Research Article

Modeling and Analysis of Postdisaster Aviation Medical Rescue Process Using SPN-MC

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Analyzing the time characteristics of the aviation medical rescue process after sudden natural disasters is an extremely important guarantee for efficient rescue. In view of the problem of the significant increase in the complexity and uncertainty of the postdisaster aviation medical rescue process under time constraints, this study sorted out and analyzed the postdisaster aviation medical rescue process. The dynamic discrete modeling of the postdisaster aviation medical rescue process was carried out in combination with the stochastic Petri net (SPN) theory, and the effectiveness of the process of postdisaster aviation medical rescue was analyzed by using the isomorphism relationship between SPN and Markov chain (MC). Finally, the Sichuan Jiuzhaigou Earthquake event was taken as a case study to carry out the performance analysis and sensitivity analysis of the postdisaster aviation medical rescue process model. The results showed that information accumulation tends to occur in the process of flight planning, flight preparation, flight information transmission, and field information feedback. On-site rescue, casualty transfer, preflight preparation, and personnel preparation take a relatively long time. In the actual rescue process, emergency decision-makers and rescue crews should focus on optimizing and improving these links. The route formulation and airspace application as the main factors affecting the operation time of the postdisaster aviation medical rescue process system should be used as the key to process optimization so as to improve the efficiency of postdisaster aviation medical rescue.

1. Introduction

Aviation medical rescue is an indispensable public service in contemporary society. In addition to the normalized medical rescue operations in daily life, it also plays a vital role in emergency rescue activities in some sudden natural disasters. According to statistics from the International Disaster Database, the average annual number of natural disaster events recorded in the past 10 years is about 333, almost twice as much as in the 1980s [1]. The occurrence of natural disasters often has the characteristics of sudden, urgency, and uncertainty. Postdisaster emergency rescue work is a very critical and urgent decision-making issue related to the well-being of disaster-stricken victims [2]. The aviation medical emergency rescue response speed is fast, which can ensure the rapid arrival at the disaster relief site in a complex environment, provide more golden rescue time for the wounded in the disaster area, and greatly improve the survival rate of the affected people. Furthermore, aviation medical rescue is less restricted by terrain and roads and can use hovering or airborne to rescue personnel and materials with little flight space limit, which plays an irreplaceable role in emergency medical rescue in sudden natural disasters. With the rapid development of the general aviation industry, more and more countries have begun to pay attention to the development of aviation medical rescue. Aviation medical rescue after natural disasters has gradually become a hot research issue in the field of emergency management.
In the field of aviation medical emergency rescue, some scholars from developed countries have carried out relevant research earlier. By analyzing the previous disaster cases and the relationship between rescue time and mortality, aviation medical rescue is seen to have a significant time advantage compared with ground medical rescue [3–5]. It is suggested that experienced accompanying doctors should be provided in the execution of aviation medical rescue missions, and special intensive training should be conducted according to the characteristics and difficulty of rescue missions [6]. After a detailed analysis of the current emergency rescue standard system, the problems of less research and lack of universality of research results on standards related to aviation medical rescue are pointed out [7]. In addition, in order to improve rescue efficiency and maximize the positive role of aviation medical rescue, scholars also have put forward a series of targeted suggestions [8, 9]. Re\-positiveroleofaviationmedicalrescue,scholarsalsohave ordered to improve rescue efficiency and maximize the versatility of research results on standards related to aviation medical rescue are pointed out [7]. In addition, in order to improve rescue efficiency and maximize the positive role of aviation medical rescue, scholars also have put forward a series of targeted suggestions [8, 9]. Researchers put forward a series of proposed measures to establish and perfect the management of the country's aviation emergency rescue system [10–12] and point out the development direction of China's aviation medical rescue [13–15]. In order to improve the efficiency of postdisaster aviation medical rescue, some scholars have studied the route of multihelicopter rescue missions [16, 17], and other scholars have determined the key elements of aviation medical rescue missions [18].

In recent years, postdisaster rescue has become a hot research issue. Scholars have conducted research on issues such as transportation supply and path design under evacuation conditions [19, 20]. Besides, with the widespread use of aircraft, the role of wireless sensor networks (WSNs) and unmanned aerial vehicles (UAVs) in natural disaster management is identified [21]. Rescue Chain was developed to improve the security of drones during data transmission for efficient data sharing in disaster rescue [22]. In order for rescuers to more effectively access the disaster area and start rescue operations, some scholars have evaluated the performance of UAVs in mapping the disaster area [23]. It has also been suggested that the integration of drones into the Internet of Things could be used to build safety maps of disaster areas [24]. In addition, UAVs can be used to deploy WSNs for postdisaster monitoring [25].

