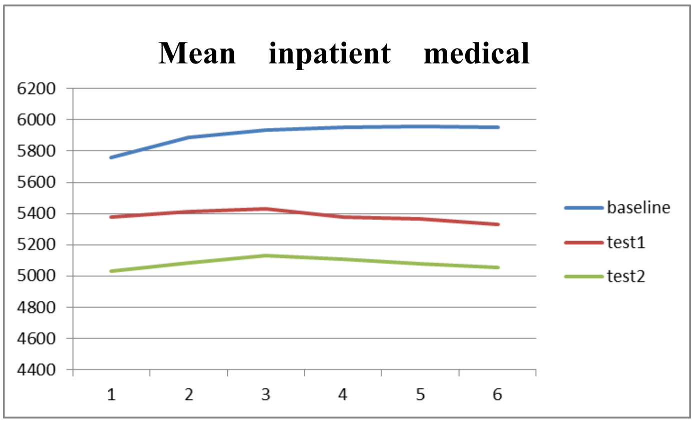

Figure 5-7. Experimental result 2.

5.3 Policy recommendations

MAS is an integration of multiple agents, and its objective is to use large and complex systems to construct small and easily managed systems that can mutually communicate and coordinate. Multi-agent modeling is a "bottom-up" or "process-based" modeling method in which simulation is used to reproduce complex phenomenon in the real world, which can be achieved by employing Swarm, RePast, NetLogo, ASCAPE, and AnyLogic multi-agent modeling software. The operation of public hospitals can be considered to be the result of interactions between multiple agents, of which patients' medical seeking choice is the main theme. Our study employed AnyLogic modeling software to divide public hospital benefits agents into autonomous and mobile agents such as patients, physicians, medical institutions, health insurance institutions, and government agencies, and confer behavioral rules for each agent. The public hospital benefits agent model could be divided into two modules, namely, population disease occurrence and consultation choice module, and medical expense generation module, which were successively used to construct a public hospital benefits agent conceptual model, logical framework, and multi-agent model, thereby providing a detailed explanation of the interactions of public hospitals' relevant benefits agents.

By combining the policy intervention experiment results of the public hospital benefits agent model and using public hospitals, physicians, and patients as agents, we propose policy recommendations to improve the level of benefits of public hospitals agents.

(1) Implementation of public hospital measures and promoting rational consultation choices in patients

The return of public welfare in public hospitals can be promoted by further implementation of "medical separation" "management separation," "political separation," and "profit and non-profit separation" starting from the core problem of public hospital operation and development. Rapid promotion of the community-first consultation system and bi-directional referral system, and increasing investment in community health service centers, which includes improving the allocation of hardware facilities and strengthening the skill levels of medical staff in community health service centers should be carried out to improve the medical service capabilities of community health service centers to obtain patients' trust and change current unreasonable medical-seeking choice preferences. To promote these two systems, further confirmation and optimization of system specifications and processes, and promoting acceptance by physicians and patients are required. This will enable effective and rational patient triage and encourage patients with common illnesses and minor illnesses to be triaged to community health service centers and district hospitals.

(2) Regulation of physician behavior and maintenance of proper physician benefits

Physician behavior should be regulated at the system level to reduce the occurrence of large prescriptions, thereby decreasing patients' medical expenses.

Reforming the current physician wage system, further rationalization of physician wage benefits, attempting trial methods of increasing medical service fees for physician, and increasing reasonable income for physicians can decrease the probability of receiving kickbacks and issuing large prescriptions.

Further trial optimization and promotion of multi-point practice in physicians can propel the flow of more qualified physicians in different grades of hospitals. In these policies, specifications of the type, level, and quantity of practicing hospitals can be added to encourage physicians to rationally choose multiple hospitals for practice, accelerate the flow of talent, and benefit citizens.

6 Policy intervention experiment of emergency system in public hospitals

Authors: Wenya Yu, Boyang Yu, Lulu Zhang

6.1 Model simulation

6.1.1 Model introduction

The Shanghai mass casualty emergency medical rescue system uses the fastest response speed and optimal resource allocation to carry out emergency medical rescue on casualties after a mass casualty incident (MCI) has occurred. Given that Shanghai is located at China's southeastern coast where natural disasters are rare, this system model was constructed based on mass casualty incidents caused by non-natural disasters. This system can simulate traumatic events at different scales and provide policy intervention protocols to improve system efficiency, thereby decreasing the mortality rate of mass casualties. As Shanghai has abundant and high-quality medical resources, and is covered by 43 tertiary hospitals with 500 or more beds that can satisfy emergency medical rescue needs of mass casualties caused by non-natural disasters at different scales, this model assumes that medical treatment institutions used for treating mass casualties are tertiary hospitals in Shanghai. Therefore, this model mainly simulates organizational command response speed, emergency resource allocation, and pre-hospital first aid times after different scales of MCIs, and provides an optimized protocol for decreasing trauma mortality rate.

In the conceptual model of the Shanghai mass casualty emergency medical rescue system, MCIs will result in casualties with different conditions. With the exception of patients who die on-site, the remaining casualties all have medical needs. After MCIs have occurred, the speed at which the government emergency response organization receives information and the emergency response speed and responsiveness of the organization determines the execution status of the emergency organization. The manpower and material resource allocation of the 120 emergency centers determine whether the level of urgency of medical emergency needs and pre-hospital duration can be satisfied. After casualties are admitted, the pre-hospital duration, emergency cap of the medical institution, injury severity, and intra-hospital treatment are integrated to determine the final outcome.

The conceptual model based on the mass casualty emergency medical rescue system was combined with critical factors that affect the trauma mortality rate to construct a causal relationship. In the literature, studies found that the pre-hospital and intra-hospital emergency treatment, scale of MCI, injury severity in casualty, medical rescue duration (including rescue, basic treatment, and evacuation time), and emergency decisions are critical factors affecting the mortality rate. By combining China's situation and our previous study on MCIs in Shanghai, this model involves factors that affect trauma mortality rate such as the scale of the MCI, pre-hospital emergency time, intra-hospital rescue capability, and organizational command efficiency.

Further quantification of the model, including parameters, was carried out for more precise and rational analysis and evaluation of the model. In this model, the observation variable is trauma mortality rate, which is the total mortality rate from the MCI to the time of discharge of the last casualty; it is composed of the casualty rates of mild, moderate, and severe casualties, and onsite mortality rate. When MCIs occur, the number of people involved and the coverage of the MCI in that population will result in casualties at different scales with different injury characteristics. The condition of casualties is classified as mild, moderate, or severe according to the abbreviated injury scale (AIS). The number and condition of casualties will result in different types of medical needs. Whether the medical needs of casualties are fully met depends on the level of the hospital's trauma emergency treatment capability, which is reflected in the medical supply-demand ratio. This capability level is affected by the total number of medical staff, total amount of hospital resources, and per capita output. In addition, after an MCI has occurred, the response speed of government emergency organizational command institutions determines the level of urgency of emergency medical rescue force intervention. The time at which the government emergency organizational command structure receives information, and the judgment, planning, decision-making, and execution capabilities of mass casualty emergency rescue will all affect the implementation rate of organizational command. The organizational command implementation rate will directly affect the dispatch of emergency services by the 120 emergency centers and indirectly affect the timeliness of the pre-hospital duration. The pre-hospital duration is jointly determined by the on-site waiting time of casualties, duration of injury examinations and first aid, and duration of evacuation; it is mainly affected by the number of dispatched medical staff and ambulances. The mortality rate of casualties is ultimately affected by the severity of injury and condition progression, the hospital's trauma emergency treatment capacity, and the timeliness of pre-hospital duration. It can be seen that these four agents are mutually connected and interact with each other to jointly determine the mortality rate after MCIs. Therefore, the Shanghai MCI emergency medical rescue system includes five subsystems: MCI occurrence subsystem, hospital emergency medical rescue force subsystem, government emergency organization command system, 120 emergency centers' subsystem, and MCI casualty outcome prediction subsystem.

6.1.2 Simulation commissioning

(1) Effectiveness validation

Actual data of a stampede event on The Bund in Shanghai on December 31, 2014 was used for a fit analysis with the model simulation results. The population base of the model was set as 1040 based on the population density during the stampede event. Model analysis was used to observe the final mortality rate and the mean ratios of mild, moderate, and severe casualties during the pre-hospital duration. Table 6-1 shows the validation results. It can be seen that the differences between actual and simulated values were within the −7.14%–3.03% range, and the deviation is within a reasonable range. Therefore, this model can be considered reliable and reasonable.

Table 6-1. Model effectiveness validation.

	Trauma mortality rate	**Mean pre-hospital duration (hours)**	**Proportion of mild casualties**	**Proportion of moderate casualties**	**Proportion of severe casualties**
Actual value	0.424	2.16	0.39	0.28	0.33
Simulated value	0.411	2.156	0.4	0.26	0.34
Difference	−3.07%	−0.19%	2.56%	−7.14%	3.03%

(2) Model sensitivity analysis

Model sensitivity analysis is used to observe whether drastic changes will occur when some parameters and structure are changed; these are used to assess the reliability and rationality of the model. To carry out parameter sensitivity analysis, sensitivity parameters must first be confirmed and limited to a reasonable range to observe the variation range of the model. Parameter sensitivity is determined based on DY(t)/Y(t), which shows changes in output variables (e.g., trauma mortality rate in this study), and DX(t)/X(t) (changed variables). Therefore, the expression formula for sensitivity analysis is $S(t) = \left|\frac{\Delta Y(t)/Y(t)}{\Delta X(t)/X(t)}\right|$.

In this study, four sensitivity parameters were selected: the ambulance dispatch rate, information system performance, increase in risk of complications, and initial on-site first aid efficiency. The variation rate was -10%–10% and the model was run 200 times. Vensim was used to carry out sensitivity simulation analysis and results are shown in Figure 6-1. In the sensitivity analysis, parameter changes will result in minor changes in the system but will not result in changes to the overall trend. Of the 200 model simulations, 50% were in the yellow zone, 75% were in the green zone, 95% were in the blue zone, and 100% were in the gray zone. It can be seen that the overall trend for trauma mortality rate remained unchanged and only showed minor and reasonable fluctuations in values. Increasing the ambulance dispatch rate will decrease the evacuation duration. Increasing the information system efficiency will increase the organization command implementation rate, decrease pre-hospital duration, and increase the timeliness of pre-hospital duration. Increasing the risk of complications will increase the mortality rate. Increasing the efficiency of on-site first aid can decrease the on-site mortality rate. The changes in these factors will directly or indirectly affect the trauma mortality rate. Therefore, the simulation results showed that changes to these constants will result in minor fluctuations to the output variable (trauma mortality rate) but not cause drastic fluctuations; it can be seen that the model is stable, reliable, and suitable for simulation analysis.

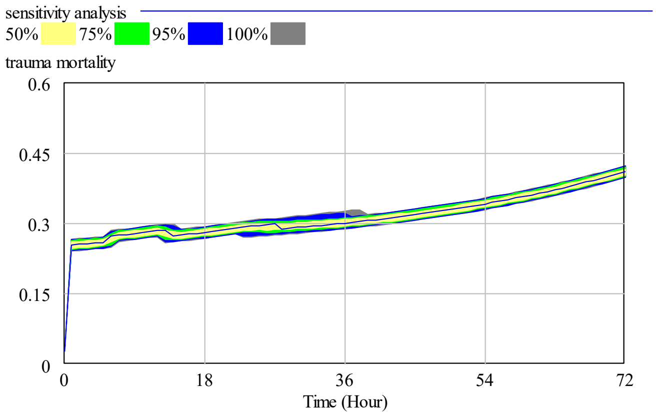

Figure 6-1. Model sensitivity analysis.

6.2 Policy intervention experiment

6.2.1 Intervention experiment 1: different incident scale experiments for mass casualties

(1) Intervention experiment protocol

In intervention experiment 1, the different number of casualties from the different scale of casualty incidents determines the medical needs and emergency rescue efficiency for different scales, thereby affecting the mortality rate. Therefore, the population base involved in an MCI was adjusted in the intervention experiment to simulate the differences in mortality rate in different scales of casualty incidents to enable critical factors that affect trauma mortality rate to come into play. Given that different scales of casualty incidents generate different medical needs, the effects of intervention measures in different scales of casualty incidents are different. Therefore, intervention experiments 2 and 3 examined the effects of different intervention measures on different scales of casualty incidents. The system simulation duration was set at 72 hours. Table 6-2 shows the parameters of intervention experiments.

Table 6-2. Policy intervention experiment 1 protocol.

Group	Name of experiment	Protocol	Parameter 1	Value
1	Current1-baseline	Scale adjustment for mass casualty incident	Population base	1000
	Current2	80% reduction		200
	Current3	100% increase		2000
	Current4	400% increase		5000

(2) Intervention experiment results

In this experiment, we changed the population base to simulate different scales of MCIs, thereby simulating and comparing the changes and differences in trauma mortality rate, trauma treatment capacity, organization command implementation rate, level of timeliness for pre-hospital duration, on-site waiting time, injury examination and treatment time, and evacuation duration (Figure 6-2). In the intervention experiment, except for changes in population base, other parameters remained unchanged. The results showed that the greater the scale of the MCI, the higher the final mortality rate. When the population base is 200, trauma treatment capacity reaches its optimal level. When the population base is 1000 and 2000, the trauma treatment capacities of the system are the same, that is, at a good level. When the population base is 5000, treatment capacity decreases to its poorest level. The organization command implementation rate is not affected by the scale of the event. After four hours from the MCI, the implementation rate shows a significant increase. However, from five to eight hours, the implementation rate shows a drastic decrease, reaching its lowest point at eight hours before showing a continuously increasing trend. The timeliness of pre-hospital duration is generally poor, with a good level for a population base of 200, a poor level at 24 hours for a population base of 1000, and an extremely poor level when the population base is 2000 and 5000. Among the three phases of pre-hospital duration, on-site waiting time is not related to scale; the injury examination and treatment time will greatly increase when the population base reaches 2000, and evacuation duration significantly increases as scale increases.

According to the simulation intervention experiment results, the trauma treatment capacities of the system are good in most situations. As the probability of MCIs with a population base of 5000 and above is low, we did not conduct a trauma treatment capacity subsystem intervention experiment in this study; instead, the parameters in this section were set according to the actual situation of the current system. Therefore, critical parameters are mainly adjusted in the following intervention experiment to examine the critical determining factors of the organizational command implementation rate and their effects on trauma mortality rate, and to analyze how to shorten pre-hospital duration to decrease the trauma mortality rate. In addition, the same intervention protocol was used in the four scales of MCIs in this simulation to compare the effects of intervention protocols on different scales of MCIs.

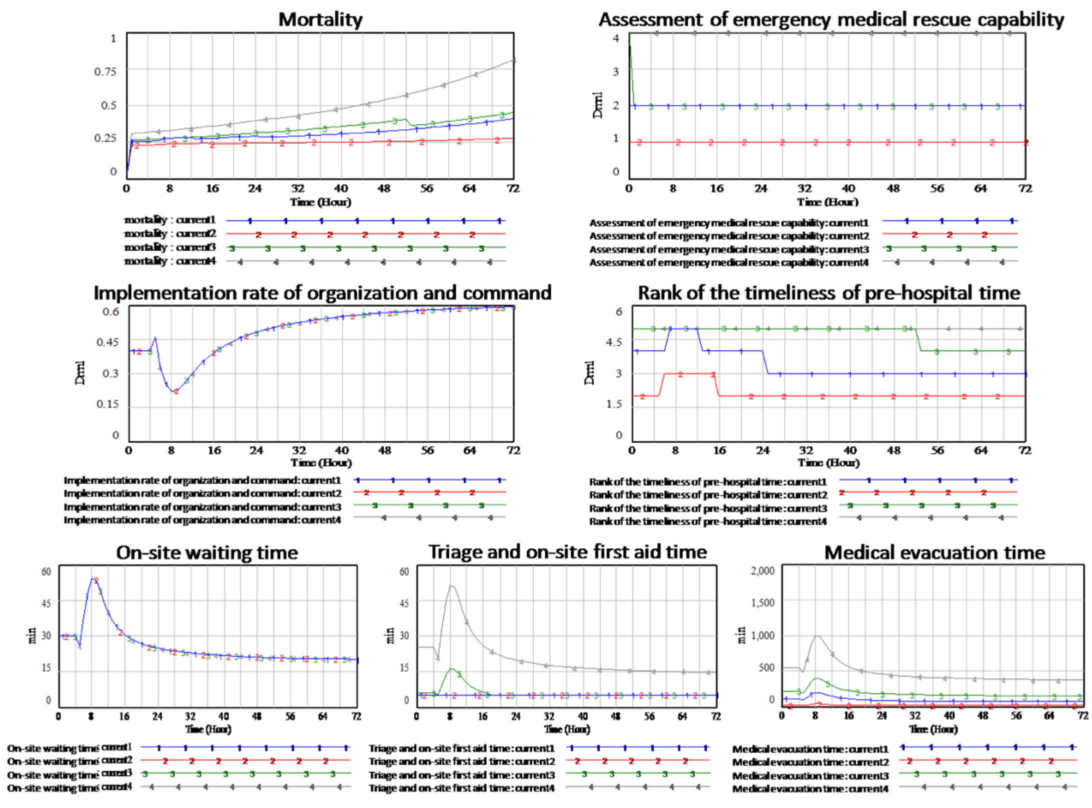

Figure 6-2. intervention experiment 1 result.

6.2.2 Intervention experiment 2: ambulance deployment experiment

(1) Intervention experiment protocol

In intervention experiment 2, the number of dispatchable ambulances and their dispatch rate were adjusted to simulate the effects of evacuation duration on the timeliness of pre-hospital duration, and the effects of timeliness of pre-hospital duration on trauma mortality rate. The system simulation duration was set as 72 hours.

Table 6-3. Policy intervention experiment 2 protocol.

Group	Name of experiment	Protocol	Parameter 1	Value	Parameter 2	Value
2	Current1/2/3/4-baseline	Adjustment of the number of ambulances and its dispatch rate	Number of dispatchable ambulances	47.65	Ambulance dispatch rate	0.5
	Test1-1/2/3/4-1	50% reduction		23.83		0.25
	Test1-1/2/3/4-2	20% increase		57.18		0.6
	Test1-1/2/3/4-3	50% increase		71.48		0.75

(2) Intervention experiment results

In this experiment, we changed the number of dispatchable ambulances and the ambulance dispatch rate while other variables remained unchanged to observe the effects of this intervention measure on emergency medical rescue system efficiency after different scales of MCIs; this is reflected as two output indicators (trauma mortality rate and timeliness of pre-hospital duration) (Figure 6-3). Results showed that when the population base is less than 5000 people, increasing the number of dispatchable ambulances and the ambulance dispatch rate can effectively decrease the trauma mortality rate. However, when the population base is 200, increasing the number of dispatchable ambulances and the ambulance dispatch rate does not significantly affect the mortality rate. When the population base is 1000, this can decrease the 24h trauma mortality rate. When the population base is 2000, the 72h mortality rate is significantly decreased. Once the population base is 5000, the current intervention protocol does not affect the trauma mortality rate. Similarly, increasing the number of dispatchable ambulances and the ambulance dispatch rate can increase the timeliness of pre-hospital duration at a population base of below 5000. Among these models, the trauma model with a population base of 2000 shows the most significant effects. When the trauma scale is 200, decreasing the number of dispatchable ambulances and the ambulance dispatch rate will decrease the level of timeliness but increasing the number of dispatchable ambulances and the ambulance dispatch rate does not have a significant effect. When the population base is 1000, this intervention protocol can effectively increase the level of timeliness within 24 hours compared with the current situation.

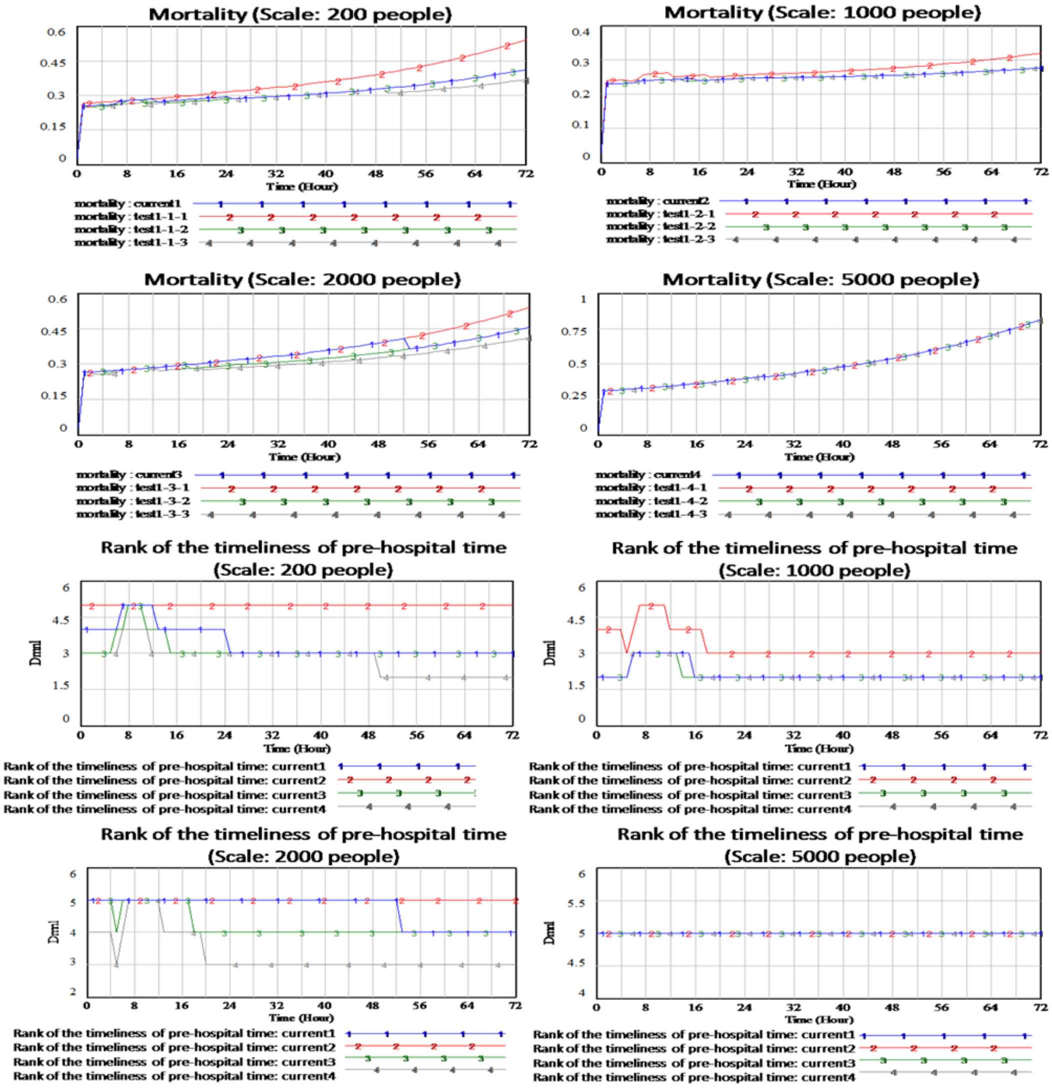

Figure 6-3. Intervention experiment 2 results.

6.2.3 Intervention experiment 3: paramedics deployment experiment

(1) Intervention experiment protocol

In intervention experiment 3, the number of dispatchable emergency medical staff was adjusted to observe the effects of changes in injury examination and treatment time on the timeliness of pre-hospital duration and trauma mortality rate. The system simulation duration was set as 72 hours. Table 6-4 shows the parameters of intervention experiments.

Table 6-4. Policy intervention experiment 3 protocol.

Group	Name of experiment	Protocol	Parameter 1	Value
3	Current1/2/3/4-baseline	Adjustment to number of dispatchable emergency medical staff	Number of dispatchable emergency medical staff	153.44
	Test2-1/2/3/4-1	50% reduction		76.72
	Test2-1/2/3/4-2	20% increase		184.13
	Test2-1/2/3/4-1	50% increase		230.16

(2) Intervention experiment results

In this experiment, only the number of dispatchable emergency medical staff was adjusted while other variables remained unchanged. Changes in the trauma mortality rate and injury examination and first aid time were observed (Figure 6-4). Results showed that changes in the number of dispatchable emergency medical staff have no significant effects on the trauma mortality rate and do not have any significant effects on the current mortality rate. Only when the population base is 2000 does increasing the number of dispatchable emergency medical staff increase the trauma mortality rate after 52 hours. In addition, increasing the number of dispatchable emergency medical staff can reduce the injury examination and first aid time in a population base of 2000 and above. Among these scales, the effects on the population base of 2000 are more significant within 4–16 hours, and persistent effects can be produced on a population base of 5000.

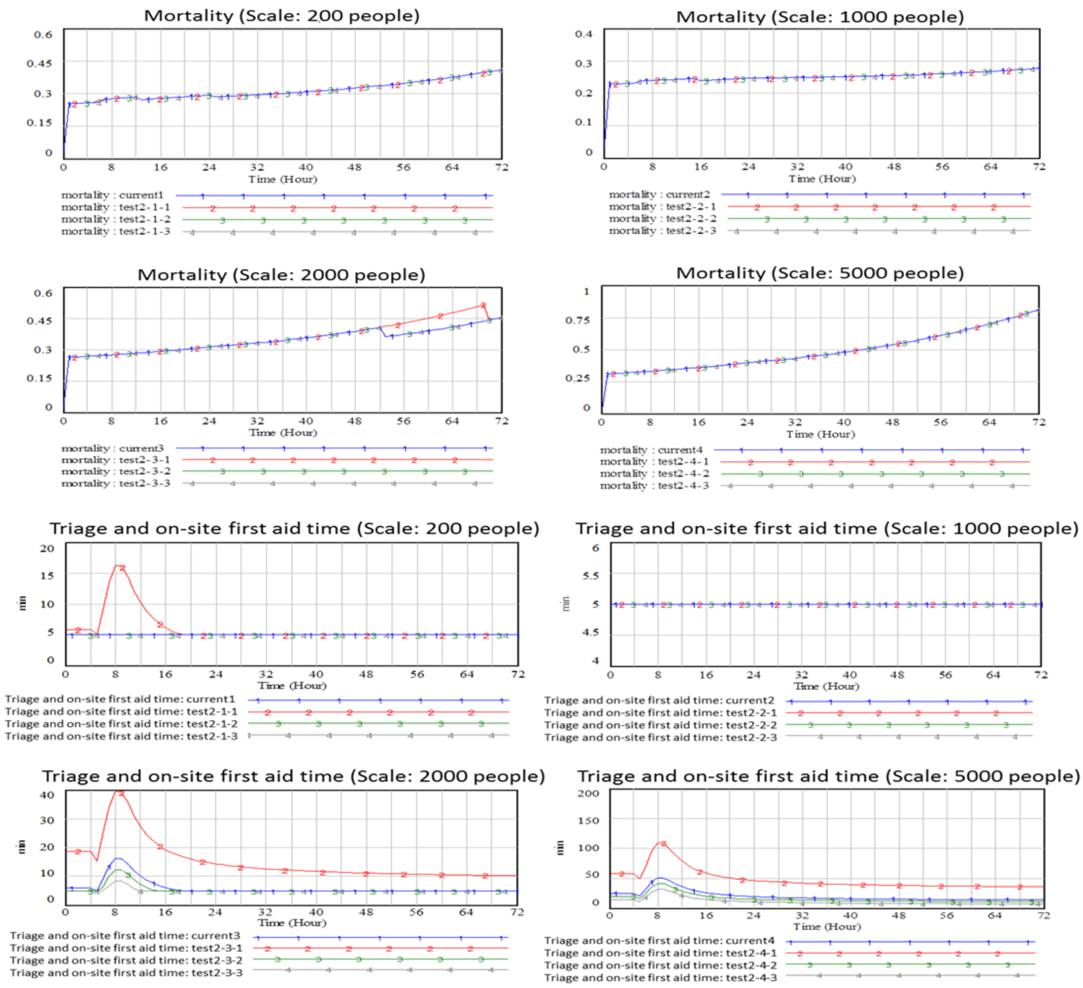

Figure 6-4. Intervention experiment 3 results.

6.3 Policy recommendations

According to the intervention experiment results, there is still considerable room for improvement in the emergency medical rescue system efficiency in MCIs. Different emergency medical rescue protocols were used for different scales of mass casualties; they mainly shorten the pre-hospital duration and increase the organization command implementation rate. Maximal application of these resources can increase rescue efficiency to the maximum.

(1) The mortality rate of MCIs will increase as the scale increases. The current emergency medical rescue system can only satisfy small-scale rescue, and the efficiency of large-scale rescue is low.

First, this model assumes that the trauma treatment capacities of hospitals are the sum of the capacities of ten tertiary hospitals in Shanghai. This scale of treatment capacity can basically satisfy treatment for 5000 people and less. However, when the population base is more than

5000, the current treatment capacity is significantly insufficient, suggesting that treatment forces from more hospitals should be dispatched. Second, the current organizational command implementation rate is low, particularly within four hours, which is the optimal rescue period for casualties. However, there is no significant increase in the organizational command implementation rate during this period. This may be because the government emergency organizational command department has a slower response rate, and different rescue departments only employ routine rescue protocols and do not carry out emergency medical rescue suitable for mass casualties. The organizational command implementation rate shows a significant increase within four–five hours, showing that four hours after trauma is the timepoint with optimal efficiency for organizational command. However, this has passed the critical rescue period. At five hours after trauma, rescue has basically reached the intra-hospital treatment stage. At this stage, the organizational command implementation rate shows a drastic and continuous decrease. A possible reason for this is the disorderly organizational implementation in the hospital, which makes it difficult to adapt to emergency medical rescue in MCIs. These results suggest that increasing the 4-hour organizational command implementation rate and accelerating the time of appearance of the implementation rate peak has significance for the pre-hospital emergency medical rescue. Increasing the 5–8-hour organizational command implementation rate and shortening the duration of decrease in the implementation rate can increase intra-hospital treatment efficiency. In addition, the current timeliness of pre-hospital duration is poor and only reaches good levels when the number of mass casualties is 200. This suggests that existing treatment medical resources cannot satisfy emergency medical rescue for mass casualties. In particular, pre-hospital rescue is extremely late for MCIs with 1000 or more casualties, which is far from the standard of the "platinum 10 minutes and golden hour." Analysis of the pre-hospital duration structure found that rescue significantly lags behind injury examination and treatment time when there are more than 2000 casualties. An insufficient number of rescue medical staff is the major limiting factor, which results in casualties queuing at the site and large numbers of retained casualties. Due to limitations in the number of ambulances, the rapid evacuation of casualties cannot be carried out, and the evacuation duration shows a significant increase as the scale of the traumatic event increases. Therefore, increasing the number of emergency medical staff for traumatic events with 2000 or more casualties and increasing the number of ambulances according to the scale of the traumatic event are key to shortening pre-hospital duration.

(2) The timeliness of pre-hospital duration is mainly determined by the number of dispatchable ambulances and dispatch rate, and the number of dispatchable emergency medical staff.

Increasing the number of dispatchable ambulances and their dispatch rate has no significant effects on treatment efficiency for 200 casualties, but drastic reduction in the number of dispatchable ambulances will increase the trauma mortality rate, suggesting that the existing number of dispatchable ambulances is sufficient to meet this scale of rescue requirements and allocation should not be decreased. For traumatic events with 1000 casualties, increasing the number of ambulances and their dispatch rate can effectively increase the timeliness of 24h pre-hospital duration and decrease trauma mortality rate within the period. This suggests that this scale of medical rescue can increase the number of ambulances within 24 hours, which increases efficiency during the critical rescue period. At the same time, current allocation levels can be restored after 24 hours to prevent wastage of medical resources and temporary additional ambulances can be withdrawn. When the population base reaches 2000, the existing number of ambulances will be unable to satisfy mass casualty treatment and will require a drastic increase in the number of ambulances and their dispatch rate to decrease medical evacuation lag, increase treatment efficiency, and decrease mortality rate. It is worth noting that the intervention experiment protocol set for this study does not have any effect on traumatic events with 5000 or more casualties. This may be because this experimental protocol is unable to satisfy medical needs at this scale. Due to severe insufficiency in resource allocation, it is difficult to reach the threshold for increasing rescue efficiency and not produce effects on pre-hospital duration and trauma mortality rate.

(3) The effects of changes in the number of emergency medical staff on trauma mortality rate is not significant and increasing the number of emergency medical staff allocated is not the key to increasing treatment efficiency.

Experimental results showed that increasing the number of emergency medical staff can significantly decrease the injury examination and treatment duration for 2000 or more casualties; the effects are most significant at 4–16 hours for a scale of 2000 casualties and there are continuous effects on a scale of 5000 casualties. These results suggest that although the current intervention protocol cannot decrease the trauma mortality rate, increasing the number of emergency medical staff, adopting timelier and more rational on-site first aid measures, and reducing on-site first aid duration can decrease the probability of conditions worsening in 2000 or more casualties. In addition, increasing the number of emergency medical staff can increase triaging speed and the accuracy of triage, thereby increasing intra-hospital treatment efficiency. It is worth noting that increasing the number of emergency medical staff has continuous effects on the injury examination and treatment duration for 5000 casualties. This once again suggests that the existing number of emergency medical staff is unable to satisfy medical needs at this scale and requires a large increase in resource allocation.

7 Policy intervention experiment of community first aid for casualties

Authors: Jing Du, Yincheng Wang, Lulu Zhang

7.1 Model simulation

Community casualty first aid refers to the administration of timely and effective first aid in the community on emergency patients before the arrival of pre-hospital emergency staff [56,57]. Community casualty first aid is an extension of pre-hospital first aid and is becoming more and more valued in the pre-hospital first aid network.

In the first aid domain, time is life and saving lives is a race against time. After sudden illness and traumatic events have occurred, whether patients can obtain first aid within the "platinum 10 minutes and golden hour" is an important indicator of first aid efficiency. According to epidemiological surveys, 80% of emergencies occur in the community [58-60]. Communities are the basic unit of social management, an important site for residents to work and live, and are also the first site of disaster and direct patient treatment, and a frontline in disaster relief and emergencies. Community health service institutions are an important foundation of urban health service system and include basic medical services such as community on-site emergency ambulances and other public health services [61,62]. Due to various limitations, there is no connection between the community health service system and the emergency medical service system in China at the moment. This causes 120 pre-hospital emergency staff to be unable to reach the site within 10 minutes. Therefore, inclusion of community health service institutions in the emergency medical service system, complete utilization of its station distribution, and familiarity with the health status of community residents will enable community emergency staff to reach the site faster and provide the most basic first aid measures for severe casualties. This will effectively shorten the response time, reduce mortality rate and morbidity, and increase pre-hospital emergency performance and the health response capacity for public emergencies in the community.

7.1.1 Model introduction

Construction of a community first aid system agent model revolves around pre-hospital resuscitation success rates and critical influencing factors. Integrated optimization of community first aid resources, increasing organizational efficiency, and solving problems such as longer first aid response time and irrational use of first aid resources were carried out for an optimal and feasible pre-hospital first aid service protocol as they improve the efficiency and quality of pre-hospital first aid.

(1) In structural analysis, this model involves the first on-site responder, community medical resources, pre-hospital first aid force, and the hospital emergency department. After initiation of different first aid modes, linked behaviors or decision rules constitute a first aid network. Different behaviors or decision protocols produce different causal relationships, thereby deciding the dynamic changes of the entire system. In this model, the site of cardiac arrest casualties, response speed of the emergency department, location of the community first aid site, first aid capability of medical staff, and first aid resource allocation are all important influencing factors affecting pre-hospital resuscitation success rates.

(2) The community casualty first aid network agent model includes five agents, namely, the patient that called the pre-hospital first aid services, first responder, 120 emergency center (station), community health service center (station), and secondary and tertiary emergency department. The various agents are linked to and affect each other. Pre-hospital first aid casualties refer to critically ill patients who called for emergency medical services out of the hospital. The first responder refers to the on-site person(s) that provide first aid to sudden injury or critically ill patients, and includes people beside the patient (relatives, colleagues, EMS

paramedics, policeman, fireman, security guard, etc.) who usually participate in first aid training, are awarded training-related certificates, and who use first aid knowledge and techniques to save patients. The 120 emergency center is the core strength of pre-hospital first aid and its response speed and response force is determined by the rescue protocol of the government organizational command department. The emergency response time by the 120 emergency center, time of arrival at the site, on-site first aid time, and duration of emergency transportation to the emergency department of a nearby hospital jointly determine the pre-hospital first aid duration. The community health service center (station) is an important component of pre-hospital first aid resources. Combining the convenience and accessibility strengths of community health services with pre-hospital first aid can greatly expand pre-hospital first aid services, enabling first aid services to be available to community residents, and effectively increase the operating efficiency of the pre-hospital first aid system [63]. The emergency department of this hospital is mainly responsible for taking over from the pre-hospital first aid force after on-site treatment and evacuation, communicating and cooperating with pre-hospital emergency staff, opening a green channel, and pre-admission preparatory work for patients, thereby constituting a complete first aid chain of “disease onset-pre-hospital first aid-emergency department treatment-admission.”

(3) On the basis of the pre-hospital first aid simulation model, three groups of intervention experiments were carried out by using the community health service institution factor, first responder factor, and ratio of defibrillator as intervention parameters. The parameters were adjusted to see if they affected first aid response time and cardiopulmonary resuscitation success rate. Specifically, construction of the pre-hospital first aid community agent model and analysis of factors affecting pre-hospital first aid can effectively increase the operational efficiency of pre-hospital first aid; the major benefits are as follows.

