Simulation Analysis of a Military Casualty Evacuation System

Sumana Biswas, Hasan Huseyin Turan and Sondoss El Sawah
Capability Systems Centre
University of New South Wales
Canberra, Australia
sumana.biswas@adfa.edu.au, h.turan@adfa.edu.au
s.elsawah@adfa.edu.au

Abstract

This paper aims to analyse several parameters of the casualty evacuation system and their effects through the simulation platform. A discrete event simulation (DES) model is used for the analysis. Five scenarios contemplating different fleets' prerequisites for survival, ambulance allocation and casualty treatment allocation parameters are used to test the performance of the military evacuation system. The result shows that change in parameters such as ambulance return time, redeployment time, transport duration etc., effects the time of evacuation as well as the time of resuscitation and damage control surgery. The percentage of casualties that required damage control surgery that received it within the required time is on average, 63.78 % and the waiting time for bed is 0 minutes. In order to facilitate the evacuation of combat casualties, this simulation model supports decision-making. This analysis can also be used to support the resource allocation of the military casualty evacuation system.

Keywords
Casualty, Evacuation system, Simulation, Resource allocation and Decision making.

1. Introduction
Evacuating the wounded from the battlefield has been a persistent problem since the dawn of warfare, and it remains the same as today (Lam 2001). The movement of casualties is a significant component of military medical health systems. To enhance the individual's prognosis and reduce long-term disability, in casualty evacuation en route, medical care and emergency medical intervention are provided according to the medical requirements (ATP 4-02.2 2019). It plays a vital role in saving the lives of combat casualties and reducing the rate of mortality and morbidity.

Since World War II, warfare has seen tremendous changes (Moses et al. 2001). Nowadays, the application of emerging technologies (war drones, nuclear weapons) has constantly been changing the nature of the battlefield and unfortunately, leading to raise in the severity of casualties. The nonlinear and enlarged nature of the modern battlefield necessitates modifications in the way combat health assistance is provided (Moses et al. 2001). Maintaining the fighting units' care becomes increasingly crucial for the success or failure of the mission as the battlefield gets more dangerous. It is evident that future operating environments will give rise to new clinical, logistics and organisational challenges (Scallan et al. 2020). Therefore, an effective evacuation system can be provided by military with comprehensive planning, which ultimately improves the likelihood of the injured soldier surviving (Moses et al. 2001).

In order to examine military systems, numerical models are frequently developed as war games, and field training exercises are exceedingly expensive (Eubanks et al. 2020). The military evacuation system is dynamic in nature and contains many stochastic characteristics. Hence, the simulation tool would be the optimal approach for modelling and analysing the system.

1.1 Objectives
Our study aims to analyse the casualty evacuation system of the military through simulation. A technique known as discrete event simulation (DES) is used to simulate real-world systems that may be divided into a number of logically distinct processes that advance independently across time (Med. upenn). DES is a method for imitating the behaviour and functionality of a process, facility, or system in real life (Allen 2015). In our paper, we use DES as our simulation

platform to assess the performance of a military evacuation system. This work considers three main decision-making criteria for casualty evacuation systems. They are (i) fleet's prerequisites for survival, (ii) casualty treatment requirements and (iii) ambulance allocation. In this work, several scenarios by considering a number of parameters such as ambulance return time, redeployment time, ambulance speed, number of beds, waiting time for bed, transport duration, waiting time of dispatch etc., have been studied to investigate how the change of these parameters affect the outcome of the evacuation system in the battlefield. Here, the outcome we examine is the distribution of evacuation time, resuscitation time, damage control surgery time, waiting for a bed, bed occupancy for the bed for different treatment facilities and ambulance availability.

The rest of the paper is organized as follows: Section 2 discusses the related literatures. Section 3 demonstrates the description of the simulation models. The explanation of the simulation analysis is described in Section 4. Section 5 presents the results and discussion. The paper is concluded in section 6.

