Chapter 122
Modeling and Simulation of Wartime Casualty Surgical Treatment

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Abstract The objective of this paper is to model and simulate the wartime casualty surgical treatment with a discrete simulation tool (Simio) based on treatment process analysis and medical data. Firstly, the surgical treatment process is analyzed. Then, a 3D visual simulation mode is built with Simio. Seven scenarios about different casualty arrival rates are used to test the surgical capability of the field hospital of the PLA. The results show that two hundred casualties may reach the maximum throughput in the field hospital equipped with one operation table. The modeling and simulation of wartime casualty surgical treatment contributes to obtaining the system performance indicators, and simulation model developed can support medical resources estimation and allocation optimization.

Keywords Casualty · Modeling · Simulation · Wartime

122.1 Introduction

Warfare has changed significantly in modern time. Range and accuracy of the lethal modern weapon systems are far more effective than ever, and the army has transformed into modular units that are smaller, more deployable and flexible.

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The field characteristics of dispersion, rapid military operations, increased mobility, rapid task organization, and extended lines of communications make the battlefield more lethal than ever. These directly impact the medical service. The medical facility must adjust to these impacts (Nuhut and Sabuncuoglu 2002). As known to all, the operating room (OR) is the most demanding department in field hospital of the PLA. The process of the operating room directly influences the treatment efficiency of the medical treatment facility. Since the OR treatment process is dynamic and contains many stochastic elements, simulation is used in this research to model and analyze the related problems.

The objective of this paper is to model and simulate the wartime casualty surgical treatment. Firstly, the surgical treatment process is analyzed. Then, a 3D visual simulation mode is created with Simio, a quite new simulation platform. Seven scenarios about different casualty arrival rates are used to test the surgical capability of the medical aid station. The results show that two hundred casualties may reach the maximum throughput in the field hospital equipped with one operation table. The modeling and simulation of wartime casualty surgical treatment contributes to obtaining the system performance indictors, and simulation model developed can support medical resources estimation and allocation optimization.

122.2 Casualty Surgical Treatment Process

Casualties are treated at medical facilities organized into a series of echelons in wartime. The facilities at the forward echelons have the greatest mobility but least surgical capability (Fleet marine force manual (FMFM) 1990). Each facility establishes some treatment areas and treats casualties based on treatment range, rules and capability, which are defined by treatment rules of the army. The field hospital, equipped with necessary operation resources, has the surgical capability. The casualty surgical treatment process in the field hospital is shown in Fig. 122.1.

When casualties arrive at the facility, they are distributed to different treatment areas after triage. The casualties, who immediately need operation disposition, are sent to preoperative room, and the others, to the areas of Lab, X-ray, serious or minor injury treatment, etc. In addition, some casualties flow between these areas and could then get to the preoperative room. When the personnel and equipment

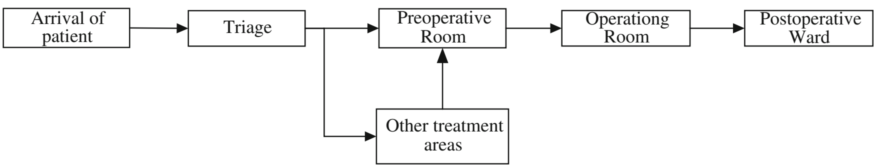


Fig. 122.1 Flowchart of patient movement in the field hospital

required to treat the casualty are available, the casualties are delivered to OR and then flow to postoperative ward.

In the OR, the casualties would receive operation disposition based on their traumatic conditions. The treatment process in the OR could be considered as a series of treatment tasks connected with each other, which could then be named operation treatment task sequence (Zhang and Wu 2011a). There are 2 types of treatment tasks according to the relative order between each other:

(1) Sequential tasks are those performed one after another.
(2) Concurrent tasks are those completed simultaneously.

The operation treatment task sequence is shown in Fig. 122.2. This task sequence is obtained by literature investigation and expert consultation.

So, a casualty surgical treatment process could be considered as this casualty flowing through the above operation treatment task sequence and all casualty surgical treatment processes actually make up this sequence.