(a) Effectively shorten the first aid response time: Prominent characteristics of community health service institutions are convenience and accessibility. If community health services institutions are included in the pre-hospital first aid network, the emergency dispatcher will first inform the nearest community medical staff to reach the site after receiving an emergency call. These staff can provide effective first aid before emergency medical staff reach the site and save patients’ lives thereby decreasing the mortality rate and morbidity. At the same time, community medical staff are familiar with the terrain and people of that community and can assist pre-hospital emergency staff to reach the site accurately and assist in effective on-site treatment [63,64].

(b) Providing reliable past medical history and aiding disease evaluation and judgment: Health records of community residents are stored in community health services institutions. Therefore, community physicians are more familiar with the past medical history and treatments of high-risk populations in the community and can provide reliable and detailed case reports to pre-hospital emergency staff and the emergency department of the hospital; this helps in evaluation and determination of the patient’s condition.

(c) Improving the treatment efficiency of pre-hospital emergency staff: After the emergency dispatcher has conducted a preliminary evaluation of the patient’s condition, he/she will instruct nearby community medical staff to go to the site for treatment. Most non-critically ill patients can be properly treated by community physicians, thereby restricting limited pre-hospital emergency resources. In community medical services, if patients who are difficult to treat or require hospitalization due to condition changes are encountered, timely handovers with pre-hospital first aid institutions and the emergency department of hospitals are carried out so that patients can be transferred efficiently and accurately to a nearby hospital with treatment capacity.

(d) Determination of high-risk community population, improving the self-treatment and mutual treatment capabilities of community residents: Community medical staff possess a more comprehensive understanding of the medical history, treatment status, and address of community high-risk populations, which facilitates focused monitoring of the population for community first aid and proposing corresponding plans. At the same time, community medical staff can carry out targeted first aid education for patients and their family members [61,64]. Community medical staff can periodically conduct pre-hospital first aid knowledge and skills training in community residents to improve their pre-hospital first aid awareness, self-treatment, and mutual treatment capabilities.

(e) Act as an outpost for evacuation after community emergencies occur: Community medical staff are the first line of defense for community emergencies. When public emergencies occur, they are able to accurately inform treatment staff of the emergency's status, assist in on-site investigation, guide evacuation, and rapidly conduct on-site first aid, thereby assisting subsequent medical evacuation.

(f) Tracker for subsequent treatment of community residents: When emergency patients have received effective treatment in specialist medical institutions and require long-term recovery in medical institutions due to stable conditions, community physicians can carry out subsequent treatment. Community physicians participate in first aid and rehabilitation, possess a comprehensive understanding of disease onset and treatment in patients, and can act as a tracker for subsequent treatment in such patients, which will improve subsequent treatment results and prevent adverse events from reoccurring [65].

7.1.2 Simulation commissioning

Simulation commissioning of the model includes effectiveness validation and sensitivity analysis.

(1) Effectiveness validation of the model

Five-year continuous pre-hospital first aid data of Shanghai's Minhang district were used for fit analysis of the model simulation results. Simulation analysis was used to observe the conditions of casualties, pre-hospital first aid response time, and resuscitation success rate for critically ill patients. This thereby proves that this model is reliable and robust.

(2) Model sensitivity analysis

Model sensitivity analysis is used to observe whether drastic changes will occur when some parameters and structure are changed; these are used to assess the reliability and rationality of the model. To carry out parameter sensitivity analysis, sensitivity parameters must first be confirmed and limited to a reasonable range to observe the variation range of the model. The simulation results of this study showed that changes that affect these constants will result in minor fluctuations to the output variable (pre-hospital first aid success rate) but will not cause drastic fluctuations; it can be seen that the model is stable and suitable for simulation analysis.

7.2 Policy intervention experiment

7.2.1 Intervention experiment 1: intervention experiment of first aid-community

(1) First aid-community intervention experiment protocol

(a) Model operation rules

(I) Community health service institutions are included in the community first aid system. When cardiac arrest cases occur, the emergency center and community health service center are notified. While emergency staff and ambulances are dispatched from the emergency center, the nearest community health service center (station) will dispatch medical staff (equipped with a first aid box and defibrillator) to reach the site on emergency electric cars. (If the emergency center staff takes a shorter time to reach the site, community health service staff do not need to be dispatched). After community health service staff have reached the site, they will immediately carry out on-site first aid while waiting for emergency center staff to arrive. After emergency center staff has arrived, they will continue on-site first aid on the patient and decide whether to continue on-site first aid or transport the patient to a secondary or tertiary hospital for resuscitation according to the patient's condition.

(II) If on-site resuscitation exceeds 30 minutes and the patient is dead, the patient will no longer be transported (except when the patient's family members request transport).

(III) Giving up treatment by physician: Resuscitation is not carried out when the patient is decapitated, incinerated, decomposed, or stiffened, or when the brain, liver, or heart have separated from the body.

(b) Significance of variables and parameters

(I) Classification of cardiorespiratory arrest: Cardiorespiratory arrest can be classified into three types according to the location: Death after emergency vehicle has arrived on site, on-site death, and en route death.

(II) Number of cardiorespiratory arrest patients requiring cardiopulmonary resuscitation = number of en route deaths + number of successful cardiopulmonary resuscitation patients + (number of on-site deaths – number of deaths due to giving up treatment by the physician – number of deaths due to treatment refusal by family members).

Notes: Giving up treatment by physician means that resuscitation is not carried out when the patient is decapitated, incinerated, decomposed, or stiffened, or when the brain, liver, or heart have separated from the body.

(III) Number of en route or on-site deaths: This number is 1/10 of the total number of cardiorespiratory arrest patients. As medical staff are beside the patient during death, the actual resuscitation duration is less than four minutes, and the default cardiopulmonary resuscitation success rate is 50%.

(IV) Emergency response time: Emergency response duration from emergency vehicle arrival to death = emergency call time (one minute) + vehicle dispatch time (one minute) + time taken for emergency staff to arrive on site from the emergency center (station) or for the community physician to arrive on site from the community center (station). The emergency response time for en route or on-site death is one minute.

(V) Emergency vehicle speed: The main mode of transport for patients by the Shanghai emergency center is emergency vehicles. During peak periods, differences in urban and suburban roads will result in different degrees of road congestion. This causes differences in the speed of emergency vehicles at different times. The speed of emergency vehicles in an independent factor affecting the emergency response time. Analysis of the data provided by the emergency center showed that the mean speed of emergency vehicles at various time periods is as follows.

Table 7-1. Mean speed of emergency vehicles at various times.

Transportation tool	Working hours	Speed (km/hour) urban, suburban areas	Speed (km/hour) outskirts
Emergency cars	20:00-07:00	24	40
	07:00-08:00	14	
	08:00-09:00	16.8	
	09:00-10:00	21	
	10:00-11:00	18.7	
	11:00-12:00	16.8	
	12:00-13:00	14	
	13:00-14:00	14	
	14:00-15:00	21	
	15:00-16:00	16.8	
	16:00-17:00	18.7	
	17:00-18:00	16.8	
	18:00-19:00	12	

(VI) Speed of emergency electric car: As community health service centers (stations) are more concentrated than emergency centers (stations), the first aid radius is 2–3 km, and community physicians can be transported by electric cars equipped with a first aid kit (containing an AED) to the site for first aid. The speed is as follows.

Table 7-2. Mean speed of emergency vehicles at various times.

Transportation tool	Working hours	Speed (km/hour) urban, suburban areas	Speed (km/hour) outskirts
Emergency electric car	08:00–17:00	20	20
	17:00–08:00 (+1)	0	0

(VII) Cardiopulmonary resuscitation success rate: As first aid response time increases, cardiopulmonary resuscitation success rate decreases. On-site duration time: First aid treatment generally does not last more than half an hour, except when on-site cardiopulmonary resuscitation is required for cardiac or respiratory arrest.

Table 7-3. Changes in pre-hospital cardiopulmonary resuscitation success rate as emergency response time changes.

Emergency response time	Pre-hospital cardiopulmonary resuscitation success rate (survival rate)
< 1 min	90%
1–3 min	70–80%
3–5 min	50%
5–6 min	40%
6–7 min	30%
8–9 min	20%
9–10 min	10%
>10 min	1%

(VIII) On-site duration time: First aid treatment generally does not last more than half an hour, except when on-site cardiopulmonary resuscitation is required for cardiac or respiratory arrest.

(IX) Latitudes and longitudes of various emergency centers (stations), community health service centers (stations), and secondary and tertiary hospitals (with emergency departments) in Shanghai.

(X) Defibrillation start time: After emergency staff have reached the site, first aid and defibrillation will be carried out according to the patient's condition. This can therefore be regarded as the emergency response time by default.

(2) First aid-community intervention experiment results

The emergency center first aid + community health center first aid model was activated by using Shanghai as an example and the operation duration was one year. A total of 7212 cardiorespiratory arrest patients requiring cardiopulmonary resuscitation occurred, cardiopulmonary resuscitation success rate was 11.36%, and mean first aid response time was shortened by 3.77 minutes compared with the simulated emergency center model. The cardiopulmonary resuscitation success rate was 11.36%, which was an increase of 6.78% compared with 4% of the current average level for the entire city. This is shown in Table 7-4.

Table 7-4. First aid-community first aid model intervention experiment results.

Operation method	Model operation duration (hours)	Number of cardiorespiratory arrest patients	Number of successful cardiopulmonary resuscitation cases	Cardiopulmonary resuscitation success rate
Simulation	8783	7351	337	4.58%
Intervention experiment 1	8788	7212	819	11.36%

7.2.2 Intervention experiment 2: intervention experiment of first aid, community, and first responder

(1) First aid-community-first responder intervention experiment protocol

(a) Model operation rules

(I) When cardiorespiratory arrest occurs, the first responder will first call for help, determine the patient's condition, and carry out on-site first aid. The actual cardiopulmonary resuscitation skill level of the first responder and first aid knowledge popularization rate were used to determine the first responder's first aid skill, which in turn determines the cardiopulmonary resuscitation success rate. One minute after calling for help, the community first aid and emergency center model was activated so that nearby emergency staff could reach the site as soon as possible for further first aid and transportation, thereby increasing the survival rate for cardiorespiratory arrest patients.

(II) When the first responder is treating the patient, first aid ability is multiplied by cardiopulmonary resuscitation success rate before comparison with the cardiopulmonary resuscitation success rate after emergency center staff or community physicians have reached the site. The higher of the two values is used as the final cardiopulmonary resuscitation success rate.

(III) If on-site resuscitation exceeds 30 minutes and the patient is dead, the patient will no longer be transported (except when the patient's family members request transport).

(IV) Giving up treatment by physician: Resuscitation is not carried out when the patient is decapitated, incinerated, decomposed, or stiffened, or when the brain, liver, or heart have separated from the body.

(b) Significance of variables and parameters

Model parameters

(I) Classification of cardiorespiratory arrest: Cardiorespiratory arrest can be classified into three types according to the location: Death after emergency vehicle has arrived on site, on-site death, and en route death.

(II) Number of cardiorespiratory arrest patients requiring cardiopulmonary resuscitation = number of deaths during transportation + number of successful cardiopulmonary resuscitation patients + (number of on-site deaths – number of deaths due to giving up treatment by the physician – number of deaths due to treatment refusal by family members).

Notes: Giving up treatment by physician means that resuscitation is not carried out when the patient is decapitated, incinerated, decomposed, or stiffened, or when the brain, liver, or heart have separated from the body.

(III) Number of on-site deaths or deaths during transport: This number is 1/10 of the total number of cardiorespiratory arrest patients. As medical staff are beside the patient during death, the actual resuscitation duration is less than one minute and the default cardiopulmonary resuscitation success rate is 90%.

(IV) Emergency response time:

Emergency center first aid + community health center first aid + responder first aid model emergency response time = first aid start time of first responder (one–three minutes).

If the responder does not possess first aid skills, intervention experiment 1 is used for operation.

Emergency response time from emergency vehicle arrival to death = emergency call time (one minute) + vehicle dispatch time (one minute) + time taken for emergency staff to arrive on site from the emergency center (station) or for the community physician to arrive on site from the community center (station).

The emergency response time for en route or on-site death is one minute.

(V) Emergency vehicle speed: The main mode of transport for patients by the Shanghai emergency center is emergency vehicles. During peak periods, differences in urban and suburban roads will result in different degrees of road congestion. This causes differences in the speed of emergency vehicles at different time periods. The speed of emergency vehicles in an independent factor affecting the emergency response time. Analysis of the data provided by the emergency center was used to obtain the mean speed of emergency vehicles at various time periods (Table 7-1).

Speed of emergency electric car: As community health service centers (stations) are more concentrated than emergency centers (stations), the first aid radius is two–three km and community physicians can be transported by electric cars equipped with a first aid kit (containing an AED) to the site for first aid. Table 7-2 shows the specific speed.

(VI) Cardiopulmonary resuscitation success rate: As first aid response time increases, cardiopulmonary resuscitation success rate decreases.

Table 7-5. Cardiopulmonary resuscitation success rate of first responder (without AED).

Start time for cardiopulmonary resuscitation by first responder	Cardiopulmonary resuscitation success rate
<4 min	40-50%
4-6 min	10%
6-10 min	4%
>10 min	1%

Table 7-6. Cardiopulmonary resuscitation success rate of emergency center staff and community physicians.

Emergency response time	Pre-hospital cardiopulmonary resuscitation success rate (survival rate)
< 1 min	90%
1–3 min	70–80%
3–5 min	50%
5–6 min	40%
6–7 min	30%
8–9 min	20%
9–10 min	10%
>10 min	1%

(VII) On-site dwell time: First aid treatment generally does not last more than half an hour, except when on-site cardiopulmonary resuscitation is required for cardiac or respiratory arrest.

(VIII) Latitudes and longitudes of various emergency centers (stations), community health service centers (stations), and secondary and tertiary hospitals (with emergency departments) in Shanghai.

(IX) First aid ability of first responder: The operational ability of first responders is divided into four grades: grade 1: medical staff; grade 2: People who periodically participate in standardized first aid training; grade 3: People who participated in standardized first aid training but did not undergo periodic refreshers; grade 4: People who did not participate in any first aid training. The first aid abilities of various persons are arranged as follows.

Table 7-7. First aid ability of various persons and occurrence probability.

Persons	First aid ability	Occurrence probability
Operational ability of medical staff	1	0.5%
Periodic participation in standardized training	50%	0.5%
Participated in standardized first aid training and mastered first aid but did not undergo periodic refreshers (every two years)	28%	1%
Did not participate in training	0%	98%

Under the joint activation model for emergency center (station), community health service center (station), first responder, the cardiopulmonary resuscitation success rate of the first responder is multiplied by first aid ability.

Note: In all first aid models, only the emergency vehicle from the emergency center is responsible for sending the casualty to secondary/tertiary hospitals.

(2) First aid-community-first responder intervention experiment results

The emergency center first aid + community health center first aid + first responder first aid model was activated by using Shanghai as an example and the operation duration was one year. A total of 7326 cardiorespiratory arrest patients requiring cardiopulmonary resuscitation occurred, and the cardiopulmonary resuscitation success rate was 13.26%. From this, we can see that cardiopulmonary resuscitation success is three times the current level when first responders are included as volunteers in the pre-hospital first aid system. This is shown in Table 7-8.

Table 7-8. First aid-community-first responder first aid model intervention experiment results.

Operation method	Model operation duration (hour)	Number of cardiorespiratory arrest patients	Number of successful cardiopulmonary resuscitation cases	Cardiopulmonary resuscitation success rate
Simulation	8783	7351	337	4.58%
Intervention experiment 2	8784	7326	976	13.32%

7.2.3 Intervention experiment 3: intervention experiment of first aid, community, first-responder, and AED

(1) First aid-community-first responder-AED intervention experiment protocol

(a) Model operation rules

(I) Existing AED (476 AEDs) model operation rules: When cardiorespiratory arrest occurs, the first responder will first call for help, determine the patient's condition, and carry out on-site first aid. The actual cardiopulmonary resuscitation skill level of the first responder and first aid knowledge popularization rate were used to determine the first responder's first aid skill and the time required to retrieve the nearest defibrillator (AED) is used to determine the cardiopulmonary resuscitation success rate. One minute after calling for help, the community first aid and emergency center model was activated so that nearby emergency staff could reach the site as soon as possible for further first aid and transportation, thereby increasing the survival rate for cardiorespiratory arrest patients.

(II) AED density operation rules: When the first responder is treating the patient, if the AED is retrieved before arrival of emergency center staff or community physicians, first aid ability is multiplied by the cardiopulmonary resuscitation success rate before comparison with the cardiopulmonary resuscitation success rate after emergency center staff or community physicians have reached the site. The higher of the two values is used as the final cardiopulmonary resuscitation success rate.

When the first responder is treating the patient, if the nearest AED is not retrieved before the arrival of professional personnel, first aid ability is multiplied by cardiopulmonary resuscitation success rate before comparison with the cardiopulmonary resuscitation success rate after emergency center staff or community physicians have reached the site. The higher of the two values is used as the final cardiopulmonary resuscitation success rate.

If on-site resuscitation exceeds 30 minutes and the patient is dead, the patient will no longer be transported (except when the patient's family members request transport).

(III) Giving up treatment by physician: Resuscitation is not carried out when the patient is decapitated, incinerated, decomposed, or stiffened, or the brain, liver, or heart have separated from the body.

(b) Significance of variables and parameters

Model parameters

(I) Classification of cardiorespiratory arrest: Cardiorespiratory arrest can be classified into three types according to the location: Death after emergency vehicle has arrived on site, on-site death, and en route death.

(II) Number of cardiorespiratory arrest patients requiring cardiopulmonary resuscitation = number of deaths during transportation + number of successful cardiopulmonary resuscitation patients + (number of on-site deaths – number of deaths due to giving up treatment by the physician – number of deaths due to treatment refusal by family members).

Notes: Giving up treatment by physician means that resuscitation is not carried out when the patient is decapitated, incinerated, decomposed, or stiffened, or the brain, liver, or heart have separated from the body.

(III) Number of on-site deaths or deaths during transport: This number is 1/10 of the total number of cardiorespiratory arrest patients. As medical staff are beside the patient during death, the actual resuscitation duration is less than one minute and the default cardiopulmonary resuscitation success rate is 90%.

(IV) Emergency response time: Emergency center first aid +community health center first aid + responder first aid model emergency response time = first aid start time of first responder (one–three minutes).

If the responder does not possess first aid skills, intervention experiment 1 is used for operation.

Emergency response time from emergency vehicle arrival to death = emergency call time (one minute) + vehicle dispatch time (one minute) + time taken for emergency staff to arrive on site from the emergency center (station) or for the community physician to arrive on site from the community center (station).

The emergency response time for en route or on-site death is one minute.

(V) Emergency vehicle speed: The main mode of transport for patients by the Shanghai emergency center is emergency vehicles. During peak periods, differences in urban and suburban roads will result in different degrees of road congestion. This causes differences in the speed of emergency vehicles at different time periods. The speed of emergency vehicles in an independent factor affecting the emergency response time. Analysis of the data provided by the emergency center was used to obtain the mean speed of emergency vehicles at various times (Table 7-1).

Speed of emergency electric car: As community health service centers (stations) are more concentrated than emergency centers (stations), the first aid radius is two–three km, and community physicians can be transported by electric cars equipped with a first aid kit (containing an AED) to the site for first aid. Table 7-2 shows the speed.

(VI) Cardiopulmonary resuscitation success rate: As first aid response time increases, cardiopulmonary resuscitation success rate decreases. The cardiopulmonary resuscitation success rate of first responder (without AED) is the same as Table 7-6. The cardiopulmonary resuscitation success rate for emergency center staff, community physicians, and first responders (with AED) is the same as Table 7-10.

(VII) On-site duration time: First aid treatment generally does not last more than half an hour, except when on-site cardiopulmonary resuscitation is required for cardiac or respiratory arrest.

(VIII) Latitudes and longitudes of various emergency centers (stations), community health service centers (stations), and secondary and tertiary hospitals (with emergency departments) in Shanghai.

(IX) Defibrillation start time: Under model 1, as the first responder does not carry a defibrillator (AED), other responders will retrieve the nearest AED.

Defibrillation start time (minutes) = distance between AED and incident site *2/10 (km/hour = distance (m)*12/1000).

Under model 2, the defibrillator density (S) at AED/m^2 was set

$$S\ (m^2) = \pi\times(r\text{^}2) = \text{extraction of the root of } S/\pi$$

$$\begin{gathered}\text{First responder defibrillation start time (minutes)}\\ = r\ (km) * 2/10\ (km/hour) * 60\\ = \text{extraction of the root of } S/\pi * 2/10\ (km/hour) * 60\\ = \text{extraction of the root of } S/\pi * 12\end{gathered}$$

If the AED was not retrieved before emergency center staff or community physician reached the site, the defibrillation start time is the arrival time of professional personnel.

(X) Latitude and longitude of sites in which defibrillators (AEDs) are installed in Shanghai at present.

(XI) First aid ability of first responder: The operational ability of first responders is divided into four grades: grade 1: Medical staff; grade 2: People who periodically participate in standardized first aid training; grade 3: People who participated in standardized first aid training but did not undergo periodic refreshers; grade 4: People who did not participate in any first aid training. The first aid ability of various persons and occurrence probability are the same as Table 7-8.

Under the joint activation model for emergency center (station), community health service center (station), first responder, the first aid response time of the first responder is one–three minutes and the cardiopulmonary resuscitation success rate of the first responder must be multiplied by first aid ability.

Note: In all first aid models, only the emergency vehicle from the emergency center is responsible for sending the casualty to secondary/tertiary hospitals.

(2) First aid-community-first responder-AED intervention experiment protocol

Shanghai was used as an example and the emergency center first aid + community health center first aid + responder (AED) first aid model was activated; there are 476 AEDs in the city and operation duration was one year. A total of 7351 cardiorespiratory arrest cases requiring cardiopulmonary resuscitation occurred, and the cardiopulmonary resuscitation success rate was 14.79%. The defibrillator density was set as 2.78 per m^2, and operation duration was one year. A total of 7340 cardiorespiratory arrest cases requiring cardiopulmonary resuscitation occurred, and cardiopulmonary resuscitation success rate was 13.07%. Therefore, increasing the mean AED density does not effectively increase the cardiopulmonary resuscitation success rate, and AED should be rationally placed at public places with high population density according to the actual situation to effectively shorten the emergency notification time and ensure first aid quality. This is shown in Table 7-9.

Table 7-9. First aid-community-first responder first aid model intervention experiment results.

Operation method	Model operation duration (hour)	Number of cardiorespiratory arrest patients	Number of successful cardiopulmonary resuscitation cases	Cardiopulmonary resuscitation success rate
Simulation	8783	7351	337	4.58%
Intervention experiment 3 (Existing 476 AEDs)	8787	7351	1087	14.79%
Intervention experiment 3 (2.78 AEDs/m^2)	8789	7340	959	13.07%

7.3 Policy recommendations

Currently, the pre-hospital first aid system of China has inherited the traditional station model, which is independent of community health services and cannot be combined with the advantages of community health services. Manpower, material, and first aid technique limitations in community health services centers have left them unable to conduct simple first aid treatment before the arrival of emergency vehicles, and the best timing for patient resuscitation is missed. At the same time, it is difficult for the community health service system to independently bear a large burden, high intensity, and multi-layered first aid tasks out of the hospital due to hardware and software limitations. In addition, unified coordination cannot be carried out due to regional limitations. If these service centers are allowed to develop independently, it will inevitably lead to institutional overlap and resource wastage. Referencing the successful experiences of foreign countries by establishing community first aid stations, utilizing the advantages of the pre-hospital first aid system and community health service centers, and a close combination of secondary and tertiary medical institutions in the community to form a comprehensive community first aid network is a future trend in the development of a first aid medical service system.

(1) Rational planning and scientific operation of first aid stations

(a) Overall planning of the community health services network and pre-hospital first aid network construction based on the local "regional health plan." As the setting rules for the two systems are generally identical, that is, a specific service population, service radius, and urban population coverage are considered, therefore a first aid station could be set up at every community health service center and appropriate adjustments made according to the characteristics of the two types of institutions. Community health services centers that are not included in the first aid station construction plan must also shoulder pre-hospital first aid responsibilities and obligations. The construction of community first aid stations must satisfy construction criteria, and the number of ambulances should be determined according to the scale and characteristics of the community first aid service population. In communities with crowded traffic, these centers can be equipped with motorcycles and bicycles. Specific requirements for the first aid station management system may not be needed. First aid stations may dispatch institutions in municipal or district emergency centers or be set up in the community by community organizations (such as Red Cross); they may be constructed by hospitals or constructed alone by community health services centers. A station construction application can be made to the health administrative department only when the station conforms to the construction criteria and first aid network plan.

(b) Organizational structure: As a component of the pre-hospital emergency network, all first aid stations must comply with the command and dispatch by the emergency command center, undergo supervision and management by the health administrative department, shoulder the responsibility of pre-hospital first aid, and conduct first aid work according to the pre-hospital first aid medical service standards.

(c) Staff composition: The staff of the community first aid station can be drawn from the first aid backbone of the community health service center dispatch center or from the "120" emergency center. After community first aid staff have undergone unified pre-hospital first aid theory and actual practice with the vehicles, they will execute pre-hospital first aid tasks after passing their examinations. Through rational planning and arrangement of community health services institutions and emergency institutions and on the basis of ensuring the completion of pre-hospital first aid tasks, staff can participate in the shifts and medical services of the community health services center. To some extent staff from both units can be used interchangeably to facilitate improvement in their operation levels. Understanding the health status and health risk factor of community residents, monitoring the risk factor of various critical illnesses at any time, and aggressive intervention for potential emergencies will enable staff to have an idea of the patient's condition once emergencies occur, enabling them to employ safe and effective first aid measures and increasing the resuscitation success rate.

(d) Information resource sharing: Achieving information sharing from the information systems of community health services centers and "120" emergency system. The medical files of residents in the community health services center can be used by the "120" emergency system. Once a call from the community resident is received, the health data of that resident can be made immediately accessible so that emergency staff can understand the resident's past medical history, which will facilitate the implementation of resuscitation treatment. A general practitioner information database of the community under the jurisdiction of the emergency command and dispatch institution can be constructed so that emergency command and dispatch staff can obtain first aid resource data on that community at any time and determine whether on-site management should be carried out by community physicians or a first aid team should be dispatched on top of management by community physicians according to the disease type and condition of the patient. Regulations are used to clarify the responsibilities and obligations of community health services institutions, and general practitioners who participate in first aid services. The community health services information system should be accessible for emergency dispatch staff so that the command and dispatch staff can conveniently obtain information about patients to facilitate command, dispatch, and coordination with the treatment hospital in a timely manner.

(e) Community screening: Daily medical service, periodic physical examinations, and population disease screening can be used to obtain information on high-risk populations. The special service requirements of high-risk populations and residents can be used to advocate for consultation with a community emergency call system that connects families, community health services centers, and command and dispatch centers.

(2) Strengthening first aid skills training and promotion and popularization of first aid knowledge

Improving the community first aid level is dependent on the first aid capabilities of the professional emergency team as well as the level of mastery of first aid knowledge and skills in ordinary residents. Community medical staff can participate in pre-hospital first aid work by utilizing the geographical advantages of community health services centers as well as the understanding of residents' health status by community physicians. This will increase the pre-hospital first aid treatment capabilities of community health service staff and improve the emergency response time, while simultaneously increasing the management and utilization rate of residents' medical files. Community health services service staff and pre-hospital emergency staff can be rotated to increase the professional first aid skills of community medical staff while effectively solving the problem of streaming ≥ 45-year-old pre-hospital emergency staff. At present, the most prominent problem in community first aid is the lack of trust in the first aid level of general practitioners by residents. Therefore, strengthening the first aid knowledge and skills training of general practitioners and improving their pre-hospital first aid level is key to constructing a community-based pre-hospital first aid network. Systematic and standardized first aid training requirements for general practitioners can be proposed according to the "General Practitioner Training Outline" and "Pre-hospital Emergency Staff Entry Criteria and Training," so that they have a basic grasp of advanced life support techniques.

Studies have shown that the first aid awareness and level of first aid knowledge of the community first responder in most emergency call sites directly affect the treatment measures used, thereby affecting the resuscitation success rate of critical patients. The popularization of first aid knowledge and skills is a common responsibility of community health services centers and emergency stations. The faculty strength of pre-hospital emergency institutions and community health services institutions should be used to periodically conduct first aid knowledge training for community residents to improve the effectiveness of first aid by first responders. Utilizing the advantage that community health services institutions are located near community residents, guiding community residents, particularly high-risk populations and family members, and timely and accurate calls for help, self-treatment, mutual treatment, hazard avoidance, and escape when emergencies occur can be used to achieve correct on-site first responder and effective first aid medical services by the first responder at any time and place thereby increasing the overall first aid level.

(3) Improving the medical rescue capabilities for public emergencies in the community

With the establishment of the binary urban community and specialist medical system in China, there is unprecedented construction and development of community health services; the community health services network is basically formed, and the “six agencies in one body” function is gradually realized. As a basic function of community health services, community first aid is gradually achieved. The national community health services policy specifies the requirements for community first aid services: The national community health services institution construction standards clearly stipulate essential basic first aid equipment and devices. The General Practitioner Training Outline stipulates that general practitioners must undergo 30 hours of emergency first aid training in addition to theoretical learning to lay a foundation for community first aid services. Community health services institutions possess the basic conditions for conducting first aid medical service: Although community health services institutions are not officially included in the municipal first aid medical service system, they possess basic first aid functions as a basic role of community health services and this will play an important role in medical service practice [65]. Some communities have accumulated certain first aid medical service experience: Their community health services institutions will carry out certain unique community first aid medical services according to the actual situation of that community.

A medical rescue mechanism for public emergencies in the community should be established, the “response plan for public emergencies in the community should be drafted,” and the division of labor according to job roles should be carried out to shoulder the community medical rescue role for public emergencies. Strengthening cooperation between residents’ committees, police stations, fire stations, security, and housekeeping companies, expanding first aid concepts to every aspect of community life, and conducting aggressive intervention for possible first aid problems should be carried out. Defibrillators should be installed in public places in a reasonable manner, health bureaus and the Red Cross should increase the installation density of defibrillator and utilize Internet media to announce additional defibrillator sites and other relevant information in a timely manner so that defibrillators are accessible and can provide a safe and convenient first aid network for citizens.

8 Policy intervention experiment of hospital emergency treatment

Authors: Haiping Chen, Wenya Yu, Lulu Zhang

8.1 Model simulation

8.1.1 Model introduction

(1) Model definition: Hospital emergency treatment of traumatic events

With the increasing acceleration of urban development and construction, the number of migrants in cities and population mobility has increased, which causes an increase in various types of traffic accidents, construction and accident injuries, resulting in frequent batches of casualties seeking medical treatment [66,67]. In recent years, the incidence of mass casualty incidents in cities has increased, particularly in large cities. Around the world, mass casualty incidents such as the September 11 attacks in the United States, Indian Ocean tsunami, Wenchuan earthquake, Tianjin explosions, and Jiangsu tornado, have occurred [68]. Due to the sudden production of large numbers of casualties in mass casualty incidents, casualties are treated in batches. Because of the suddenness of the event, large numbers of casualties, and complex and severe injuries [69], there are higher requirements for the hospital emergency treatment system [70]. At the same time, there are limited emergency treatment resources in hospitals. When instantaneous patient flow is overly high, such as during mass casualty events, there is a continuous influx of a large number of patients in the emergency department and existing mature emergency treatment procedure and measures in the hospital are unable to meet the treatment needs of a large number of trauma patients. This causes congestion and prolongs patient retention time in the emergency department, which further exacerbates congestion and results in a vicious cycle [71,72]. In recent years, frequent mass casualty events in cities have increased the emergency response stress in the emergency departments of hospitals, thereby resulting in adverse effects on the outcomes of trauma patients [73].

With the development of modeling theory and computer software techniques, foreign scholars have started applying modeling techniques in trauma response studies [74]. In these studies, simulation and further optimization of trauma emergency treatment procedures and resources were used to promote scientific and rational trauma treatment procedures [75]. This study started from the perspective of medical management to conduct management resource allocation simulation experiments for possible irrational emergency manpower resource allocation problems in trauma treatment in tertiary hospitals' emergency departments. It was intended to provide theoretical support for rational allocation of emergency manpower resources (types and number of medical staff) according to changes in the number of patients in the emergency department (patient flow and injury severity proportion) and ensure that there was sufficient medical staff allocated to alleviate the stress of concentrated consultation in the emergency department. At the same time, this avoided manpower resource wastage and increased the ability to respond to increased medical needs. Discrete event simulation and the AnyLogic software platform were used to construct simulation models for possible low emergency manpower resource allocation efficiency during trauma treatment in tertiary hospitals according to the hospitals' actual trauma treatment process and to conduct an exploratory study on emergency manpower resource allocation for the emergency department. The aim of the model was to simulate and analyze the effects of adjustments to emergency manpower resource allocation on treatment efficiency in the emergency department, examine optimization protocols for emergency manpower resource allocation, increase the ability of hospitals to respond to increased medical needs, and ultimately reduce the risk of death in trauma patients.

(2) Model procedure analysis: Hospital emergency treatment procedure for trauma casualties

First, rational simplification and assumption concerning the trauma treatment process in hospital emergency departments, and determination of model parameters (including the type and number of medical manpower resources, classification of patients by injury severity, types of examination equipment resources) and operation were carried on. Second, trauma patient arrival in hospitals, pretesting and triaging, condition diagnosis, patient treatment, and the basic procedures and model subjects of other stages were analyzed by using logic structure and operating procedures for dynamic simulation of the treatment procedure of patients in the hospitals' emergency departments. Finally, under the premise that the proportion of injury severity of trauma patients was fixed, the mortality rate of trauma patients, patient retention time, and manpower resource utilization rate were used as evaluation markers to simulate and analyze the effects of adjustments to medical manpower resource allocation on emergency department treatment efficiency, and to study emergency manpower resource allocation optimization protocols in different instantaneous patient flows for certain medical service targets.

The trauma hospital emergency department treatment model included four submodules (patient arrival module, pre-test and triage module, condition diagnosis module, and patient treatment module). Each module could operate independently. The patient arrival module involved the transportation of trauma patients and patient arrival in the hospital. The severity of trauma patients who required emergency department treatment in this module included mild-moderate, severe, and critical categories. Based on the treatment procedure for emergency department patients in multiple tertiary hospitals in Shanghai and data from the literature, it was assumed that the pre-testing and triage module was completed by two nurses at the nursing station. After pre-testing and triaging, trauma patients would enter the condition diagnosis stage in which physicians would diagnose the patient's condition or carry out basic vital signs support. This stage required medical manpower resources (general physicians and experts) and medical material resources (examination equipment resources) as emergency medical resources. Finally, the emergency manpower resources in the trauma patient treatment module included general physicians, experts, and nurses. Patients with different injury severity required different medical manpower for treatment. The operating rule for this module was that critically ill patients were given priority for treatment. Based on the survival duration of patients, patients with short resuscitation survival duration had the treatment priority and treatment descending order was critical, severe, and mild-moderate.

8.1.2 Simulation commissioning

(1) Effectiveness confirmation of the theoretical model

The existing patient consultation procedure for emergency department patients in multiple tertiary hospitals in Shanghai is used for checking the agent framework and overall procedure for the constructed models in this study. In addition, many emergency physicians were invited to review the procedure for the logical framework and submodules in this module to ensure that the specific procedure of the model matches the actual operating procedure for trauma treatment in the emergency department of the hospital so that the constructed model matches reality. In addition, the group members also carried out strict testing of the computer program method and content used for modeling to ensure that the model programming language is correct.

(2) Model internal effectiveness evaluation

As the internal structure of the model contained some randomness, the output results from multiple repeated model operations were used in this study to confirm that the random variability of the internal structure of the model. According to the on-site follow-up investigation of trauma patients in the emergency department and emergency department medical staff interviews, under the premise of fixed injury severity proportion—the percentage of mild-moderate, severe, and critical patients was 70.8%, 21.2%, and 8.0%, respectively—when the instantaneous patient flow was 20, the emergency manpower resource allocation default protocol (three experts, six general physicians, and ten nurses) was run 100 times, and there were the output results which showed that the maximum absolute error for most output results was within the acceptable range and the random variability of the internal structure of the model was low.

Table 8-1. Model internal effectiveness evaluation.

Simulation output results	Category	Variation range	Maximum absolute error
Patient mortality rate	Mortality rate of mild-moderate patients	0.000–0.000	0.000
	Mortality rate of severe patients	0.000–0.000	0.000
	Mortality rate of critical patients	0.320–0.480	0.160
	Mean mortality rate	0.032–0.048	0.016
Retention time (minutes)	Retention time of mild-moderate patients	56.486–58.911	2.425
	Retention time of severe patients	90.893–94.122	3.229
	Retention time of critical patients	139.530–145.569	6.039
	Mean retention time	96.010–99.067	3.057
Manpower resource utilization rate	Experts	0.624–0.645	0.021
	General physicians	0.606–0.618	0.012
	Nurses	0.509–0.523	0.014

8.2 Policy intervention experiment

8.2.1 Intervention experiment 1: intervention experiment of emergency manpower resource allocation

(1) Emergency manpower resource allocation adjustment experimental protocol

The evaluation markers for trauma treatment efficiency in the emergency department of the hospital included patient mortality rate, emergency department retention time, and manpower resource utilization rate, which were used to simulate the effects of emergency manpower resource allocation adjustment on emergency treatment efficiency. The number of model iterations was 200, and the mean statistical values of model operation were obtained. Under the premise of fixed trauma severity proportion, a single manpower resource quantity in the model was successively adjusted when the instantaneous patient flow was 20 and the effects of this adjustment on emergency treatment efficiency were observed.