2. Literature Review

This section discusses the literatures related to military medicine and simulation application in casualty evacuation. World War II, pilots and infantry soldiers trained with simulators and mockups to prepare for battle. Since then, modelling and simulation (M&S) have become a crucial component of military training for warfighters (Eubanks et al. 2020). There is growing research on the application and importance of simulation and modelling on the battlefield. Eubanks et al. (2020) studied the past, present and future of simulation in the domain of military medicine. Leitch et al. (2002) discuss the importance of simulation and its relation to the future of military medicine. The applicability of Military medical modelling and simulation in the 21st century is analysed by Moses et al. (2001). The author discussed four categories of medical simulation to address some real-world challenges of military medicine. PC-based multimedia, digital mannequins, virtual workbenches, and total immersion virtual reality (TIVR) are some of these categories. Casualty evacuation is one of the significant parts of the military medical system.

There have also been a number of studies on the analysis of casualty evacuation. Most of them used simulation modelling (Simo) for the analysis of specific purposes. Du and Wang (2011) applied a computer simulation model to investigate the type of selection of ambulance helicopters (AH). In the simulation model, the dynamic metric chosen to examine the effectiveness of AH's evacuation in a tactical zone is the number of stretcher patients. They looked at a variety of indicators, including airspeed and patient numbers, through output measures like the mean waiting time for evacuation. A simulation analysis of army casualty evacuations is conducted by Nuhut and Sabuncuoglu (2002). The authors of this paper use simulation to investigate a brigade casualty evacuation system (BCES). The goal of the model is to give the commanders of a manoeuvre, logistics, and medical unit the necessary information about casualties, such as time spent in medical facilities, wait times in doctor queues, doctor utilisation, and percentages of casualties who return to duty or are transferred to higher level medical facilities. Mitchell et al. (2004) used NHRC's Tactical Medical Logistics (TML+) planning tool for the simulation analysis and model of the mortality of casualties from the point of injury (POI) through more definitive care. In their model, they describe three mortality risk categories. A visual simulation model of wartime casualty evacuation was developed by Zhang et al. (2011). They used Simio (simulation tool) for the simulation trials for the optimal placement of the casualty evacuation assets. Zhang et al.'s (2011) research focus on the application of a Simio simulation tool to investigate the modelling of casualty treatment on the battlefield. In their paper, using the simulation experiment model, a personal allocation was evaluated. Based on an investigation of the treatment procedure and medical data, Zhang et al. (2013) created a model and used a discrete simulation tool to recreate the surgical care given to combat casualties. They also used Simio as their simulation platform. Seven scenarios with various casualty arrival rates are utilised in their study to evaluate the surgical capability of the PLA field hospital.

Therefore, we need a thorough analysis based on simulation to improve the performance of the evacuation system in the battlefield.

3. Simulation Model Description

CASEVAC model developed by Capability Systems Centre, UNSW, Canberra, Australia, is used in this research work to analyse the military casualty evacuation process. The DES-based CASEVAC model is a Java application. It takes input as a collection of Excel files containing data as model input. Using this information, the model simulates the CASVAC system, and it outputs the results as static HTML pages. There are numerous sub-models that constitute the CASVAC model. Figure 1 illustrates the overview of the CASEVAC model. The CASEVAC model is the combination of several sub models. In our study, we worked on three sub models: Ambulance Survivability sub model, Casualty Treatment Allocation sub model and Ambulance Allocation sub model. The inputs are the parameters of the sub models, and they are described at Section 4.