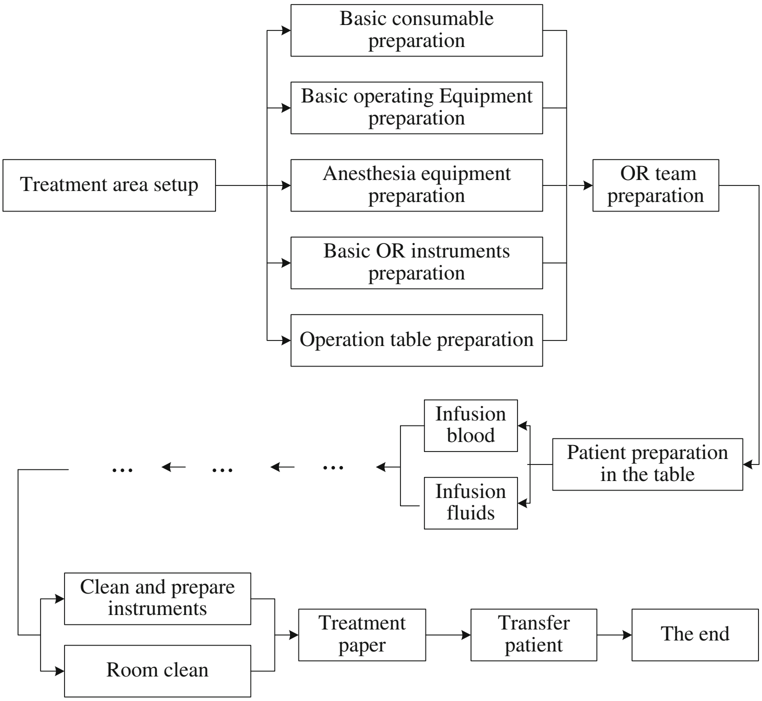


Fig. 122.2 Treatment task sequence of an operating room

122.3 Modeling and Simulation

122.3.1 Simulation Scenario

The simulation scenarios provided are a typical medical support context in which a field hospital of the PLA provides emergency treatment to the casualties involved according to the treatment rules defined by the PLA. In the baseline mode, each patient arrives randomly with an exponential time between arrivals with a mean of 14 min. They would receive first aid treatment within 10 min after injury and then be evacuated to the regiment aid station and get to the preoperative room randomly following an uniform distribution with parameters 0.5–3.5 h. This time internal is defined by the treatment rules of the PLA. There is 1 operation table equipped with necessary medical personnel and resources in the OR. In order to test the OR capability, the casualty arrival rate would successively increase by 25 % in other scenarios.

122.3.2 Modeling and Simulation Tool

Selection of a proper modeling and simulation tool is critical to the outcome of data needed for analysis. In this paper, Simio is selected as the modeling and simulation platform for its various advantages. Simio is a quite new simulation tool, which has functions of visual, interactive, and interpretative modeling. Using Simio, modeling is based on describing system's objects and evolution of system behavior by interaction of these objects. Its graphics and extended capabilities are able to help the researchers easily model the system and determine how an existing or a proposed system will perform. In addition, Simio provides the most advanced real-time 3D technology, which strengthens the interaction of simulation (Zhang and Wu 2011b; Pegden 2008; Dennis Pegden 2009).

122.3.3 Evaluation Measures for Modeling and Simulation

The main focus of modeling and simulation is to valuate the system's surgical treatment capability. For the system, the average casualty wait length and time for operation, operation time, and mortality rate must be accepted by the treatment rules. Since the model developed is a baseline model, and only the casualty arrival rate is changed in other scenarios, the same metrics to measure the performance of system would be used. This allows us to collect similar data in each of the simulations and compare data obtained from several runs of the simulation. Once the data are collected, statistical analysis is performed and the results are used in the analysis of different allocation of the operation room.

122.3.4 Medical Parameters

122.3.4.1 Casualty Types and Generation

The casualty types in this simulation research mostly come from the U.S. army Deployable Medical System (DEPMEDS) PC Code and are adjusted by the subject experts of the PLA. These PC codes occur during deployment and combat operations and range from snake bites, to severe hearing impairment, to more serious injuries (James et al. 2005; Deployable Medical System (DEPMEDS) 2003). The casualties needing operation treatments involve in 87 PC codes. In the simulation, casualties are randomly generated based on an exponential distribution. The casualty cumulative probability distribution obtained from historical accounts of ground operations and adjusted by factors such as recent of operation and medical advances is used for simulation model to indentify a certain PC Code for each injury event.