Under the premise of fixed injury severity proportion (the percentage of mild-moderate, severe, and critical patients was 70.8%, 21.2%, and 8.0%, respectively), when the instantaneous patient flow was 20, a single manpower resource in the default emergency manpower resource allocation protocol (three experts, six general physicians, and ten nurses) was adjusted to two persons/time and the effects of allocation adjustment of experts, general physicians, and nurses on emergency treatment efficiency were observed.

(2) Emergency manpower resource allocation adjustment experiment results

(a) Adjustment to number of experts

Assuming that the number of general physicians and nurses remained unchanged, the adjustment range for the number of experts was from 1 to 9. Table 8-2 showed the model operation results. Adjustments to the number of experts had significant effects on the mortality rate of trauma patients and emergency department retention time. The simulation results showed that when the number of experts was increased from one to five, the mortality rate of critical and severe trauma patients was significantly decreased from 83.3% to 37.0% and 60.6% to 0.0%, respectively. However, when the number of experts increased to a certain number, the mortality rate of various injury severity patients plateaued. This showed that as the number of experts increased, the effects on emergency treatment efficiency showed diminishing marginal effects.

When the number of specialists was overly low (decreased from three to one), the mean retention time in the emergency department for trauma patients would significantly increase (from 97.428 minutes to 183.171 minutes). The retention time of severe patients increased from 91.644 to 213.855 minutes, and the retention time of critical patients increased from 143.188 minutes to 170.966 minutes, with severe patients showing a greater increase in retention time. In addition, data in Table 8-2 show that as the number of experts increases (from one to nine), the utilization rates of general physicians and nurses first increased before becoming stable.

Table 8-2. Model operation results for adjustment to number of experts.

Evaluation marker	Category	1 expert	3 experts	5 experts	7 experts	9 experts
Patient mortality rate	Mortality rate of mild-moderate patients	0.000	0.000	0.000	0.000	0.000
	Mortality rate of severe patients	0.606	0.000	0.000	0.000	0.000
	Mortality rate of critical patients	0.838	0.440	0.370	0.375	0.362
	Mean mortality rate	0.205	0.044	0.037	0.037	0.036
Retention time (minutes)	Retention time of mild-moderate patients	164.691	57.453	57.162	56.957	56.904
	Retention time of severe patients	213.855	91.644	89.094	88.899	86.519
	Retention time of critical patients	170.966	143.188	139.267	138.537	139.583
	Mean retention time	183.171	97.428	95.174	94.798	94.335
Manpower resource utilization rate	Experts	0.892	0.638	0.399	0.282	0.221
	General physicians	0.381	0.616	0.644	0.631	0.639
	Nurses	0.249	0.519	0.541	0.533	0.540

Note: Emergency department retention time was defined as the period from entry of trauma patient into the emergency department to confirmed treatment measures. This included the pre-testing and triage stage (time taken for triaging and waiting time before triaging), condition diagnosis stage (time taken for diagnosis and diagnosis waiting time), and waiting time before confirmed treatment measures.

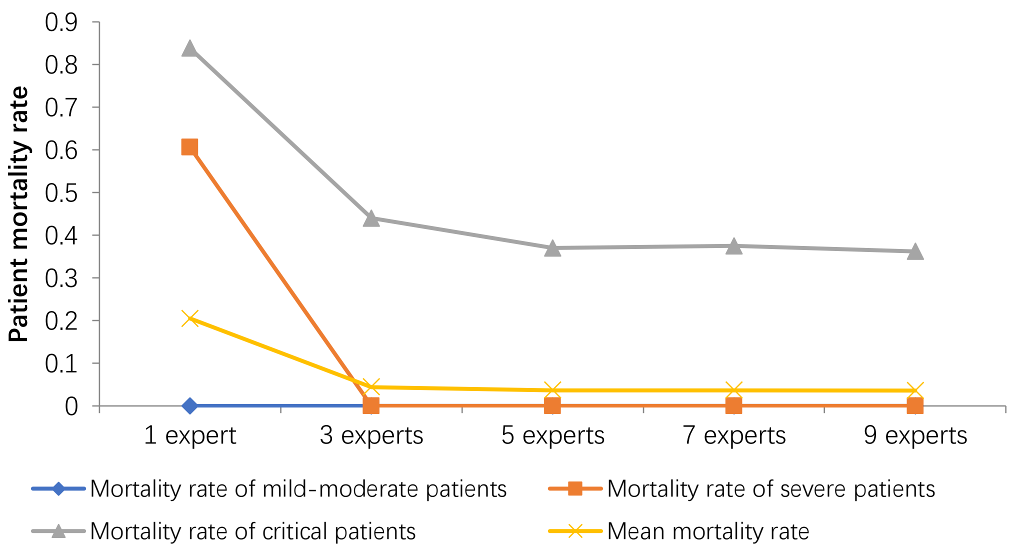

Figure 8-1. Effects of adjustment in number of experts on patient mortality rate.

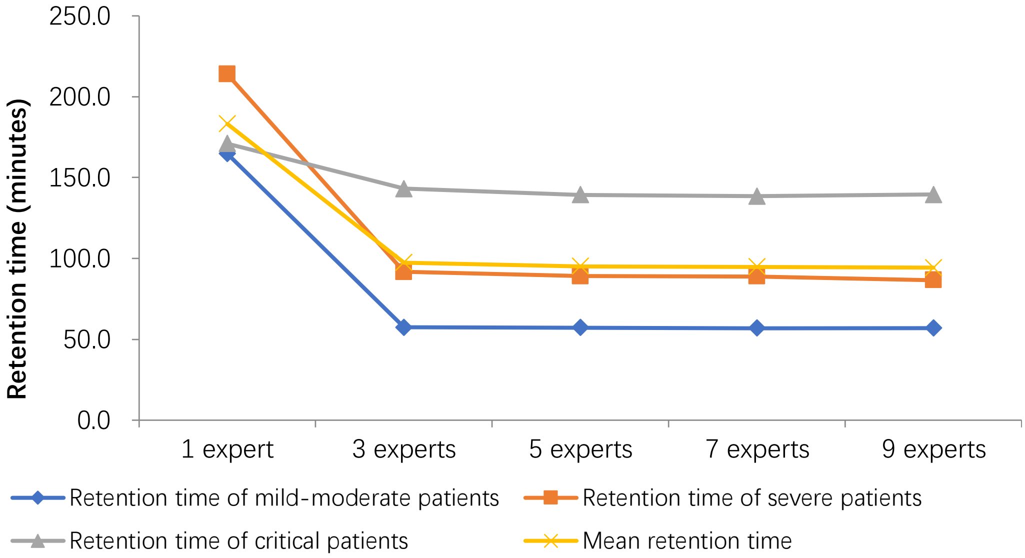

Figure 8-2. Effects of adjustments to number of experts on retention time.

(b) Adjustment to number of general physicians

Assuming that the number of experts and nurses remained unchanged, the adjustment range for the number of general physicians was from 4 to 12. Table 8-3 showed the model operation results. In this model, as the number of general physicians increased (from four to eight), the mean mortality rate and mean emergency department retention time of trauma patients gradually decreased, and the manpower resource utilization rates of experts and nurses increased. After the number of general physicians in the default protocol (n = 6) was increased by four, further increases resulted in minor effects on various evaluation indices.

The simulation results showed that when the number of general physicians was decreased from six to four, the mortality rate of severe patients was increased from 0.0% to 3.4%, and the mortality rate of critical patients increased from 44.0% to 54.2%; mean emergency department retention time of trauma patients increased from 97.428 to 123.806 minutes, of which the retention times for mild-moderate, severe, and critical patients increased by 19.579, 33.215, and 26.340 minutes, respectively.

Table 8-3. Model operation results for adjustment to number of general physicians.

Evaluation marker	Category	4 physicians	6 physicians	8 physicians	10 physicians	12 physicians
Patient mortality rate	Mortality rate of mild-moderate patients	0.000	0.000	0.000	0.000	0.000
	Mortality rate of severe patients	0.034	0.000	0.000	0.000	0.000
	Mortality rate of critical patients	0.542	0.440	0.435	0.430	0.417
	Mean mortality rate	0.061	0.044	0.043	0.043	0.042
Retention time (minutes)	Retention time of mild-moderate patients	77.032	57.453	52.184	50.396	50.510
	Retention time of severe patients	124.859	91.644	87.257	87.316	87.330
	Retention time of critical patients	169.528	143.188	144.463	143.413	141.781
	Mean retention time	123.806	97.428	94.635	93.708	93.207
Manpower resource utilization rate	Experts	0.561	0.638	0.642	0.646	0.636
	General physicians	0.811	0.616	0.469	0.372	0.310
	Nurses	0.457	0.519	0.525	0.523	0.520

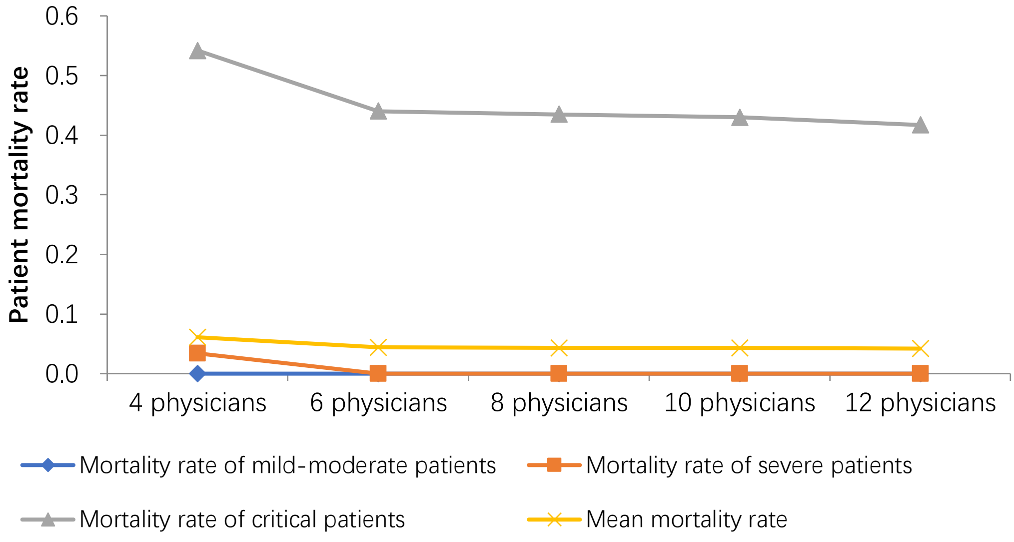

Figure 8-3. Effects of adjustment to number of general physicians on patient mortality rate.

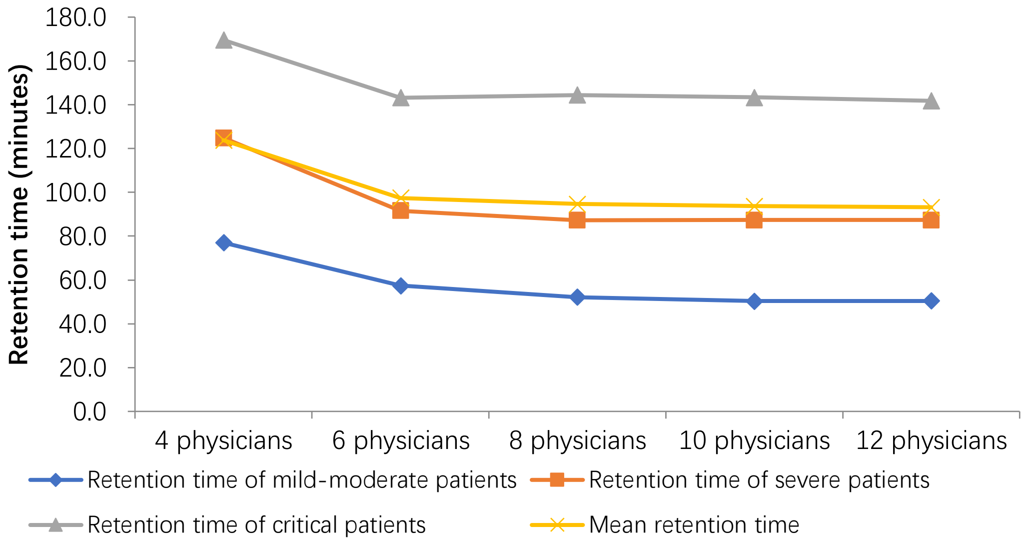

Figure 8-4. Effects of adjustments to number of general physicians on retention time.

(c) Adjustment to number of nurses

Assuming that the number of physicians remained unchanged, the adjustment range for the number of nurses was from 6 to 14. The following table showed the model operation results. In this model, the adjustment range of the ratio of nurses was 0.64–1.50. The simulation results showed that when the number of nurses was increased from eight, the effects on patient mortality rate, physician utilization rate, and emergency department retention time were minor. However, when the number of nurses was decreased from eight to six, the mean mortality rate of trauma patients was increased from 4.7% to 7.1% and mean retention time was increased from 97.529 to 115.917 minutes. Among these patients, the retention time was increased by 5.610, 17.431, and 32.124 minutes in mild-moderate, severe, and critical patients, respectively, of which the increase was the greatest for critical patients.

Table 8-4. Model operation results for adjustment to number of nurses.

Evaluation marker	Category	6 nurses	8 nurses	10 nurses	12 nurses	14 nurses
Patient mortality rate	Mortality rate of mild-moderate patients	0.000	0.000	0.000	0.000	0.000
	Mortality rate of severe patients	0.030	0.020	0.000	0.000	0.001
	Mortality rate of critical patients	0.667	0.463	0.440	0.427	0.445
	Mean mortality rate	0.071	0.047	0.044	0.043	0.045
Retention time (minutes)	Retention time of mild-moderate patients	64.070	58.460	57.453	57.302	57.621
	Retention time of severe patients	109.063	91.632	91.644	90.035	92.744
	Retention time of critical patients	174.618	142.494	143.188	144.828	143.829
	Mean retention time	115.917	97.529	97.428	97.388	98.065
Manpower resource utilization rate	Experts	0.577	0.637	0.638	0.637	0.639
	General physicians	0.556	0.622	0.616	0.621	0.619
	Nurses	0.780	0.653	0.519	0.435	0.372

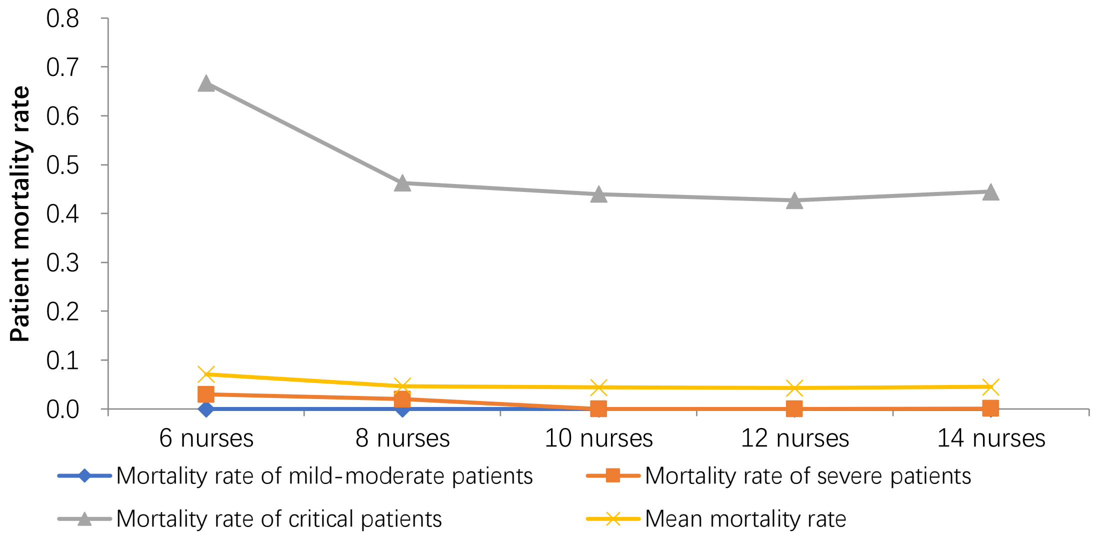

Figure 8-5. Effects of adjustment to number of nurses on patient mortality rate.

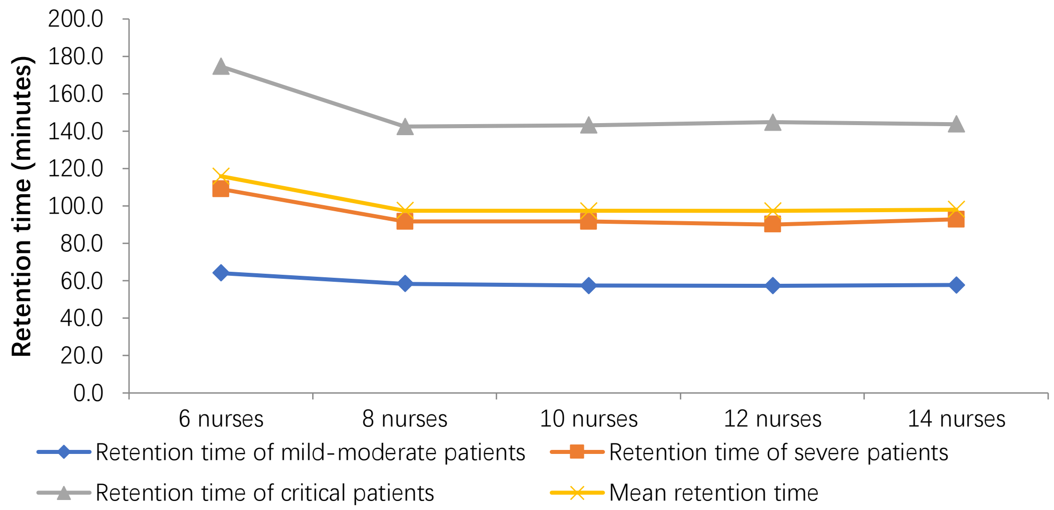

Figure 8-6. Effects of adjustment to number of nurses on retention time.

The model operation results on the effects of adjustments to emergency manpower resource allocation on emergency treatment efficiency showed that given a certain patient flow, the allocation of medical staff should match the severity proportion of different trauma patients. Under the premise that the severity proportion of patients was fixed and the instantaneous patient flow was 20, reasonable increase in the number of experts (chief or deputy chief physician) could significantly decrease the mortality rate of severe and critical trauma patients, affect the emergency department retention time of patients, and increase the utilization rate of general physicians and nurses. As the disease worsened quickly in severe and critical trauma patients and the mortality rate at the early stage of emergency consultation was high, when the proportion of severe or critical trauma patients was high, emergency department management should dispatch more experts as early as possible for trauma treatment to decrease the risk of death of these patients and prevent congestion due to retention of a large number of patients in the emergency department. This was significant in increasing the emergency treatment efficiency. In addition, when the allocation of general physicians (attending or resident physicians) and nurses was insufficiency, the risk of death of trauma patients, particularly critical patients, would increase and emergency department retention time would also increase. However, for a certain scale of trauma, an excessive increase in the numbers of general physicians and nurses would have minor effects on increasing emergency treatment efficiency and would drastically decease the utilization rate of emergency manpower resources, leading to resource wastage. During emergency manpower resource allocation in the emergency department by hospital management, the treatment results of trauma patients and manpower resource utilization rates should be considered so that there are sufficient medical staff to alleviate stress caused by overload in the emergency department and also avoid wastage of medical staff.

8.2.2 Intervention experiment 2: intervention experiment of emergency manpower resource allocation for different instantaneous patient admission volumes

(1) Protocol for intervention experiment of emergency manpower resource allocation for different instantaneous patient admission volumes

This model was used to conduct exploratory studies on emergency manpower resource allocation under different instantaneous patient flows. On the basis of certain hospital service targets and fixed proportion of injury severity, the emergency manpower resource allocation optimization protocol was simulated when instantaneous patient flow was 20, 30, and 40.

In this study, the number of emergency manpower resources estimated by emergency department medical staff for different trauma patients was used as a default protocol for this model. Under the premise that the severity proportion of trauma patients was fixed as mild-moderate (70.8%), severe (21.2%), and critical (8.0%), the AnyLogic modeling software was used to conduct the optimization experiment to examine the optimal protocols for experts, general physicians, and nurses when instantaneous patient flow was 20, 30, and 40, respectively.

Literature data were used for analysis of trauma patients' treatment data in the emergency department of tertiary hospitals and historical data of mass casualty events, which are summarized as follows: Liang et al. analyzed 1020 trauma patients admitted to the emergency department and found that the mean treatment duration was 73.0 ± 41.0 minutes, the emergency department treatment duration of severe trauma patients was 82.0 ± 47.0 minutes, and the mortality rate of trauma patient was 7.8% [76]. Li et al. [77] conducted a survey of 5464 trauma patients in the emergency department and found that the retention time was less than two hours for 95.0% of trauma patients, and the mortality rate of trauma patients was 4.6%. Ye et al. conducted a survey of emergency department retention of 1046 multiple trauma patients and found that the median retention time was 4.4 hours (lowest: 2.8 hours, highest: 14.0 hours). Wang et al. [78] conducted a survey of the retention time of 1084 severe trauma patients in the green channel of the emergency department and found that the 87.7% of severe trauma patients had a retention time less than 3 hours and a mortality rate of 3.5%. In the 2010 Nanjing Explosion, the emergency department of the Nanjing Drum Tower Hospital treated 124 trauma patients (34 with severe injuries) and one died (mean mortality rate: 0.8%, mortality rate of severe patients: 2.9%) [79]. In the 2015 Tianjin Explosion, the emergency department of the Chinese People's Armed Police Force Medical College Affiliated Hospital treated 298 trauma patients (11 with critical injuries) and three died (mean mortality rate: 1.0%, mortality rate of critical patients: 27.3%) [80].

In the optimization experiment for this model, the adjustment range for experts, general physicians, and nurses was fixed at 1~50 and the number of model iterations was 200. The mean values of the final statistical model operation were used as the optimized protocol for emergency manpower resource allocation in the emergency department. The model constraint condition assumptions are as follows: Firstly, based on the aforementioned literature data on emergency treatment of trauma cases, the services targets for the emergency departments in tertiary hospitals were set as follows: mortality rate of trauma patients ≤ 5.0%, mean emergency department retention time for trauma patients: ≤ 110.0 minutes. Secondly, to prevent exhaustion of medical staff during emergency treatment, the utilization rate of various types of medical manpower resources should not exceed 80.0%. Thirdly, the total medical manpower resource allocation was obtained from the smallest value from solving the MIN function and the function was set as (Nexpert * Lexpert + Ndoctor * Ldoctor + Nnurse * Lnurse) where Nexpert, Ndoctor, and Nnurse represent the number of various types of medical manpower resources. Variable L represents the medical capability of medical staff and the medical capability for nurses, general physicians, and experts was set as Lnurse = 10, Ldoctor = 20, and Lexpert = 30 according to the literature data [81-83]. The higher the value, the higher the medical capability of the medical staff.

(2) Emergency department emergency manpower allocation optimization experiment results for different instantaneous patient flow

(a) Allocation optimization protocol for instantaneous patient flow of 20

When instantaneous patient flow was 20, the default protocol (experts: 3, general physicians: 6, nurses: 10) was input into the trauma emergency manpower resource allocation model. The simulation results showed that the mean mortality rate for trauma patients was 4.4%, of which the mortality rate for critical patients was 44.0%; the mean emergency department retention time for trauma patients was 97.428 minutes, of which the retention time for mild-moderate, severe, and critical patients was 57.453, 91.644, and 143.188 minutes, respectively. At this time, the utilization rate for experts, general physicians, and nurses was 63.8%, 61.6%, and 51.9 %, respectively.

When instantaneous patient flow was 20, the model output for emergency manpower resource allocation optimized protocol was five experts, eight general physicians, and nine nurses. Comparative analysis of the optimized protocol and default protocol found that firstly, the mean mortality rate of trauma patients in the optimized protocol decreased to 3.8%, and the mortality rate of critical patients decreased to 37.8%. Secondly, the mean emergency department retention time for trauma patients decreased to 93.205 minutes. The retention time for mild-moderate, severe, and critical patients was 53.292, 85.756, and 140.567 minutes, respectively. Thirdly, the utilization rate for experts, general physicians, and nurses in the optimized protocol was 38.6%, 46.9%, and 58.2%, respectively.

Table 8-5. Comparison of default protocol and optimized protocol when instantaneous patient flow was 20.

Evaluation marker	Category	Default protocol	Optimized protocol
Manpower resource allocation (n)	Experts	3	5
	General physicians	6	8
	Nurses	10	9
Patient mortality rate	Mortality rate of mild-moderate patients	0.000	0.000
	Mortality rate of severe patients	0.000	0.000
	Mortality rate of critical patients	0.440	0.378
	Mean mortality rate	0.044	0.038
Retention time (minutes)	Retention time of mild-moderate patients	57.453	53.292
	Retention time of severe patients	91.644	85.756
	Retention time of critical patients	143.188	140.567
	Mean retention time	97.428	93.205
Manpower resource utilization rate	Experts	0.638	0.386
	General physicians	0.616	0.469
	Nurses	0.519	0.582

(b) Allocation optimization protocol for instantaneous patient flow of 30

When instantaneous patient flow was 30, the model simulation results for the emergency manpower resource allocation default protocol (5 experts, 9 general physicians, and 15 nurses) showed that: the mean mortality rate of trauma patients was 4.9%, of which the mortality rate for critical patients was 71.0%; the mean emergency department retention time for trauma patients was 110.202 minutes, of which the retention time for mild-moderate, severe, and critical patients was 61.506, 105.046, and 164.053 minutes, respectively. At this time, the utilization rate for experts, general physicians, and nurses was 42.5%, 47.1%, and 38.4%, respectively.

When instantaneous patient flow was 30, the optimized protocol for emergency manpower resource allocation contained 8 experts, 10 general physicians, and 13 nurses. The following table showed the various output data from the model. Comparative analysis of the optimized protocol and default protocol found that in the optimized protocol, the mean mortality rate for trauma patients and the mortality rate for critical patients was 4.5% and 65.0%, respectively; and the mean emergency department retention time for trauma patients was 101.230 minutes, of which the retention time for mild-moderate, severe, and critical patients was 6.990, 5.313, and 14.611 minutes, respectively. In the optimized protocol, the utilization rate for experts, general physicians, and nurses was 21.0%, 42.3%, and 43.9%, respectively.

Table 8-6. Comparison of default protocol and optimized protocol when instantaneous patient flow was 30.

Evaluation marker	Category	Default protocol	Optimized protocol
Manpower resource allocation (n)	Experts	5	8
	General physicians	9	10
	Nurses	15	13
Patient mortality rate	Mortality rate of mild-moderate patients	0.000	0.000
	Mortality rate of severe patients	0.002	0.000
	Mortality rate of critical patients	0.710	0.650
	Mean mortality rate	0.049	0.045
Retention time (minutes)	Retention time of mild-moderate patients	61.506	54.516
	Retention time of severe patients	105.046	99.733
	Retention time of critical patients	164.053	149.442
	Mean retention time	110.202	101.230
Manpower resource utilization rate	Experts	0.425	0.210
	General physicians	0.471	0.423
	Nurses	0.384	0.439

(c) Allocation optimization protocol for instantaneous patient flow of 40

When instantaneous patient flow was 40, the model simulation results for the emergency manpower resource allocation default protocol (9 experts, 12 general physicians, and 18 nurses) showed that the mean mortality rate of trauma patients was 6.7%, of which the mortality rate for critical patients was 87.2%; and the mean emergency department retention time for trauma patients was 127.993 minutes, of which the retention time for mild-moderate, severe, and critical patients was 70.641, 123.924, and 189.415 minutes, respectively. At this time, the utilization rate for experts, general physicians, and nurses was 36.1%, 41.8%, and 37.8%, respectively.

When instantaneous patient flow was 40, the optimized protocol for emergency manpower resource allocation included 13 experts, 18 general physicians, and 22 nurses. Under this optimized protocol, the simulation output results showed that the mean mortality rate for trauma patients, and the mortality rate for critical patients decreased to 4.9% and 67.5%, respectively; and the mean emergency department retention time for trauma patients was 108.230 minutes, of which the retention time for mild-moderate, severe, and critical patients was 11.151, 18.781, and 29.359 minutes, respectively. In the optimized protocol, the utilization rate for experts, general physicians, and nurses was 19.5%, 28.2%, and 31.2%, respectively.

Table 8-7. Comparison of default protocol and optimized protocol when instantaneous patient flow was 40.

Evaluation marker	Category	Default protocol	Optimized protocol
Manpower resource allocation (n)	Experts	7	13
	General physicians	12	18
	Nurses	18	22
Patient mortality rate	Mortality rate of mild-moderate patients	0.000	0.000
	Mortality rate of severe patients	0.001	0.000
	Mortality rate of critical patients	0.872	0.675
	Mean mortality rate	0.067	0.049
Retention time (minutes)	Retention time of mild-moderate patients	70.641	59.490
	Retention time of severe patients	123.924	105.143
	Retention time of critical patients	189.415	160.056
	Mean retention time	127.993	108.230
Manpower resource utilization rate	Experts	0.361	0.195
	General physicians	0.418	0.282
	Nurses	0.378	0.312

The model simulation results from the emergency manpower resource allocation default protocol suggests that there are some problems during the emergency treatment of trauma patients at present in the emergency department of tertiary hospitals: Firstly, the mortality rate for critical patients is high. This is consistent with the actual situation. Critical patients usually have multiple traumatic injuries and the incidence of lethal traumatic injuries such as hemopneumothorax, and organ rupture, are higher, and the condition of disease worsened quickly. During treatment in hospitals, such patients tend to develop shock, loss of consciousness, respiratory arrest, cardiac arrest, and other acute complications. Therefore, the risk of death is higher. Secondly, the emergency department retention time of trauma patients is longer. In this situation, the emergency departments of hospitals will be occupied by large numbers of trauma patients who are queuing and awaiting treatment for a long period of time. This may result in congestion in the emergency department, thereby affecting the service quality and emergency treatment efficiency of medical staff.

The emergency manpower allocation simulation results for different instantaneous patient flow under certain hospital services showed that when the instantaneous patient flow was 20, compared with the default protocol (three experts, six general physicians, and ten nurses), increasing the number of experts and general physicians by 66.7% and 33.3%, respectively, and reducing the number of nurses by 10.0% was a better emergency manpower allocation method. When the instantaneous patient flow was 30 and compared with the default protocol (five experts, nine general physicians, and 15 nurses), increasing the number of experts and general physicians by 60.0% and 11.1%, respectively, and reducing the number of nurses by 13.3% was a better emergency manpower allocation method. When the instantaneous patient flow was 40, compared with the default protocol (7 experts, 12 general physicians, and 18 nurses), increasing the number of experts and general physicians by 85.7% and 50.0%, respectively, and increasing the number of nurses by 22.2% was a better emergency manpower allocation method.

8.3 Policy recommendations

(1) Deepening hospital trauma emergency treatment modeling research

Trauma caused by various reasons has become a public health problem seriously affecting people's life and health. Continuous increase in urban mechanization, increasing traffic congestion, tall residential buildings, and continuous increase in permanent population density are all factors that result in increasing risk of trauma. In 2013, more than 4.78 million people died of trauma in the world every year. According to the U.S. Centers for Disease Control, there are 27 million patients in USA who are treated at the emergency department due to trauma every year, of whom 3 million are hospitalized. In 2011, Injury Study Report in China pointed out that the total number of people who died of various types of trauma in China has reached 700000 every year, and trauma is the primary cause of death and disability of people under 45 years old. The Chinese Statistical Yearbook showed that trauma is the fifth leading cause of death. The mortality rate due to trauma in urban and rural residents in China in 2014 was 37.77 (1/100000) and 55.29 (1/100000), respectively. An increase in trauma and mass casualty events has caused a rapid increase in residents' demands for trauma emergency services. Shanghai faces a serious challenge in emergency organization for trauma, particularly in mass casualty events.

After trauma patients arrive at the emergency department of hospitals, they will first be sent to the nursing station for examination and classification of injuries. Medical staff will carry out initial evaluation and triage based on respiratory status, circulation status, bleeding, and level of consciousness. Patients with different trauma severity will be further segregated, of which mild-moderate and severe casualties will enter the centralized waiting area to wait for consultation while physicians and nurses will immediately carry out resuscitation on critical patients. The outcomes of trauma patients after emergency treatment are mainly dependent on two factors: patient factors (age, trauma mechanism, trauma site, trauma condition, and trauma severity) and medical institution factors (overall healthcare capacity, timeliness and effectiveness of treatment, and complications). For hospitals, patient factors represent the worsening speed of disease and medical resources to be occupied. For example, when the condition of critical patients worsens rapidly, patients require more medical manpower and material resources. Carrying out model construction and operation analysis through introduction of discrete event modeling, agent modeling, and other modeling theories and different modeling software can provide more quantifiable improvement methods for hospital emergency trauma treatment studies. Our study started from the perspective of medical management and employed discrete event simulation and AnyLogic software to conduct an exploratory study on emergency manpower resource allocation for trauma patients. The treatment process of trauma patients in the emergency departments of tertiary hospitals was used as the study subject. The simulation results on the effects of adjustments to emergency manpower resource allocation on emergency treatment efficiency showed that under a certain scale of trauma patients, the allocation of medical staff should match the changes in injury severity proportion for trauma patients. The simulation results of emergency manpower allocation optimized protocols for different instantaneous patient flows showed that under certain hospital service targets, adjustments to the number of experts, general physicians, and nurses in the optimized protocol had some effect in reducing the mortality rate and emergency department retention time of trauma patients, compared with the default protocol.

(2) Focusing on critical patients during treatment of mass casualties

As trauma can occur randomly and suddenly, the difficulty of treating critical trauma patents is high. Because of limitations in manpower and materials in the emergency department, many patients visiting the hospital all at once, or a high proportion of severe trauma patients, routine medical resource allocation cannot meet the treatment needs of all patients at the same time. Thus, the risk of death increases.

Severe and critical patients usually have multiple traumatic injuries and the incidence of lethal traumatic injuries such as hemopneumothorax and organ rupture, are higher, the condition of disease worsens quickly. During treatment in hospitals, such patients tend to develop shock, loss of consciousness, respiratory arrest, cardiac arrest, and other acute complications. Therefore, the risk of death is higher. As condition progression speed in severe and critical trauma patients is fast and mortality at the early stage of emergency consultation is high, when the proportion of severe or critical trauma patients is high, emergency department management should rationally allocate more emergency treatment resources and increase the emergency treatment efficiency to decrease the risk of death in severe and critical patients, and prevent congestion in the emergency department due to retention of a large number of patients. This is important to increase the emergency treatment efficiency. When severe trauma patients or mass casualties require medical-seeking simultaneously, accurate condition evaluation, triage, and priority treatment of critical patients are important steps in decreasing patient mortality. Hospitals should combine their actual status and the "Emergency Patient Triage Guidelines" proposed by National Health and Family Planning Commission for dying patients, critical patients, emergency patients, and non-emergency patients to accelerate the promotion of the trauma emergency triage, diagnosis, and treatment system, carry out reasonable triaging based on the patient's condition on admission, accurately set up reference indexes for vital sign abnormalities, rationally allocate various medical resources, and set up rational emergency diagnosis and treatment regions in the hospital. In addition, domestic and foreign literature showed that the key factors ensuring timely and effective treatment of trauma patients is whether there is sufficient allocated number of medical staff and whether the proportion of various types of medical staff is reasonable. During emergency treatment in hospitals, the reasonable allocation of the type, number, and proportion of medical staff will ensure timely and effective resuscitation of patients. Our group conducted a hospital emergency trauma treatment model simulation study and found that a reasonable increase in the number of experts (chief or deputy chief physicians) during emergency treatment of trauma could affect the mortality rate of critical and severe trauma patients and shorten the emergency department retention time of patients; early allocation of more experts for the treatment of critical-severe trauma patients, carrying out real-time vital sign tests, multidisciplinary consultation meeting, basic life support for these patients, and dispatching anesthesiologists and other related clinical experts in a timely manner for emergency surgeries could reduce the mortality rate of severe-critical trauma patients.

(3) Rational allocation of emergency manpower resources based on trauma patient flow

Trauma is one of the common conditions seen in the emergency departments of tertiary hospitals. As the deaths caused by acute trauma account for more than 30% of the total deaths in the emergency department of the hospitals, particularly in severe trauma patients who have critical condition and rapid worsening, the emergency department must provide fast medical treatments. Efficient emergency treatment work is important in saving the lives of trauma patients. Medical staff are the main force in emergency treatment in hospitals and a key resource that determines health service quality. Reasonable emergency manpower resource allocation can ensure timely resuscitation of trauma patients and good treatment results [82,83]. The hospital managers should combine possible changes in trauma casualty in the emergency department and establish a reasonable and detailed medical manpower allocation [84].

Considering trauma patient treatment effects and economics of medical manpower resource allocation, the optimized protocol obtained from simulation in this study has some effects in decreasing the mortality rate of trauma patients and reducing the emergency department retention time. This can provide some reference for establishing a rational and detailed emergency medical manpower allocation protocol by the medical management. Hospital managers can rationally carry out emergency allocation of different types and numbers of medical staff according to the actual medical service targets and different instantaneous patient flow and dispatch manpower resources to prevent large wastage of resources on the basis of ensuring emergency service rates.