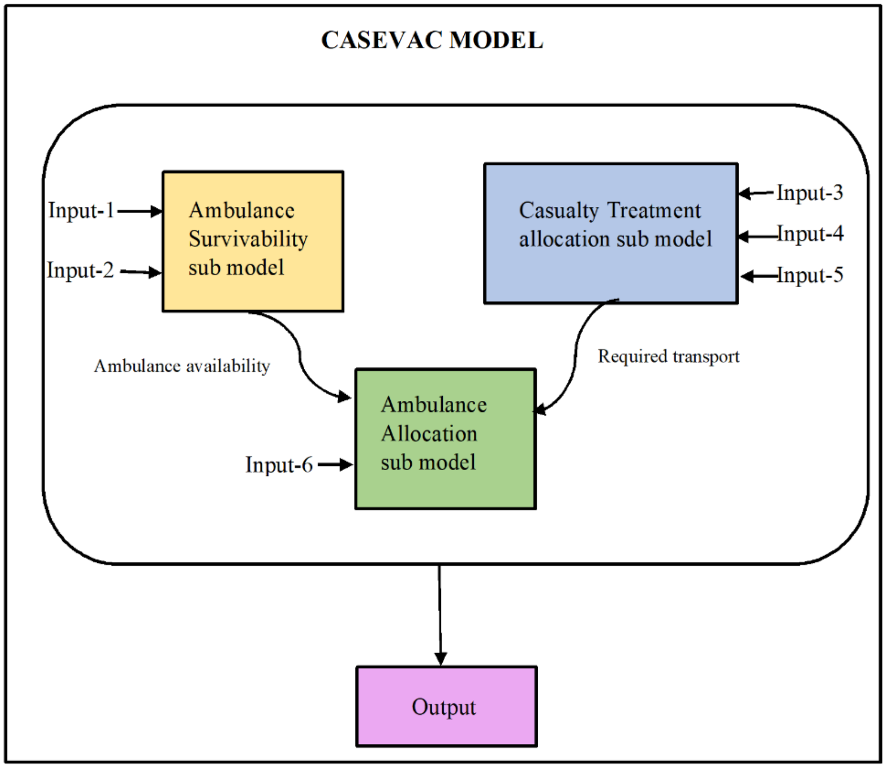

Figure 1. The layout of the casualty evacuation model

In this study, on the 10-1-2 metric, shown in Table 1, at the critical nodes such as casualty collection point (CPP) and medical treatment facilities (R1, R2 etc.), the simulation model demonstrates CASVAC transportation and ambulance fleet mix.

In this model, it needs to be setting up scenarios for terrain, threats, operation intensity, and duration. The scenarios will include the definition of facilities and the zones they are located at that are to be simulated, such as CCP, R1, R2 etc., including the distances between zones and the terrain and threats at each zone. Simulated scenarios will have timesteps of one minute and last for a period of weeks (Table 1).

Table 1. Evacuation metric

Time imperative	Treatment
1 Hour	Resuscitation metric (Advanced resuscitative care)
2 Hours	Surgery metric (Surgery within two hours of wounding or injury.)
20 minutes	Evacuation Metric (In care of evac team (reach Triage at first location)

In order to facilitate patient evacuation during battle, this modelling endeavor aims to analyse the simulation model that will be utilised to support long-term strategic decision-making.

4. Simulation Analysis

The analysis of the casualty evacuation system is investigated through three sub-models: (i) Ambulance Survivability, (ii) Casualty Treatment Allocation and (iii) Ambulance Allocation. The ambulance survivability sub model provides the availability of the ambulance fleet over the course of an operation. The Casualty Treatment Allocation sub models is used to determine course of action for each casualty as it arrives at the zone. The Ambulance Allocation model handles the allocation and dispatch of ambulances. From these sub-models, three decision-making criteria are analysed. They are given below:

4.1 Fleet's Prerequisites for Survival

In this work, fleets prerequisites for survival are analysed from the Ambulance Survivability sub model. Using this criterion, it is possible to assess how each scenario is modified fleet mix and assignment affect the availability and survival rates of casualties and ambulances. In this case, we use the following parameters for analysis:

(i) Ambulance return time (in minutes)
(ii) Ambulance refurbishment time (in minutes)
(iii) Ambulance redeployment time (in minutes)
(iv) Ambulance quantity

For analysis we varied the above parameters considering several scenarios.