It can be seen that comprehensive studies have been carried out on the development status, system construction, and existing problems of aviation medical rescue. But there are few studies on sorting, optimizing, and standardizing the process of aviation medical rescue. For postdisaster rescue, scholars have mostly focused on the efficiency and performance of UAVs, applying them to data transmission and terrain mapping in postdisaster rescue to better understand the situation and provide a basis for rescuers to carry out their work, but there is a lack of research related to medical rescue activities with the help of aerial vehicles after disasters. Distinguishing from existing UAV survey studies, this study addresses the rescue activities of medical rescue teams entering disaster areas. After a natural disaster, rescuing the affected people is the top priority of the rescue mission, so the aviation medical rescue under sudden disasters needs to implement the most reasonable rescue plan in the shortest time. And the postdisaster aviation medical rescue sometimes needs to be carried out in areas with damaged roads and inconvenient traffic, even accompanied by harsh weather conditions. Compared with the normal aviation medical rescue, the rescue process of the postdisaster aviation medical rescue is more complex, the information in the process is more complicated, and the rescue is more difficult. In postdisaster aviation medical rescue, it is particularly important to scientifically and effectively standardize rescue procedures and improve rescue efficiency.

The emergency rescue process is characterized by complexity and uncertainty, and the main purpose of the postdisaster aviation medical rescue is to rescue and transfer the disaster-affected people as soon as possible and carry out the rescue work safely and efficiently. Therefore, time is one of the most critical considerations. Research on the postdisaster aviation medical rescue process not only requires a scientific and comprehensive establishment of an intuitive process model but also requires dynamic system simulation of the model and rigorous mathematical analysis of the performance indicators of the rescue process. Among the current common process modeling methods, Petri net is a state-based analysis technology with both intuitive graphical expressions and rigorous mathematical analysis methods, which can be used in both theoretical research and practical work. In recent years, many scholars have used Petri net models to analyze emergency response processes in different fields [26–31], introducing temporal parameters on the basis of Petri nets in order to model and analyze the performance of systems with complexity and uncertainty characteristics, which also illustrates the effectiveness of the Petri net model for analyzing emergency response processes. In the field of aviation emergency rescue, Petri net theory has not yet been introduced to study and analyze the process. The Petri net model can reflect the dynamic characteristics of the aviation medical rescue process, clarify the relationship between the states in the process, and analyze the links that are prone to information buildup in the process. The combination of changes and average delay of continuous stochastic variables can represent the working time of each part of the aviation medical rescue process and then analyze the parts of the process that need to be optimized and the length of time spent on the whole process.

Based on this, this paper applies the mathematical modeling methods and tools of stochastic Petri nets and Markov chain theory to the postdisaster aviation medical rescue process and analyzes and describes the whole process of postdisaster aviation medical rescue process. According to the postdisaster aviation medical rescue process and their respective characteristics and the relationship between the links, the stochastic Petri net model of the postdisaster aviation medical rescue process is constructed from the perspective of information...
processing. The model is constructed to explore the information flow and work efficiency of the postdisaster aviation medical rescue process in each step, which provides a basis for the analysis of the aviation medical rescue process under different rescue tasks. Through the performance analysis and sensitivity analysis of the process, the optimization direction of improving the efficiency of postdisaster aviation medical emergency rescue is pointed out. The work provides theoretical support and technical guidance for the standardization of the postdisaster aviation medical emergency rescue process, which is innovative in the field of aviation emergency rescue.

The remainder of this paper is organized as follows: Section 2 introduces the definition and classification of aviation medical rescue, as well as the process of postdisaster aviation medical rescue. Section 3 describes the process of postdisaster aviation medical rescue, and the model of stochastic Petri net and isomorphic MC is established step by step. Section 4 takes Sichuan Jiuzhaigou Earthquake as a case study to analyze the performance and sensitivity of the SPN model. Section 5 is the conclusion of this study.