In the face of an overly high instantaneous patient flow in the emergency department, early and reasonable allocation of emergency manpower resources is important in reducing the mortality rate of trauma patients and the emergency department retention time. The nursing station is the major site of contact with emergency patients. Therefore, a corresponding warning mechanism should be established. When the patient flow for medical-seeking exceeds a certain range during a short period of time, medical staff responsible for triage will immediately report to the senior management through the three-grade organization reporting mode of chief of department/head nurse, emergency department managers, and medical affairs manager. The hospital management will dispatch suitable emergency manpower resources in a timely manner according to the flow of trauma patients and the severity proportion. This will ensure that there are sufficient medical staff to be allocated to alleviate overloading at the emergency department while avoiding wastage of medical manpower. This will better satisfy the medical needs of trauma patients and reduce the risk of patient deaths.

9 Policy intervention experiment of hospital outpatient procedure

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9.1 Model simulation

The outpatient department is the frontline department of hospital services and encounters immense consultation stress. Studying reasonable resource allocation, strengthening management, and fully utilizing the capabilities of existing resources have significance in alleviating hospital service stress and improving patient satisfaction [85]. Outpatient process layout, service time, and quality are major factors affecting patient satisfaction. With regard to the "three long, one short" problem (i.e., long registration and queuing time, long waiting time for medical-seeking and test , long payment and drug collection time, and short physician consultation time), waiting time is one of the major indices for evaluating patient satisfaction and has major effects on overall patient satisfaction [86]. An excessive number of patients who are retained at the outpatient department will severely interfere with hospital management and medical work and affect outpatient service quality. In addition, patient congestion in urban general hospitals, in which medical resources are relatively concentrated, has been present for a long time. Hence, research on how to better meet patient's needs has practical significance [87]. With the rapid development in technology (particularly information technology), overseas scholars in the 1990s have introduced "business process reengineering" from business into healthcare systems for reorganization of operation procedures. Subsequently, the appointment system, consultation by time, one-stop services, and other measures were widely promoted by domestic and overseas researchers, and effective applications were obtained in practice. Major achievements were made in shortening the waiting time of patients [88]. However, as some management mechanisms are still incomplete, there are still key factors or segments that result in prolonged service procedures [89].

9.1.1 Model introduction

This model simulated the distribution of healthcare resources. First, the GIS system was used to label the current distribution status of medical institutions. A patient occurrence module was constructed used to generate a patient discrete model. This was used to simulate the patient medical-seeking distribution status and healthcare resource allocation system efficiency by time. Eleven hospitals (GIS geographic distribution map) were entered into the total measurement module to construct the public hospital total-GIS model. Finally, model evolution was used to present patient medical-seeking status, and the results reporting module was used to present data on healthcare resource allocation system efficiency for simulation of healthcare resource allocation.

This model was divided into six layers, and the top layer is the geographical information of public hospitals (the geographical position of every hospital is individually shown).

The positions of the 11 hospitals are shown on the map.

(1) The top layer is the main menu button.

(2) Second layer (the geographical position of every hospital is individually shown)

(3) The third layer is the data information of every hospital. After entering the menu for each hospital, nine lower menu buttons of the hospital strength will be shown: 1) Safeguard tasks, 2) Institution, 3) Bed number, 4) Manpower, 5) Equipment, 6) Costs, 7) Outpatient, 8) Inpatient, 9) Department.

(4) The fourth layer: clicking the menu on the third layer will enter 1) Safeguard tasks and show two lower menu buttons (I) Safeguard tasks and (II) Access safeguard unit; 2) Institution will show text information (copy and paste); 3) Bed number will show text information (copy and paste); 4) Manpower will show text information (copy and paste); 5) Equipment will show

two lower menu items (I) Total quantity of equipment and (II) Equipment information; 6) Costs menu will show hospital expenditure information (input form); 7) Outpatient will show two lower menu items: (I) Outpatient information and (II) Outpatient database; 8) Inpatient will show two further sub-menu items: (I) Inpatient information and (II) Inpatient database; 9) Department will show three further menu items: (I) Bed number, (II) Manpower, and (III) Equipment.

(5) The fifth layer: 1) After clicking Safeguard tasks in the fourth layer, the user will enter (I) Safeguard tasks that involves text information (copy and paste), (II) Inspect safeguard unit that is form information (input form); 2) Equipment at the fourth layer will enter (I) Total quantity of equipment, namely, text information (copy and paste), (II) Equipment information that is form information (input form); 3) Outpatient at the fourth layer will enter (I) Outpatient information (input form), (II) Outpatient procedure (flowchart); 4) Inpatient at the fourth layer will enter (I) Inpatient information (input form), (II) Inpatient database (input form); 5) Department at the fourth layer will enter (I) Bed number (input form), (II) Manpower (input form), (III) Equipment (input form); and 6) Sixth layer (dynamic consultation procedure model, individual patient procedure model).

When the AnyLogic software is running, the main interface of the discrete event model can be divided into four modules including the logic module, data statistics module, 2D module, and 3D and user interaction module.

(1) Logic module

All procedure segments are input into the system and starts from the source. After going through different segments, the sink segment is reached, and the procedure is completed. The entire procedure includes many segments such as referral, triage, registration, outpatient wait, consultation, payment, examination, report collection, follow-up consultation, payment, drug collection, treatment, and hospitalization. Click the run button once to run the model before opening the display window for main activity subject. The animation display in the flowchart can show the current status of the constructed model flowchart subject. On observation of the subject icon, it can be seen that the icon displays the statistical information of the entity when it enters and exits the flowchart. The number on the top of the subject icon shows the number of currently transmitted entities. The number near the subject end shows the number of entities that passed through that end (Figure 9-1).

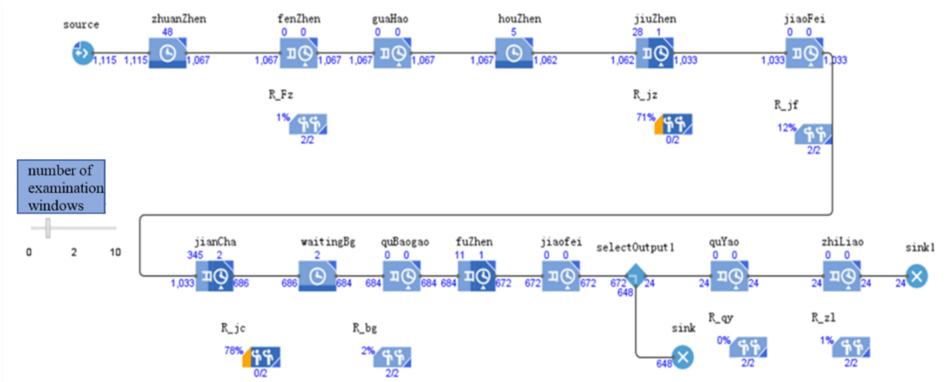


Figure 9-1. Model logic module.

(2) Data statistics module

After running the model and repeated commissioning, different parameter settings will be modified, and the model has been run for a period of time to obtain statistical data results. These results include the number of inpatients, the number of patients discharged, mean retention time, referral window utilization rate, triage window utilization rate, registration window utilization rate, consultation window utilization rate, payment window utilization rate, examination window utilization rate, report collection window utilization rate, follow-up consultation window utilization rate, second payment window utilization rate, drug collection window utilization rate, and treatment window utilization rate (Figure 9-2).

Figure 9-2. Data statistics module.

(3) 2D module

Elements that support the drawing mode (shown as a brush icon on the drawing board) can be added to the drawing by dragging them. In this mode, the drawing steps are extremely simple. Ovals or rectangles of specific dimensions can be drawn, or a polyline drawn point by point. Double-clicking on the drawing elements in the "drawing board" can activate the drawing mode. At this time, the icon will change into a brush, and the required shape can be drawn on the graphics editor. The name of the rectangle can be entered in the "Name" field in the "attributes" view. Selecting "no fill" in the drop-down menu for "fill color" will cause the rectangle to be transparent. Following that, select blue in the drop-down list for "line color."

The "attributes" view displays the attributes of the selected element. To edit the attribute of an element, click on that element once in the graphics editor or the project view and that attribute can be changed by the "attribute" view. The "attributes" view includes many pages. Click on the corresponding label once to open different pages. The selected subjects' name and type are shown at the top of the view. Double click the "polyline" element in the "demonstration" panel to activate this drawing mode. Draw a polyline from left to right. Click once to specify the start point and click twice to specify the end point and name the polyline. The polyline is used in cohort animation demonstrations as the cohort subject will successively add entities (the start point of the polyline is the start of the cohort) from the start to the end points of the polyline. The start point of the polyline should be correctly placed. When the polyline is double-clicked, the start point will show a circular label containing a dot. As no animations are added for subjects in the standard library, the subject of cohort bodies must be set. Only after selecting the body subject will the "attributes" view show its attribute. Drag the border of the view upwards to expand the "attributes" view. Select the "maximum capacity" checkbox to expand the cohort capacity to the maximum. Select bag in the animation type to specify the guide figure for the animation. Enter initials and press Ctrl + spacebar (Alt + spacebar for Apple Mac OS system) to activate the code completion assistant and select from the drop-down menu.

(4) 3D and user interaction module

This is used to construct three-dimensional animation models. Open the demonstration panel which provides geometric shapes for drawing models, such as rectangles, lines, ovals, polylines, and curves. Drag the image subject from the panel to the drawing board and select the layout to be shown. Click on the “add image” button once in the “routine” items in the “attributes” view and select the outpatient process-layout.png image document (AnyLogic8.0 or higher) in the AnyLogic folder/resources/AnyLogic in 3 days/outpatient process path.

The simulation model constructed by using the AnyLogic software was used to study and analyze the hospital outpatient process and quantitatively analyze the eigenvalues of the outpatient process: on-system time, number of people in the waiting cohort, service desk efficiency, and medical-seeking waiting time. Following that, this model was used as a foundation for testing the process improvement model (triage counter, outpatient appointment) widely used in hospitals at present. The optimization results of this model were objectively evaluated in three respects (whether patient on-system time was decreased, maximum patient flow, and system suitability) to provide guidance for further reform of hospital outpatient management. The conclusions of the study are as follows: 1) The description of the outpatient “three long and one short” problem is not stringent. Firstly, the service time of different outpatient processes that are determined by objective laws is different, and the on-system time should be separately calculated. Secondly, the perception and observation angles of consultation time and waiting time for outpatient services are different in physicians and patients. 2) Besides a shortage of resource and service deficiencies that are widely known, an important internal reason for outpatient congestion is that both physicians and patients are unable to predict the consultation time. Most patients will reach the outpatient department as early as possible to reduce waiting time. 3) Due to the limitations of social, medical level, and resource conditions, reconstruction of outpatient process can only appear as an improved form. Under the situation in which hospital outpatient resource allocation is reasonable, the hospital outpatient optimized protocol cannot drastically reduce the on-system time of patients, but it can greatly improve outpatient work performance to increase patient satisfaction.

9.1.2 Model commissioning

The development of computer simulation technology has made research on complex systems convenient. Simulations of system behavior enable us to understand how systems work and are used for prediction and evaluation of future behaviors [90]. Therefore, application of simulation techniques in reorganization of medical process will greatly save time and implementation expenses. However, current hospital simulation studies do not attach importance to the actual problems. One of the reasons is that the simulation lacks completeness, particularly in outpatient processes. There are very few simulations on clinical departments and inpatient departments [91]. This is because a longer treatment time tends to cause system congestion. In addition, the combined analysis of simulation results and statistical methods is not comprehensive, causing some managers to ignore the significance of simulation. In this study, we employed AnyLogic and Microsoft Office Excel for simulation of clinical departments and inpatient departments in hospitals to evaluate whether the medical processes and resource allocation in different departments was reasonable. The rank sum ratio method was used for optimization of departments that required improvement [92]. Finally, a reasonable inpatient ward round schedule was arranged for inpatient departments. This study has some integrity and proposes a reasonable protocol for model operation for the problem of long treatment duration. Patient flux can be adjusted by adjusting the service duration and number of service windows for every segment.

Human consciousness is a reflection of objective reality. Although the visiting time of patients is a random event, it is not completely dependent on the patient’s subjective intention [93]. The patient’s decision on what time to arrive at the hospital is determined by their ability to tolerate the disease, judgment of the outpatient process, and evaluation of their own interests. This type of human behavior is hard to be measured [94]. However, the outpatient process performance based on synthesizing subjective intentions in patients can be objectively evaluated. A single segment model based on queuing theory can identify the optimal deployment of the service targets and service settings of every department but is unable to analyze the interactions and effects between departments in the entire outpatient system. This study employed queuing theory, system dynamics theory, and simulated decision-making theory and techniques to study the outpatient processes of medical services in major hospitals in the city [95,96] to establish a systematic simulation model that could objectively describe outpatient processes.

The study focused on the outpatient consultation process of public hospitals and studied the problem of the outpatient resource utilization rate to control consultation duration and increase consultation efficiency. This agent behavior study on improving consultation efficiency could provide a feasibility reference for subsequent expansion of resource allocation reform to all hospital outpatient departments.

Domestic and foreign medical resource allocation survey-related data: domestic and foreign AnyLogic modeling-related information; discrete event modeling-related information. On-site survey data: A survey of 78 grassroots units, eight hospitals, and 22 grassroots medical institutions was carried out to fully understand the current medical resource allocation status, the current status of supplier hospitals and departments, and demand side and grassroots medical institutions. Public accessible data information: China Health Statistical Yearbook, National Health Services Survey, World Health Statistics. Expert consultation: consultation resource allocation survey scale, outpatient process control discrete event model construction, and consultation with experts from related fields.

Data search: Database search was employed with keywords such as modeling, outpatient process, medical expense, and AnyLogic. Major local and overseas medical literature databases (Pubmed, Web of Science, Embase) were used. The Chinese terms for medical resource allocation, outpatient process, discrete event model, and modeling were used to search in the Chinese biomedical literature databases.

9.2 Policy intervention experiment

9.2.1 Intervention experiment 1: intervention experiment of service window quantity

(1) Window quantity intervention experiment protocol

In this study, the number of windows and patient passage duration of an outpatient segment were adjusted to control the medical resource utilization rate. The resource utilization rate could be used to deduce the optimal number of windows and patient passage duration. Three types of intervention experiment protocols were designed according to different variables. Different intervention conclusions were obtained by using the three intervention experiment protocols on eight hospitals. One of the hospitals was used as an example.

The consultation model was a discrete event, and a single soldier was used for process simulation. Patient flux could be adjusted by changing the service duration and number of service windows for every segment. This was to achieve the shortest hospital duration for patients. The effects of patient source and other segments on outcome were analyzed. The passage duration for various segments was controlled to be unchangeable, and the number of windows was adjusted to observe changes in resource utilization rates in different departments.

The simulation experiment was divided into ten groups (one segment was used as an example):

Test 1: the number of windows in one outpatient segment was 1;
Test 2: the number of windows in one outpatient segment was 2;
Test 3: the number of windows in one outpatient segment was 3;
Test 4: the number of windows in one outpatient segment was 4;
Test 5: the number of windows in one outpatient segment was 5;
Test 6: the number of windows in one outpatient segment was 6;
Test 7: the number of windows in one outpatient segment was 7;

Test 8: the number of windows in one outpatient segment was 8;
Test 9: the number of windows in one outpatient segment was 9;
Test 10: the number of windows in one outpatient segment was 10.

(2) Window quantity intervention experiment results

The examination window was used as an example. The mean examination duration was 1490 seconds, and number of windows was adjusted from 1 to 10. The intervention experiment results are as follows (Figure 9-3).

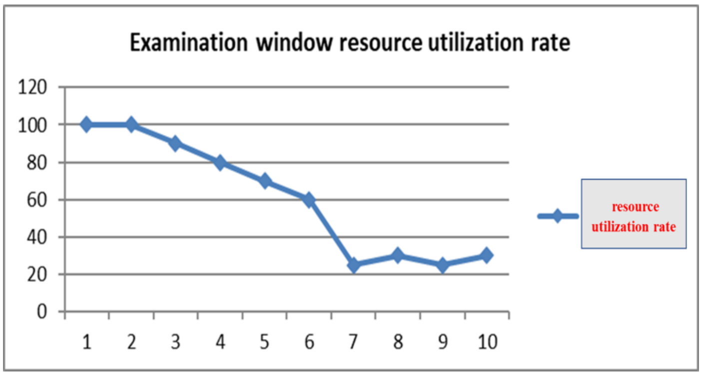


Figure 9-3. Examination window resource utilization rate.

Time parameters of various segments (1 hospital was used as an example): The first consultation rate and inpatient rate are optimized as follows (Table 9-1).

Table 9-1. Various segments in outpatient.

Segment	Name	Time (seconds)	Number of windows (n)	Notes
1	First consultation			First consultation rate: 0.49%
2	Referral	15408	1	
3	Triage	20	2	
4	Registration	60	2	
5	Waiting	1429	2	
6	Consultation	726	2	
7	Payment	60	2	
8	Examination	1493	2	
9	Report collection	1800	2	
10	Follow-up consultation	300	2	
11	Payment	60	2	
12	Drug collection	60	2	
13	Treatment	600	2	
14	Hospitalization rate			3.26%

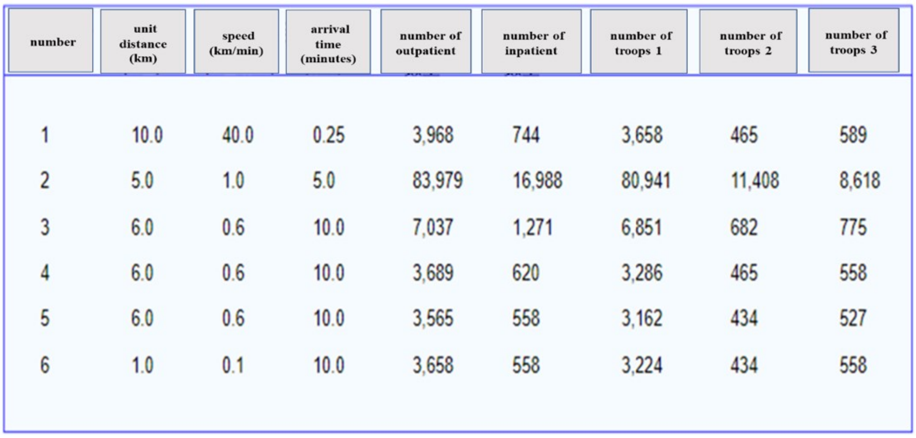
Test 1: Outpatient examination window utilization rate 100%, number of windows: 1.
Test 2: Outpatient examination window utilization rate 100%, number of windows: 2.
Test 3: Outpatient examination window utilization rate 90%, number of windows: 3.
Test 4: Outpatient examination window utilization rate 80%, number of windows: 4.
Test 5: Outpatient examination window utilization rate 70%, number of windows: 5.
Test 6: Outpatient examination window utilization rate 60%, number of windows: 6.
Test 7: Outpatient examination window utilization rate 25%, number of windows: 7.
Test 8: Outpatient examination window utilization rate 30%, number of windows: 8.
Test 9: Outpatient examination window utilization rate 25%, number of windows: 9.
Test 10: Outpatient examination window utilization rate 30%, number of windows: 10.

When the passage duration for outpatients in each window was fixed, as the number of windows increased, the resource utilization rate decreased. When the passage duration for outpatient in each window was fixed, as the number of windows decreased, the resource utilization rate increased. The optimal state for examination windows was 4–6 windows, and the resource utilization rate was 60%–80%.

9.2.2 Intervention experiment 2: intervention experiment of passage duration

(1) Passage duration intervention experiment protocol

The number of windows was fixed, and work processes were changed to adjust passage duration. Changes in the resource utilization rate were observed. Changes of intervention results occurred in the different experiment groups (Figure 9-4).



number	unit distance (km)	speed (km/min)	arrival time (minutes)	number of outpatient	number of inpatient	number of troops 1	number of troops 2	number of troops 3
1	10.0	40.0	0.25	3,968	744	3,658	465	589
2	5.0	1.0	5.0	83,979	16,988	80,941	11,408	8,618
3	6.0	0.6	10.0	7,037	1,271	6,851	682	775
4	6.0	0.6	10.0	3,689	620	3,286	465	558
5	6.0	0.6	10.0	3,565	558	3,162	434	527
6	1.0	0.1	10.0	3,658	558	3,224	434	558

Figure 9-4. Experiment group.

The consultation window was used as an example, and the starting number of windows was set as two. Simulation experiment 1 was divided into ten groups (one segment was used as an example):

Test 1: Consultation time of 60 seconds in one segment of consultation;
Test 2: Consultation time of 120 seconds in one segment of consultation;
Test 3: Consultation time of 180 seconds in one segment of consultation;
Test 4: Consultation time of 240 seconds in one segment of consultation;
Test 5: Consultation time of 300 seconds in one segment of consultation;
Test 6: Consultation time of 360 seconds in one segment of consultation;
Test 7: Consultation time of 420 seconds in one segment of consultation;
Test 8: Consultation time of 480 seconds in one segment of consultation;
Test 9: Consultation time of 540 seconds in one segment of consultation;
Test 10: Consultation time of 600 seconds in one segment of consultation.

(2) Passage duration intervention experiment results

When the number of windows for outpatients was fixed, as passage duration increased, the resource utilization rate increased. When the number of windows for outpatients was fixed, as passage duration decreased, resource utilization rate decreased. Using examination window as an example, when the passage duration was 120 seconds, the resource utilization rate was 77.1%. When passage duration was 180 seconds, the resource utilization rate increased to 80.5%. When passage duration was 240 seconds, resource utilization rate was 91.2% (Figure 9-5).

Figure 9-5. Retention time.

Using consultation window as an example, when passage duration was 60 seconds, the resource utilization rate was 33.1%. When passage duration was 120 seconds, the resource utilization rate was 43.4%. When passage duration was 180 seconds, the resource utilization rate increased to 74.2% (Figure 9-6).

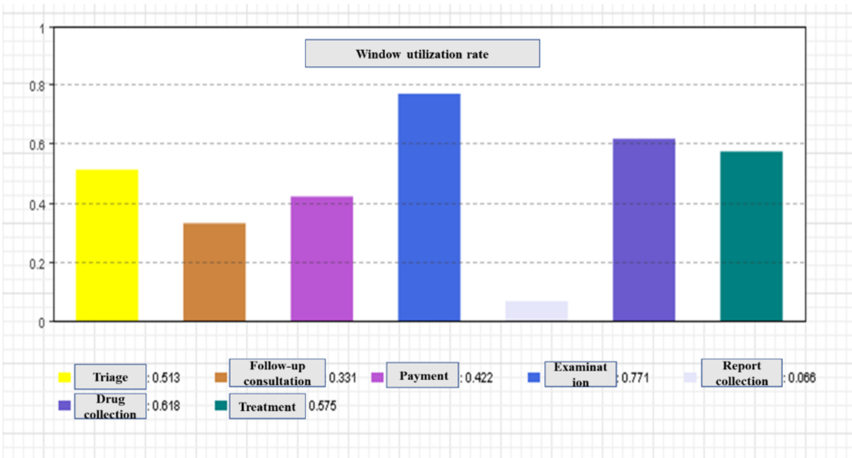


Figure 9-6. Resource utilization rate.

9.2.3 Intervention experiment 3: intervention experiment of resource utilization rate

(1) Resource utilization rate intervention experiment protocol

The passage duration and number of windows were controlled and remained unchanged while the window resource utilization rate was adjusted (Figure 9-7).

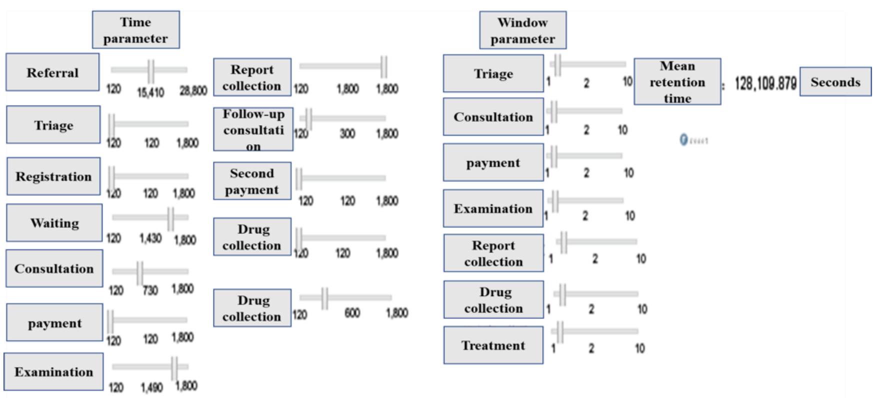


Figure 9-7. Window adjustment.

The intervention experiment was divided into 13 groups and 10% and 25% changes of the resource utilization rate were used as nodes (one segment was used as an example).

Test 1: Resource utilization rate for an outpatient segment of 0%;
Test 2: Resource utilization rate for an outpatient segment of 10%;
Test 3: Resource utilization rate for an outpatient segment of 20%;
Test 4: Resource utilization rate for an outpatient segment of 25%;
Test 5: Resource utilization rate for an outpatient segment of 30%;
Test 6: Resource utilization rate for an outpatient segment of 40%;
Test 7: Resource utilization rate for an outpatient segment of 50%;
Test 8: Resource utilization rate for an outpatient segment of 60%;
Test 9: Resource utilization rate for an outpatient segment of 70%;
Test 10: Resource utilization rate for an outpatient segment of 75%;
Test 11: Resource utilization rate for an outpatient segment of 80%;
Test 12: Resource utilization rate for an outpatient segment of 90%;
Test 13: Resource utilization rate for an outpatient segment of 100%.
(By default, two windows are used for every segment)

(2) Resource utilization rate intervention experiment results

When the resource utilization rate of an outpatient segment was fixed, increasing the number of work windows would reduce queue duration. Conversely, reducing the number of work windows would increase queue duration. The retention time in the cohort would change (Figure 9-8).

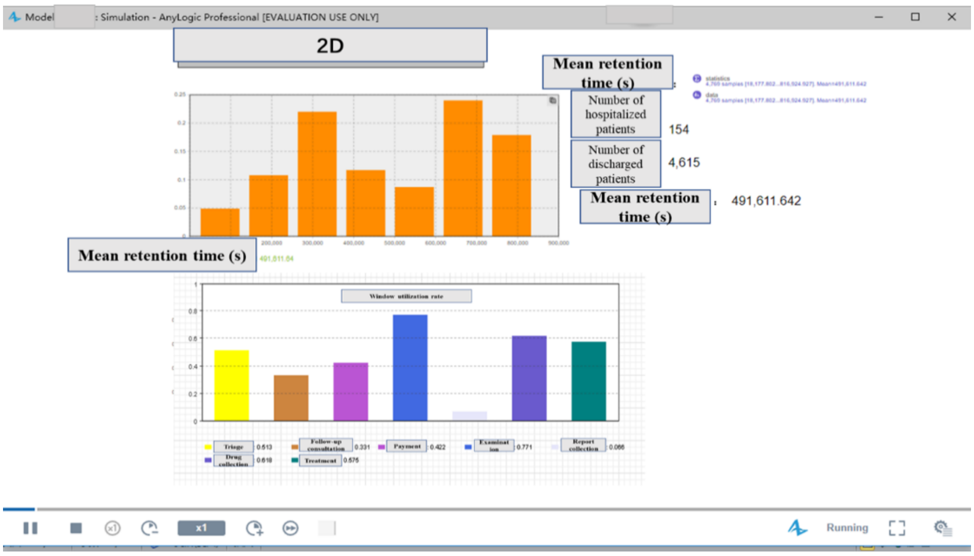


Figure 9-8. Intervention experiment results.

The parameter groups of different intervention experiments were recorded. After the model ran and repeated commissioning was carried out, different parameter settings were modified, and the model ran for a period of time to obtain statistical data results. These results included the number of inpatients, the number of patients discharged, the referral window utilization rate, examination of the window utilization rate, mean retention time, registration window utilization rate, triage window utilization rate, consultation window utilization rate, payment window utilization rate, report collection window utilization rate, follow-up consultation window utilization rate, second payment window utilization rate, drug collection window utilization rate, and treatment window utilization rate. The positive experiment results are as follows: (Figure 9-9).

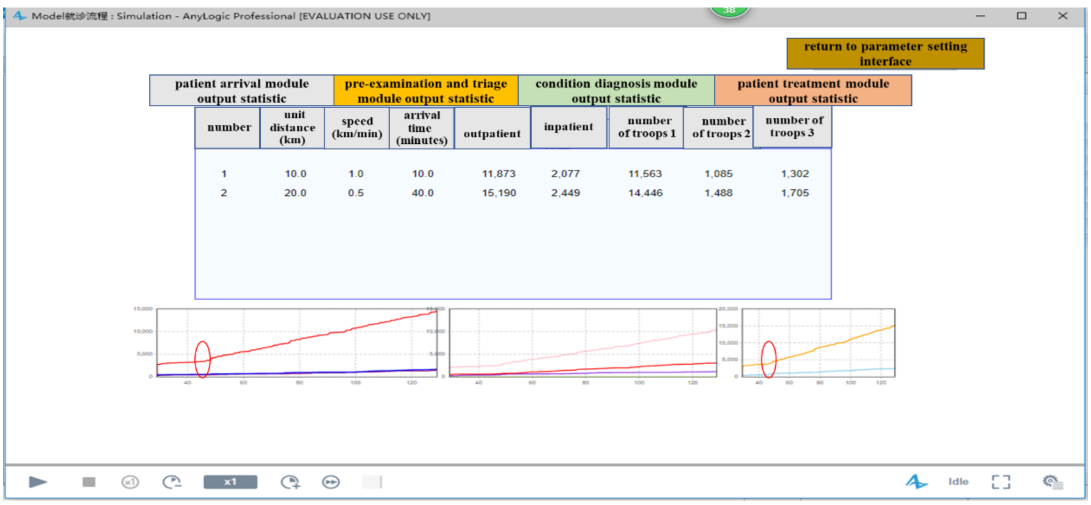


Figure 9-9. Output.

A recording of specific parameters was carried out by time in different experiments. The outpatient resource allocation model was used for simulation analysis of the number of windows for every segment and consultation duration to control resource utilization. The experimental results of computer model simulation found six sets of positive experimental results. The optimal state for examination windows was 4–6 windows, and resource utilization rate was 60%–80%.

When the passage duration of outpatients for every window was fixed, increasing the number of windows by one would decrease resource utilization rate by 10%. When the passage duration for outpatient in each window was fixed, as the number of windows decreased, the resource utilization rate increased, When the number of windows for outpatients was fixed, as passage duration increased, the resource utilization rate increased. When the number of windows for outpatients was fixed, as passage duration decreased, the resource utilization rate decreased. Using the examination window as an example, when passage duration was 120 seconds, the resource utilization rate was 77.1%. When passage duration was 180 seconds, the resource utilization rate increased to 80.5%. When passage duration was 240 seconds, the resource utilization rate was 91.2%.

When the number of windows for every segment was fixed, adjusting the number of experts, physicians, and nurses could change the window passage duration, which ultimately changed the window resource utilization rate, reduced the ineffective waiting time of patients, and increased the medical resource allocation rate [86]. Using the consultation window as an example, when passage duration was 60 seconds, resource utilization rate was 33.1%. When passage duration was 120 seconds, the resource utilization rate was 43.4%. When passage duration was 180 seconds, the resource utilization rate increased to 74.2%. The optimal work efficiency results for all actual windows in every hospital can be used to propose policy recommendations for the resource allocation rate in navy hospitals and to propose an optimized protocol that matches the actual situation of various hospitals (Table 9-2).

Table 9-2. Intervention experiment results.

Constant	Independent variable	Change	Dependent variable	Change	Note
Passage duration	Number of windows	Increase	Resource utilization rate	Reduction	Non-linear changes
	Number of windows	Reduction	Resource utilization rate	Increase	
Number of windows	Passage duration	Increase	Resource utilization rate	Increase	
	Passage duration	Reduction	Resource utilization rate	Reduction	
Resource utilization rate	Number of windows	Increase	Passage duration	Increase	
	Passage duration	Reduction	Number of windows	Reduction	

9.3 Policy recommendations

As an enormous system, there are many problems to be solved in hospital operation. To improve medical quality efficiency, many hospitals have started formulating quality management protocols that are suitable for their own development [12]. In practice, the most important steps include studying large volumes of medical records for statistical analysis of data and continuous revision and improvements to medical processes to obtain optimal medical process reorganization. As the degree of hospital informatization continuously increases, medical statistics become relatively easy. Researchers have identified many feasible and effective statistical methods for evaluation and screening of large volumes of data. Among these methods, the rank sum ratio method is a set of analytical methods that was obtained based on the current status of grassroots healthcare work in China. In addition, many current medical process reorganization studies that are dependent on practical experience, and statistical data have obtained many valid results. However, the implementation of the reorganized protocol and feedback on optimization results is a long cyclical process. Researchers and managers must carry out long-term observations and carry out continuous revision and re-implementation of process reorganization to obtain a protocol that is suitable for that hospital. Outpatient process optimization is a continuously improving dynamic process. Domestic and foreign researchers focus on the application researches and emphasize the solutions of problems faced in each segment of the actual outpatient process [97]. The following measures and recommendation are proposed in view of the current status and problems in outpatient process optimization in China, and problems discovered in existing studies such as long patient waiting times in the outpatient departments, cumbersome consultation processes, unclear consultation instructions, uneven consultation time period distribution, and uneven distribution of patient flow.

(1) Improving the appointment and registration system and strengthening consultation guidance for time periods

By establishing separate outpatient appointment and registration timings, priority systems for special populations, and setting up special consultation zones, the number of windows can be adjusted when the resource utilization rate and single patient passage duration are fixed which allows the optimal number of windows and passage duration for various segments to be achieved when the number of outpatient windows and the resource utilization rate are the best [98]. Simulation of the number of windows for every segment and consultation duration based on the outpatient process model can be carried out to control resource utilization. A scientific and effective research method is provided that is based on the results of the experiment by studying the model's medical resource allocation through computer simulation. Policy recommendations for medical resource allocation efficiency in public hospitals and personalized reforms to match the actual situations of various hospitals are proposed. Large general hospitals should first provide as many appointment numbers as possible and gradually increase the appointment/registration ratio, particularly for specialist outpatients to alleviate the situation of "difficulty in registration", strengthen notification and guidance for separate appointment and registration to reduce ineffective waiting times, such as on-site queuing [99], construct a unified appointment platform, promote actual name registration, explore real-time payment and appointments and convenient appointment cancellation paths to avoid selling appointment numbers and a high missed appointment rate and ensure the orderly execution of outpatient appointment services and avoid wastage of medical resources.

(2) Increasing outpatient management efficiency and rational allocation of medical service resources

In the face of increasing outpatient volume, various services and management efficiency should be improved while ensuring medical quality and safety [100]. For example, the patient flow at various outpatient time periods and the temporal patterns of seasonal variation trends can be used as a basis for reasonable adjustment to manpower, materials, and other medical resources. In addition, one-stop services can be improved, stratified registration and payment windows can be established, double rest days for the outpatient department can be set up, and medical guidance service volume can be increased so that the medical-seeking needs of patients are satisfied [101]. At the same time, deep implementation of health policies under high-quality medical resources should be carried out, paired assistance should be used to improve the technical levels of grassroots medical institutions, and bi-directional referral and triage should be promoted to solve the problem of over-concentration of patients on the ground.

(3) Establishing robust information technology support

Improving the overall level of information technology in outpatient services can provide a good operating platform for improving the outpatient process, and existing computers, networks, and artificial intelligence can be continuously improved. Promoting the application of the "one bank-hospital card" information system on the existing foundation of medical cards and bank-hospital cards [102] and concentrating multiple information platforms into one have the practical advantages of consultation with actual names, safety, efficiency, and convenience. At the software popularization stage, exhibition boards and electronic screens can be used to improve advocacy and guidance on information technology and specialized consultation service staff can be trained to provide guidance on actual patients' operations. When improving the internal system of the hospital, a unified digital platform can be established as the sharing of medical resources and patient medical information is a future development trend.

The outpatient process model can be used as a basis for simulation analysis of the number of windows for each segment, consultation time, and control resource utilization. Computer simulation results and studies using this model for medical resource allocation can provide a scientific and effective study method. Policy recommendations for medical resource allocation efficiency in public hospitals and personalized reforms are proposed to match the actual situations of various hospitals.

10 Policy intervention experiment of complex causes of trauma

Authors: Peng Kang, Fangjie Zhao, Lulu Zhang

10.1 Model simulation

10.1.1 Model introduction

The earthquake mass casualty and treatment simulation model was based on the AnyLogic simulation software and can be used to simulate earthquake zone residents under the combined effects of the surrounding environment, individual behavior, and rescue operations. The health of these residents was used as a decision factor and rational adjustment and improvements to environmental factors, individual behavioral factors, and rescue operation factors were made to decrease the casualty rate effectively and mortality rate of residents in earthquake zones. The system boundaries of the earthquake mass casualty and treatment simulation model include the earthquake mass casualty and treatment system structure, earthquake mass casualty and treatment system agent, and system-related external environment. The core of the system was the mechanism of mass casualties after earthquake zone residents had experienced mass casualties and received treatment. The earthquake mass casualty and treatment system modeling study was carried out within the system boundaries. At the same time, the system and external environment formed several feedback relationships that inversely determine the development and changes in system structure, function, and agent behavior.