4.2 Casualty Treatment Requirements

The Casualty Treatment Allocation sub model is used to evaluate the needs for casualty treatment. This criterion facilitates to assess the impact of various degrees of resource allocation and prioritising techniques on patient survival and performance as measured by the 10-1-2 metric. The following parameters are used for analysis in this situation:

(i) Survival percentage
(ii) Intervention duration
(iii) Waiting time for transport
(iv) Waiting time for intervention
(v) Bed type
(vi) Bed availability

4.3 Ambulance Allocation

The allocation of ambulance is examined from the Ambulance Allocation sub model of the simulation model. This sub model is used to evaluate the effect on patient survival and performance for different transport prioritization strategies. In this instance, the following criteria are employed for analysis:

(i) Ambulance selection
(ii) Ambulance dispatch
(iii) Maximum waiting time for dispatch (in minutes)
(iv) Ambulance transport duration
(v) Dispatch rules

Five scenarios are examined by varying the above-mentioned parameters to investigate the outcome of the simulation process. In this case, the outcomes that we look at are the distribution of the times required for evacuation, resuscitation, damage control surgery, waiting time for a bed, the occupancy of beds at various treatment facilities, and the accessibility of ambulances.

5. Results and Discussion

In this research work, five scenarios are considered by varying the input parameters of the CASEVAC model for analysis. In each scenario, there is a combination of fifteen parameters as the input of the model. In each scenario, the input parameters are varied to see their effect on the model output. Table 2 describes the parametric value of five scenarios.

Table 2. Scenarios for simulation analysis

Parameters	**Scenario-1**	**Scenario-2**	**Scenario-3**	**Scenario-4**	**Scenario-5**
Ambulance return time (minutes)	30	20	40	50	60
Ambulance refurbishment time (minutes)	60	80	100	120	150
Ambulance redeployment time (in minutes)	10	20	30	40	50
Ambulance quantity	1	2	3	1	2
Survival percentage	100	90	95	85	90
Intervention duration (minutes)	1000	1500	2000	1000	1500
Waiting time for bed	3000	2500	2000	3500	2500
Waiting time for transport	3000	3500	2500	4000	3000
Waiting time for intervention	3000	4000	3500	3000	2500
Bed type	3	3	3	3	3
Ambulance selection	No Yes No				
Ambulance dispatch	No yes	Yes No	No yes	Yes No	yes
Maximum waiting time for dispatch (in minutes	10	15	20	10	8
Ambulance transport duration	10	15	20	25	10
Dispatch rules	0 60	0 60	0 60	0 80	0 60

(Timeout)-for CCP	240	120	240	200	240

5.1 Graphical Results

Figure 2 to Figure 4 shows the distribution time for advanced resuscitation, damage control surgery and evacuation time respectively. The details of the time spent in different states is illustrated in Figure 5.