2. Postdisaster Aviation Medical Rescue

2.1. Characteristics of Postdisaster Aviation Medical Rescue

Aviation medical rescue refers to flight activities that the operation people use aircraft (mainly including helicopters and fixed wings) to provide emergency medical services and public emergency medical rescue, including life support, treatment, and monitoring during the transport of the sick and wounded to the medical institutions, in order to eliminate the impact of traffic, distance, and terrain, shorten the rescue time, and achieve the purpose of reducing disability and mortality. China’s aviation medical rescue can be divided into normal aviation medical rescue and postdisaster aviation medical rescue according to different rescue scenes and rescue objects.

Normal aviation medical rescue is mainly applied to road traffic accidents, the guarantee of large-scale activities and competitions, daily sudden diseases, and so on. It usually does not require multiple aircraft to participate in the rescue, involving fewer agencies, the aircraft rescue radius is relatively small, and the rescue process is relatively simple. However, the postdisaster aviation medical rescue is mainly used after natural disasters, and other major public emergencies occur. Postdisaster aviation rescue missions usually require a large number of aircraft for centralized rescue and participation in multiple aircraft, which is different from normalized aviation medical rescue. During the rescue, it is necessary to plan the route reasonably, transfer the wounded in large quantities, and play a role in diversion. In the postdisaster aviation medical rescue process, more agencies are involved, and the process is more complicated, which tends to waste resources and affect rescue efficiency. In this paper, the process of postdisaster aviation medical rescue is mainly studied.

2.2. Postdisaster Aviation Medical Rescue Process

Summarizing the common contents of the postdisaster aviation medical rescue, it mainly includes three parts: the early-warning process, the emergency response and on-site rescue process, and the postdisposal process. In order to facilitate subsequent process-based modeling, this paper simplifies other methods of postdisaster emergency rescue, organizational structure and responsibilities, safeguard measures, and so on and focuses on the research of emergency response and on-site rescue process. The postdisaster aviation medical rescue process is described as follows:

1. After a sudden disaster, the local government immediately sets up the emergency command center and launches the corresponding emergency plan. According to the analysis of the disaster, the emergency command decided to immediately convene the general aviation force to go into the disaster area for professional aviation medical rescue.

2. After assigning rescue tasks to general aviation companies and related medical institutions, the general aviation company and medical institutions respond quickly and cooperate with each other to start aviation medical rescue activities and formulate rescue plans.

3. The general aviation company and medical institutions, respectively, select flight crews and medical teams with rescue experience and capability. The general aviation company formulate flight plans, approve flight routes, and prepare aircraft before flight; medical institutions allocate medical resources according to the information of injuries collected on-site and install and wait for the takeoff instruction.

4. After the aircraft takes off, the flight crew flies the aircraft carrying medical teams and medical resources to the disaster area. After the aircraft arrives at the disaster area and lands at the appropriate takeoff and landing point, medical personnel first make preliminary judgment and stability of the on-site casualties, report the situation to the emergency command center in a timely manner, and then immediately transfer the wounded to the plane and transport them to the medical institutions by aircraft for follow-up treatment.

5. Aviation medical rescue activities ended.

The process of postdisaster aviation medical rescue is shown in Figure 1.

3. Modeling of Postdisaster Aviation Medical Rescue Process Based on SPN

3.1. Stochastic Petri Net Modeling and Performance Analysis Methods

Transition implementation rate is introduced on the basis of Petri net, and each transition is associated with an implementation rate to obtain an SPN. SPN can provide
modeling and performance analysis for systems with the stochastic process, which are suitable for modeling aviation medical rescue process after the disaster and system performance index analysis.

An SPN consists of six elements, $SPN = (P, T, F, W, M, \lambda)$. The establishment and performance analysis steps of aviation medical rescue process model based on SPN are as follows:

**Step 1.** According to the process of aviation medical rescue after disaster, the characteristics of each process, and the relationship between them, combined with SPN-related theories, the SPN model of the postdisaster aviation medical rescue process is constructed.

**Step 2.** According to the isomorphism relationship between SPN and MC, the SPN reachability diagram is constructed, and the transition $t_i$ on the SPN reachability diagram is converted into the average implementation rate $\lambda$ to obtain the MC. MC is used for model validity analysis.

**Step 3.** According to the relevant theorem of the Chapman–Kolmogorov equation and MC stationary distribution, the matrix equation is obtained as follows: 
\[
X_Q = 0 \quad \sum_{i=1}^{n} x_i = 1
\]
In the formula, $x_i$ represents the state stability probability of each marker.
Step 4. Based on the obtained MC stable-state probability, the relevant performances of the postdisaster aviation medical rescue process are analyzed and evaluated. System performance indicators include busy rate of places, utilization rate of transitions, and average delay time.