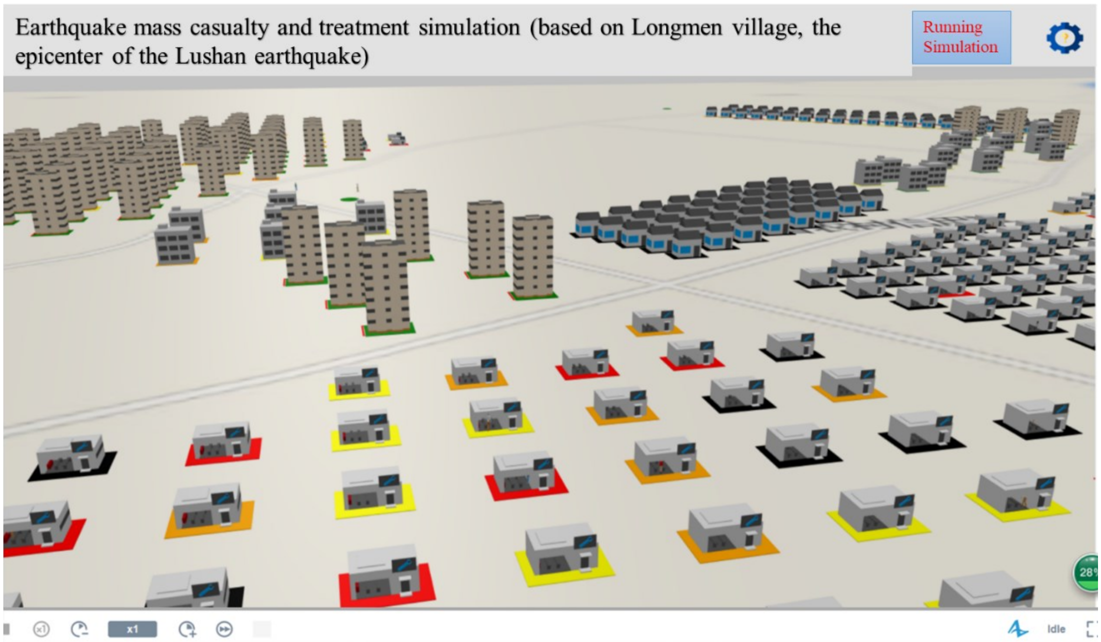


Figure 10-1. Earthquake mass casualty and treatment model interface.

10.1.2 Simulation commissioning

(1) Complex earthquake trauma causes agent model stratification

As the earthquake mass casualty and treatment system had relatively complex causal relationships and involved many factors, and there were many factors leading to earthquake mass casualties, it was difficult to comprehensively describe and analyze the system. In this study, earthquake mass casualty occurrence and treatment were first considered as the basic structural unit. As there were many factors affecting trauma occurrence and treatment, the aforementioned analyzed characteristics were used to divide these factors into two major layers of an earthquake mass casualty occurrence system and an earthquake trauma treatment system.

The former could be divided into demographic factors, individual behavior factors, disaster environmental factors, and construction factors to examine the corresponding emergency rescue decisions in the system structure. This study assumed that the goal of the earthquake mass casualty and treatment system was to increase the earthquake rescue force deployment efficiency, decrease the earthquake trap duration, and the waiting time for earthquake trauma treatment so that system results and efficiency were greatly increased.

(2) Observation markers of the complex earthquake trauma causes agent model

The observation markers were mainly the casualty rate, mortality rate, effective treatment rate, and disaster zone resource utilization rate. In addition, the total number and classification of earthquake mass casualties and the total strength and structure of rescue force deployment were used as auxiliary observation markers.

(3) Intervention markers of the complex earthquake trauma causes agent model policy

The intervention markers were mainly classified according to the various influencing factors and mainly included architectural factors, individual behavioral factors, disaster environmental factors, and earthquake epicenter factors, organizational command factors, and rescue force deployment factors.

10.2 Policy intervention experiment

10.2.1 Intervention experiment 1: earthquake environment intervention environment based on earthquake scale

The site used for this intervention experiment is Longmen village, Lushan county, Ya'an city, Sichuan province, and the earthquake core region was used for building simulation and attack simulation of 1234 buildings of various types in the region. The time of the earthquake in the simulation was 7.15 AM, the earthquake epicenter had a depth of 13 km, the earthquake duration was 25 seconds, and the number of residents in the earthquake zone was set as 500. The intervention marker was the earthquake Richter scale. Earthquakes of different magnitudes on the Richter scale were set to observe changes in building damage at the epicenter and casualties under the same earthquake time, local population, disaster zone buildings, and epicenter depth. The intervention results showed that as the earthquake magnitude increased, building destruction in the disaster zone gradually increased. When the simulated earthquake was 8.0 on the Richter scale, seismic intensity was X and most buildings collapsed, resulting in more severe casualties in the disaster zone. When the simulated earthquake was 8.5 on the Richter scale, seismic intensity was XI, and building collapse and casualties were more severe.

(1) Expected regional seismic intensity is VIII when the simulated earthquake is 7.0 on the Richter scale

In this simulation, the earthquake was set as 7.0 on the Richter scale, with 13km epicenter depth, 25s earthquake duration, 500 residents in the earthquake zone. The earthquake occurred at 7.15 a.m. During this time, the number of people who were indoors was significantly higher than the number who were outdoors, and the expected seismic intensity was VIII. After the earthquake, 27% of buildings showed severe damage or complete collapse, resulting in mainly mild casualties. The percentage of uninjured or mildly injured people was 87% and two people died.

(2) Expected regional seismic intensity is IX when the simulated earthquake is 7.5 on the Richter scale

In this simulation, the earthquake was set as 7.5 on the Richter scale, with 13km epicenter depth, 25s earthquake duration, 500 residents in the earthquake zone. The earthquake occurred at 7.15 a.m. During this time, the number of people who are indoors is significantly higher than the number who are outdoors, and the expected seismic intensity was VIII. After the earthquake, 45% of buildings showed severe damage or complete collapse, resulting in mainly mild casualties. The percentage of uninjured or mildly injured people was 82%, 10 people were critically injured, and one person died.

(3) Expected regional seismic intensity is X when the simulated earthquake is 8.0 on the Richter scale

In this simulation, the earthquake was set as 8.0 on the Richter scale, with 13km epicenter depth, 25s earthquake duration, 500 residents in the earthquake zone. The earthquake occurred at 7.15 a.m. During this time, the number of people who were indoors was significantly higher than the number who were outdoors, and the expected seismic intensity was VIII. After the earthquake, 72% of buildings showed severe damage or complete collapse, resulting in mainly mild casualties; the percentage of uninjured or mildly injured people was only 15%. The casualties at the disaster zone were extremely severe: 17 people were severely injured (82%), 13 people were critically injured, and 51 people died on-site.

(4) Expected regional seismic intensity is XI when the simulated earthquake is 8.5 on the Richter scale

In this simulation, the earthquake was set as 8.5 on the Richter scale, with 13km epicenter depth, 25s earthquake duration, 500 residents in the earthquake zone. The earthquake occurred at 7.15 a.m. During this time, the number of people who were indoors was significantly higher than the number who were outdoors, and the expected seismic intensity was VIII. After the earthquake, 79% of buildings showed severe damage or complete collapse, resulting in mainly mild casualties; the percentage of uninjured or mildly injured people was only 10%. The casualties at the disaster zone were extremely severe: 24 people were severely injured (5%), 17 people were critically injured, and 57 people died on-site.

10.2.2 Intervention experiment 2: individual behavior intervention experiment based on escape training rate

The site used for this intervention experiment was Longmen village, Lushan county, Ya'an city, Sichuan province, and the earthquake core region was used for building simulation. The time of the earthquake in the simulation was 6.15 AM, earthquake magnitude was 7.6 on the Richter scale, with 13km epicenter depth, 25s earthquake duration, 500 residents and 1234 buildings in the earthquake zone. The intervention marker was earthquake escape training rate. Different escape training rates were set to observe for changes in casualties under the same earthquake magnitude, earthquake time, local population, disaster zone buildings, and epicenter depth. The intervention results showed that as escape training rate continuously increases, the casualty rate gradually decreased under the background when the simulated earthquake was 7.6 in magnitude on the Richter scale. When the simulated earthquake escape training rate was 100% and everyone was assumed to have undergone earthquake escape training, the earthquake casualty rate was significantly decreased.

(1) Simulation of earthquake escape training proportion of 30% in local residents

In this simulation, the earthquake was set as 7.6 on the Richter scale, with 13km epicenter depth, 25s earthquake duration, and 500 residents in the earthquake zone. The earthquake occurred at 7.15 a.m. During this time, most people were generally indoors, and the expected seismic intensity was IX. When the proportion of local residents who received earthquake escape training was 30%, which is low, casualties caused by the simulated earthquake were serious: 16% had severe injuries, 6% had critical injuries, and 12% died.

(2) Simulation of earthquake escape training proportion of 70% in local residents

In this simulation, the earthquake was set as 7.6 on the Richter scale, with 13km epicenter depth, 25s earthquake duration, 500 residents in the earthquake zone. The earthquake occurred at 7.15 a.m. During this time, most people were generally indoors, and the expected seismic intensity was IX. When the proportion of local residents who received earthquake escape training was 70%, which was an increase in the proportion who received earthquake escape training, casualties caused by the simulated earthquake were significantly decreased: 12% had severe injuries, 6% had critical injuries, and 8% died. The proportion of uninjured and mildly injured people was significantly increased.

(3) Simulation of earthquake escape training proportion of 100% in local residents

In this simulation, the earthquake was set as 7.6 on the Richter scale, with 13km epicenter depth, 25s earthquake duration, 500 residents in the earthquake zone. The earthquake occurred at 7.15 a.m. During this time, most people were generally indoors, and the expected seismic intensity was IX. When the proportion of local residents who received earthquake escape training was 100%, meaning that everyone received earthquake escape training, casualties caused by the simulated earthquake were significantly decreased further: only 8% had severe injuries, only 5% had critical injuries, and 5% died. The proportion of uninjured and mildly injured people was significantly increased, and the number of casualties was significantly decreased.

10.2.3 Intervention experiment 3: disaster population intervention experiment based on age ratio

(1) Elderly: adult: adolescent proportion was 24.9: 68.9: 6.2 (actual age group composition of Lushan residents who experienced an earthquake)

In this simulation, the earthquake was set as 7.6 on the Richter scale, with 13km epicenter depth, 25s earthquake duration, 500 residents and 1234 buildings in the earthquake zone. The earthquake occurred at 7.15 a.m. During this time, most people were generally indoors, and the expected seismic intensity was IX. According to the age ratio at this point, 8% had critical injuries, 12% died, and most patients had mild to moderate injuries (54%).

(2) Elderly: adult: adolescent proportion was 68.9: 24.9: 6.2

In this simulation, the earthquake was set as 7.6 on the Richter scale, with 13km epicenter depth, 25s earthquake duration, 500 residents and 1234 buildings in the earthquake zone. The earthquake occurred at 7.15 a.m. During this time, most people were generally indoors, and the expected seismic intensity was IX. The earthquake casualty simulation was carried out according to the age ratio at this point in which the proportion of elderly people was the highest. 12% had severe injuries, 7% had critical injuries, 13% died, and most patients had mild to moderate injuries (57%).

(3) **Elderly: adult: adolescent proportion was 6.2: 68.9: 24.9**

In this simulation, the earthquake was set as 7.6 on the Richter scale, with 13km epicenter depth, 25s earthquake duration, 500 residents and 1234 buildings in the earthquake zone. The earthquake occurred at 7.15 a.m. During this time, most people were generally indoors, and the expected seismic intensity was IX. The earthquake casualty simulation was carried out according to the age ratio at this point in which the proportion of elderly people was the lowest. 10% had severe injuries, 5% had critical injuries, 12% died, the proportion of severe casualties was slightly decreased, and most patients had mild to moderate injuries (54%). The proportion of uninjured people was significantly increased (18%).

10.3 Policy recommendations

(1) Effects of demographic factors on earthquake casualty and correlation between age and earthquake casualty ratio

The results of foreign and Chinese studies [103-105] generally found a significant correlation between age and earthquake casualty rate. This was because of many reasons, for example, elderly people are less able to trauma resistance, moving, ability in avoiding failing objects during escape, especially for those who live alone. In addition, women are more prone to injury or dead than man because of the work attributes, division of labor, and certain behavioral habits. However, there were many studies that did not find a significant correlation between age, gender, and earthquake casualty rate [106]. However, there were definite differences in the correlation between age, gender, and earthquake casualty in Chinese and foreign studies [107-109]. Our study results found that the number of earthquake casualties in the 65-year-old age group was significantly higher than uninjured people, and the risk of injury was 2.01 times that of the 15–35-year-old population. This showed that elderly people were a high-risk population for earthquake trauma. However, we did not find gender differences in earthquake casualties in this study, and the risk of earthquake injury was similar between men and women. A study on the 1980 southern Italy earthquake [110] found that the 5–9-year-old age group was a high-risk population for earthquake casualty. In the 1994 Northridge earthquake in the United States [111], the risk of earthquake deaths in refugees aged 60 years and above is 6.1 times that of 30–39 years age group and 2.7 times that of the 50–60 years age group. According to the casualty statistics of the 1995 Hanshin-Awaji earthquake [112], most earthquake deaths were elderly people aged 60 years and above, and the proportion of females was higher. A study on the 1999 Kocaeli earthquake in Turkey [113] found that the casualty rate in women was significantly higher than in men, the risk of death was higher in 7–19-year-old children, and the risk of earthquake injury in 30–49-year-old adults was higher. In 2002, the Afyon earthquake in Turkey occurred in rural areas and housewives, elderly people, and children were populations of high risk for earthquake injuries; the earthquake casualty rate was significantly higher than for local males and women who were working outside [114]. From this, we can see that the above results showed that more attention should be paid to elderly people and women in pre-earthquake preparations and post-earthquake rescue in order to reduce the risk of earthquake trauma and deaths.

(2) The earthquake environment greatly affects building structure and directly affects the ratio of earthquake casualties

The time of the earthquake was significantly correlated with the earthquake casualty rate. If the earthquake had struck in the middle of the night, the casualty rate in residential buildings would have risen. If it had happened during rush hour, especially during office hours, the street casualty rate would have been higher. If it had occurred during working hours when most people were still at their jobs, it would have caused widespread casualties. The Lushan earthquake occurred on a Saturday morning, when most residents were at home. Therefore, house collapse was the main cause of casualties.

The seismic fortification criterion for China ranged from a seismic intensity of 6 to 9. Buildings in regions with an intensity of 9 were not allowed to exceed 3 stories in height. Using the 2008 Wenchuan earthquake as an example, the seismic fortification criterion for Wenchuan in Sichuan was 7. The seismic fortification criterion was different from the earthquake magnitude as a degree of 7 corresponds to an earthquake magnitude of 5. The newly revised magnitude of the Wenchuan earthquake was 8 and seismic intensity was 11. The seismic intensity was far greater than the seismic fortification criterion, resulting in the collapse of many houses and causing mass casualties. In the Armenia earthquakes in the late 1970s and early 1980s, severe building collapses occurred due to poor construction quality [115]. A similar situation occurred in the 1999 Turkey earthquake and the collapse rate of buildings with unqualified design, materials, and quality was significantly higher than that of recent high-quality buildings. Armenian [103] found that the most effective method for controlling earthquake casualties was to improve construction quality and buildings' earthquake resistance.

The building life for earthquakes usually needs to consider all time-related factors for earthquake construction. In the 1994 Northridge earthquake [116], the risk of severe earthquake injuries in houses constructed before 1960 was 4.6 times that of those constructed after 1976 [111]. This means that the longer the building life, the greater the risk of casualties due to building collapse. However, we did not find a correlation between the building life and earthquake casualties in this study. A different conclusion was obtained from other studies: In Turkey [113], houses constructed according to new building standards suffered more serious collapse. Investigations found that uninjured people lived in houses dating to 1980 while casualties lived in houses dating to 1983. Some researchers proposed that continuously accelerated urbanization and self-constructed reinforced concrete houses were an important threat to earthquake casualties [113]. The earthquake casualty rate was positively correlated with the height of buildings during an earthquake. In Lushan, low-rise buildings were more common but caused more severe damage. Studies about Armenia [115] and Turkey [113] found that high-rise buildings resulted in more earthquake casualties.

Earthquake casualties caused by building collapse during earthquakes and different degrees of damage were collectively termed construction casualties. According to the discussion above, most earthquake casualties were due to architectural factors. However, the casualties caused by non-architectural factors in some buildings cannot be overlooked. For example, cabinets, boxes, and heavy objects in houses during earthquake could cause extremely severe casualties [117].

(3) Earthquake individual behavioral factors are significantly correlated with earthquake casualties and earthquake escape training can significantly decrease the casualty rate

From the individual behavioral presentation of earthquake refugees after an earthquake, we can see that acute stress reaction occurs, causing refugees to exhibit psychological behaviors such as anxiety, fear, and mania. Such excessive behaviors may directly led to varying degrees of trauma or death. An investigation of the 1979 California earthquake found that 50% of casualties suffered injuries from knocking into tables and door frames while escaping in panic. Our study found that most earthquake zone residents were extremely fearful during an earthquake, which resulted in an increase in the odds ratio of earthquake casualties (OR: 1.93). Different individual behaviors during an earthquake were related to earthquake casualties. Mahue-Giangreco [111] found that some people overestimate their valuables during an earthquake, leading to severe trauma in the upper limbs. A study found that immediate escape during an earthquake was safer than staying in the house [115] and similar conclusions were obtained in other studies [110,118]. Individual behavioral responses of refugees during an earthquake were affected by their location, seismic intensity, behavior, and routine training and education. Calm responses during an earthquake and rapid rescue after it will greatly reduce the casualty rate. The first response after an earthquake was to protect the lives of the surrounding people. However, casualties occur many times during an earthquake due to the scramble for valuables. Therefore, there was an urgent need for an in-depth investigation of individual behaviors of refugees to identify the correct method of escape during an earthquake.

At present, research on psychological trauma after an earthquake had gradually become a hotspot and the psychological health of disaster zone residents after an earthquake had gradually attracted attention. In the 1999 Kocaeli earthquake in Turkey [113], 13% of casualties still required psychological assistance 20 months after the earthquake and major problems included anxiety (40%), depression (26%), and fear (25%). In China, psychological assistance had gradually attracted attention since the 2008 Wenchuan earthquake, and psychological counseling was carried out for refugees, students, and children during the rescue [119-124]. After the 2010 Yushu earthquake, experts in the Ministry of Health Emergency Response Organization arrived on the second day of the earthquake to conduct psychological needs assessment. National experts in the organization were dispatched to Xining to carry out training on 186 post-earthquake psychological rescue assistance staff who were familiar with local ethnic groups and customs. These people were trained to conduct psychological counseling on evacuated casualties and people in the disaster zone. Subsequently, psychological rescue teams were dispatched to conduct psychological assistance for different populations. In many subsequent disaster rescue operations, psychological assistance was used as routine rescue work for continuous development [125,126].

11 Policy intervention experiment of medical evacuation

Authors: Yipeng Lv, Xixi Wang, Lulu Zhang

11.1 Model simulation

11.1.1 Model introduction

In the battlefield, the casualty medical evacuation is according to the battlefield casualty status, including health resource allocation, the combat treatment unit, and the deployment of combat treatment resources, which are selected according to the actual on-site attrition status. Construction of a scientific and rational maritime casualty simulation system based on actual combat data is the foundation for the system. In this study, we employed discrete event simulation to carry out casualty evacuation simulation. The timeline of casualty occurrence was established based on casualty characteristics, and discrete simulation of the casualties was carried out according to a fixed occurrence time distribution and injury characteristic patterns.

The maritime casualty medical evacuation includes the treatment and casualties' evacuation. Setting up the casualty treatment ladder and selection of evacuation channels are key factors affecting casualty treatment outcomes and these two features complement each other. After casualties occurred, the casualty treatment module was used to simulate the casualty treatment process by using every doctor as the service workstation in the queuing workstation; casualties are treated successively. This system includes the consumption of casualty treatment time and changes in life expectancy after casualty treatment; the output is attributes after casualty treatment. After treatment, different evacuation tools were used as the evacuation unit and evacuation simulation of different casualties were carried out according to certain evacuation rules. The model was used for repeated judgment of casualties' vital signs to determine whether to enter the circulation simulation and record relevant information.

The maritime casualty occurrence and medical evacuation Arena simulation system was constructed in this study. This system was constructed by integrating the "3-dimensional" information model structure for casualties, the maritime casualty treatment conceptual model, and the maritime casualty medical evacuation conceptual model. This system was used to simulate the casualty treatment and evacuation process when combat casualties occur. The corresponding health resource allocation and evacuation force deployment were improved to determine the optimal solution for rapid casualty evacuation under limited health resources. The system includes six modules: casualty occurrence, medical treatment, medical evacuation, result information display, parameter settings, flow control; It involves six databases, 224 model variables, 45 adjustable parameters, 216 information loops, and 17 judgment loop statements. The casualty outcome simulation subsystem can simulate the distribution of casualty occurrence time, positional information simulation, and injury simulation, which are used to determine the lifespan and other attributes of each casualty. The casualty treatment and evacuation process was divided into the three stages, namely, ship evacuation treatment stage, hospital ship evacuation treatment stage, and evacuation to rear hospitals. These stages mainly include injury determination, treatment workstation allocation, treatment process, changes in casualty lifespan, and treatment outcome and withdrawal modules. The model can be used to adjust the number of medical staff, evacuation tool settings, evacuation tool performance, number of evacuation tools, transfer tool parameters, maritime environment, and evacuation rule settings. In addition, 3-dimensional visual technology, development system results display, and 3-dimensional display system were combined to intuitively simulate the casualty treatment and evacuation process and treatment outcomes.

11.1.2 Simulation commissioning

After the first construction of the simulation system is completed, the system cannot be directly used and requires system testing. System testing refers to the testing of model construction requirement satisfaction for the model is based on the orientation of fixed operating environment and problems. Potential problems are discovered after multiple tests, and the model and parameters are adjusted to ensure that the system can operate in a scientific, safe, and stable manner. System testing mainly includes accuracy testing, utility testing, and sensitivity testing.

(1) Accuracy testing

The model construction process was to carry out mathematical modeling of a complex reality status, concentrating on major problems and influential factors, which will carry out computer modeling of the study subjects. Therefore, during modeling, screening of major modeling parameters and information is required for the major problems and case model, particularly complex models in which multiple factors interact and a slight deviation will result in erroneous results. Therefore, the constructed model must undergo accuracy testing and test cases are used for boundary testing. In multi-parameter simulation systems, a stepwise construction method is used starting from the simplest model. Other parameters are fixed; stepwise commissioning is carried out for some important parameters, the complexity of test parameters is increased, and the stability and accuracy of model output results are confirmed.

(2) Sensitivity testing

Sensitivity testing was used to test the sensitivity of the model toward changes in variables. If the model was extremely sensitive to one or more parameter changes and results show large changes, the model must be retested or a suitable range of parameter settings must be used. The primary method for sensitivity analysis is parameter fine-tuning, repeated model operation, and observing for changes in results. Usually, random numbers were input for testing. The results of multiple simulations of random input parameters were used to analyze whether the output results were related to the distribution of random numbers and whether a large differential change was produced, in order to analyze the model's sensitivity.

(3) Utility testing

Utility testing was the test of model effectiveness, which was mainly used to test the goodness of fit between the model and actual situation. The model was used to solve actual problems. Therefore, the output result information must match reality. Model utility testing was used to test whether the case model matches the study problem and whether results are reliable. The test method was to compare the model results and actual case results.

In the specific judgment process, attention should be paid to the fact that the adopted situation should conform to the situation simulated by the model and the collected data should be true and reliable. It was necessary to analyze whether the difference was meaningful and whether the difference was caused by random noise. The correct results obtained by the model needed to analyze the reproducibility of the results and the stability of the model itself.

11.2 Policy intervention experiment

11.2.1 Intervention experiment 1: effects of the quantity of evacuation tools and distance deployment on evacuation

(1) Evacuation tool quantity intervention experiment protocol

The evacuation distance involved in this study mainly included 3 stages and 5 methods. In the 3 stages, ambulance ships, medical transport ships, and medical transport helicopters were used in combination for a total of 5 methods. Changes in evacuation distance affect the evacuation duration of evacuation tools and will also correspondingly affect the judgment of evacuation signs (judgment on whether evacuation or on-site treatment should be carried out). In this study, the total evacuation distance remained unchanged while the positions of ambulance ships and hospital ships were adjusted to affect the implementation of evacuation effects. Specifically, forward deployment and backward deployment were used for ambulance ships and hospital ships. Before casualty evacuation, casualties were assessed for evacuation criteria. Lifespan was adjusted according to the deployment of evacuation tools, and the shortest treatment conditions for casualties were changed correspondingly. Expected treatment was carried out on casualties whose lifespan was shorter than the shortest evacuation duration and they were not evacuated to the next treatment unit for treatment. In protocol 1, the forward deployment distance of treatment unit was increased by 50%. In protocol 2, the distance of the treatment unit was postponed by 50%.

(2) Evacuation tool quantity deployment intervention experiment protocol

In this study, the evacuation tools included medical transport ships, ambulance ships, and transport helicopters. During model design, the 3 types of evacuation tools were allocated to the three evacuation stages and combined with baseline model results for adjustment to the number of evacuation tools for waiting time, which is the adjustments to the number of ambulance ships and medical transport helicopters. Protocol 1 mainly increased the number of ambulance ships and medical transport helicopters by 1-fold. Protocol 2 mainly increased the number of evacuation ships by 50% on the basis of protocol 1.

11.2.2 Intervention experiment 2: effects of evacuation initiation rules and deployment rules for core-carrying capacity on evacuation time efficiency

(1) Departure waiting-time standard setting intervention experiment protocol

The main objective of casualty evacuation was to ensure that a large number of casualties was treated. The evacuation process could be divided into two states, awaiting vessel boarding, and awaiting departure after vessel boarding. For casualties awaiting vessel boarding, the longer the time the evacuation vessel took to dock, the more opportunities were available for treatment. For casualties awaiting evacuation after boarding, the earlier the vessel reached the next treatment institution, the greater the probability of survival. Therefore, both considerations must be managed when setting the departure rules for vessels so that the treatment benefits of casualties were maximized. Therefore, during the initial setting up of the model, the evacuation vessel departure standard included time and quantity: Firstly, the evacuation vessel will depart after a certain period of time regardless of the loading capacity to ensure the safety of the vessel and the timeliness of casualty treatment. Secondly, with regard to the number of casualties of all different degrees, the total number of moderate and severe casualties to total casualties should be above the loading capacity proportion for the corresponding vessel. In the intervention experiment, only one variable was adjusted, which was increased or decreased by 50%.

(2) Intervention experiment protocol for adjustment to number of different injury severity casualties loaded

Casualties with different injury severity had different needs for evacuation timeliness. In the simulation system, the evacuation process was started after a proportion of casualties with different injuries in the vessel reaches a fixed number. During the intervention experiment, this standard was decreased or increased by 50% as the intervention experiment protocol.

11.2.3 Intervention experiment 3: intervention experiment of evacuation method setup

In the study, medical transport helicopters were used to transport severe casualties to decrease the time taken for evacuation, enable severe casualties to receive treatment as soon as possible, and thereby increase their survival rate. Before casualty evacuation, their injury severity was assessed. The assessment criteria were an important basis for selecting evacuation modes. In this model, assessment of casualties' lifespan and triage were mainly used for selection of the evacuation tool. Adjustment to the evacuation tool selection rules could aid in developing more rational and comprehensive evacuation rules to improve evacuation efficiency and results. In this study, helicopters were initially set to transport casualties with a lifespan of less than one hour while other casualties were transported by ships. In the intervention experiment, the lifespan of casualties evacuated by helicopters was adjusted to six hours.

11.2.4 Intervention experiment 4: effects of number of healthcare staff and rescue capability allocation on evacuation time efficiency

(1) Medical staff number deployment intervention experiment protocol

The number of medical staff in treatment force deployment for different treatment units will directly affect the casualty treatment efficiency. A limited number of physicians during treatment often consumes some consultation time. Therefore, queuing often happened, which affected the treatment efficiency of casualties. However, due to the unique characteristics of the combat environment, the number of medical staff was limited. How to allocate medical resources to provide the best treatment results under limited resources was the main objective of the study. Therefore, in this model, we did not infinitely increase the deployment of medical treatment force for medical staff number deployment but consider the adjustment of the medical staff in different treatment institutions under certain medical resource quantity conditions. Two methods were used, namely, forward deployment and delayed deployment of medical staff; the effects of different deployment methods on medical treatment results and efficiency were examined to optimize the allocation of medical resources.

During the adjustment to medical resource allocation, the number of medical staff on ambulance ships was not only the number of medical staff on one ship but the total number of medical staff on ships that can provide treatment in stages. In primary treatment units, this included the number of permanent medical staff in the treatment room on ships and the number of medical staff on ambulance ships. The design of the two intervention experiment protocols in this study ensures that the total number of medical staff remained unchanged while the medical staff allocation units were adjusted to strengthen forward deployment in ambulance ships and to strengthen deployment in hospital ships.

(2) Medical staff treatment level intervention experiment protocol

The professional competency of medical staff not only affected treatment rate but also affected treatment outcomes. Skilled medical staff can determine the injury of casualties, diagnose disease, and carry out emergency treatment in a fast and accurate manner. On this basis, determining whether forward deployment or concentrated deployment was required for medical resources can improve the treatment results of combat casualties under limited medical resources, which was similarly an important research content for the intervention experiment. In this study, data collected by medical officers during treatment in past exercises were used to conduct an intervention study.

11.3 Policy recommendations

With regard to maritime medical treatment and evacuation, medical resources and evacuation resources were major influencing factors that limited the treatment results and efficiency of casualties. Improving evacuation resources and rational setting of evacuation rules could ensure that casualties receive reasonable evacuation as soon as possible and receive medical treatment in the shortest time. Sufficient medical resources could ensure that casualties that enter the treatment ladder unit can receive early treatment and improve treatment results. To fully utilize limited medical resources and implement rapid, accurate, and standardized treatment of casualties as much as possible, interventions on evacuation resources and medical resource allocation have become necessary research methods.

(1) Increasing the number of stage 1 evacuation tools and increasing the efficiency of early casualty evacuation

The rational deployment of evacuation tools was a key influencing factor that limited the timeliness of treatment received by casualties. During combat, a large number of casualties would be simultaneously produced, which resulted in a rapid increase in casualties within a short period of time and results in a large number of casualties awaiting evacuation at the casualty assembly point. However, under a complex combat environment, the transport, transfer, and evacuation of casualties were relatively complex, and it was not possible to provide an infinite number of evacuation tools. Therefore, the evacuation performance of evacuation tools should be maximized under limited resource conditions. The casualty evacuation process was similar to the stepwise "dam water flow" structure as a large number of casualties accumulate at the early stage, resulting in immense pressure on treatment and evacuation institutions; eventually, the number of casualties requiring evacuation and treatment reaches a peak. Subsequently, the various levels of treatment institutions were akin to a "dam's" treatment and triage enabled some casualties to be treated and return to their unit or remain for treatment or further evacuation. Their evacuation needs were greatly alleviated compared with stage 1 and they decreased stage by stage. Under limited medical evacuation resource conditions, evacuation tools should be deployed as early as possible to satisfy the early treatment tasks of casualties. At the same time, casualty evacuation was a continuous and progressive process. During analysis of evacuation tool deployment, the connections between various evacuation processes should not be severed. For example, the simulation intervention results show that increasing the number of primary evacuation tools would decrease evacuation waiting time and the number of evacuated casualties, particularly severe casualties would increase, and subsequent helicopter evacuation would also increase. Therefore, in consideration of the entire process of evacuation and treatment, paying attention to structural changes in evacuation casualty characteristics, combined with information processing, targeting the increase in severe casualties, force grouping and target increase in corresponding evacuation tool deployment, and ensuring that casualties could obtain continuous and effective treatment would help to increase the treatment rate and survival of casualties.

(2) Integrating battlefield attrition characteristics, increasing evacuation loading criteria, full utilization of evacuation performance, and increasing evacuation quality

Different types of combat modes produce different types of casualties, and their severity distribution had their own characteristics. Setting evacuation rules only based on general evacuation standards was not rational. There were differences in the evacuation needs of casualties with different degrees. With regard to the evacuation of combat casualties, the structural characteristics of injury severity in a large number of casualties had great guiding significance in the deployment of evacuation tools. Similarly, the model intervention results showed that a larger proportion of casualties had severe injuries during amphibious assault and the characteristics of a large number of casualties occurred within a short period. For casualties awaiting evacuation after boarding, the earlier the vessel reached the next treatment institution, the greater the probability of survival. Therefore, both considerations must be managed when setting the departure rules for vessels so that the treatment benefits of casualties were maximized. The evacuation vessel departure standard includes two parts, namely, time and quantity: Firstly, the evacuation vessel would depart after a certain period of time regardless of the loading capacity to ensure the safety of the vessel and the timeliness of casualty treatment. Secondly, with regard to the number of casualties of all severities, the total number of moderate and severe casualties to total casualties should be above the loading capacity proportion for the corresponding vessel. Under the prerequisite of complying with basic evacuation rules, appropriate adjustment to evacuation rule settings according to the actual battlefield environment and mass casualty characteristics would improve treatment efficiency in casualties and improve the utilization efficiency of evacuation tools. This would achieve more results with less effort under scarce evacuation resources in the battlefield.

(3) Increasing treatment force at various levels is key to ensuring treatment results in casualties and improving the competency of medical staff is a factor that affects the treatment results of severe casualties

Unified ladder treatment and time-effect treatment for combat casualties should be carried out. Casualties receive corresponding treatment at different treatment institutions, including first aid, early resuscitation, resuscitation, definitive treatment, and rehabilitation therapy at the recovery stage. When mass casualties occur, casualties need to receive corresponding treatment in a timely manner so that they can subsequently receive further treatment. From the intervention experiment, it can be seen that the number of medical staff and their distribution structure are factors limiting casualty treatment, and they had important effects on the treatment outcomes of severe casualties. With regard to improving overall treatment results, the forward deployment of medical staff and increasing the number of frontline medical staff will greatly improve treatment results. Increasing the competency of medical staff to increase their treatment success rate and reducing the time needed for treatment can positively affect treatment outcomes, particularly increasing severe casualties that were lifespan sensitive, but the degree of these effects was not as high as strengthening medical staff manpower.

(4) Coordinated evacuation and treatment process, strengthening the early evacuation force, focusing on late-stage changes and treatment of severe casualties, and overall improvements in medical treatment results

Through the execution of multiple intervention experiments, it was found that changing each variable did not comprehensively improve treatment results. For example, strengthening the early evacuation force can greatly increase the number of casualties receiving primary treatment, particularly severe casualties. However, in subsequent evacuation the lack of medical manpower and the aggregation of a large number of casualties results in cumbersome treatment tasks, the worsening of conditions in a large number of casualties, and the increase in the proportion of severe casualties. This caused immense stress on helicopter evacuation, thereby affecting the improvement in the overall treatment outcome. Therefore, during the establishment of the medical evacuation system, comprehensive consideration of the entire evacuation process is necessary. During early evacuation, emphasis should be placed on the number of evacuated casualties and the number of treated casualties. In the subsequent process, emphasis should be placed on the evacuation and treatment needs of severe casualties to ensure that casualties could receive a sustainable treatment process and improve overall treatment results. Therefore, “early” and “late” evacuation should be combined and “evacuation” and “treatment” should be combined for judgment and analysis to examine the condition and lifespan changes of casualty flow during evacuation, adjust settings for evacuation tools, and improve the treatment results and efficiency for “late stage” severe casualties so as to improve overall evacuation and treatment results.

In summary, from the structural analysis, modeling, and intervention experiments on maritime casualty occurrence and medical evacuation, it could be seen that casualty treatment and evacuation was a systemic process that integrated many factors and involved the evacuation force, treatment force, injury severity structure, and evacuation environment, which jointly affected the entire process. During analysis and study on the evacuation system construction, it was necessary to distinguish and integrate the effects of various factors. Under different combat modes and environments, “Combat Treatment Rules” and other basic evacuation principles, actual combat situations, and attrition injury distributions should be used as a basis for the employment of a flexible and scientific evacuation system; evacuation force and treatment forces should be rationally combined to achieve efficient and sensitive casualty evacuations during battles, carry out early casualty evacuation and treatment, improve the treatment results of severe casualties at the late stage and, finally, improve the treatment results and efficiency of combat casualties.

12 Policy intervention experiment of stress analysis

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12.1 Model simulation

12.1.1 Model introduction

This model was a stress level model. This model included four subsystems, which were described as follows.

Tool comparison subsystem. This system included the number of #1, #2, #3, and #4 ships of the enemy and us and quantification of their performance values. This was a subsystem that compares various tools by comparing the total performance values of the various ships.

Personnel comparison subsystem. This system included the number of category 1, 2, 3, and 4 staff of the enemy and us. This was a subsystem that provided weapon comparison by comparing the total strength of the combatants.

Preparedness subsystem. This subsystem searched for expense ratios, per capita expenditure, integrated national strength ranking, level defense mobilization, level of knowledge in the general public, level of national defense education, ethnic solidarity, national defense ocean development, biotechnology level, national information technology, space technology level, national new material technology, new energy source technology, supply capacity, and level of command and control to achieve preparedness.

12.1.2 Simulation commissioning

The model was a reality simulation. To effectively ensure that the constructed model can simulate the real world under certain conditions, model validation must be carried out [127-129]. The effectiveness validation of the model validated the goodness of fit between all constructed models and reality to test whether information and behavior obtained from the model reflected the actual system characteristics and variation patterns and validate whether model analysis can accurately identify and understand problems to be solved. As the system unifies structure and function, it was necessary to validate model effectiveness, and carry out testing and sensitivity analysis of the structural and functional aspects [130,131].