122.3.4.2 Casualty Survival Probability

The wartime casualty survival probability data are obtained by expert questionnaires. After preliminary analysis, casualties are identified and designated as having either a high (H), medium (M), or low (L) risk of mortality according to the severity of life-threatening. In addition, the casualty survival probability data are fitted by the Weibull survival function with MATLAB. Then the survival functions based on types of medical treatment facility and treatment delays are obtained (Zhang and Wu 2011; Mitchell et al. 2004).

In a certain medical treatment facility, the casualty survival model based on a treatment delay would be obtained by the functions known. A certain type of casualty starts treatment at $c_{0,}$ and this time point is between c_1 and c_2 ($c_1 < c_0 < c_2$), then the casualty survival model based on c_0 treatment delay is:

$$\begin{aligned} S(t)_{c0} &= \Pr[T > t] \\ &= ((c_0 - c_1))\left(\exp\left(-(t/a_1)^\wedge b_1\right)\right) \\ &\quad + ((c_2 - c_0)/(c_2 - c_1))\left(\exp\left(-(t/a_1)^\wedge b_2\right)\right) \end{aligned} \tag{122.1}$$

Using this model and the function parameters fitted, a certain type of casualties' survival probability at any point and time during their treatment processes could be obtained.

122.3.4.3 Casualty Treatment Data

The casualty treatment process is a continuous one composed of a series of treatment tasks required to treat that specific type of casualty. Each type of casualty is linked to a set of treatment tasks, and each treatment task is linked to the resources required to accomplish that task. These tasks could be connected together based on their relative order and compose a casualty treatment sequence. Actually, each casualty treatment task sequence is a subset of the OR treatment task sequence. When this casualty arrives at the operating room, he/she would flow through the OR treatment task sequence. The treatment task sequences are mostly obtained from the U.S. army treate file. The treatment time, personnel and necessary equipment and supplies are obtained by consulting with experts and researching books.

122.3.5 Modeling Process

122.3.5.1 Modeling Casualty Treatment Task Sequence

The treatment process could also be considered as a series of treatment tasks connected by a series of junctions. A new junction object from scratch and a treatment task object sub-classed and redesigned from the standard Time Path object are developed with Simio (Jeffrey and Roberts 2011; Dennis Pegden 2009). Linking the junction and treatment task objects together and setting the object properties, the casualty treatment task sequence is developed as shown in Fig. 122.3.