3.2. Construction of SPN Model of Postdisaster Aviation Medical Rescue Process. According to the flowchart of postdisaster aviation medical rescue, the modeling is carried out by using SPN modeling steps. The SPN model of the postdisaster aviation medical rescue process is shown in Figure 2.

In the SPN model of the postdisaster aviation medical rescue process, the places represent all kinds of information generated in the postdisaster aviation medical rescue process, and the transitions represent each link of the postdisaster aviation medical rescue process. The definitions of places and transitions are shown in Table 1.

Postdisaster aviation medical rescue process SPN model description is as follows.

After the occurrence of transition $T_4$, places $P_5$ and $P_6$ have token at the same time, $T_5$ and $T_6$ are concurrent relationships, and after contacting the air navigation companies and medical institutions with rescue capabilities and experience, the air navigation companies and medical institutions that receive rescue tasks simultaneously carry out the formulation of rescue plans and collaborate to carry out the next air medical rescue operations. After the occurrence of the transition $T_7$, the places $P_9$, $P_{10}$, $P_{11}$, and $P_{12}$ have token at the same time, $T_8$, $T_9$, $T_{10}$, and $T_{11}$ belong to the concurrent relationship, and the excitation of the change does not affect each other. That is, immediately after the aviation medical rescue mission is issued, the route development, preflight preparation, flight and medical personnel preparation, and medical resources preparation work. The place $P_{21}$ is the feedback from the paramedics to the emergency command center about the casualties at the scene after the air vehicle arrives at the disaster site.

3.3. The Isomorphic MC and Effectiveness Analysis of the SPN Model. In the process of postdisaster aviation medical rescue, there is no information flow in the initial stage. Therefore, in the initial state of the SPN model of postdisaster aviation medical rescue process, there is only one token in $P_1$ and $P_{21}$, respectively, the initial mark $M_0 = (1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0)$ indicates that, among the 22 places in the model, there is one token in each of $P_1$ and $P_{21}$, which is marked as 1, and the rest of the locations are 0. Accordingly, the initial identity set can be represented as

- $M_0 = (1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0)$
- $M_1 = (0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$
- $M_2 = (0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$
- $M_3 = (0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$
- $M_4 = (0, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$
- $M_5 = (0, 0, 0, 0, 1, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$
- $M_6 = (0, 0, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$
- $M_7 = (0, 0, 0, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$
- $M_8 = (0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$
- $M_9 = (0, 0, 0, 0, 0, 0, 0, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)$

| Place | Initial Mark |
|-------|--------------|
| $P_1$ | 1             |
| $P_{21}$ | 1            |
| $P_2$ | 0             |
| $P_3$ | 0             |
| $P_4$ | 0             |
| $P_5$ | 0             |
| $P_6$ | 0             |
| $P_7$ | 0             |
| $P_8$ | 0             |
| $P_9$ | 0             |
| $P_{10}$ | 0          |
| $P_{11}$ | 0          |
| $P_{12}$ | 0          |
| $P_{13}$ | 0          |
| $P_{14}$ | 0          |
| $P_{15}$ | 0          |
| $P_{16}$ | 0          |
| $P_{17}$ | 0          |
| $P_{18}$ | 0          |
| $P_{19}$ | 0          |
| $P_{20}$ | 0          |
| $P_{21}$ | 0          |
| $T_1$ | 0             |
| $T_2$ | 0             |
| $T_3$ | 0             |
| $T_4$ | 0             |
| $T_5$ | 0             |
| $T_6$ | 0             |
| $T_7$ | 0             |
| $T_8$ | 0             |
| $T_9$ | 0             |
| $T_{10}$ | 0           |
| $T_{11}$ | 0           |
| $T_{12}$ | 0           |
| $T_{13}$ | 0           |
| $T_{14}$ | 0           |
| $T_{15}$ | 0           |
| $T_{16}$ | 0           |
| $T_{17}$ | 0           |
| $T_{18}$ | 0           |
| $T_{19}$ | 0           |
| $T_{20}$ | 0           |
| $T_{21}$ | 0           |

Figure 2: SPN model of postdisaster aviation medical rescue process.
According to the reachable identity set of the SPN model of the postdisaster aviation medical rescue process, substituting the transition $T_6$ in the model into the average implementation rate $\lambda_k$, the isomorphic MC of the SPN is obtained, as shown in Figure 3.