The system structure and boundary test were mainly completed during the construction of the conceptual model and logical model. The system boundary test mainly tested important concepts in the system and whether variables were endogenous. At the same time, the system behavior was tested for sensitivity to changes in system boundary assumptions [132,133]. The system structure test mainly tested whether the model structure fitted with descriptive system cognition, whether model generalization was suitable, and whether the model captured the behavioral characteristics of system participants. In this study, a large volume of literature was reviewed during the construction of the conceptual model and expert opinions were solicited during the construction of the logical model. Therefore, the system structure and boundary of the model were reasonable [134,135].

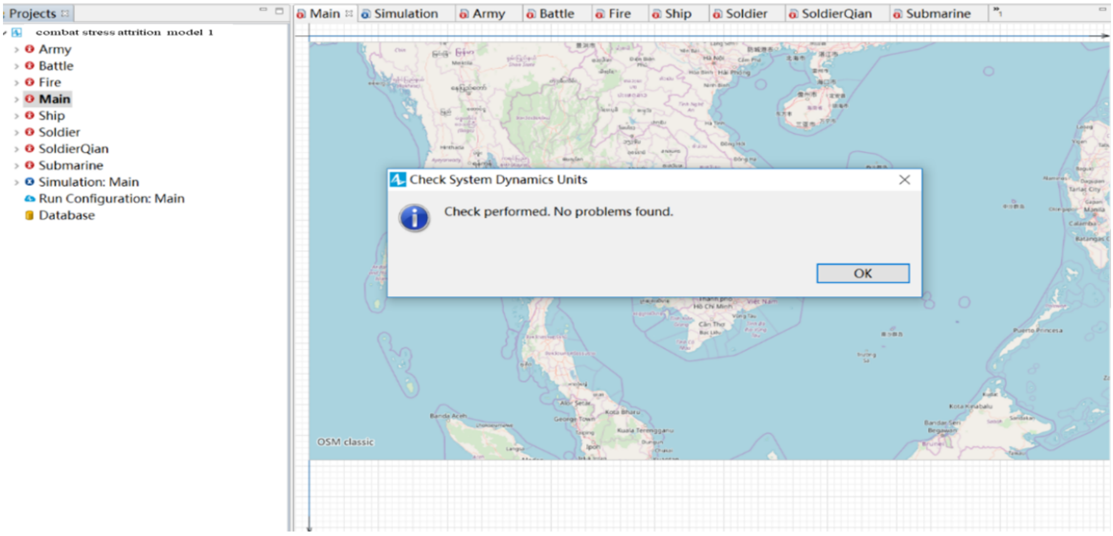

Figure 12-1. Simulation commissioning.

12.2 Policy intervention experiment

12.2.1 Intervention experiment 1: effects of the number of ships on stress

(1) Protocol on effects of the number of ships on stress

The number of ships participating in the simulation was increased to understand the effects on our stress level. Due to the different number of different participating ships, the combat effectiveness value of our side's participation in the war was determined, thus affecting the pressure level rate.

(2) Experimental results of effects of the number of ships on stress

In experiment 1, this might be due to the stress level rate characteristics of this type of ship after being attacked by submarines; This laboratory showed that as the number of ships participating in the battle increases, the effector variation trends of stress level rates decreased as the battle duration progresses and finally reached a stable level.

12.2.2 Intervention experiment 2: effects of battleground on stress

(1) Protocol for effects of battlefield environment on stress

The main objective of this study was to examine the effects of natural environmental factors on stress level. This was simulated and analyzed by adjusting different natural environments.

(2) Effects of battlefield environment on stress

In experiment 2, the effects of the environment on stress level rate are complex. In this study, the quantification of environmental influencing factors was used to examine the effects of the environment on stress level rate. In the intervention experiment, (sunny, gentle) was the control group, and it could be seen that (sunny, extremely hot), (clear, extremely hot), and (gloomy, gentle) environmental factors decreased stress level rates. However, the variation trend of these effects decreased with time. Results showed that a damp, windless and gloomy, gentle environment was more favorable for combat and can decrease stress level rate to the maximum. With regard to wave factor, the greater the wave, the less favorable it was for combat as this tended to increase the stress level rate [136-140].

12.2.3 Intervention experiment 3: effects of commander ranks on stress

(1) Protocol for effects of commander ranks on stress

This experiment was used to examine the effects of commander ranks on attrition. Commander ranks were adjusted and the effects of different commander ranks on stress level rate observed. The table showed the parameter settings used in the intervention experiment.

(2) Effects of commander ranks on stress

In experiment 3, it could be seen that the effects of changes in commander ranks on stress level rate in the early phase of combat were great and there was a significant downward fluctuating trend. The higher the commander's rank, the smaller the fluctuation in daily stress level rate, which effectively controlled the daily combat stress level rate of our side.

12.3 Policy recommendations

According to the intervention experiment results, there was considerable room for improvement in stress level rates. For protocols employing different combat modes, increasing the number of various types of ships and maximizing our performance value could decrease stress level rate to the maximum.

(1) Increasing the number of ships and decreasing the stress level of officers

Simulation of stress level rates in different scales of naval battles showed that naval combat stress level would decrease as the number of participating ships increases. Firstly, this model assumed that the number of enemy ships participating in the battle would be maintained at a certain level. As our number of #1 and #2 ships increased, our total stress level rate would decrease. However, it could be seen that when the number of #2 ships participating in the battle increases, the daily stress level rate would significantly increase within 8~10 days. The reason for this might be due to the stress level rate of #2 ships. Therefore, during short-term naval combat, the number of #2 ships should be carefully increased. Although increasing the number of #2 ships considerably could increase our weapons' performance value the stress level of this submarine would be high after it was attacked. Therefore, the number of ships should be carefully adjusted in the battle plan according to the status of the enemy [141,142].

(2) A suitable combat environment has environmental effects on the stress level of officers

Although the intervention experiment found that the effects of the environment on stress level rate fluctuation was not high, there were still some effects. During the commander's decision to engage in battle, he must select a combat mode that was more favorable to our side. From various experimental results, our analysis found that weather options such as (sunny, extremely hot), (clear, extremely hot), and (gloomy, gentle) are favorable to reducing stress level rates. However, analysis of the seas found that higher waves would increase stress levels during combat. Therefore, we recommend fighting when the sea was relatively calm as it would decrease the stress level rate [143].

(3) Selecting experienced commanders can decrease the stress level in officers

Minimally, senior commanders should be selected for battle, and it was preferable to select very senior commanders. The seniority of commanders had great effects at the beginning of combat, had extremely strong effects on stabilizing morale, and can effectively decrease stress level rates from occurring. From the experimental results, we found that the effects of junior and intermediate ranks on the stress level rate are mild and senior ranks can somewhat decrease the stress level rate [144]. However, very senior ranks have mild effects on stress level rate but greater effects on attrition. Therefore, very senior commanders should be selected for combat as they can effectively decrease stress level rates [145].

(4) Increasing political education can effectively decrease stress levels

From this intervention experiment, we found that improving political education could significantly decrease the attrition rate due to combat stress in officers. How to improve the effectiveness of political education was a challenge in today's army. Currently, the People's Liberation Army's political education methods were too procedural and officer acceptance was low [146,147]. We proposed the following recommendations for political education methods for officers. Firstly, political, education, and scientific thinking should be promoted; political departments should strengthen research on this education in the military and knowledge content in education. Secondly, political education humanist thought should be promoted, and political education should set an example of being people centered. In the process of education, it was emphasized to respect the officers and soldiers' subjectivity and mobilize their enthusiasm. Thirdly, education and modernization of ideological should be promoted in the military so that they could adapt to the demands of development and military political education thought could satisfy the demands of the times. For example, how to conduct political education thought in the military with the development of the Internet should be considered [148,149].

(5) Employing rapid combat and resolution can decrease attrition due to stress

Previous studies showed that the effects of psychological stress would show a U-shaped increase over time. From this experiment, we found that as combat duration increases, the psychological state score and number of staff lost due to combat stress reaction showed varying degrees of increase, which was consistent with the results of previous studies [150]. Therefore, increasing in combat duration was not favorable for the psychological health of our officers. Hence, we recommend that a rational combat mode must be selected so as to achieve combat objectives as soon as possible [151].

13 Policy intervention experiment of medical service force selection and deployment

Authors: Chen Xue, Lulu Zhang

13.1 Model simulation

13.1.1 Model introduction

The medical service force (medical treatment force) was the structural resource basis for a country or military to execute emergency medical service assurance activities. Accurate medical service force selection and deployment were important for good medical service assurance work. The medical service force selection and deployment agent-based model mentioned in this section consists of three agents, namely, the event agent, medical institution agent (including medical manpower), and casualty agent. Among these agents, the event agent was the premise, and the corresponding medical service force selection and deployment were carried out against treatment needs of casualties under specific emergencies. The medical institution agent was the main carrier for implementation of medical service assurance work and was also the carrier for various medical service forces. Casualties were treated within this agent. As a type of medical service force, the medical service manpower agent was the agent for implementing medical treatment in casualties. To simplify the model in this section, the medical institution agent was simplified to the rescue force agent. With regard to the medical service force selection and deployment agent, medical service force selection mainly targets medical manpower selection, that was, the demand for medical manpower in various medical institutions during medical assurance work in emergencies and a certain number of medical workers are drawn from various grades of medical institutions. Medical service force deployment refereed to the deployment of medical service assurance institutions and various types of medical workers to different regions to ensure that medical service assurance work was successfully carried out. Analysis of casualty treatment tasks in a certain emergency was carried out and three major types of agents were abstracted from the system, that was, the casualty agent, medical service institution agent, and medical service staff agent.

In the AnyLogic model, casualties were intuitively displayed as icons on the map. Given that emergencies would result in mass casualties within a small area, casualties were displayed in an overlapping manner. The main attributes of the casualty agent model included the number of casualties, injury structure, and spatial distribution. A “red cross” symbol was used to represent various grades of medical institutions (this section mainly considers hospitals; other institutions were not included). The medical service force agent was mainly divided into three types: the national strategic rescue force, regional rescue force, and disaster zone rescue force. The attributes of medical service staff included gender, age, profession, and job title. In addition, the medical service force selection and deployment model also included the rules model, which included restrictions on various agent behaviors in the multi-agent model. The behaviors of the casualty agent mainly include the probability of casualty occurrence in different regions due to the event, injury evolution laws when casualties were untreated, and injury evolution laws after casualties were treated. The medical service institution agent rules mainly included whether various staffs in medical service institutions could be drawn on and the restrictions for drawing on them. The medical service force agent rules included those used by medical service staff and the competency of medical service staff in performing medical treatment.

13.1.2 Simulation commissioning

After the medical service force selection and deployment multi-agent model was constructed, model simulation commissioning and validation were carried out. The validity of the simulation results was dependent on the reliability of the system model. Therefore, model validation was an indispensable aspect and even occurs from the start to the end of the “system modeling-simulation experiment” until satisfactory simulation experiment results were obtained. Attention must be paid to the following problems during model simulation commissioning and validation: Firstly, simulation commissioning and validation was a process in which the modeler’s perceptual understanding of the research problem is improved by rational knowledge; it usually required many repetitions. Secondly, there was uncertainty in the simulation commissioning and validation process. Thirdly, it was usually impossible to carry out comprehensive simulation validation, especially for some complex system model problems. Simulation commissioning and validation require large amounts of statistical data that were difficult to obtain, and it was impossible to carry out comprehensive model validation.

The primary objective of model simulation commissioning and validation was to construct an effective and reliable model, which could be used in actual applications. The key points of this process included verification, validation, and credibility.

Commissioning the simulation computer program, which was also called model validation that was about determining whether the "hypothesis file" has been correctly translated into the computer language. This mainly included verification of a large number of potential logic paths, such as

(1) Main program of commissioning model

During the programming of the medical service force selection and deployment multi-agent model, the main program and several critical subprograms of the model were first written and commissioned, and other essential subprograms were expressed as others. Subsequently, other subprograms were added and successful commissioning was carried out until the model required for the study in this section was developed.

(2) Validation of input parameters

The model was run under several input parameters, and output was examined for rationality. This system was based on the AnyLogic simulation tool and combined the medical institution medical manpower resource structure table, and the medical force selection model to present a visualization of medical force selection. On the basis of the medical service force selection and deployment agent model, this section mainly used 1 or 2 emergency event cases; collected data was input into the model for simulation to observe if the model could run routinely until it was normal. The simulation results were observed to determine whether overall behavior conforms to requirements. Commissioning was carried out if behavior does not conform to requirements until the behavior did conform. Finally, the simulation results were assessed. The medical service force simulation of the Sanya emergency. A specific place in Sanya (latitude 18.32363621761 N, longitude 109.6862983704 E), an emergency event involving 500 people occurred that required rapid and accurate assessment by the mobile medical service team. The distance of the mobile medical service force from the field hospital and the suitability of its characteristics for the emergency were considered. “Shortest distance and most suitable characteristic” were used as targets and the “lowest and sufficient selection” principle was used to generate an optimal protocol for selection of the mobile medical service force. Details were as follows: I) Grouping the No.002 field medical team, which consisted of 50 people and 50 beds, with the treatment capacity of 200 people per day; II) Grouping the No.005 field medical team, which consisted of 120 people and 100 beds, with treatment capacity of 400 people per day. The temporary grouping medical staff was required to supplement the field medical center. We assumed that this temporary support force consisted of 6 types of staff (orthopedic specialist, surgeon, emergency physician, dermatologist, nurse, and medical technician). A selection of medical institutions within 50km of the emergency was carried out. The number of 6 types of medical manpower resources required were $Xi = \{11, 26, 30, 21, 8, 10\}$. The proportion of staff drawn from local medical institutions was $K1 = 30\%$. The maximum proportion of staff drawn from each medical institution over that institution’s staff was $K2 = 15\%$. The first task of the field medical center was to focus on safety, which was beneficial for implementation and retreat; near the emergency site to achieve the fastest receipt of casualties was best controlled within 2-4 km; the implementation site should be near major roads that were controlled within a range of 0.5-1 km; the implementation site should be far from polluted water sources, higher in attitude than water sources, at a safe distance from major water bodies during the rainy season, and usually set up within a safe area of 30-50 m; the site selected should be as flat as possible so that the terrain advantage can be maximally utilized—the area was usually larger than 100×100 m. In addition, the site should be closely combined with the natural geographical environment and avoid pollution caused by various sources (atmospheric or water pollution). The site should be selected in a leeward direction to the emergency site and regions that were prone to landslides and debris flows should be avoided. We could calculate the number of the 6 types of medical staff to be selected from medical institutions through the medical service force selection model. The proportions of selected staff from various medical institutions were lower than the maximum proportion (15%) of staff and the total number of medical staff drawn from three local medical institutions was 30% more than the total number of medical manpower required. From the results, this selection ratio appears more reasonable.

(3) Observation of simulation output animation

With regard to the medical service force selection and deployment multi-agent model, we observed the simulation output animation to see if the model operation results fit our expectations (Figure 13-1).

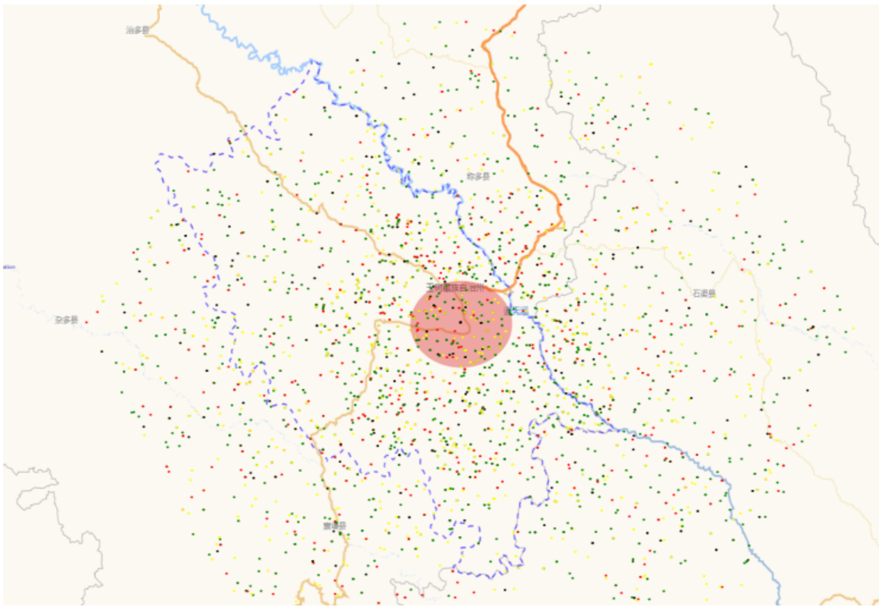

Figure 13-1. Model simulation output animation.

(4) Model validation

Model validation was a process of confirming whether the simulation model was a system-ready representation of the specific objectives of the study.

13.2 Policy intervention experiment

13.2.1 Intervention experiment 1: effects of tertiary medical service force selection and deployment on rescue outcomes

A tertiary emergency medical rescue force is implemented in China currently, including the national strategic rescue force, regional rescue force, and local disaster zone rescue force.

The national strategic rescue force is usually the main force of medical service support; **The regional rescue force** is a supporting force near the disaster zone which is an important force for early treatment and response; **The local disaster zone rescue force** is mainly responsible for post-earthquake resuscitation and emergency treatment tasks.

(1) Design of medical service force deployment protocol

The medical service force involved in this study mainly included **the national strategic rescue force**, **the regional rescue force**, and **the local disaster zone rescue force**. Different forces possess different on-site capabilities and treatment capabilities. Rational deployment ratios and division of labor were an important guarantee of rescue results. This section focused on the effects of different medical service force deployment ratios on rescue results. Protocol 1 was referenced from data on emergency medical rescue during the Wenchuan earthquake in which the ratio of the strategic force, regional force, and local force was 8:1:1. Protocol 2 referenced data on emergency medical rescue during the Yushu earthquake in which the ratio of the strategic force, regional force, and local force was 7:2:1. In protocol 3, the proportion of strategic force was decreased and the ratio was 6:3:1.

Table 13-1. Intervention experiment protocol for medical service force deployment ratio.

Type	Protocol 1 (proportion)	Protocol 2 (proportion)	Protocol 3 (proportion)
National strategic rescue force	8	7	6
Regional rescue force	1	2	3
Local disaster zone rescue force	1	1	1

During earthquakes, the proportion of trauma and crush injuries was more than 80%, which significantly increased surgical treatment needs. A professional medical treatment force must be established with an emphasis on specialist treatment. If the proportion of specialist treatment force during the emergency phase of an earthquake (within 72 hours after an earthquake) was increased, what are the effects on casualty treatment? At present, the surgical rescue force accounts for 20% of the emergency medicine force. In protocol 1, the ratio of the surgical rescue force, epidemic prevention force, and other medical forces was 2:2:6. In protocols and 3, the ratios were 3:2:5 and 4:2:4, respectively.

Table 13-2. Intervention experiment protocol for surgical rescue force ratio.

Type	Protocol 1 (proportion)	Protocol 2 (proportion)	Protocol 3 (proportion)
Surgical rescue force	2	3	4
Epidemic prevention force	2	2	2
Other medical forces	6	5	4

(2) Model intervention results

From the model simulation, it could be seen when the number of casualties is confirmed. I) When the proportion of the national strategic rescue force was reduced, the treatment duration for the same number of casualties was decreased (Figure 13-2). We analyzed the possible reasons, which can be summarized as follows: When the local disaster zone rescue force was fixed, increasing the national strategic rescue force and regional rescue force—although the national strategic rescue force exceeded the other forces—the regional rescue force could reach the disaster zone faster for casualty treatment, thereby decreasing the total rescue time. This was one of the reasons for high efficiency during rescue operations in the Yushu earthquake. II) When the proportion of the surgical rescue force was increased, it was found that the treatment duration for the same number of casualties was decreased (Figure 13-3). We analyzed the possible reasons and summarized them as follows: earthquake casualties have a pressing need for the surgical rescue force as many types of injuries (e.g., brain trauma and serious crush injuries) require treatment by the surgical rescue force in a short time period for patients to be saved. When a higher proportion of the surgical rescue force was dispatched to the front-line of the disaster zone, more severe casualties could be treated within the golden treatment time and treatment efficiency could be increased.

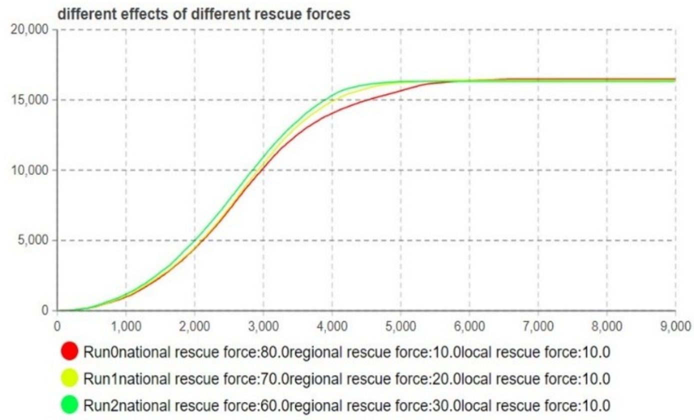

Figure 13-2. Intervention experiment results for medical service force deployment ratio.

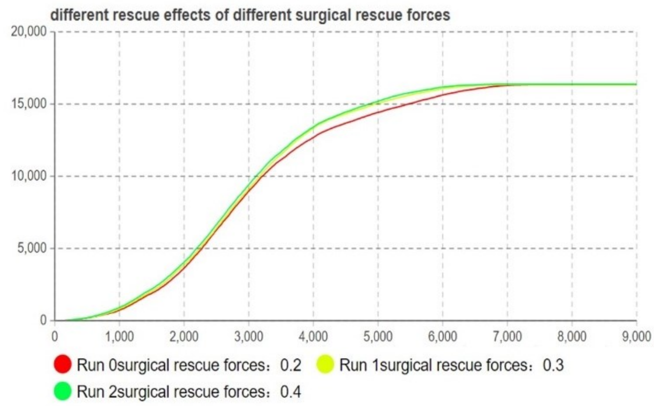

Figure 13-3. Intervention experiment results for surgical rescue force ratio.

13.2.2 Intervention experiment 2: effects of medical force deployment regional adjustment on rescue outcomes

In this section, medical service force deployment regions refereed to the distance between the medical service force deployment site and the disaster zone; this was divided into the primary disaster zone, secondary disaster zone, and scattered casualty zones, which determined the deployment of the medical service force. The primary disaster zone had the greatest number of casualties and was a relatively dangerous region after a disaster.

(1) Design of medical service force deployment regions

The medical service forces involved were all termed as emergency medical rescue teams in this study. This section focuses on the effects of different medical service force deployment region ratios on treatment results. Protocol 1 was based on the deployment ratios in different regions for the medical teams that arrived within 72 hours of the Wenchuan earthquake; the ratio of medical teams in the primary disaster zone, secondary disaster zone, and scattered casualty zones was 4:3:3. Protocol 2 was based on deployment ratios in different regions for the medical teams that arrived within 72 hours of the Yushu earthquake; the ratio of medical teams in the primary disaster zone, secondary disaster zone, and scattered casualty zones was

6:3:1. In protocol 3, the ratio of medical teams in the primary disaster zone, secondary disaster zone, and scattered casualty zones was 5:3:2.

Table 13-3. intervention experiment protocol for deployment of medical service force in different regions.

Type	Protocol 1 (proportion)	Protocol 2 (proportion)	Protocol 3 (proportion)
Primary disaster zone	4	6	5
Secondary disaster zone	3	3	3
Scattered casualty zones	3	1	2

(2) Model intervention results

From the model simulation, it could be seen that when the number of casualties was confirmed, and when the treatment force was concentrated in the primary disaster zone from scattered casualty zones, the treatment duration for the same number of casualties was decreased (Figure 13-2). We analyzed the possible reasons and found that the number of casualties at the primary disaster zone was several times or several dozen times that of the secondary disaster zone and scattered casualty zones, and these casualties have urgent medical treatment needs. When the main rescue force was dispatched to the primary disaster zone, a large number of casualties could receive timely treatment, so as to improve the effectiveness and efficiency of rescue. But from another side, the ratio of rescue force deployment in disaster zones must be determined based on the geographical distribution of casualties. The most ideal scenario was that the ratio of the rescue force deployed was based on the number of casualties. On the one hand, estimation of attrition due to natural disasters was still a challenge in current research. On the other hand, destruction of the primary disaster zone was severe, and it was difficult for the main rescue force to reach the frontline rapidly. Therefore, precise force deployment cannot be achieved at present.

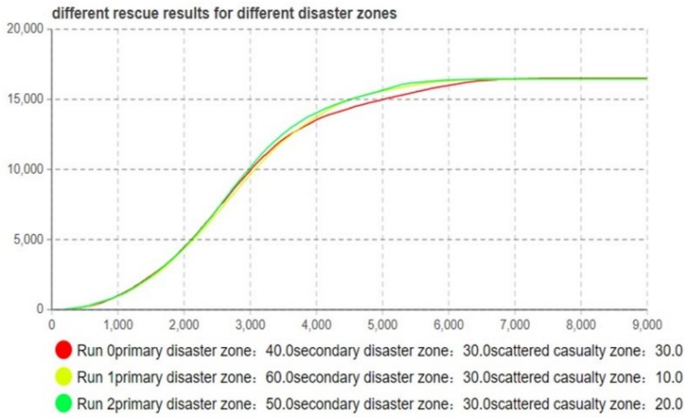

Figure 13-4. Intervention experiment result for deployment of medical service force regions.

13.2.3 Intervention experiment 3: effects of medical service force selection and deployment adjustments on rescue outcomes

The effects of medical service force selection and deployment on medical treatment results are presented in the following areas: Firstly, the number of medical service forces. Secondly, the structure of the medical service force (ratio of the three rescue forces). Thirdly, the deployment regions of the rescue forces. From a summary of previous emergency medical rescue experiences, it could be seen that to improve emergency medical rescue efficiency and results, the quantity, structure, and distribution of medical service forces should not be unchangeable and can be dynamically adjusted with time. Therefore, in the third intervention experiment, we focused on the dynamic adjustment of medical service force structure and distribution.

(1) Design of medical service force selection and deployment adjustment protocol

The two previous intervention experiments purely focused on intervention and simulation of the medical service force structure and distribution. Here, we designed a dynamic protocol of medical service force selection and deployment with time. It was widely known that it took time for the strategic medical service force and regional support medical service force to reach the disaster zone. As shown in Figure 1-11, at 72 hours after the earthquake (phase 1), the medical service force that could reach the disaster zone within 12 hours, 48 hours, and 72 hours was 20%, 60%, and 70%, respectively. Between 72 hours to 2 hours after the earthquake (phase 2), the medical service force that could reach the disaster zone is basically 100%. Dispatching more forces to the disaster zone during the golden period for rescue could significantly improve medical rescue results.

Table 13-4. Medical service force dispatched within 72 hours.

Time period	Protocol 1 (proportion)	Protocol 2 (proportion)	Protocol 3 (proportion)
24 hours	20%	30%	40%
48 hours	60%	70%	70%
72 hours	70%	80%	90%

(2) Model intervention results

From the model simulation results, it could be seen that when the number of casualties was confirmed, enabling rescue forces to reach the disaster zone faster within 48 and 72 hours could shorten the duration for the treatment of the same number of casualties (Figure 13-5). We analyzed the possible reasons for this, injury evolution follows the "platinum 10 minutes and golden 1 hour" treatment rule. In particular, a large number of casualties must receive treatment within a certain time period for them to live. When medical service forces were dispatched to the disaster zone sooner, more casualties could be treated.

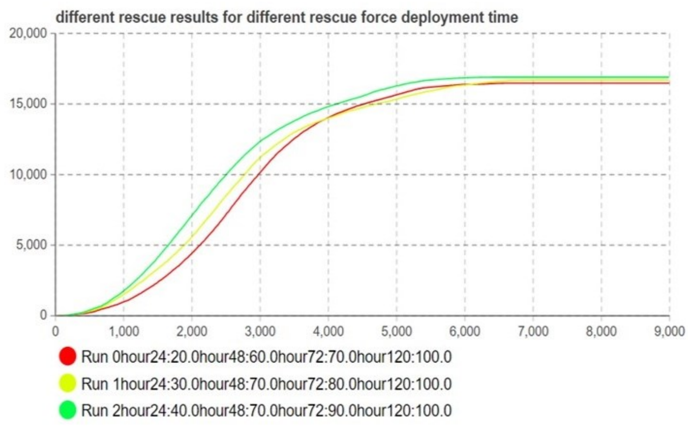

Figure 13-5. Intervention experiment results for medical service force deployment time and ratio.

13.3 Policy recommendations

In this section, we constructed the medical service force selection and deployment multi-agent model to achieve tertiary medical service force selection and deployment according to the idea of "individual agent model construction-multi-agent model construction-model commissioning and optimization", which could provide assistance in decisional support for medical service force assurance in emergencies. We used the earthquake relief medical service force selection and utilization as an example to carry out policy intervention experiments on medical service force selection and deployment and analyzed its results. We summarized medical service force selection and deployment policy recommendations as follows.

(1) Rational selection of strategic, region, and local medical service force to improve medical service force utilization efficiency

The national strategic rescue force-was usually the main force that the country used for medical service assurance, which possessed advanced technical equipment and high standardization. The regional rescue force was a supporting force near the disaster zone and was important for early treatment and response. The local disaster zone rescue force was mainly responsible for post-earthquake resuscitation and emergency treatment tasks. During emergency medical rescue in disasters, it was necessary to establish usage principles for various grades of emergency medical rescue force and to clarify the responsibilities and rescue requirements of every level of rescue force. Various professional forces should be used in a concentrated manner, there should be adherence to zonal management (divided according to responsibility), assurance by area, and clarification of the technical scope of treatment and casualty evacuation system should be carried out. Targeted selection and deployment of emergency medical rescue should be carried out according to the characteristics of different time-points and the high medical needs of the disaster zone should be fully considered for early, sufficient, efficient, and modular selection of the rescue force. With regard to force deployment, it was necessary to adhere to rapid forward deployment, establish a fully modular deployment system, achieve highly consistent force selection and deployment, reduce low efficiency loss of force, and improve emergency medical rescue efficiency.

(2) Force deployment should be based on needs and modular operation should be implemented during rescue

The use of medical service force under emergencies should be based on the medical needs of the emergency and the intention of the emergency rescue command institution, in combination with terrain and road conditions, epidemiological characteristics, and other medical-geographical environmental factors. The possible development trends of the event should be analyzed, actual initiation should be carried out objectively, and the following principles must be followed. Firstly, the use of the medical service force should conform to the needs of emergency medical rescue and benefit on-site resuscitation and rapid evacuation of casualties. Secondly, an efficient emergency medical rescue system should be set up. Usually, this was based on a combination of different assurance regions, points, lines, and planes and the cluster deployment of different forces to achieve a combination of the local force, regional support, and strategic force at the disaster zone; a combination of linear deployment and region deployment, a combination of prevention, treatment, and evacuation forces, and avoiding overlapping forces at the same time can be achieved. Thirdly, medical service force deployment should correspond to objective conditions such as roads. The deployment site should be close to major roads, with some area for deployment and a corresponding water source, and other nearby rescue forces to facilitate the emergency medical rescue of other rescue forces. Emergency medical force selection must be carried out according to the functional modal, standby deployment elements and types must be complete, and modular deployment must be employed during the entire process.

(3) Strengthening the professional basis of staff and appropriate establishment of the frontline surgical force

From the foreign military mobile medical force construction process, it could be seen that small, easily deployed, and highly mobile surgical teams had increasingly attracted more and more attention. The nature of life support demonstrated the importance of first-line surgical force in medical service assurance during non-combat military operations. In China, the surgical team consisted of only seven people, and equipment was also relatively simple. The main tasks of the surgical team were to strengthen the ability of field medical centers (teams) in carrying out specialist surgeries. However, it was hard for these teams to carry out their responsibilities at the frontline during emergencies; this could be compensated for by the Forward Surgical Team (FST). To establish FSTs, a pressing need was to determine the staff composition according to the task requirements for medical service assurance in non-combat military operations, to formulate the corresponding scope, principles, types, and timing of surgeries, and the daily casualty flow, working hours, postoperative observation period, and other critical techniques and combat markers. With regard to the different staff in the mobile medical team, on-site casualty resuscitation training should be popularized. At the same time, staff should master treatments for unfamiliar injuries that tended to occur during non-combat military operations, such as on-site resuscitation for crush syndrome during earthquakes; rescue, warming, and fluid replacement in casualties with seawater immersion injuries that were rescued during maritime disasters; on-site treatment of smoke inhalation, asphyxiation, and burns in fires; and on-site resuscitation of near-drowning casualties during floods.

(4) Emphasis on rescue force construction and rational deployment of specialist force according to requirements

The age, gender, and injury in which casualties occur during non-combat military operations were complex and medical service assurance must be fast, mobile, forward-deployed, and consisted of multiple functions. Using earthquake relief as an example, the proportion of trauma and crush injuries was more than 80%, which significantly increased surgical treatment needs. A professional medical treatment force must be established with an emphasis on specialist treatment. For example, the rapid response medical support teams constructed by the U.S. army contained dedicated team and emergency treatment rapid response support teams and a trauma treatment rapid response support team, of which the responsibilities of the burns treatment rapid response support team are very clear: Providing technical advice and assurance during the triage, treatment, stabilization, care, and evacuation of burn patients; Use of local equipment, resources, and portable medical kits emergency treatment; assisting in determining subsequent specialist technique and medical resource needs; Assisting in formulating a treatment transition plan so that recovery to normalcy proceeds in an orderly manner. Good specialist treatment levels are significant in completing resuscitation in non-military combat operations. With regard to medical service force delivery methods, emphasis should be placed on overall delivery principles for functional modules and ensuring that internal functional elements, staff, and equipment in the module can be simultaneously deployed. This will reduce separation between staff and equipment and batch transportation. Modular grouping should become an important guideline for establishing the specialist rescue force in non-combat military operations and an important route for improving the mobility of medical rescue forces.

14 Policy intervention experiment of tornado casualties

Authors: Qiangyu Deng, Bo Wang, Lulu Zhang

14.1 Model simulation

14.1.1 Model introduction

System definition. The model focuses on the traumatic occurrence process during tornadoes. The disaster agent, refugee agent, and emergency management form a basic system structure. The casualty occurrence process of the refugees agent is the main logical line of the whole system. At the same time, the status change of refugees is affected by the dual role of the disaster agent and emergency management. This model is mainly used to simulate the traumatic occurrence process during tornadoes and analyze the effects of various factors on the final number of casualties.

Main agent definition. In this model, three agents were defined: tornadoes (disaster agent), refugees (disaster-bearing agent), and buildings (emergency management).

Tornadoes. Tornadoes are specific disaster agents in this model. The main attribute of a tornado that causes casualties is wind intensity. Different wind intensity produces different central destruction areas (length and width) and different casualty rates: (1) The international EF scale is used as a standard for tornado intensity [152]; (2) the central destruction area (length and width) is directly correlated with the tornado EF scale rating; and (3) the casualty rate refers to the probability of different casualties caused by different tornado intensity on refugees in the disaster zone.

Refugees. In this model, residents in the tornado region were defined as refugees. Refugee attributes include age, individual behavior, disaster zone population density, warning time, and injury severity. (1) Age is an important demographic factor, age affects disaster avoidance behavior and casualty probability of disaster refugees [153-157]. (2) Indoor/outdoor location refers to whether refugees are indoors or outdoors when the tornado occurs. (3) Individual behavior refers to proactive behavior adopted to refugees to escape from the tornado, which generally includes staying put at the original site, escaping indoors, or running far away. Staying put at the original site refers to taking shelter from the tornado at the original site, escaping indoors refers to running indoors when a tornado occurs, and running far away refers to running away from the tornado. (4) Population density refers to the population number per unit area in the disaster zone and is an important predictive marker for the number of casualties. (5) Warning time refers to the time of the advance warning received by refugees before the tornado, which is related to the warning information released by the emergency management department and is also simultaneously related to the timing in which refugees received warnings. The final observation point is the warning information received by refugees, therefore, this is an attribute of refugees. When refugees receive warning, they will adopt individual behaviors to escape the tornado. (6) Family income refers to the income of the refugees. (7) Disaster prevention exercise awareness refers to whether refugees are aware of the need for exercise. (8) Injury severity refers to the injuries suffered by casualties and is an outcome attribute of refugees after the model operation; it is usually determined according to Abbreviated Injury Scale (AIS).

Buildings. In this model, buildings are major factors that can be regulated in emergency management. Intact buildings are a protective factor for trauma occurrence while collapsed buildings are an important risk factor for injuries. House attributes include degree of building collapse and house density. (1) Degree of building collapse based on international disaster research cases is divided into five categories: mild, moderate, severe damage, partial and complete collapse. During a disaster, different proportions of house damage will occur, which produces different casualty probabilities. (2) House density refers to the number of houses per unit area in the disaster zone.

14.1.2 Simulation commissioning

Yancheng tornado simulation commissioning

(1) Tornado status

According to the Yancheng tornado study results, the tornado was grade EF4, no warning was given, and the central destruction (i.e., an extremely severely destroyed region as set by the National Meteorological Center) area was 133 m^2.

(2) Refugee status

According to the Yancheng tornado study results, the daily initial status of different age groups of refugees who did not receive warning about the tornado is as follows (Table 14-1).

Table 14-1. Basic status of different age groups.

Age group	Proportion (%)	Initially indoor proportion (%)	Escape speed (km/h)
<20	3.19	33.33	0.50
20–65	63.83	86.67	1.00
>65	32.98	87.10	0.30

The choices made by indoor/outdoor residents during the tornado are as follows (Table 14-2).