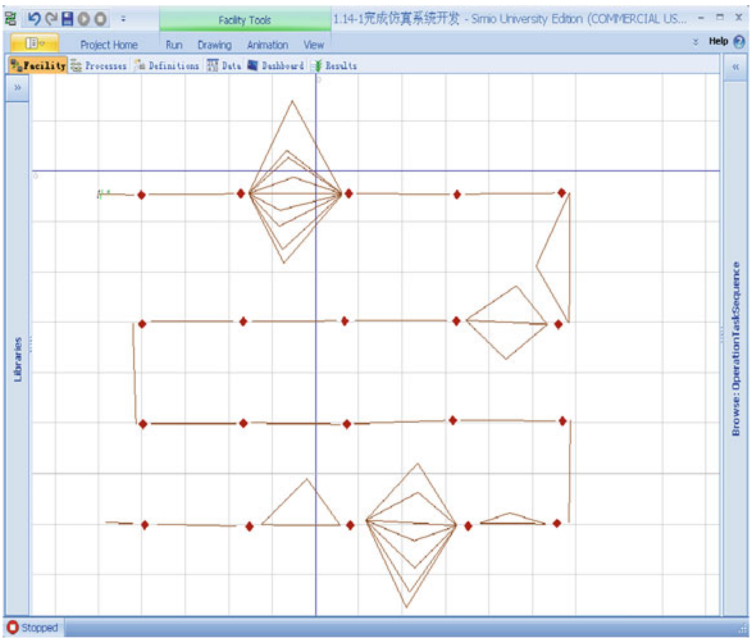


Fig. 122.3 Casualty treatment task sequence in Simio

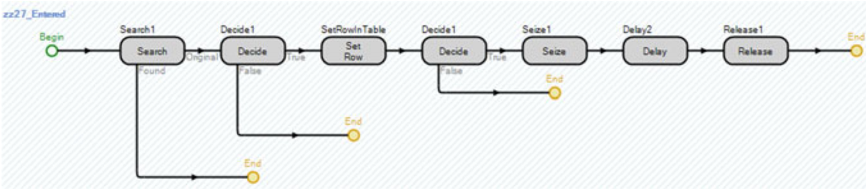


Fig. 122.4 Typical treatment task logic

122.3.5.2 Modeling Resources Consumed by Casualty Treatment Task

The medical personnel are modeled with Worker object, medical equipment with Resource object, and time consumed by the task with triangle distributions got by consulting with subject experts. The logic of each treatment task is designed using the graphical process flows. Figure 122.4 depicts typical treatment task logic. When a casualty flows to this task process, the Search and Decide steps are used to decide whether this task is required by the casualty from a casualty treatment task data table which would be described below. The Set Row and the next Decide steps are used to link the task to the required resources in the table. Then, the Seize, Delay and Released step are used together to model the resources to be seized, delayed and released (Simio user's manual 2009; Dennis 2009).

122.3.5.3 Modeling Casualty Survival Situation

There are four types of risk of mortality and five types of internal of treatment delay. Each type of mortality risk and internal of treatment delay is distinguished by the Decide step. The survival model is used following the next Decide step to determine the casualty survival situation. If the casualty is still alive, he/she would then flow the next treatment process. These logics are shown in Fig. 122.5.

122.3.5.4 Setting Simulation Data

In addition to entering data directly into the modeling objects, a casualty table, including casualty types, composition of proportions, litter conditions, treatment chances and priorities, is defined to set all casualties' basic information, and a treatment task table, including casualty types, task types, task time and treatment probabilities, is defined to set all casualties' treatment information, which is shown in Fig. 122.6.

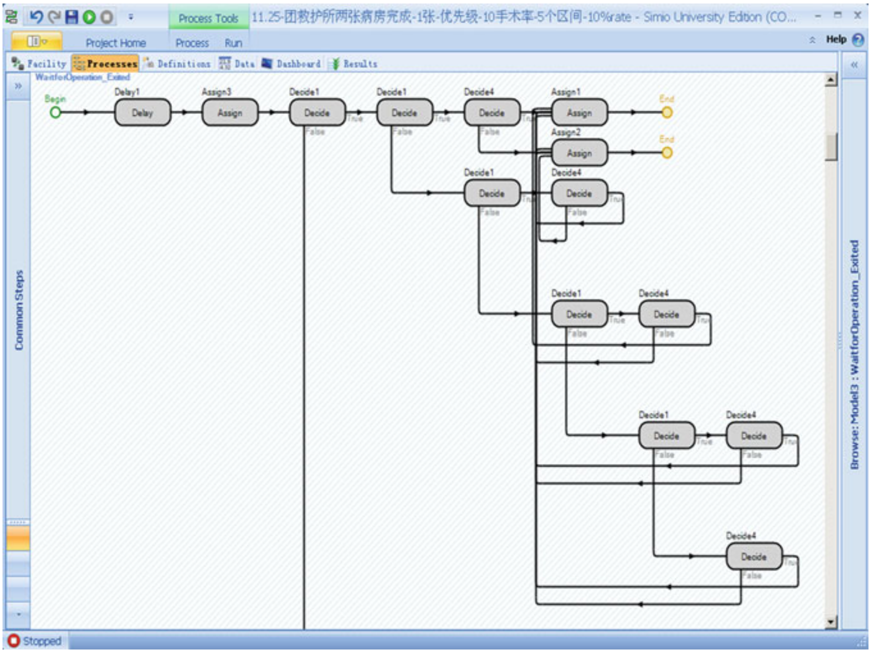


Fig. 122.5 Casualty survival situation modeling logic

122.3.5.5 Achieving Simulation Results

Though Simio platform has powerful statistical functions and makes most statistical data automatically, the surgical system still needs some special data statistics. So, some statistic elements are created to record the treatment data in Simio, as shown in Fig. 122.7.