Analyzing the validity of the SPN model of the post-disaster aviation medical rescue process, the following conclusions are obtained:

1. The flow of token in the entire SPN model is not unsmooth or unable to proceed, and the model is reachable. It means that the postdisaster aviation medical rescue mission can be carried out smoothly, and each rescue link is closely related.

2. In the SPN model, there is only one token in any place, which means there is no bottleneck in the postdisaster aviation medical rescue process, and the model is safe and bounded.

3. Any state in the MC can be implemented by transition, and there is no phenomenon of transition or deadlock that can never be implemented, which indicates that there is no deadlock in the model.

Therefore, the SPN model satisfies the reachability, safety, boundedness, and liveness of Petri net, indicating that the model is reasonable and feasible.
4. Model Performance Analysis Based on Sichuan Jiuzhaigou Earthquake Case

China is a large country with a vast area and a large territory. It is also one of the countries with the most natural disasters in the world. 41% of China’s land, 50% of its cities, and 70% of its large and medium-sized cities with a population of more than one million are located in areas with high earthquake intensity of 7° or above. There is an earthquake-intensive zone from Ningxia through eastern Gansu, central and western Sichuan to Yunnan where there have been many strong earthquakes in history with heavy casualties. In a city with complex terrain and poor traffic conditions, once a strong earthquake occurs, it is extremely easy to cause road damage and difficulty in rescue, resulting in a significant increase in mortality. Therefore, this paper selects an earthquake case as the background to analyze the performance of the post-disaster aviation medical rescue process and verify the rationality of the process.

On August 8, 2017, a 7.0-magnitude earthquake occurred in Jiuzhaigou County, Aba Prefecture, Sichuan Province. Hundreds of thousands of people were affected by the earthquake. The roads in the epicenter were severely damaged, making it difficult for rescue vehicles to enter the disaster site. Aviation medical rescue has played an irreplaceable role in this disaster. With reference to the aviation medical rescue case and empirical data conducted by the general aviation company after the Jiuzhaigou earthquake, the occurrence time delay of each transition in the postdisaster aviation medical rescue process can be known, as shown in Table 2. Based on this, the average implementation rate of each time delay transition in the postdisaster aviation medical rescue process SPN model can be obtained, that is, the assignment of λ. The specific values are shown in Table 3, and the performance analysis of the postdisaster aviation medical rescue process is carried out on this basis.

Let the probabilities of each state be \( x_i = \{x_1, x_2, x_3, ..., x_{27}, x_{28}, x_{29}\} \); the stable-state probability equation can be obtained as follows:

\[
\begin{align*}
\lambda_1 x_1 &= \lambda_{12} x_{29}, \\
\lambda_1 x_2 &= \lambda_2 x_2, \\
\lambda_2 x_2 &= \lambda_3 x_3, \\
\lambda_3 x_3 &= \lambda_4 x_4, \\
\lambda_4 x_4 &= (\lambda_5 + \lambda_6) x_5, \\
\lambda_5 x_5 &= \lambda_6 x_7, \\
\lambda_6 x_8 &= \lambda_8 x_8, \\
\lambda_9 x_9 &= (\lambda_9 + \lambda_{10} + \lambda_{11}) x_9, \\
\lambda_{10} x_{10} &= (\lambda_8 + \lambda_9 + \lambda_{10}) x_{10}, \\
\lambda_{11} x_{11} &= (\lambda_8 + \lambda_9 + \lambda_{11}) x_{11}, \\
\lambda_{12} x_{12} &= (\lambda_9 + \lambda_{10} + \lambda_{11}) x_{12}, \\
\lambda_{13} x_{13} &= (\lambda_8 + \lambda_{10} + \lambda_{11}) x_{13}, \\
\lambda_{14} x_{14} &= (\lambda_8 + \lambda_{10} + \lambda_{11}) x_{14}, \\
\lambda_{15} x_{15} &= (\lambda_9 + \lambda_{10} + \lambda_{11}) x_{15}, \\
\lambda_{16} x_{16} &= (\lambda_8 + \lambda_9 + \lambda_{10}) x_{16}, \\
\lambda_{17} x_{17} &= (\lambda_9 + \lambda_{10} + \lambda_{11}) x_{17}, \\
\lambda_{18} x_{18} &= (\lambda_9 + \lambda_{10} + \lambda_{11}) x_{18}, \\
\lambda_{19} x_{19} &= (\lambda_8 + \lambda_{10} + \lambda_{11}) x_{19}, \\
\lambda_{20} x_{20} &= (\lambda_9 + \lambda_{10} + \lambda_{11}) x_{20}, \\
\lambda_{21} x_{21} &= (\lambda_9 + \lambda_{10} + \lambda_{11}) x_{21}, \\
\lambda_{22} x_{22} &= (\lambda_8 + \lambda_{10} + \lambda_{11}) x_{22}, \\
\lambda_{23} x_{23} &= (\lambda_8 + \lambda_{10} + \lambda_{11}) x_{23}, \\
\lambda_{24} x_{24} &= (\lambda_8 + \lambda_{10} + \lambda_{11}) x_{24}, \\
\lambda_{25} x_{25} &= (\lambda_8 + \lambda_{10} + \lambda_{11}) x_{25}, \\
\lambda_{26} x_{26} &= (\lambda_8 + \lambda_{10} + \lambda_{11}) x_{26}, \\
\lambda_{27} x_{27} &= (\lambda_8 + \lambda_{10} + \lambda_{11}) x_{27}, \\
\lambda_{28} x_{28} &= (\lambda_8 + \lambda_{10} + \lambda_{11}) x_{28}, \\
\lambda_{29} x_{29} &= (\lambda_8 + \lambda_{10} + \lambda_{11}) x_{29}, \\
\sum_{i=1}^{29} x_i &= 1.
\end{align*}
\]
Table 2: Occurrence time delay of each transition.