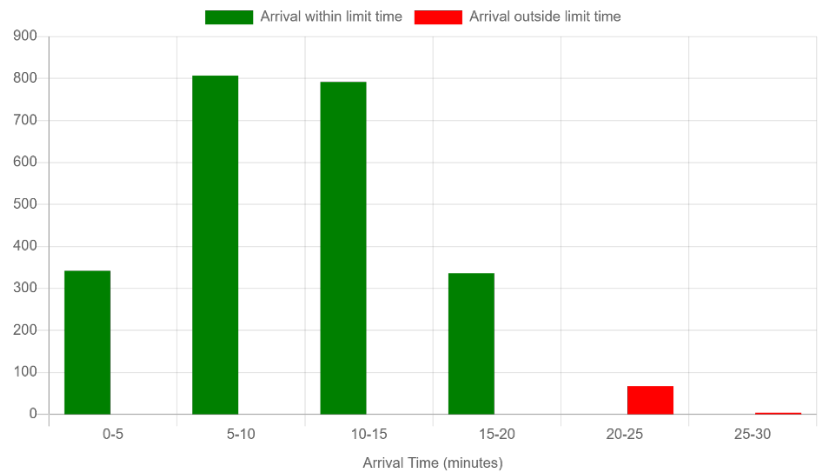

Figure 2. Distribution of times to evacuation

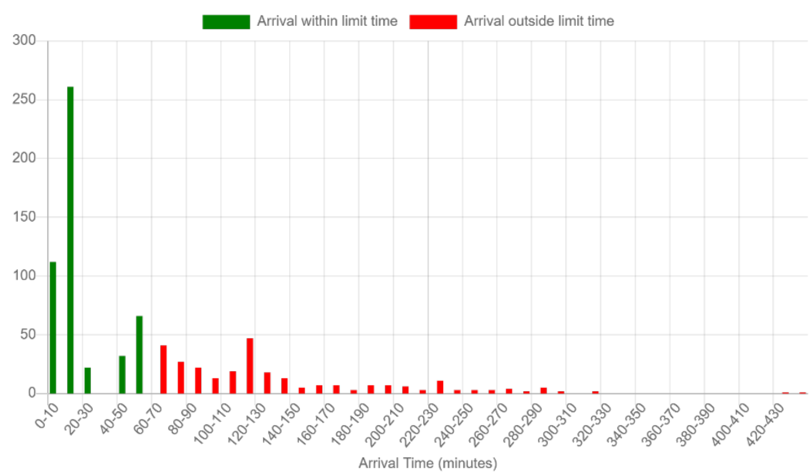

Figure 3. Distribution of times to advanced resuscitation

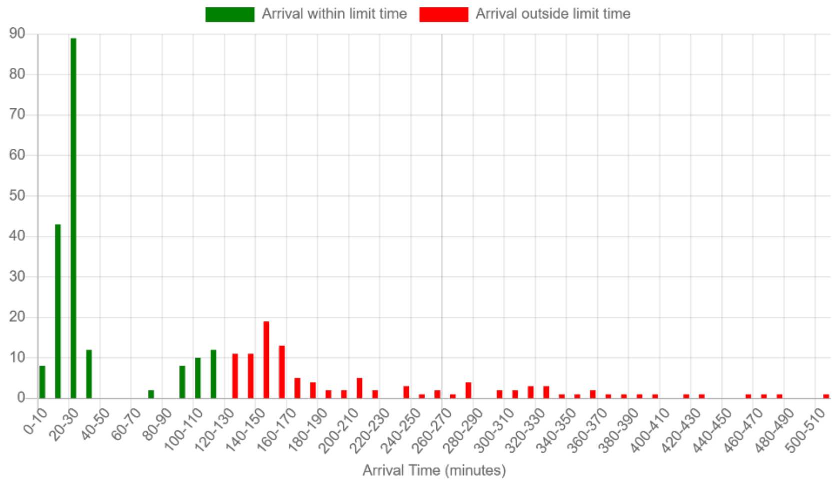

Figure 4. Distribution of times to damage control surgery

The result shows that on average, 63.78% of cases who needed damage control surgery had it done in the allotted amount of time. It is also found that the percentage of casulties that required resusitation that received it within the required time is about 65%.

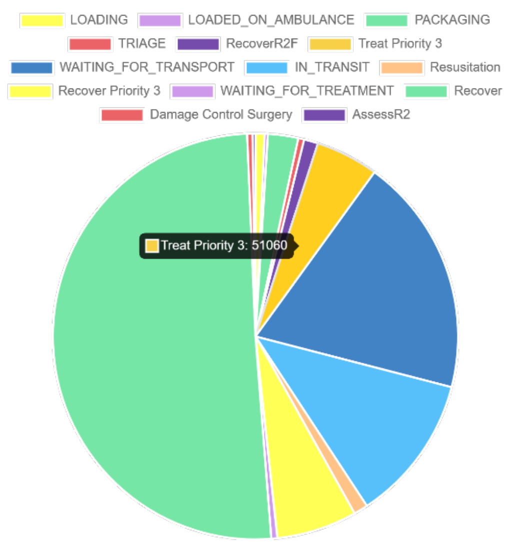

Figure 5. Summary of the total minutes spent in each state

Figure 6 and Figure 7 shows the graph regarding causality in a period of week. Figure 8 illustrate the waiting time for transport indicator at different medical treatment facilities. The condition of bed occupancy at R2 facility in a day and waiting for bed is described in Figure 9 and Figure 10 respectively. Figure 11 and Figure 12 shows the graph related to ambulance availability and allocation in a daily period.