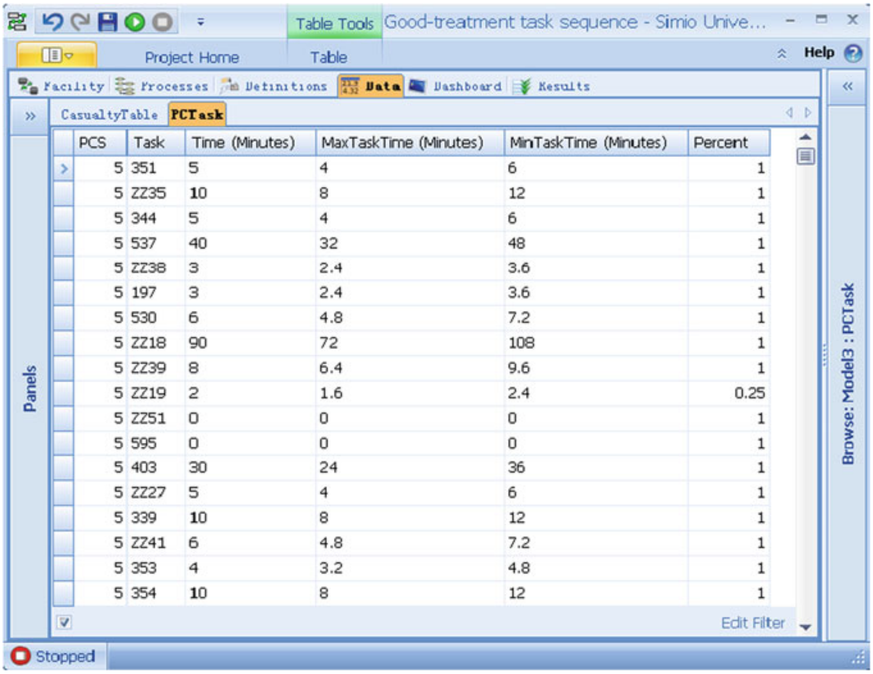
In addition, some process logics, accompanied with statistical elements, are created to trace the simulation data.

122.3.5.6 Visual Simulation Model of Casualty Treatment

The 3D casualty, medical personnel, equipment, and operating room objects are developed by 3D modeling software and imported to create the realistic 3D casualty treatment model with Simio, which is shown in Fig. 122.8 (Dennis 2009).

122.3.6 Results and Discussion

Seven scenarios about different casualty arrival rates are built in the experiment window within Simio. The simulation time lasts for 34 h, and the first 10 h is not



PCS	Task	Time (Minutes)	MaxTaskTime (Minutes)	MinTaskTime (Minutes)	Percent
5	351	5	4	6	1
5	ZZ35	10	8	12	1
5	344	5	4	6	1
5	537	40	32	48	1
5	ZZ38	3	2.4	3.6	1
5	197	3	2.4	3.6	1
5	530	6	4.8	7.2	1
5	ZZ18	90	72	108	1
5	ZZ39	8	6.4	9.6	1
5	ZZ19	2	1.6	2.4	0.25
5	ZZ51	0	0	0	1
5	595	0	0	0	1
5	403	30	24	36	1
5	ZZ27	5	4	6	1
5	339	10	8	12	1
5	ZZ41	6	4.8	7.2	1
5	353	4	3.2	4.8	1
5	354	10	8	12	1