| Transition occurrence time delay | Unit time | Transition occurrence time delay | Unit time | Transition occurrence time delay | Unit time |
|---------------------------------|-----------|---------------------------------|-----------|---------------------------------|-----------|
| $\tau_1$                        | 6         | $\tau_7$                        | 6         | $\tau_{13}$                     | 9         |
| $\tau_2$                        | 12        | $\tau_8$                        | 20        | $\tau_{14}$                     | 30        |
| $\tau_3$                        | 15        | $\tau_9$                        | 30        | $\tau_{15}$                     | 24        |
| $\tau_4$                        | 9         | $\tau_{10}$                     | 15        | $\tau_{16}$                     | 12        |
| $\tau_5$                        | 12        | $\tau_{11}$                     | 12        | $\tau_{17}$                     | 6         |
| $\tau_6$                        | 12        | $\tau_{12}$                     |           |                                 |           |

Table 3: Average implementation rate of each delay transition.

| $\lambda_i$ | Value | $\lambda_i$ | Value | $\lambda_i$ | Value |
|-------------|-------|-------------|-------|-------------|-------|
| $\lambda_1$ | 10    | $\lambda_7$ | 10    | $\lambda_{13}$ | 7    |
| $\lambda_2$ | 5     | $\lambda_{14}$ | 2     | $\lambda_{15}$ | 2.5   |
| $\lambda_3$ | 4     | $\lambda_9$ | 2     | $\lambda_{16}$ | 5     |
| $\lambda_4$ | 7     | $\lambda_{10}$ | 4     | $\lambda_{17}$ | 10    |
| $\lambda_5$ | 5     | $\lambda_{11}$ | 5     |                |       |
| $\lambda_6$ | 5     | $\lambda_{12}$ | 7     |                |       |

The steady-state probability of the reachable marker can be obtained by calculation, as shown in Table 4.

The system performance index can be calculated according to the steady-state probability and system performance calculation formula in the above table.

4.1. The Busy Rate of Place. The busy rate of places are, respectively, $P \{M (P_1) = 1\} = 0.03042$, $P \{M (P_2) = 1\} = 0.06084$, $P \{M (P_3) = 1\} = 0.07605$, $P \{M (P_4) = 1\} = 0.04346$, $P \{M (P_5) = 1\} = 0.06084$, $P \{M (P_6) = 1\} = 0.06084$, $P \{M (P_7) = 1\} = 1.00140$, $P \{M (P_8) = 1\} = 0.06084$, $P \{M (P_9) = 1\} = 0.06084$, $P \{M (P_{10}) = 1\} = 0.15767$, $P \{M (P_{11}) = 1\} = 0.06084$, $P \{M (P_{12}) = 1\} = 0.06084$, $P \{M (P_{13}) = 1\} = 0.18301$, $P \{M (P_{14}) = 1\} = 0.18301$, $P \{M (P_{15}) = 1\} = 0.19822$, $P \{M (P_{16}) = 1\} = 0.04346$, $P \{M (P_{17}) = 1\} = 0.15210$, $P \{M (P_{18}) = 1\} = 0.06084$, $P \{M (P_{19}) = 1\} = 0.12168$, $P \{M (P_{20}) = 1\} = 0.06084$, $P \{M (P_{21}) = 1\} = 0.24336$, and $P \{M (P_{22}) = 1\} = 0.03042$.