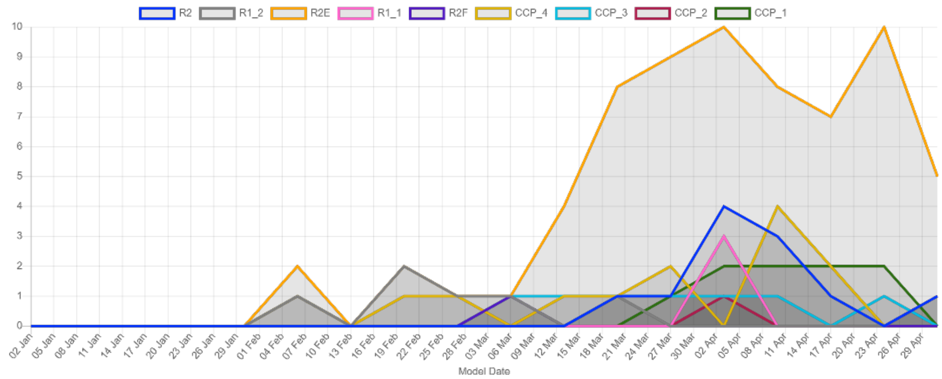

Figure 6. Number of active casualties over time in a week

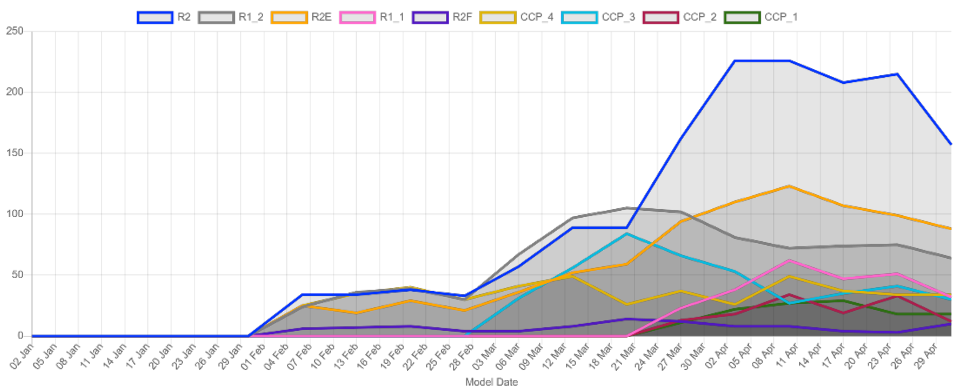

Figure 7. Number of arriving casualties over time in a week

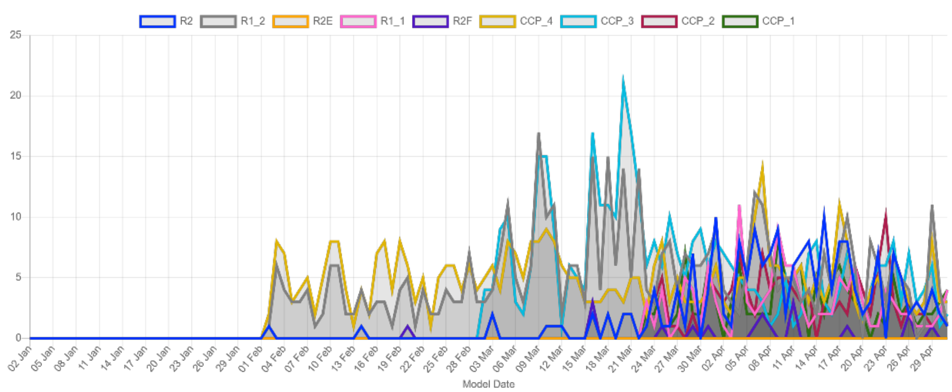

Figure 8. Count of waiting for a transport indicator in the chosen period daily

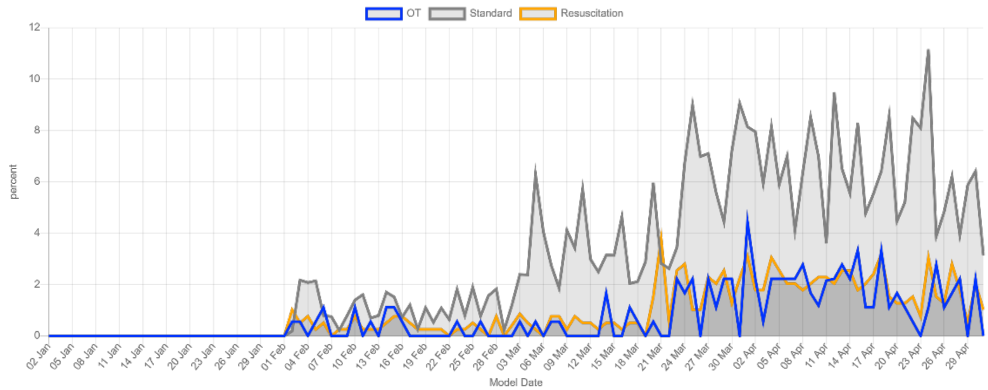

Figure 9. Bed occupancy in zone-R2 in the chosen period daily

Figure 10. Waiting for a bed indicator in the chosen period daily

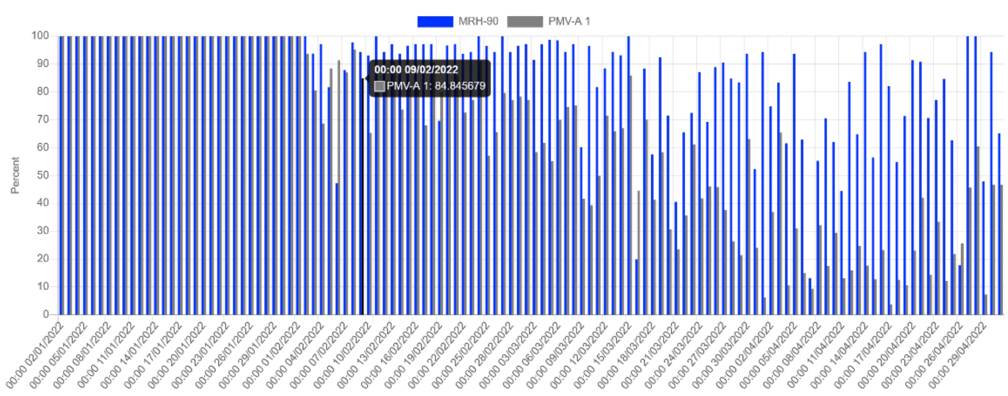

Figure 11. Availability of ambulance class in the chosen period daily