Fig. 122.6 Casualty treatment data tabe

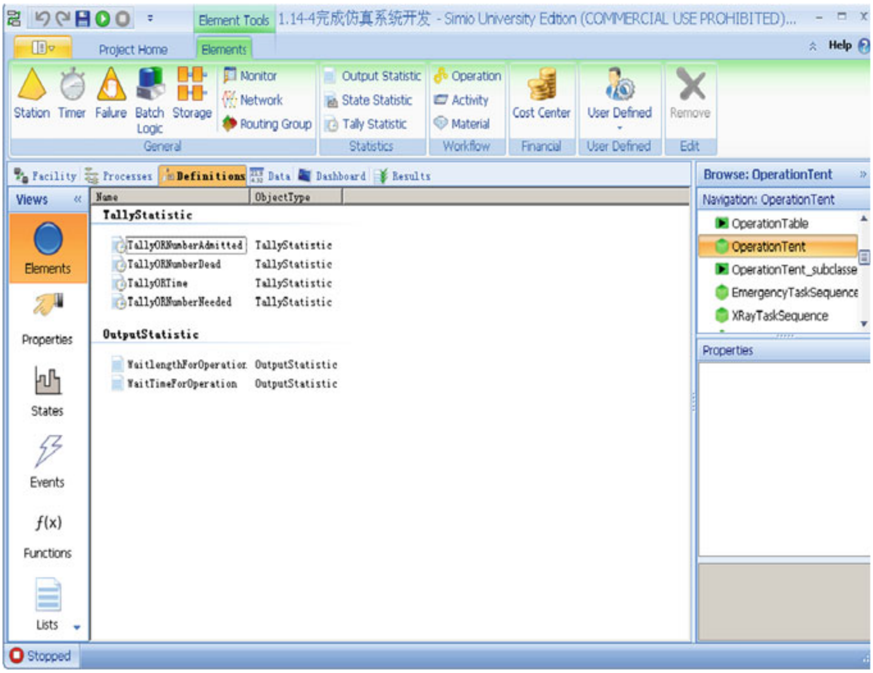


Fig. 122.7 Statistic elements created to record simulation data in Simio

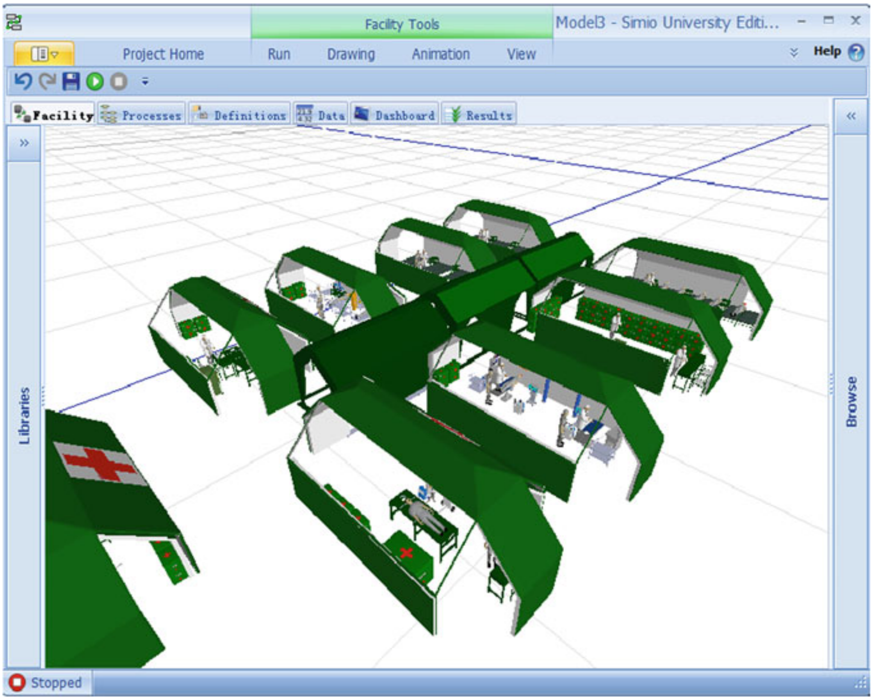


Fig. 122.8 Simio model with animation 3D

used for collecting data. The scenario 1 is the baseline model, and the arrival rate is increased by 25 % after each scenario. We take 100 replications for each scenario and the results are within the 95 % confidence interval.

All the important performance indicators of the system are obtained. Parts of mean value of average data are shown in Table 122.1.

Two hundred casualties have long been considered as the maximum throughput in the field hospital researched in this paper. Though, long time has passed, the performance indicators still reflect this situation. As shown in Table 122.1, the

Table 122.1 Performance indicators of the field hospital with one operation table

Scenario	Casualty arrival number	Mortality rate (%)	Operation number	Wait length for operation	Wait time for operation (h)	Operation time (h)
1	103.46	1.42	8.40	0.25	0.53	1.23
2	128.21	1.48	10.50	0.46	0.74	1.24
3	160.89	1.99	12.94	0.89	1.20	1.20
4	201.07	1.89	14.83	1.37	1.48	1.21
5	249.97	2.60	16.78	2.81	2.25	1.23
6	314.26	3.03	18.26	4.97	3.06	1.25
7	392.91	3.15	18.41	9.48	3.59	1.29

average casualty arrival number is 201.07 ± 2.72 in scenario 4. In this situation, after consulting with subject experts, we consider that the wait length and wait time for operation, and the mortality rate may reach the maximum, which could be borne by the casualties. In scenario 5, 6 or 7, more operation tables should be established.

122.4 Conclusion

The objective of this paper is to model and simulate the wartime casualty surgical treatment. Firstly, the surgical treatment process is analyzed. Then, a 3D visual simulation mode is built with Simio simulation platform. Seven scenarios about different casualty arrival rates are used to test the surgical capability of the medical aid station. The results show that two hundred casualties may reach the maximum throughput in the field hospital equipped with one operation table. The modeling and simulation of wartime casualty surgical treatment contributes to obtaining the system performance indictors, and simulation model developed can support medical resources estimation and allocation optimization.

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