By calculating and analyzing the busy probability of each place, it can be seen that the values of $P_{10}, P_{13} \sim P_{16}, P_{18}, P_{19}$, and $P_{21}$ are obviously large, which indicates that the busy probability of the place is relatively high. The reason for this phenomenon is that firstly, in the actual rescue, the flight conditions of aircraft are limited by many aspects. It not only is necessary to collect flight condition information but also needs to coordinate the information with the Civil Aviation Administration and the military, which is easy to accumulate information. Secondly, before the medical rescue mission, a lot of preparation work is required, including preflight preparation, rescue personnel, and resource allocation. At the same time, general aviation companies and medical institutions are working in a cooperative mode, which can easily lead to the generation of excess information, resulting in a buildup of information in the information transfer process. Thirdly, in the flight process, the pilot receives information in a single way, which is often prone to information accumulation. In addition, the postdisaster rescue site is often chaotic, and the situation is complex, so it is difficult to summarize effective information quickly. Therefore, the feedback of the site situation is also prone to information accumulation. To sum up, it can be concluded that information accumulation is prone to occur in preflight preparation, information transmission during flight, and on-site information feedback, which can be taken as the key optimization object in the process of aviation medical rescue. General aviation companies and medical institutions should improve their response ability to deal with emergency rescue, standardize rescue procedures, and organize daily drills and training.

4.2. The Utilization Rate of Transition. The utilization rate of transitions is, respectively, $U (T_1) = 0.03042$, $U (T_2) = 0.06084$, $U (T_3) = 0.07605$, $U (T_4) = 0.04346$, $U (T_5) =$...
0.06084, \( U (T_8) = 0.06084, U (T_7) = 0.03042, U (T_9) = 0.10140, U (T_{10}) = 0.07605, U (T_{11}) = 0.06084, U (T_{12}) = 0.04346, U (T_{13}) = 0.04346, U (T_{14}) = 0.15210, U (T_{15}) = 0.12168, U (T_{16}) = 0.06084, \) and \( U (T_{17}) = 0.03042 \).

Through the calculation and analysis of the utilization rate of each transition, it can be seen that the values of \( T_8 \sim T_9 \) and \( T_{14} \sim T_{15} \) are obviously large, which indicates that the utilization rate is relatively high. It can be concluded that, in the process of aviation medical rescue, on-site rescue, casualty transfer, preflight preparation, and personnel preparation are relatively time-consuming. Appropriate professional rescue aircraft and professional rescue teams need to be selected according to the disaster information assessment, as aviation medical rescue is a complex rescue task. At the same time, route application is also a relatively time-consuming work. Therefore, general aviation companies and medical institutions with a shorter rescue radius should be reasonably selected to reduce rescue flight time. Consideration should be given to reducing the route approval process in the event of sudden disasters. General aviation companies and medical institutions should formulate emergency disaster rescue, optimize the plan, and conduct training and simulated rescue missions regularly to improve the overall efficiency of aviation medical rescue.

### 4.3. System Average Delay Time

The system average delay time is an important index of system performance analysis, which can evaluate the rationality of the process and further standardize and optimize the process. According to the little rule, the average delay time of the system can be calculated, and by calculation, \( T = 7.0 \) h; namely, the total running time of the system at the current rate is 7.0 hours.

### 4.4. Effectiveness Analysis of SPN Model

According to the above performance analysis, the parameters of the SPN model are assumed to be improved. Assuming that the average rate of flight crew preparation before flight is increased, when \( \lambda = 3 \) is improved to \( \lambda = 5 \), the utilization rate of transition \( T_9 \) would be changed from 0.10140 to 0.06196, and the average delay time of the system would be reduced from \( T = 7.0 \) h to \( T = 6.8 \) h. In other words, the total operation time of aviation medical rescue decreased from 7.0 hours to 6.8 hours, which proved that the performance analysis results of the SPN model for this process were valid.