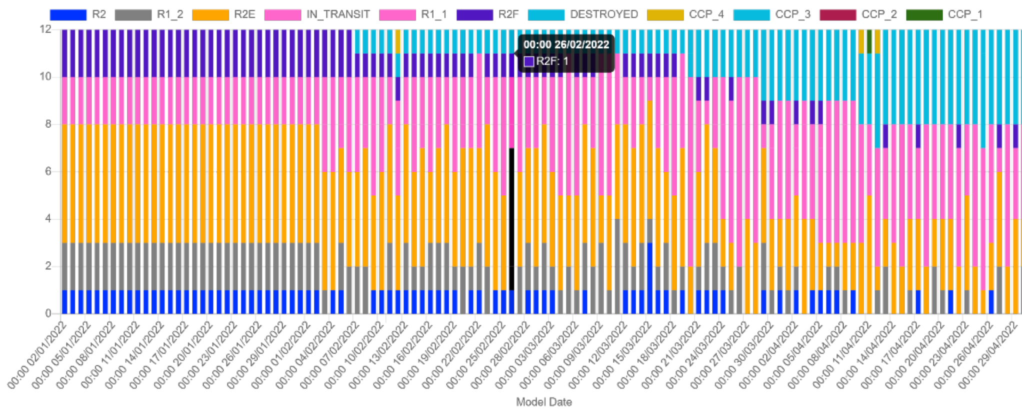

Figure 12. Ambulance allocation in the chosen period daily

From the scenario analysis, it is found that the change in the input parameters has a minor effect on the distribution times. It is observed that input parameters have a minor effect on casualty estimation, such as arriving of casualties and the active number of casualties. The parameters have a significant impact on bed occupancy and on the waiting time for beds. In addition, the result shows that there is a strong relationship between the number of casualties and ambulance allocation.