Table 14-2. Proportion of different behaviors by indoor/outdoor residents after learning about the tornado.

Type	Staying put (%)	Escape indoors (%)	Running far away from tornado (%)
Outdoor residents	14.29	71.42	14.29
Indoor residents	97.50	0.00	2.50

Data from the Funing county government website were used to obtain the population size and the number of households of various towns. The jurisdiction area of Funing county is 1438.29 m^2. For rural residents, the number of households is equivalent to the number of houses. However, with regard to population density, the on-site survey found that Funing county is a county with a large exodus of its labor force: many young adults work outside the county and children go to school outside the county, leaving the elderly in the village. Hence, the number of permanent residents in the disaster zone is far lower than the population registered in the household register. According to the 2015 Chinese demographic structure by age group released by the National Bureau of Statistics of China [158], the population ratio of the 1–14 years, 15–64 years, and ≥65 years age groups was 16.52:73.01:10.47. In our survey, the population ratios of the 1–20:20–65:>65 age groups were 3.19:63.83:32.98. From the survey, we found that the proportion of elderly people was increased to thrice that of the population in the household register, and we deduced that the actual number of residents in the disaster zone was reduced to one-third of the original population in the household register. Therefore, the population density of Funing county was 189.33/km^2 and house density was 246.20 households/km^2 (Table 14-3).

Table 14-3. Basic population information of Funing county.

Town	Number of households	Population size
Fucheng town	23301	82150
Goudun town	15588	51086
Chenliang town	13892	42651
Sanzao town	15045	53039
Guoshu town	12309	41792
Xingou town	14923	50404
Shuoji town	13334	46997
Yangzhai town	13276	45569

Lupu town	119891	11927
Banhu town	13001	46415
Donggou town	28331	90970
Yilin town	19854	69288
Guhe town	16224	57455
Luoqiao town	13320	51513
Wutan town	15391	54901
Jinshahu	6431	21012
Total	354111	817169
Density (per m^2)	246.20	568.15

(3) Casualty ratio

The proportion of various types of injury severity is set as follows according to the AIS score results in part 1 of this book and in combination with the total number of casualties (n = 846) and total deaths (n = 99) reported by the Yancheng Health Commission (Table 14-4).

Table 14-4. Proportion of various types of injury severity.

Casualty ratio	Proportion (%)	Injury severity
Death	10.48	
Critical injury	2.22	AIS = 5 or 6
Severe injury	18.94	AIS = 3 or 4
Mild injury	68.36	AIS = 1 or 2

(4) House collapse status

According to the Yancheng tornado survey results, the different probabilities of house damage and the probability of casualties caused by different types of house damage are as follows (Table 14-5).

Table 14-5. House collapse rate (%).

Type	Mild damage	Moderate damage	Severe damage	Partial collapse	Complete collapse
Probability of damage	4.26	12.77	12.77	20.21	50.00
Probability of casualties of different collapsed houses	0.00	41.67	50.00	47.37	85.11

(5) Commissioning results

After setting according to the general status of Yancheng tornado, the simulation results showed that the total number of casualties was 1093, of which there were 105 deaths, 21 critical casualties, 212 severe casualties, and 755 mild casualties (Figure 14-1). It was reported that there were 99 deaths and 846 casualties in the Yancheng tornado and the deviation in the total number of casualties in the model simulation was 6.35%. Overall, the model simulation results were close to the actual results, suggesting that the model has good reliability, and stability.

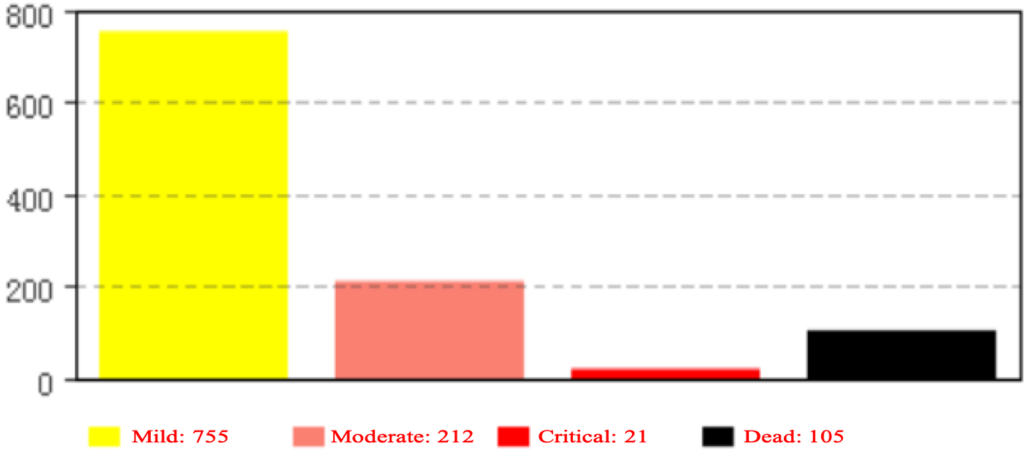

Figure 14-1. Yancheng tornado casualty occurrence commissioning results.

Chifeng tornado simulation commissioning

(1) Tornado status

According to the Chifeng tornado study results, the tornado was grade EF3 (close to grade F3), no warning was given, and the central destruction area was 6.72 m^2.

(2) Refugee status

According to the Chifeng tornado study results, the daily initial status of different age groups of refugees, who did not receive warning about the tornado, is as follows (Table 14-6).

Table 14-6. Basic status of different age groups.

Age group	Proportion (%)	Initially indoor proportion (%)	Escape speed (km/h)
<20	1.49	100.00	0.50
20–65	89.55	96.67	1.00
>65	8.96	100.00	0.30

The choices made by indoor/outdoor residents during the tornado are as follows (Table 14-7).

Table 14-7. Proportion of different behaviors by indoor/outdoor residents after learning about the tornado.

Type	Staying put (%)	Escape indoors (%)	Running far away from tornado (%)
Outdoor residents	50.00	0.00	50.00
Indoor residents	9.23	90.77	0.00

According to data from the Chifeng municipal government, the population of Chifeng was 4.6 million, the number of households was 210, and area was 90,000 m^2. Therefore, the population density of the Chifeng tornado disaster zone was around 51.11/km^2 and house density was 23.33 households/km^2.

(3) Casualty ratio

The proportion of various types of injury severity is set as follows according to the AIS score results in part 1 of this book and in combination with the total number of casualties (n = 58) and total deaths (n = 5) reported by the Chifeng Health Commission (Table 14-8).

Table 14-8. Proportion of various types of injury severity.

Casualty ratio	Proportion (%)	Injury severity
Death	7.93	
Critical injury	0.00	AIS = 5 or 6
Severe injury	17.46	AIS = 3 or 4
Mild injury	74.60	AIS = 1 or 2

(4) House collapse status

According to the on-site survey results, the different probabilities of house damage and the probability of casualties caused by different types of house damage in the Chifeng tornado disaster zone are as follows (Table 14-9).

Table 14-9. House collapse rate (%).

Type	Mild damage	Moderate damage	Severe damage	Partial collapse	Complete collapse
Probability of damage	4.48	34.33	25.37	20.90	14.93
Probability of casualties of different collapsed houses	0.00	21.74	29.41	64.29	100.00

(5) Commissioning results

After setting according to the general status of Chifeng tornado, the simulation results showed that the total number of casualties was 67, of which there were six deaths, three critical casualties, 13 severe casualties, and 45 mild casualties (Figure 14-2). It was reported that there were five deaths and 58 casualties in the Yancheng tornado; the deviation in the total number of casualties in the model simulation was 15.66%. Overall, the model simulation results were close to the actual results, suggesting that the model has good reliability and stability.

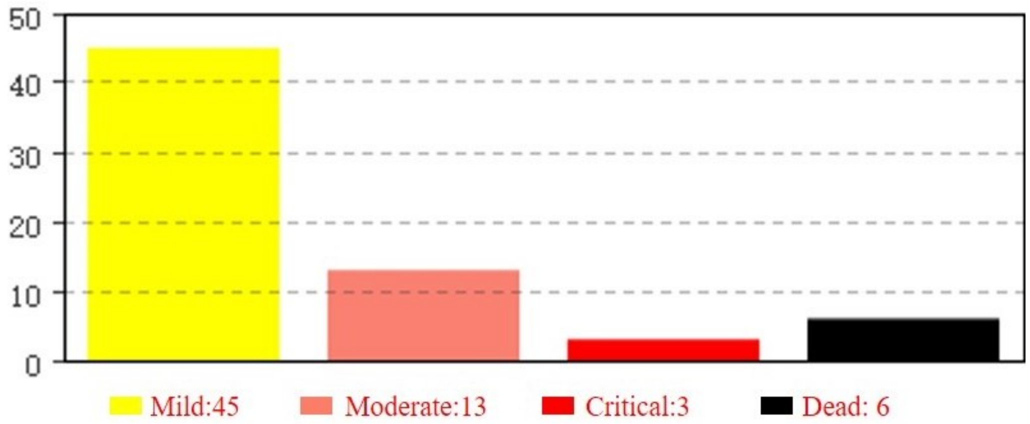

Figure 14-2. Chifeng tornado casualty occurrence commissioning results.

Dynamic commissioning of casualties' occurrence in populations during the two tornadoes was carried out based on the commissioning data from the Yancheng and Chifeng tornadoes; the differences between model simulation results and actual casualty status in the disaster as well as possible reasons were analyzed to validate model stability and reliability. The total number of casualties in the two commissioning results were slightly higher than the actual number of casualties, of which the simulation deviation of the Yancheng and Chifeng tornadoes was 6.35% and 15.66%, respectively. We analyzed the reasons for these deviations: 1) The included population density was inaccurate. The simulation population density for Yancheng was based on the number of households in Funing county while the disaster zone in the Yancheng tornado was mainly Funing county town so population density was far lower than the entire county. This results in the number of casualties in the simulation being higher than the actual number of casualties. The simulation population density for Chifeng was based on the number of households in the entire Chifeng city while the tornado disaster zone was in villages. Population density was far lower than the mean population density in the entire city. This results in the number of casualties in the simulation being higher than the actual number of casualties, which suggests that more casualties will occur if these tornadoes occur in urban areas with high population density. 2) The disaster zone is in a state of disorder after the tornado and there were some casualties that were not treated. This results in the number of casualties in official statistics being lower than the actual value.

14.2 Policy intervention experiment

The laws governing casualty occurrence during tornadoes were collected and used to simulate changes in the total number of casualties in the constructed model under different intervention conditions. Model analysis showed that government intervention measures to reduce tornado casualties mainly include warning, improving disaster avoidance behavior in refugees, and improving disaster-resistant facilities, such as buildings, for refugees. Therefore, nine sets of intervention experiments on warning time, refugee behavior, and house collapse were carried out in this section. In the intervention experiment, a reduction in the number of casualties was set as a positive result while an increase in the number of casualties was set as a negative result.

14.2.1 Intervention experiment 1: intervention experiment of warning time

(1) Intervention experiment protocol for warning time

To observe the effects of warning time on the number of casualties, three sets of intervention experiments were designed to simulate the total number of casualties under different warning times.

Experiment 1: Warning time of 0 minutes, that is, warning time is identical to the time of tornado occurrence, meaning that the government issues a tornado warning in the potential disaster zone when a tornado is detected.

Experiment 2: Warning time of -10 minutes, that is, warning time occurs 10 minutes before the tornado occurs, meaning that the government issues a tornado warning 10 minutes in advance.

Experiment 3: Warning time of 10 minutes, that is, warning time occurs 10 minutes after the tornado, meaning that the government does not issue an advance warning but rapidly collects relevant disaster information after the tornado and predicts possible disaster zones and issues a tornado warning for residents in potential disaster zones.

(2) Warning time intervention experiment results

From the intervention experiment results, it can be seen that compared with immediate warning during the disaster, a 10-minute advance warning produced positive results and the number of casualties was decreased while a warning 10 minutes after the disaster produced negative results and increased the number of casualties (Figure 14-3, Table 14-10).

This suggests that advance warning time produced fewer casualties. The number of casualties produced when the warning is issued 10 minutes before the tornado occurs is reduced by 16.38% compared with a warning time of 0 minutes. The number of casualties produced when the warning is issued 10 minutes after the tornado occurs is increased by 36.88% compared with a warning time of 0 minutes. This shows that advance warning can enable refugees to adopt effective disaster avoidance behavior, which is important to reduce the number of casualties. Even if advance warning before a tornado cannot be carried out, real-time observation of a strong convection should be carried out so that a warning can be issued to residents in potential disaster zones once a tornado forms. At this time, even if the warning does not produce protective effects on residents in these regions, the warning can have protective effects on residents in regions that will be struck by the tornado.

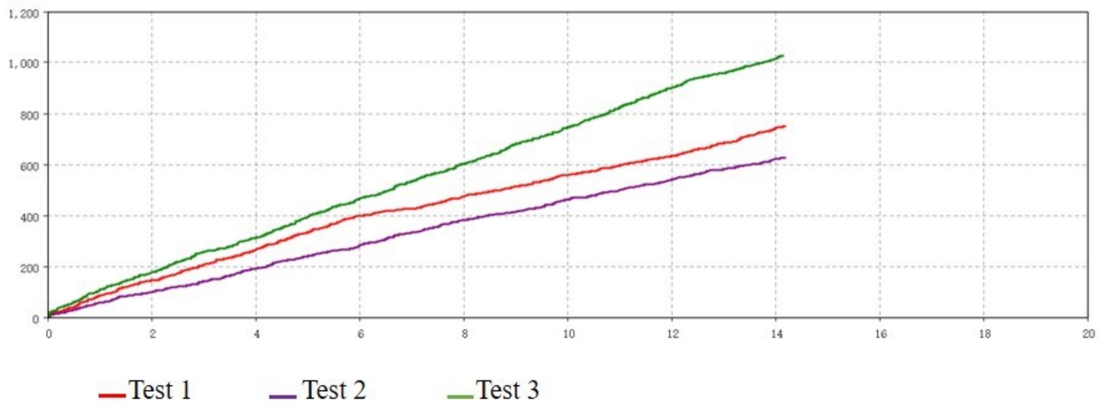

Figure 14-3. Effects of adjustment to tornado warning time on number of casualties.

Table 14-10. Changes in number of casualties after adjustment to tornado warning time.

No.	Warning time	Number of casualties	Marker change	Outcome
1	0	751	Control	Control
2	−10	628	83.62%	Positive
3	10	1028	136.88%	Negative

14.2.2 Intervention experiment 2: intervention experiment of refugee relief behavior

(1) Intervention experiment protocol for refugee relief behavior

To observe the effects of refugee disaster avoidance behavior on the number of casualties, when warning time is 0 minutes (i.e., a warning to all residents in potential disaster zones is immediately issued once a tornado is formed), three sets of intervention experiments were designed to simulate changes in the total number of casualties. From previous studies, the behaviors of refugees in intervention experiments in this section were divided into three types (staying put, escaping indoors, and running far away).

Experiment 1: Staying put, that is, refugees stay at their original site regardless of whether they are indoors/outdoors and look for shelter for disaster avoidance. Refugees that were initially indoors remain indoors when the tornado strikes while refugees that were initially outdoors remain outdoors.

Experiment 2: Escape indoors, that is, Refugees all escape indoors to find shelter. After receiving warning, outdoor refugees will run indoors while indoor refugees will remain indoors. Whether outdoor refugees can successfully escape indoors is determined by whether warning time is sufficient.

Experiment 3: Running far away, that is, after indoor and outdoor refugees receive warning, they will all run from the direction of the tornado. Finally, three outcomes of outdoors, indoors, and escape from the disaster zone are produced. Whether refugees can successfully escape from the disaster zone is determined by whether warning time is sufficient.

(2) Refugee disaster avoidance behavior intervention experiment results

From the intervention experiment results, it can be seen that compared with staying put during the disaster, escaping indoors produced positive results and the number of casualties was decreased while running away produced negative results and the number of casualties was increased (Figure 14-4, Table 14-11).

Compared with staying put, the number of casualties was decreased by 20.25% when refugees all ran indoors, showing that indoors is safer than remaining outdoors. However, the difference in the number of casualties between the two was not great, showing that indoor residents may still suffer injuries. The main reason is severe house collapse in the severe disaster zone and houses do not have good protective effects for refugees. This indirectly shows that tornado resistance should be strengthened for areas that are prone to tornadoes. It is worth noting that running further away produced far more casualties than other behaviors, an increase of 75.09% compared with staying put. This shows that when advance warning is ineffective, running away is an extremely dangerous behavior during tornadoes as the probability of escaping the tornado destruction zone is very low. Hence, refugees in tornadoes should avoid trying to flee.

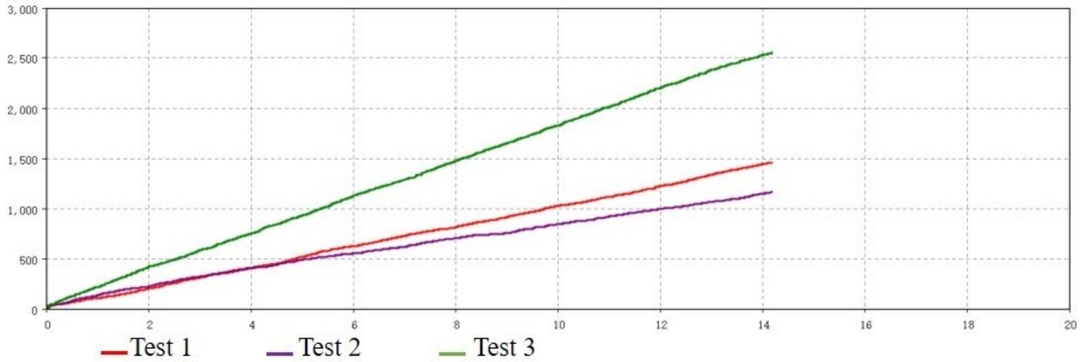

Figure 14-4. Effects of adjustment of refugee relief behavior on number of casualties.

Table 14-11. Changes in number of casualties after adjustment to refugee relief behavior.

No.	Individual behavior	Number of casualties	Marker change	Outcome
1	Staying put	1457	Control	Control
2	Escape indoors	1162	79.75%	Positive
3	Running far away	2551	175.09%	Negative

14.2.3 Intervention experiment 3: intervention experiment of degree of building collapse

(1) Intervention experiment protocol for degree of building collapse

In order to observe the effects of degree of building collapse on the number of casualties, when warning time is 0 minutes (i.e., a warning to all residents in potential disaster zones is immediately issued once a tornado is formed), three sets of intervention experiments were designed to simulate changes in the total number of casualties.

Experiment 1: Severe collapse, that is, the ratio of buildings with mild damage, moderate damage, severe damage, partial collapse, and complete collapse was 1:1:1:1:6.

Experiment 2: Moderate collapse, that is, the ratio of buildings with mild damage, moderate damage, severe damage, partial collapse, and complete collapse was 1:1:6:1:1.

Experiment 3: Mild collapse, that is, the ratio of buildings with mild damage, moderate damage, severe damage, partial collapse, and complete collapse was 6:1:1:1:1.

(2) Intervention experiment result for degree of building collapse

From the intervention experiment results, we can see that compared with severe collapse, the moderate and mild collapse of houses produced positive results and the number of casualties was reduced (Figure 14-5, Table 14-12).

The more severe the degree of house collapse, the greater the number of casualties, which shows that collapsed houses are the main cause of injuries among refugees in disaster zones. Compared with severe collapse, moderate and mild collapse can reduce the number of casualties by 24.25% and 45.88%, respectively. Hence, the protective effects of houses on refugees cannot be solely based on being indoors or outdoors, and a strong house has good protective effects whereas a collapsed house is a major cause of injuries. This shows that in order to reduce the degree of house collapse, governments should pay more attention to buildings in tornado-prone regions to increase their tornado resistance.

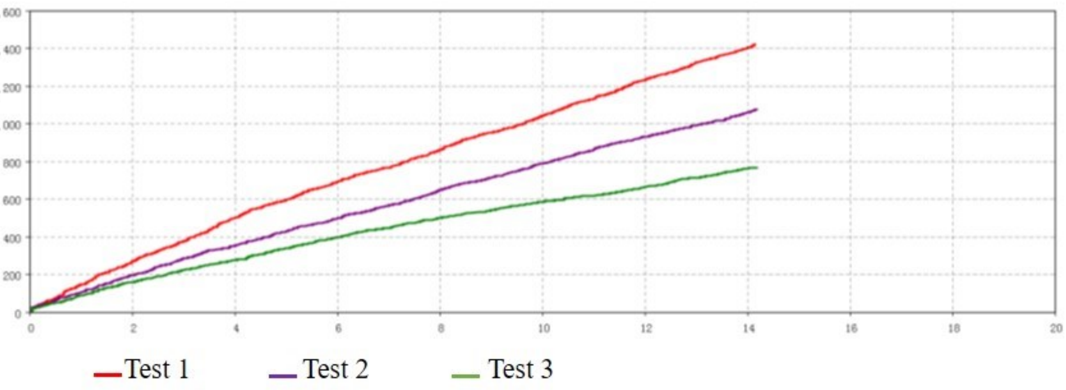

Figure 14-5. Effects of adjustment of degree of building collapse on number of casualties.

Table 14-12. Changes in number of casualties after adjustment to degree of building collapse.

No.	Degree of building collapse	Number of casualties	Marker change	Outcome
1	Severe collapse	1419	Control	Control
2	Moderate collapse	1075	75.75%	Positive
3	Mild collapse	768	54.12%	Positive

14.3 Policy recommendations

(1) Advance warning can effectively decrease the number of casualties

The intervention experiment showed that the earlier the warning time, the fewer the casualties. This shows that advance warning can enable refugees to adopt effective disaster avoidance behavior, which has important significance in reducing the number of casualties. Compared with 0 minutes of warning time, a warning time of 10 minutes before the tornado strikes can reduce casualties by 16.38%. Compared with a warning time of 10 minutes after the tornado, issuing warning when the tornado occurs (0 minutes) can also reduce the number of casualties. This suggests that even issuing warning when a tornado begins can reduce the number of casualties. The reason for this is that the area in which a tornado strike is stripe-shaped, and the tornado will persist for a period of time. Even if the post-disaster warning does not produce protective effects on residents in regions which the tornado has struck, the warning can have protective effects on residents in regions that will be struck.

In contrast to earthquakes, tornadoes are meteorological disasters due to strong convection currents; they are often accompanied by hail, strong winds, and heavy rain. Therefore, there is some warning time for tornadoes. Tornado warning information received by refugees in advance becomes an important protective factor for trauma in refugees. A U.S. study [155] showed that Internet (OR, 0.20; 95% CI: 0.09–0.49), television (OR, 0.45; 95% CI: 0.24–0.83), and siren (OR, 0.50; 95% CI: 0.30–0.85) warnings and meteorological broadcasts from the National Oceanic and Atmospheric Administration (OR = 0.40, 95% CI: 0.19–0.84) have some protective effects against trauma during tornadoes. However, the number of warning exposures also simultaneously reduces the probability of refugees in actively seeking shelters. This may be due to a lack of sensitivity toward warnings for refugees when there are too many warnings. Schmidlin found that compared with survivors, fewer people who died due to tornadoes watched television and learned of the tornado later ($p < 0.1$) [157]. Simmons found that issuing warnings 5 minutes and 6–10 minutes in advance can reduce 19% and 52% of deaths, respectively [159].

(2) Running away is a risky behavior during tornadoes

The model intervention experiment found that compared with staying put during the disaster, escaping indoors reduced the number of casualties by 20.25% and running far away from the tornado increased the number of casualties by 75.09%. The number of casualties caused by running far away is far higher than other behaviors, showing that when effective advance warning of the time and trajectory of the tornado is not available, running far away during a tornado is extremely dangerous. Given the time constraints, the probability of escaping the tornado destruction zone is very low. Hence, refugees in tornadoes should avoid running away. The number of casualties when staying put is higher than escaping indoors, showing that houses have some protective effects for refugees although they are not significant. The main reason for this is severe house collapse in the severe disaster zone.

Other studies on refugee behavior showed that there is controversy on whether driving to escape a tornado should be undertaken. In 2000, Bohonos reviewed studies on the medical impact of tornadoes in North America [160] and found that driving to escape tornadoes is a risk factor for trauma. He recommended that refugees who drive should leave their cars when a tornado occurs and seek shelter or low-lying areas. However, a recent study found that driving to escape was a protective factor in tornadoes in the United States. in 2011 (OR = 0.28, 95% CI: 0.05–1.01) [155] but the difference was not statistically significant. Similarly, Daley et al. found that compared with staying put, driving to escape is a protective factor for severe injuries (OR = 0.2, 95% CI: 0.1-0.6) and mild injuries (OR = 0.3, 95% CI: 0.2-0.7) [161]. Therefore, there is still controversy over the benefits of driving to escape tornadoes and this should be determined according to the actual disaster.

(3) Improving tornado resistance in houses can reduce casualties

The model intervention experiment found that compared with severe collapse, moderate and mild collapse can reduce the number of casualties by 24.25% and 45.88%, respectively. House collapse rate is positively correlated with the incidence of trauma in refugees: The more severe the degree of house collapse, the greater the number of casualties. This shows that a strong intact house can protect refugees, but a collapsed house is an important factor in refugees' injuries. Governments should focus on the building status in tornado-prone regions and improve buildings' tornado resistance and stable construction to reduce the number of casualties.

Other studies showed that the more stable the building structure is, the better its protective effects are for indoor refugees. Schmidlin found that in the 1994 Alabama and Georgia tornadoes the risk of mortality is higher for refugees in houses with windows ($p < 0.1$) [157]. Curtis and Fagan pointed out that multi-story buildings and condominiums tend to cause more casualties than single-story buildings and single buildings [162]. Bohonos pointed out that in tornadoes in the United States, the risk of injury is greater on high floors than on low floors and that wooden houses pose a greater risk of injury in refugees [160]. The U.S. Centers for Disease Control reported that during the 2011 tornadoes in the United States, 46.7% and 26.6% of deaths occurred in single-family homes and mobile homes, respectively [156]. In addition, Sugimoto analyzed the characteristics of subtropical buildings in Bangladesh and found that severe house collapse is a strong risk factor for casualties (OR = 67.01, 95% CI: 52.26–85.93) [153]). With regard to wall structure, the collapse of brick walls is a risk factor compared with thatched structures (OR = 6.97, 95% CI: 1.09–44.66).

15 Policy intervention experiment of blast injury

Authors: Wei Liu, Lulu Zhang

15.1 Model simulation

Attribution estimation was one of the important tasks of medical service organizational command; it had important contents for formulating medical service assurance plans and was an important basis for organizational planning and the rational usage of the medical service force. It also provides the basis for organizing medicinal material assurance and deployment of medical service resources and had vital effects on the rational usage of limited medical service manpower, medical facilities, and medicinal materials. Analysis of attrition composition and occurrence patterns had important effects on the correct formulation of medical service assurance plans, summarizing medical service assurance experience, and improving treatment work.

Since World War II, casualties with blast injuries account for more than half the total number of casualties. In modern warfare, the number of casualties caused by explosive weapons was increasing day by day. The future battlefield environment would become more and more complex, the battlefield depth would continuously expand, and the importance of airstrikes and artillery strikes would become increasingly prominent. It could be foreseen that blast injuries would still be the main type of trauma in wars. Therefore, blast injuries would be an important component in attrition estimation studies. Blast injuries were defined as injuries caused by various types of explosive weapons such as missiles, bombs, projectiles, naval mines, land mines, and grenades.

From this book, the literature review was used as a basis for constructing a theoretical model of projectile injuries, and animal experiments were used to validate this model. A projectile attrition agent model was constructed by combining the theoretical model of projectile injuries with the projectile injury spectrum. In this model, relevant parameters could be adjusted to generate projectile casualty data under different scenarios to provide a data basis for medical service force deployment, optimized allocation of medical resources, and training of medical service staff.

15.1.1 Model introduction

(1) Classification of individual agent

The classification of individual agent was generally adopted top-down functional analysis and bottom-up **entity clustering methods.** When constructing a complex model system, identical activities were usually grouped together to form a functional domain and every functional domain corresponded to an agent. However, in the projectile injury attrition influencing factor model simulation system, the model system was too simple: each person could correspond to an agent, and each person was able to respond to environmental changes. There were no dependent relationships between agents, and agents were independent of each other.

(2) Individual agent modeling

There were two types of individual agent modeling, namely, person modeling and projectile modeling.

person modeling refereed to modeling of individual persons. In this model, each person had his or her, own fixed characteristics, including velocity and posture and there were rules for posture and movement velocity. When posture was standing up, persons move at the set velocity. When persons were lying down, movement velocity was set as 0. Changes in the posture of persons were determined by changes in the external environment, that is, whether persons were within the killing range of projectiles. When persons are within the killing range of projectiles, persons will decide whether to lie down according to the preset probability.

Projectile modeling refereed to construction of a projectile model. In this model, the attributes of projectiles included the weight and blast radius. The weight determined the size of the blast injury area, and the blast radius determines the size of the fragment injury area. In a previous study, the projectile injury mechanism was used to construct a theoretical model of projectile injury, which was validated in animal experiments. Therefore, after the weight and blast radius of the projectile were set, the blast injury area and the fragment injury area could be confirmed. As the posture of persons would change according to the preset probability, when persons lied down, the exposure area was decreased and the blast radius for fragments in a prone posture should be independently calculated.

(3) Multi-agent macroscopic system model

To achieve the system construction, the attributes of the person agent model could be adjusted in a unified manner, and its parameters could be set at the initial interface. The number of agents could also be changed according to requirements. Like persons, the attributes of the projectile agent model could be set at the initial interface in a unified manner, and the rate of fire of the projectile could be adjusted according to requirements.

Agent parameters and influencing factors were set at the initial interface. They included the total number of personnel, personnel movement velocity, probability of lying down, enemy projectile rate of fire, projectile weight, and blast radius of the projectile. All parameters could be adjusted and were expressed in units.

The map size of the operating interface was set as 1200*600 m, and the agent sets off from the left side of the model. The appearance of the first person on the interface was set as the rule for a projectile attack to commence, and the projectile attack stops after the last person had passed through the right side of the model.

The judgment distance in the model refereed to the distance between the agent and where the projectile would fall.

As the injury mechanisms of blast injury and fragment injury are different, independent judgments were used for these two injuries. In this simulation system, blast injury was first determined followed by fragment injury. If the agent was judged to be killed by the blast wave, the agent was directly judged to have died and there was no need to determine fragment injury.

From previous animal experiment data, it could be seen that the number of animals who developed fragment injury was in the 1~8 range. Therefore, the agent was determined to have died in the model when the probability of getting hit by the fragment was more than 8.

An agent could still be hit by projectiles after being injured. In this simulation system, when multiple projectiles simultaneously hit the same agent, the number of wounds for every projectile was independently calculated. That is, the number of wounds was calculated for each hit. If the number of wounds was more than 8, the agent was considered to have died. If it was less than 8, a new wound severity number was given.

(a) Model process

This process mainly described the entire process from the agent moving out until injury occurs. When a projectile attack occurs, the agent would interact with the environment—the agent was able to determine the straight distance between himself and the projectile. If the distance was greater than the blast radius, the agent returned to its initial state. If the distance was smaller than the blast radius, the agent was determined to see if he or she died. If the agent dies, they would be considered as killed in action, but otherwise would be given an injury severity number.

Fragment injury was determined after blast injury was determined. If the distance was greater than the blast radius, the person continued to move forward. If the distance was lower than the blast radius, the posture of the person was determined. For example, with a 50% chance of standing and lying, there was a 50% chance of lying down. If the patient adopted a standing posture, we had to continue to determine whether the person was killed, the death condition of getting hit with the probability more than 8%. If the person was not killed in action, the possible number of wounds was selected from the wound number ratio table and an injury severity code was given. The rules for applying the injury severity code was that the first four digits of injury severity codes (injury site) should not be identical. For example, if the first injury severity code was 01050801 and the second injury severity code was 01050802, the codes did not conform to requirements and must be re-selected.

(b) Model operation

The model mainly included four types of parameters: interface parameters, personnel parameters, projectile parameters, and casualty parameters.

Interface parameters included the size of the interface and the entrance and exit directions. In the model, the interface was set to be a 1200*600m horizontal interface where personnel enter from the left side and exit from the right end.

Personnel parameters included the total number of personnel, personnel movement velocity, and probability of lying down. Projectile parameters included the projectile rate of fire, projectile weight, and blast radius.

All the initial parameters above were included in the initial interface and parameter sizes could be adjusted.

Model operation began when the first agent starts to move from the entrance and ended when all personnel had passed through the interface. The unit was minute and model operation was stopped when the last agent had passed through the interface exit.

Agent attributes included standing still and lying down, and their probabilities were initially set at 50% each. When the agent was lying down, their movement velocity would be changed to 0 and the agent would continue moving after one minute. The agent was initially a green square. If the agent was determined to be injured, it immediately stopped movement and was changed to red. If the agent was determined to have died, movement was immediately stopped and was changed to black.

When model operation ended, the statistics icon in the operating interface was clicked and the overall injury severity and injury details of all agents could be checked one-by-one.

When the statistics icon in the operating interface was clicked, statistical data on the injuries in all agents could be seen, as shown in the following figure.

15.1.2 Simulation commissioning

(1) Simulation commissioning protocol

The study results showed that blast injuries result in high casualty rates and the large number of injuries and proportion of patients with many injuries were significant characteristics. The simulation results showed that when the number of personnel was set as 500, movement velocity was set as 100 m/min, the probability of lying down was set as 50%, rate of fire was set as 50 projectiles per minute, weight was set as 15 kg, the blast radius was less than 3 m, the casualty rate was 36.9%, and injury rate was 24.3%. With regard to injury severity, critical injuries and severe injuries accounted for 18.1% and 41.2%, respectively, and the overall injury severity was severe. From the injury site, it could be seen that a high proportion of persons (74.9%) suffered from multiple injuries. The model operation results showed that the injury severity of projectile injuries produced by the projectile injury agent model conformed to actual projectile injury severity characteristics. Projectile casualties produced by simulation using this system could provide data for medical service force deployment, optimized allocation of medical resources, and medical service staff training.

A projectile injury casualty agent model was constructed by starting from the source of attrition and aggregating the occurrence of projectile injury casualties. The rationality of the results generated by the model has been validated. However, commissioning and optimization were still required to see if the effects of influencing factors in the model on casualty rates conform to previous deductions.

In combat decisions, the attrition rate was one of the important considerations of commanders, and there were many factors affecting it. Influencing factors were divided into five types through environmental definitions. The specific commissioning protocol was as follows.

Commissioning protocol 1: The number of personnel was adjusted to 100, 200, 300, 400, and 500 while other conditions remained unchanged. The effects of changing the number of personnel on casualty rate and injury rate were observed.

Commissioning protocol 2: The movement velocity of personnel was changed to 100m/min, 150m/min, 200m/min, 250m/min, and 300m/min while other conditions remained unchanged. The effects of changing the movement velocity of personnel on casualty rate and injury rate were observed.

Commissioning protocol 3: The probability of lying down in personnel was adjusted to 30%, 40%, 50%, 60%, and 70% while other conditions remained unchanged. The effects of changing the probability of lying down in personnel on casualty rate and injury rate were observed.

Commissioning protocol 4: The projectile rate of fire was adjusted to 40 rounds/min, 60 rounds/min, 80 rounds/min, 100 rounds/min, and 120 rounds/min while other conditions remained unchanged. The effects of changing the projectile rate of fire on casualty rate and injury rate were observed.

Commissioning protocol 5: The projectile caliber was adjusted to 105 mm, 122 mm, 152 mm, and 155 mm while other conditions remained unchanged. The effects of changing the projectile caliber on casualty rate and injury rate were observed.

(2) Simulation commissioning results

Result 1: The number of personnel was adjusted to 100, 200, 300, 400, and 500 while other conditions remained unchanged. The effects of changes in the number of personnel on casualty rate and injury rate were shown below.

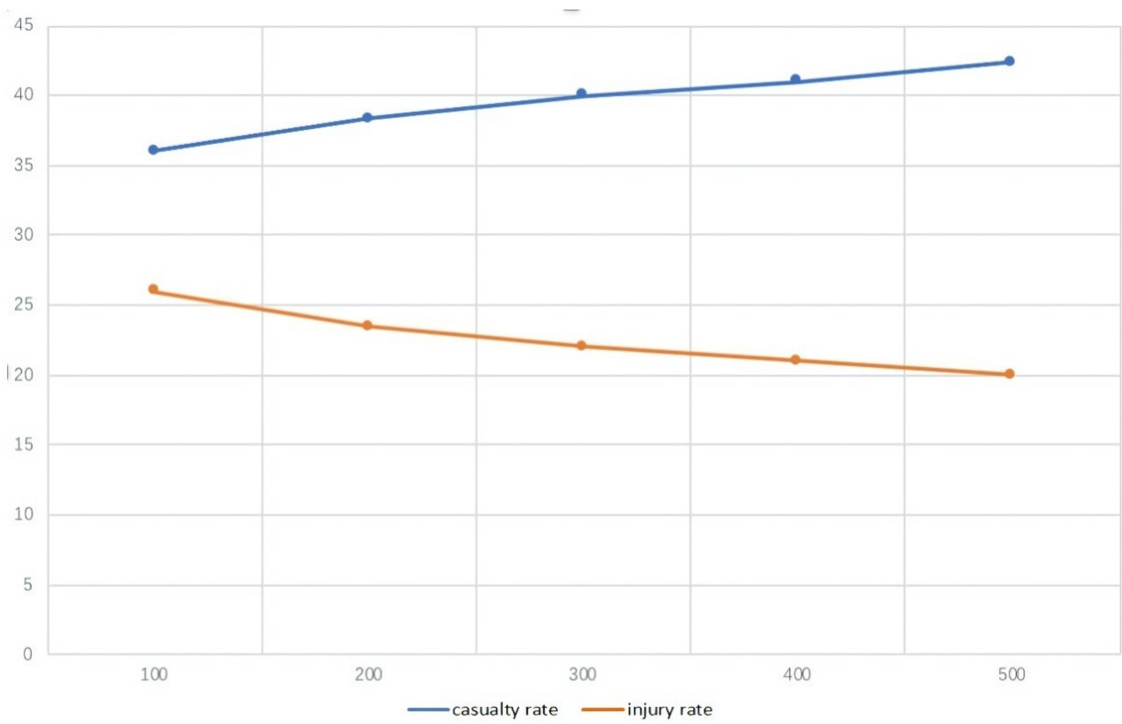

Figure 15-1. Relationship between number of personnel and casualty rate.