#### 4.5. Sensitivity Analysis of SPN Model for Postdisaster Aviation Medical Rescue Process

The system average delay time was taken as the index to analyze the sensitivity of the SPN model. Calculate the sensitivity coefficient corresponding to each transition in the postdisaster aviation medical rescue SPN model; the sensitivity coefficient is

\[ e_i = |\Delta A_i / A_i | / \Delta \lambda / \lambda_i | \]

The results of the calculation of the sensitivity coefficient \( e_i \) in the postdisaster aviation medical rescue SPN model are shown in Table 5.

As can be seen from Table 5, the sensitivity coefficients corresponding to \( T_3, T_4, T_{11}, T_{14}, \) and \( T_{15} \) are obviously large, indicating that “preflight and flight crew preparation,” “route formulation and airspace application,” “medical resources and equipment preparation,” “aircraft landing and on-site first aid,” and “aircraft transfer of casualties and injury stabilization” have a greater impact on the total system operation time of the entire postdisaster aviation medical rescue process and should be taken as the key optimization link to improve the efficiency of postdisaster aviation medical rescue.

Ranking the sensitivity coefficients corresponding to the above five links from high to low, it can be seen that \( T_9 \) “route formulation and airspace application” has the greatest impact on the total operation time of the postdisaster aviation medical rescue process, and it should be taken as the main optimization object for improvement in process optimization to improve rescue efficiency.
5. Conclusion

(1) In order to improve rescue efficiency by normative and scientific research of rescue process, this paper focuses on the postdisaster aviation medical rescue process, constructs a Petri net-based postdisaster aviation medical rescue process model from the perspective of information transmission, and analyzes the time performance and sensitivity of the model. It provides theoretical support and technical guidance to improve rescue efficiency and lead to standardized and intuitive postdisaster aviation medical rescue procedures, which makes up for the lack of current research on postdisaster aviation medical rescue procedures.

(2) The process of postdisaster aviation medical rescue is characterized by a complex rescue process and multiple types of information transfer. In this paper, Petri net theory and method are applied to the study of the aviation medical emergency rescue process, and a general SPN model of the postdisaster aviation medical rescue process is constructed. The established model can clearly simulate and analyze the structural state and dynamic behavior of the postdisaster aviation medical rescue process under different rescue tasks and provide scientific and reasonable decision support for emergency decision-makers and rescue personnel, which is innovative in the field of aviation emergency rescue.

(3) Based on stochastic Petri net and Markov theory, the performance analysis of the postdisaster aviation medical rescue process model was carried out in combination with the Jiuzhaigou earthquake event. According to the calculation, preflight preparation, information transmission during flight, and on-site information feedback process are prone to information accumulation in the postdisaster aviation medical rescue process. On-site rescue and wounded transfer, preflight preparation, and personnel preparation consume a relatively long time. Then put forward optimization suggestions such as improving the rescue response ability of general aviation companies and medical institutions to emergency rescue, formulating postdisaster rescue optimization scheme, simulation training on a regular basis, and reducing the route approval process in the event of sudden disaster. Through further sensitivity analysis of the operation time of the postdisaster aviation medical rescue process, it is concluded that the main links affecting the operation time of the postdisaster aviation medical rescue process system are route formulation and airspace application. It is proposed that this part of the process should be taken as the key to the optimization of the postdisaster aviation medical rescue process so as to provide theoretical guidance for improving the efficiency of postdisaster aviation medical rescue.

(4) In this paper, a generic postdisaster aviation medical rescue SPN model is constructed based on the characteristics of postdisaster aviation medical rescue, while postdisaster aviation medical rescue is a more complex process involving multiple units, and in practice, the emergency management programs in different regions differ. Therefore, a process more in line with the actual situation should be established for different rescue contexts, and the SPN model should be adjusted accordingly. In addition, this paper focuses on dynamic modeling from the perspective of information transfer, and the next step can be studied from the perspective of resource allocation, considering the classification of emergency resources and other issues. Postdisaster aviation medical rescue is a complex rescue activity in its early stage of development. After the performance analysis of the SPN model, the performance analysis results can be used to optimize the postdisaster aviation medical rescue process and build a more reasonable postdisaster aviation medical rescue process to improve the rescue efficiency.

Data Availability

The data used to support the findings of this study are included within the paper.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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