6. Conclusion

Time is a very crucial factor for any evacuation system. It is directly related to casualty survivability. On the other hand, proper casualty treatment by providing sufficient logistic support such as beds and transport can make the evacuation system efficient.

This study has been conducted to analyse the casualty evacuation system and support the military in decision-making. Evacuation time, resuscitation time and damage control time are evaluated based on different scenarios. Casualty estimation and ambulance allocation to transport casualty are also assessed based on several input parameters in the simulation model. It is found that there is a direct relation between the input parameters and the performance of the evacuation system. However, there are still some shortcomings; for example, it is not enough to come up with a decision by considering a few parameters for analysis. As the evacuation system is a complex system, several factors are related to its performance that needs to be considered altogether. Therefore, further rigorous analysis is needed to make efficient such a complex system like the military evacuation process that can assist the defence planner and decision maker.

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Biographies

Dr Sumana Biswas is a Researcher at the Capability Systems Centre at the University of New South Wales (UNSW), Canberra, and an Associate Fellow of the Higher Education Academy (AFHEA). She is the lecturer of the online postgraduate course- Decision Making in Analytics at UNSW. Dr. Biswas is one of the Women@UNSW Canberra Champions. She holds PhD degree in Mechanical Engineering from the University of New South Wales, Canberra, Australia. She received her B.S.C. and M.S.C. degree from Chittagong University of Engineering and Technology (CUET), Bangladesh. Dr. Biswas is an enthusiastic academic person with expertise in technology decision making, capability model development, autonomous systems planning, artificial intelligence, data-driven optimisation algorithms, and simulation models. She has more than 14 years of research and teaching experience in the higher education sector in overseas and Australia. She was an Assistant Professor at the Chittagong University of Engineering and Technology (CUET), Bangladesh.

Dr. Hasan H. Turan is a Lecturer and the Research Lead at Capability Systems Centre, University of New South Wales, Canberra. Before joining UNSW Canberra, he worked as a post-doc research fellow at Qatar University, Mechanical and Industrial Engineering Department from 2015 to 2017. He obtained his Ph.D. and master's degrees both in Industrial and Systems Engineering from Istanbul Technical University and North Carolina State University, respectively. His research interests revolve around the development and application of data-driven optimisation algorithms and simulation models arising in different domains including service and maintenance logistics, defense applications. He is currently focused on the integration of machine learning (e.g., reinforcement learning), artificial intelligence, and computational intelligence techniques (e.g., genetic algorithms) with simulation models (discrete event and system dynamics) to solve complex decision-making problems. Dr. Turan has taught a total of 15 different courses at different university levels (bachelor and master) including students from different backgrounds. Dr. Turan was the guest editor for at the Annals of Operations Research journal to organize a special issue on the recent advances in simulation-based optimisation, and he is an editorial board member of the Journal of Business Analytics. He was the convener of the 3rd and 4th IEEE Systems Modeling Conference.

Associate Professor Dr. Sondoss El Sawah is the System Engineering Teaching Coordinator at the UNSW Canberra. She is the Director of Capability Systems Center at UNSW, Canberra. She has focused her research and teaching programs on advancing the science and practice of Systems Thinking, and especially its applications in public policy, engineering, and education. She is an expert on the application of Systems Thinking and Systems Modelling methodologies. Dr. El Sawah's research has been recognized by more than 8 awards from national and international bodies, including the prestigious Research Award by the International Environmental Modelling and Software Society (2018). She is the first female recipient of the Australian Operations Research Society Rising Star Award (2016). Dr. El Sawah is the Editor of the Journal of Environmental Modelling and Software. She is the Vice President of the Modelling and Simulation Society of Australia and New Zealand (MSSANZ).