It could be seen that as the number of personnel increased, the casualty rate increases while the injury rate decreases. The reason for this is that the model was set to end when the last agent passed through the right side of the interface. Therefore, the greater the number of personnel, the longer the duration of model operation and the higher the casualty rate. As injured personnel remained at the battlefield and are repeatedly hit by projectiles, some originally injured personnel will die as time progresses and the injury rate decreases.

Result 2: The movement velocity of personnel was changed to 100 m/min, 150 m/min, 200 m/min, 250 m/min, and 300 m/min while other conditions remained unchanged. The effects of changes in the movement velocity of personnel on casualty rate and injury rate were shown below.

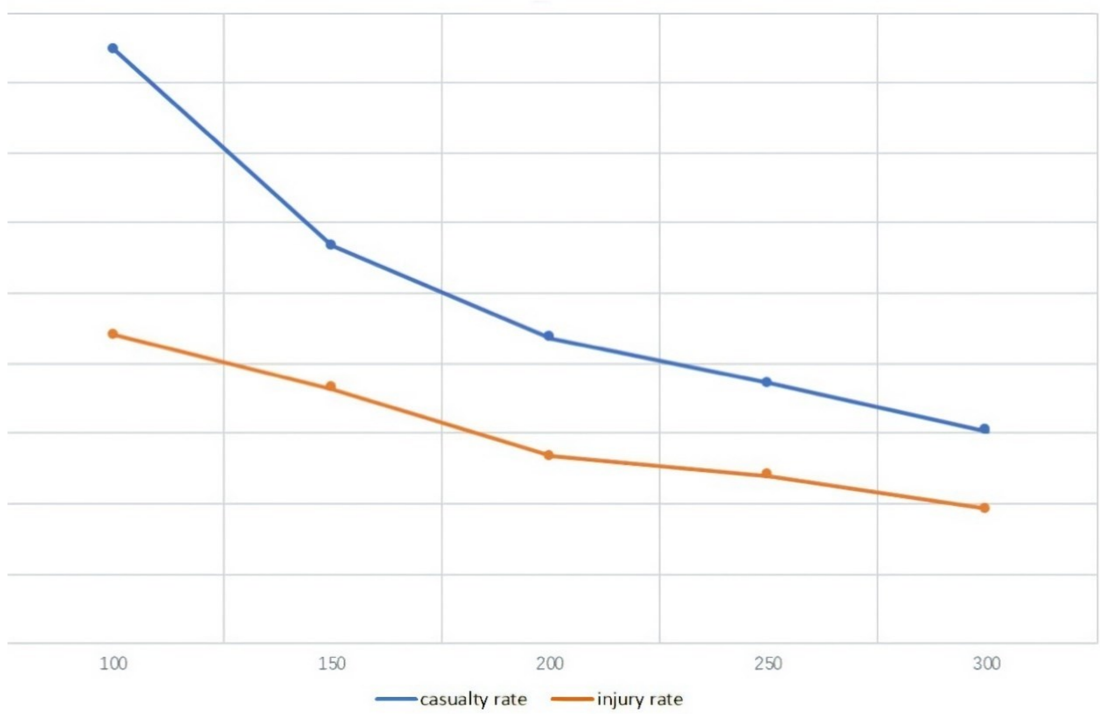

Figure 15-2. Relationship between movement velocity of personnel and casualty rate.

From the figure, it could be seen that increasing the movement velocity of personnel could effectively decrease the casualty rate. However, the benefits of increasing movement velocity progressively decreased.

Result 3: The probability of lying down in personnel was adjusted to 30%, 40%, 50%, 60%, and 70% while other conditions remained unchanged. The effects of changes in the probability of lying down in personnel on casualty rate and injury rate were shown below.

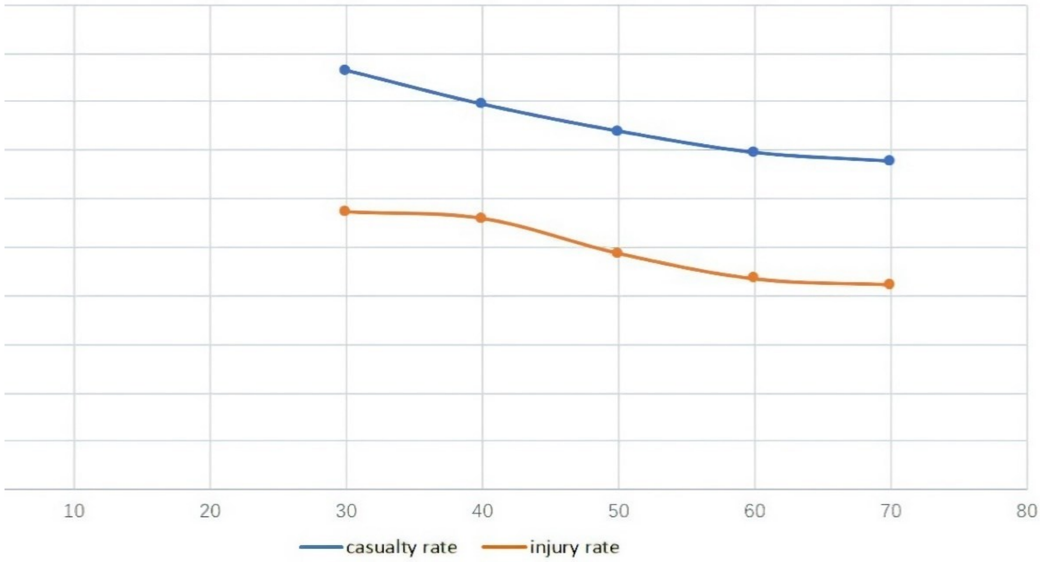

Figure 15-3. Relationship between probability of lying down and the casualty rate.

From the figure, it could be seen that increasing the probability of lying down in personnel could effectively decrease the casualty rate.

Result 4: The projectile rate of fire was adjusted to 40 rounds/min, 60 rounds/min, 80 rounds/min, 100 rounds/min, and 120 rounds/min while other conditions remained unchanged. The effects of changing the projectile rate of fire on casualty rate and injury rate were shown below.

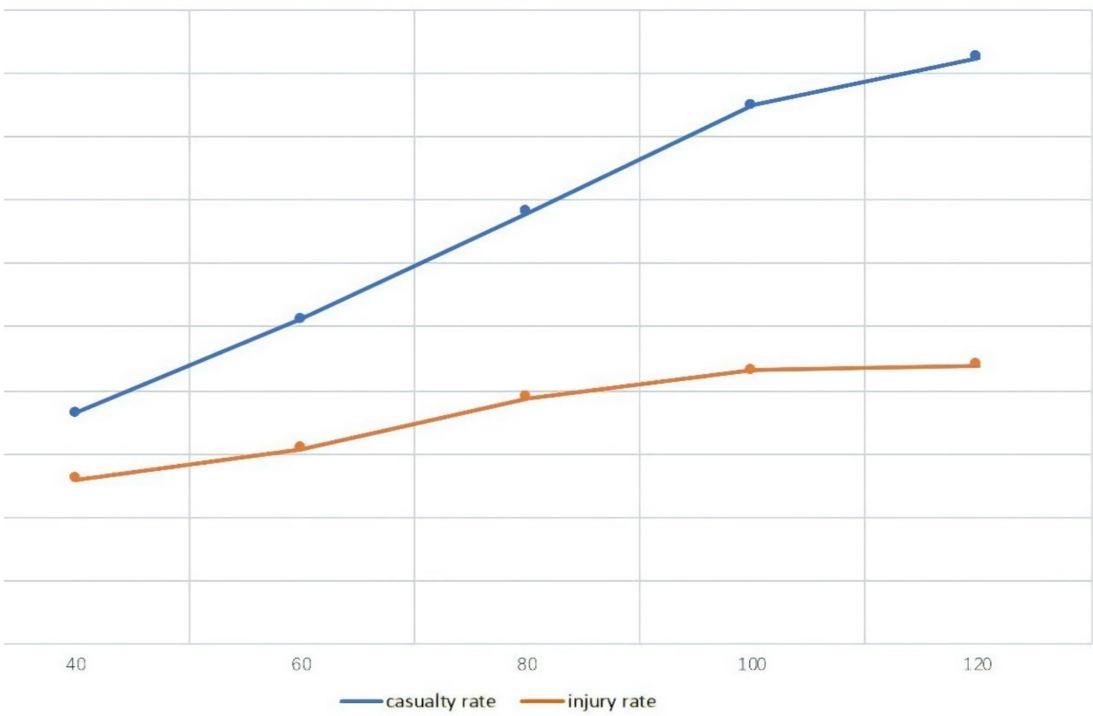

Figure 15-4. Relationship between projectile rate of fire and the casualty rate.

From the figure, it could be seen that increasing the projectile rate of fire could greatly affect the casualty rate.

Result 5: The projectile caliber was adjusted to 105 mm, 122 mm, 152 mm, and 155mm while other conditions remained unchanged. The effects of changing the projectile caliber on casualty rate and injury rate were shown below.

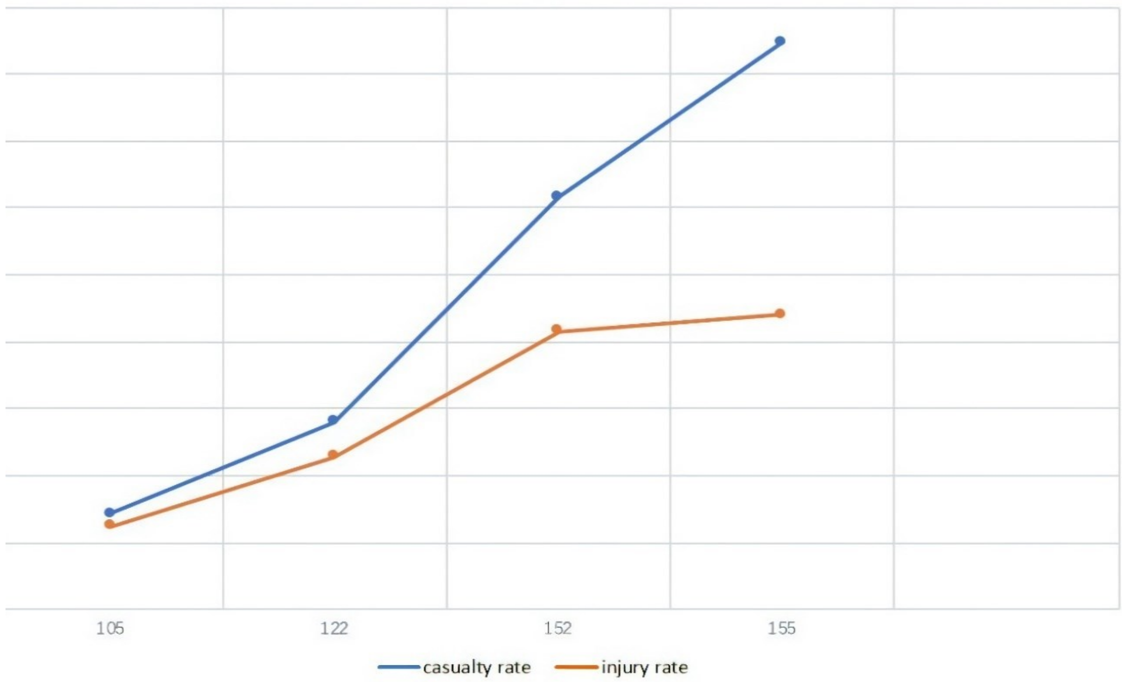

Figure 15-5. Relationship between projectile caliber and the casualty rate.

15.2 Policy intervention experiment

In addition to adjusting individual influencing factors, this model could also simulate changes on the projectile casualty rate under different fixed conditions, that is, adjusting another influencing factor when one influencing factor was changed to minimize the effects of the later one on casualty rate and provide rational decisions for commanding combat.

15.2.1 Intervention experiment 1: intervention experiment of projectile rate of fire and the probability of lying down

(1) Protocol for projectile rate of fire-probability of lying down intervention experiment

Before attacking, it was learned that the enemy has been resupplied and the projectile rate of fire was increased by 50%. Under the scenario that other conditions remained unchanged, our commander decided to change the attack mode and increase the probability of lying down in our persons, assuming that the probability of lying down was increased to 20%, 40%, 60%, 80%, and 100%. The effects of changing the probability of lying down on the casualty rate were observed.

(2) Results of projectile rate of fire–probability of lying down intervention experiment

When the probability of lying down was 20% and projectile rate of fire was 60, the casualty rate was 32.4%. When projectile rate of fire was increased to 90, the casualty rate was 45.2%. The probability of lying down was adjusted to 20%, 40%, 60%, 80%, and 100% while other conditions remained unchanged. The effects of changes in the probability of lying down on casualty rate were shown below.

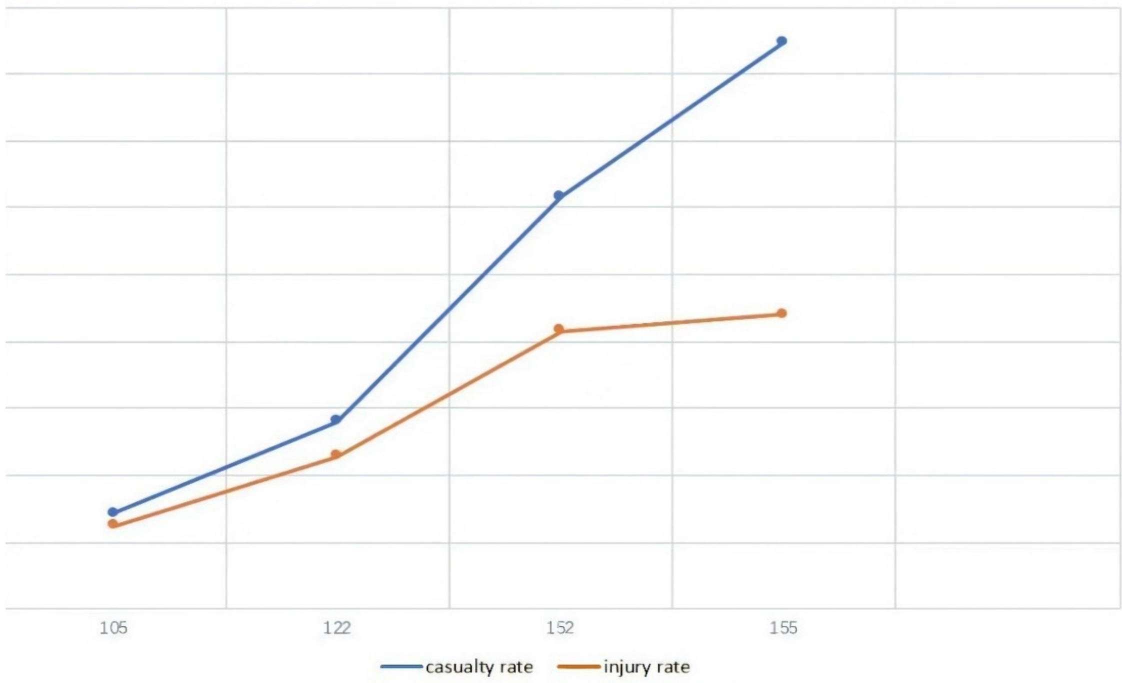

Figure 15-6. Effects of changing the probability of lying down on casualty rate.

15.2.2 Intervention experiment 2: intervention experiment of the projectile rate of fire and movement velocity

(1) Protocol for projectile rate of fire-movement velocity intervention experiment

Before attacking, it was learned that the enemy has been resupplied and the projectile rate of fire was increased by 50%. Under the scenario that other conditions remained unchanged, our commander decided to change the attack mode and change the movement velocity of our persons to 100 m/min, 150 m/min, 200 m/min, 250 m/min, and 300 m/min. The effects of changing the movement velocity of personnel on the casualty rate were observed.

(2) Results of projectile rate of fire-movement velocity intervention experiment

When the movement velocity was 100 m/min and projectile rate of fire 60, the casualty rate was 25.6%. When projectile rate of fire was increased to 90, the casualty rate was 36.4%. The movement velocity of personnel was changed to 100 m/min, 150 m/min, 200 m/min, 250 m/min, and 300 m/min while other conditions remained unchanged. The effects of changes in the movement velocity of personnel on casualty rate and injury rate were shown below.

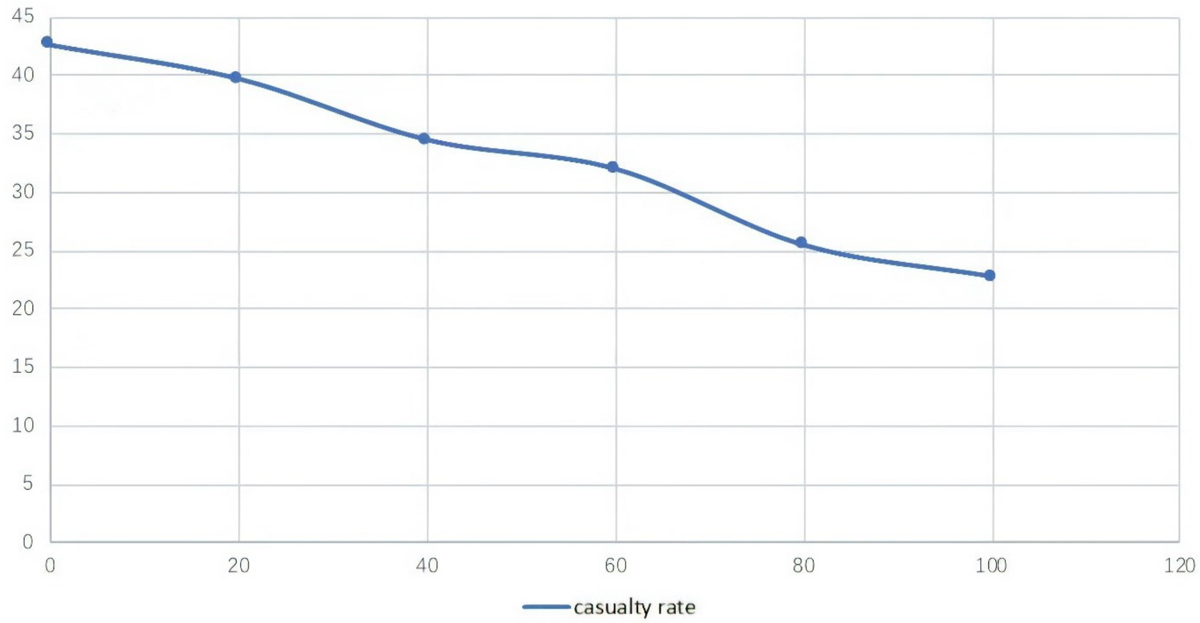

Figure 15-7. Effects of changes in movement velocity of personnel on the casualty rate.

15.2.3 Intervention experiment 3: intervention experiment of blast radius and the probability of lying down

(1) Protocol for blast radius-probability of lying down intervention experiment

Before attacking, it was learned that the enemy changed the type of projectile from 122 mm howitzer to a 155 mm howitzer. When projectile weight was increased from 3.6 kg to 9.6 kg, the blast radius was increased from 15 m to 30 m. Under the scenario that other conditions remained unchanged, our commander decided to change the attack mode and change the probability of lying down to 20%, 40%, 60%, 80%, and 100%. The effects of changing the probability of lying down on the casualty rate were observed.

(2) Blast radius-probability of lying Intervention experiment results

When the probability of lying down was 20% and projectile caliber was 122 mm, the casualty rate was 15.6%. Changing the projectile caliber to 155 mm increased the casualty rate to 51%. The probability of lying down was adjusted to 20%, 40%, 60%, 80%, and 100% while other conditions remained unchanged. The effects of changes in the probability of lying down on the casualty rate were shown below.

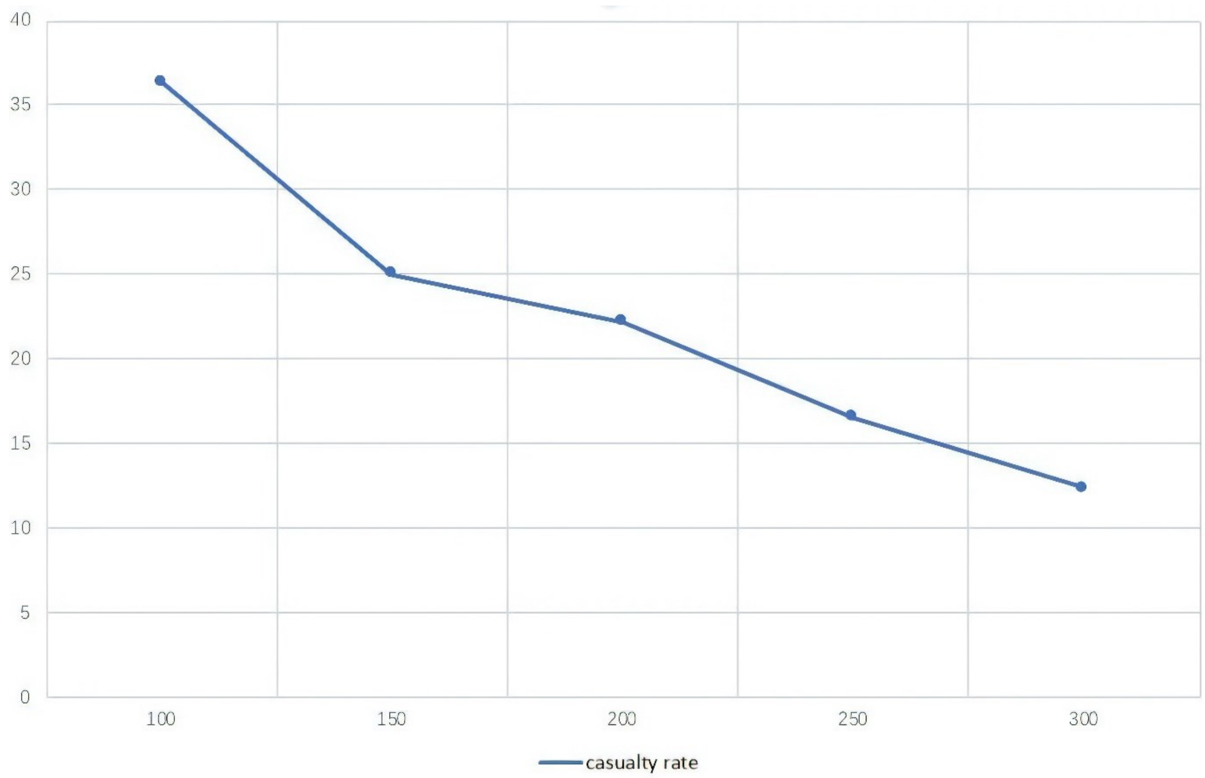

Figure 15-8. Effects of changing the probability of lying down on the casualty rate.

15.3 Policy recommendations

The intervention experiment results showed that the number of personnel, projectile rate of fire, and projectile caliber were positively correlated with the casualty rate and increasing these parameters will increase the casualty rate. Personnel movement velocity and the probability of lying down are negatively correlated with the casualty rate and increasing these parameters will decrease the casualty rate. The effects of these factors on the casualty rate were important considerations when commanders make decisions.

(1) Improving self-treatment and mutual treatment capabilities can decrease mortality rate

The mortality rate was one of the important factors that commanders must consider. The results of intervention experiment 1 showed that when the number of personnel increases, the time to exit the battlefield increases, duration for projectile attack increases, and the casualty rate increases while the injury rate decreases. This showed that the increase in mortality rate was faster than the injury rate. This was because casualties in the battlefield were not treated, and the mortality rate increased as the duration of artillery fire increases.

(2) Increasing suppression of enemy fire can decrease the casualty rate

The results of intervention experiment 2 showed that increasing movement velocity could effectively reduce the casualty rate while the results of intervention experiment 3 showed that increasing the probability of lying down could effectively decrease the casualty rate. However, from the effects on casualty rate, the effects of movement velocity were greater than the probability of lying down. The results of intervention experiment 4 showed that increasing the projectile rate of fire could greatly affect the casualty rate, showing that suppression of enemy fire before combat was significant.

(3) Formulating the corresponding projectile according to the type of enemy projectile

Different attack strategies could be formulated if the type of enemy projectile was known before the battle. From the results of intervention experiments 6 and 7, it could be seen that increasing the probability of lying down by 32% or increasing movement velocity by 47% could counter the effects of increasing projectile rate of fire by 50% on the casualty rate. Commanders could decide on the attack mode according to the actual battlefield situation. From the results of intervention experiments 8 and 9, it could be seen that increasing the probability of lying down and movement velocity when projectile caliber was increased cannot counter the increase in the casualty rate caused by increased projectile caliber. However, increasing movement velocity had more significant effects in reducing the casualty rate compared with increasing the probability of lying down. Therefore, if the enemy used larger caliber projectiles, it was recommended that commanders should increase the movement velocity of personnel.

16 Summary

Authors: Wenya Yu, Lulu Zhang

In this book, model construction and policy intervention experiment studies were carried out on routine medical service systems; they specifically include 14 model and policy intervention experiment studies. In summary, this book employed computer models to carry out policy intervention experiments to provide quantitative evaluation and results analyses for optimizing medical service structures and functions. They include policy recommendations for improving system efficiency and functions.

16.1 Medical services system

In this book, model construction and policy intervention experiment studies on medical service systems can be divided into three types, namely, the medical service system, medical emergency service system, and medical resource allocation system.

(1) Medical service system

In this book, studies were conducted on public hospital medical expense increase controls, public hospital multi-point practices, public welfare in public hospitals, hospital emergency treatments, and hospital outpatient procedure were examined to improve their efficiency and quality.

(2) Medical emergency service system

In this book, studies were carried out on earthquake casualty medical evacuations, hospital emergency system, community casualty first aid, complex causes of trauma, medical evacuation, stress analysis, tornado casualties, and blast injury casualties to improve the efficiency and quality of medical emergency service systems.

(3) Medical resource allocation system

In this book, in-depth studies on medical service force selection and deployment were carried out to provide an important theoretical basis and quantitative policy recommendations for optimizing the medical resource allocation system.

16.2 Modeling study

The models constructed in this book were mainly based on three methods: agent modeling, system dynamics modeling, and discrete event modeling.

(1) System dynamics modeling

System dynamics modeling mainly examines the dynamic characteristics of system behavior with time changes. This method considers the feedback path and effector relationships of system behavior from an overall systems' perspective. System dynamics modeling was used. The constructed models and executed intervention experiments include the public hospital multi-point practice model and hospital emergency treatment policy intervention experiments.

(2) Agent-based modeling

Agent-based modeling is a modeling method that uses the overall system's behavior to present the results of interactions between multiple individuals. In this method, simulation of multiple individual behaviors and interactions are used to present and predict complex system problems. These methods focused on agents and their behavior and can be used for simulation of changes in agent behavior. Agent-based modeling was used and the constructed models and intervention experiments included the public hospital medical expense increase control model, earthquake casualty medical evacuation model, public welfare in public hospital intervention experiment, community casualty first aid policy intervention experiment, stress analysis policy intervention experiment, complex causes of trauma policy intervention experiment, medical service force selection and deployment policy intervention experiment, tornado casualty policy intervention experiment, and blast injury policy intervention experiment.

(3) Discrete event modeling

The thought process of discrete event modeling considers the system as a process, that is, a series of operations on the entity; it is a network-based modeling method that focuses on processes and spaces that can achieve simulation from the perspective of processes and spaces. This method is suitable for the abstraction and simulation of entities and resources; it is commonly used to examine problems with queuing and delay characteristics, and is a modeling method that focuses on processes. Discrete event modeling was used for intervention experiments such as policy intervention experiments on hospital emergency system, hospital outpatient procedure, and medical evacuation.

16.3 Policy intervention experiment

In this book, multi-point practice, public welfare in public hospitals, hospital emergency systems, community casualty first aid, hospital emergency system, hospital outpatient procedures, complex causes of trauma, medical evacuation, stress analysis, medical force selection and deployment, tornado casualties, and blast injury casualties were used to carry out simulated intervention experiments on 13 different medical service policies.

(1) Policy intervention experiment based on system dynamics model

The public hospital multi-point practice system dynamics model aims to examine the key points and difficulties in physician multi-point practice policy implementation through construction of the public hospital multi-point practice system to provide a decisional thought process for comprehensive and successful promotion of this policy. The public hospital multi-point practice system dynamics model includes four types of agents (physicians, government, public hospitals, and private and grassroots medical institutions), which are used for simulation analysis of the acceptability and willingness of physicians to participate in multi-point practice, thereby providing an optimal theoretical protocol for implementing the multi-point practice policy protocol. The policy intervention experiment results showed that medical workers mainly focused on the accessibility of the medical institution when selecting medical institutions for multi-site practice. In addition to the original hospital in which they practice, 25% of subjects selected one medical institution for practice and 50% of subjects selected two medical institutions. However, the number of subjects who selected three medical institutions is significantly reduced, suggesting that practicing in more medical institutions may not necessarily be good.

The hospital emergency system policy intervention experiment showed that increasing the number of dispatchable ambulances and dispatch rate has no significant effects on the treatment at a scale of 200 people. However, decreasing the number of ambulances by a large number will increase the trauma mortality rate. For a mass casualty event of 1000 people, increasing the number of dispatchable ambulances and the dispatch rate can effectively increase the timeliness of 24h pre-hospital duration and decrease trauma mortality rate during this period. When the population was increased to 2000 people, the existing number of ambulances could not satisfy the treatment of mass casualties and required a drastic increase in the number of ambulances and their dispatch rate. The intervention experiment protocol had no effect on mass casualty events of 5000 people of more. This may be why resource allocation in this experiment protocol cannot satisfy medical needs on this scale. In addition, increasing the number of emergency medical staff can significantly decrease the injury examination and treatment duration for 2000 or more casualties and has continuous effects on a scale of 5000 casualties.

(2) Policy intervention experiment based on agent model

In the public hospital medical expense increase control model, five agents (population, physicians, medical institutions, medical insurance institutions, and government) were used and simulation of the different characteristics, behavioral rules, and interaction mechanisms of different agents was used to deconstruct the public hospital medical expense structure and irrational increase mechanisms. The policy intervention experiment suggests that when the phenomenon of irrational medical expenses of public hospitals is significant, public welfare in public hospitals should be increased. Expanding the promotion and application of the community-first consultation system can be used to optimize the consultation choices of patients and effectively control an irrational increase in medical expenses. Improving physician income and reducing workload can drive public welfare behavior in physicians and control irrational increase in medical expenses. Improving the financial compensation by the government toward public medical institutions can effectively control irrational increase in medical expenses.

The public welfare in public hospitals modeling intervention experiment shows public hospital measures should be implemented and rational consultation choices in patients should be promoted. Accelerating the promotion of the community-first consultation system and bi-directional referral system and increasing investment on community health service centers should be carried out to improve the current medical service capabilities of community health service centers in order to obtain patients' trust and change current irrational consultation choice preferences. Physician behavior should be regulated at the system level to reduce the occurrence of large prescriptions, thereby decreasing patients' medical expenses. The current physician salary system should be reformed and physicians' salaries should be further rationalized. Further pilot optimization and promotion of multi-site practice in physicians should be carried out, and rational selection and multi-site practice should be promoted to accelerate talent movement and benefit citizens.

The community casualty first aid policy intervention experiment showed that the current pre-hospital first aid system of China inherited the traditional station model, which is independent of community health services and therefore cannot be combined with its advantages. Manpower, material, and first aid technique limitations in community health services centers have made these centers unable to conduct simple first aid treatment before the arrival of emergency vehicles and the best timing for patient resuscitation is missed. At the same time, it is difficult for the community health service system to independently bear a large burden, high intensity, and multi-layered first aid tasks out of the hospital due to hardware and software limitations. In addition, unified coordination cannot be carried out due to regional limitations. Establishing community first aid stations, utilizing the advantages of the pre-hospital first aid system and community health service centers, and close combination of secondary and tertiary medical institutions in the community to form a comprehensive community first aid network is a future trend in the development of the first aid medical service system.

The policy intervention experiment for complex causes of trauma showed that earthquake zone residents experienced the combined effects of the surrounding environment, individual behavior, and rescue operations. The health of these residents is used as a decisional factor and rational adjustment and improvements to environmental factors, individual behavioral factors, and rescue operation factors are used to effectively decrease the casualty rate and mortality rate of residents in earthquake zones. Demographic factors affect the occurrence of earthquake casualties. More attention should be paid to elderly people and women during pre-earthquake preparation and post-earthquake rescue to reduce their risk of earthquake trauma and casualties. The earthquake environment has huge effects on building structure and directly affects the earthquake casualty ratio. Individual behavioral factors in the earthquake are significantly related to earthquake casualties and earthquake escape training can significantly reduce the casualty rate.

The stress analysis of the intervention experiment results suggests that there is a large room for improvement in the stress level rate. For protocols employing different combat modes, increasing the number of various types of ships and maximizing our performance values can decrease stress level rate the most. The experimental results showed that increasing the number of ships can decrease the stress level in officers. A suitable combat environment produces environmental effects on the stress level of officers. Selecting experienced commanders can reduce the stress level in officers. Improving political education can effectively decrease the stress level. Adopting rapid combat and resolution can also decrease attrition due to stress.

The tertiary medical service force selection and deployment policy intervention experiment showed that tertiary medical force selection and deployment can provide assistance in decisional support for medical service force assurance in emergencies. Rational selection of strategic, regional, and local medical service force can improve the usage efficiency of medical service force. Force deployment should correspond to requirements, and modular operations should be implemented during rescue. The professional foundation of personnel should be strengthened and frontline surgical forces should be appropriately established. In addition, attention should be paid to establishing rescue forces and specialist forces should be rationally deployed according to requirements.

The policy intervention experiment for tornado casualties showed that advance warning can effectively decrease the number of casualties. The earlier the warning time, the lower the number of casualties produced, which shows that advance warning can enable refugees to adopt effective relief behavior; this is significant in reducing the number of casualties. Running far away is a risky behavior during tornadoes. Compared with severe collapse, moderate collapse and mild collapse can reduce the number of casualties by 24.25% and 75.09%, respectively. Improving tornado resistance in houses can also reduce the number of casualties. Compared with severe collapse, moderate collapse and mild collapse can reduce the number of casualties by 24.25% and 45.88%, respectively.

The blast injury policy intervention experiment suggests that number of personnel, projectile rate of fire, and projectile caliber are positively correlated with the casualty rate and increasing these parameters will increase the casualty rate. Personnel movement velocity and the probability of lying down are negatively correlated with the casualty rate and increasing these parameters will decrease the casualty rate. The effects of these factors on casualty rate are important considerations when commanders make decisions. Improving self-treatment and mutual treatment can reduce the mortality rate. Improving suppression of enemy fire can reduce the casualty rate. Corresponding protocols should be formulated according to the type of projectiles used by the enemy.

(3) Policy intervention experiments based on discrete event model

The hospital emergency treatment policy intervention experiment showed that the treatment process of trauma patients is used as the study subject. The simulation results on the effects of adjustments to emergency manpower resource allocation on emergency treatment efficiency showed that under a certain scale of trauma patients the allocation of medical staff should match the changes in injury severity composition for these patients. The simulation results of emergency manpower allocation optimized protocols for different instantaneous patient flows showed that under certain hospital service targets, adjustments to the number of experts, general physicians, and nurses in the optimized protocol have some effects in reducing the mortality rate and emergency department retention time of trauma patients, compared with the default protocol.

The hospital outpatient procedure policy intervention experiment shows that improving the appointment and registration system and strengthening guidance for separate consultation timings can optimize the current outpatient process. By establishing separate outpatient appointment and registration timings and a priority system for special populations, and setting up special consultation zones, the number of windows can be adjusted when the resource utilization rate and single patient passage duration are fixed so that the optimal number of windows and passage duration for various segments can be achieved when the number of outpatient windows and resource utilization rate are the best. Second, increasing outpatient management efficiency and the rational allocation of medical service resources should be carried out while ensuring medical quality and safety. Finally, robust information technology support should be established to provide a good operating platform for improving the outpatient process.

The medical evacuation policy intervention experiment results suggest that medical resources and evacuation resources are major influencing factors that limit the treatment results and efficiency of casualties. The experimental results showed that increasing the number of stage 1 evacuation tools can increase early casualty evacuation efficiency. Integrating battlefield attrition characteristics, improving evacuation loading criteria, and full utilization of evacuation performance can improve evacuation quality. Increasing the various grades of treatment forces is the core to ensuring casualty treatment results; improving medical staff competency can affect the treatment results of severe casualties. Coordination of evacuation and treatment processes, strengthening early evacuation force, paying attention to changes in severe casualty conditions at the later stages, and treatment can improve overall medical treatment results.

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