Simulation of the Medical Evacuation Chain: A Conceptual Model

Kai Meisner[1*], Heiderose Stein[2], Nadiia Leopold[2], Tobias Uhlig[2], Oliver Rose[2]

[1]Medical Service Capability and Force Development, Bundeswehr Medical Academy, Neuherbergstraße 11, 80937 Munich, Germany; **kai.meisner@unibw.de*

[2]Department of Computer Science, University of the Bundeswehr Munich, Werner-Heisenberg-Weg 39, 85577 Neubiberg, Germany

SNE 34(2), 2024, 81-89, DOI: 10.11128/sne.34.tn.10684
Selected ASIM SPL 2023 Postconf. Publication: 2023-09-01
Received Rev. Improved: 2024-04-22; Accepted: 2024-05-10
SNE - Simulation Notes Europe, ARGESIM Publisher Vienna
ISSN Print 2305-9974, Online 2306-0271, www.sne-journal.org

Abstract. The casualty numbers of the ongoing war in Ukraine significantly surpass the ones of recent conflicts. Since medical resources are limited on the battlefield, efficiently utilizing the available capacities is crucial. At the same time, planning and coordinating this constantly changing logistic network is challenging due to the high dynamic of combat. As data is limited, current planning base on expert assumptions. This process can be supported by simulation models, allowing to analyze the interplay of assumptions and planning decisions. Recent studies showed that flexible dispatching policies can lead to a better utilization of the available capacities and, therefore, to better patient treatment. To further investigate different dispatching strategies in several dynamic combat scenarios, we propose a conceptual model covering the entire medical evacuation process.

Introduction

Since the Russian attack on the Ukraine, traditional warfare for national and alliance defense has once again become the cornerstone of NATO's strategic orientation [1]. Current reports of the ongoing war in the Ukraine indicate a level of combat intensity significantly surpassing the ones NATO has faced in the Afghanistan mission [2, 3]. Concurrently, the number of individuals sustaining life-threatening injuries tends to rise significantly. At the same time, the medical resources available in such conflicts are severely constrained, and the time required to evacuate the injured is prolonged [4].

To provide the best possible treatment to injured soldiers, efficiently utilizing the available medical resources is crucial. For this purpose, the patients must be evenly distributed to the medical facilities and transporters. At the same time, the specific needs of each patient, depending on the injury, needs to be taken into account. This leads to a complex logistic network that is further subject to constant changes due to the combat dynamics. The standard for medical support within the NATO is described in the regulation AJP-4.10 [5]. It shows, that the current planning process of the medical evacuation is based on expert assumptions used to estimate casualty figures and injury patterns.

From here, plans for the most likely scenarios are formulated based on expected patient flows, derived from these estimates. Consequently, there is a static planning process for a highly dynamic logistics system.

In prior work, we have demonstrated, that simulation can be applied to support this planning process [6]. This especially applies to large-scale combat scenarios, as we can currently observe in the Ukraine, where high numbers of patients must be treated with limited resources. For this purpose, a flexible simulation model is required, allowing to test a wide range of dispatching strategies for medical resources in different combat scenarios [6]. Based on these earlier considerations, we present a conceptual model covering the evacuation and preclinical care of injured soldiers.

The paper is structured as follows: First, we briefly describe the medical evacuation chain as the system under examination. In Section 2, related simulation models are briefly discussed, leading to our preliminary considerations presented in Section 3. The conceptual model is introduced in Section 4 covering the different simulated objects with underlying submodels. Finally, the paper concludes with a summary and an outlook.

1 Medical Evacuation Chain

In war, it is only rarely possible to access an existing healthcare system. Therefore, it is imperative to establish a medical service system on-site to ensure the provision of medical care. Nowadays, combat scenarios tend to occur over extensive areas, which results in prolonged evacuation times for injured soldiers. At the same time, life-threatening injuries are common and the assessment with proper treatment of such patients is time-critical. Therefore, evacuating the patients while providing timely preclinical treatment is of utmost importance for the patient's chance of survival [4].

To ensure timely evacuation of patients while providing adequate treatment, the medical evacuation chain was established [4, 7]. This chain is hierarchical and consists of different treatment levels, as visualized in Figure 1. Here, each rectangle represents one level of medical care, while the arrows represent the transportation between them.

First, injured soldiers are brought to a casualty collection point (CCP), where they receive first aid and are handed over to the medical service. From there on, the patients are treated along four successive roles, namely Role 1 to Role 4.

Each role represents a set of medical facilities with increasing capabilities and resources. For example, Role 1 facilities provide emergency care, stop major bleeding, and prepare patients for transportation to a Role 2, where first surgical interventions can be provided. Role 3 facilities extend these capabilities by providing further medical specialists, reaching the standards of a university hospital. Finally, the rehabilitation of patients takes place in Role 4, which is usually located in the patient's home country.

Transportation between these roles can either be performed ground-based or airborne. The selection of the appropriate transporter depends on both the current combat scenario and the needs of each individual patient. Plans for treating patients along the medical evacuation chain must meet the NATO clinical timelines [5].

Accordingly, critical patients must receive Role 1 treatment within one hour of after getting injured. Within two hours of injury, Role 2 must be reached. After the first surgical intervention, the patient must be evacuated to Role 3 within an additional two hours.

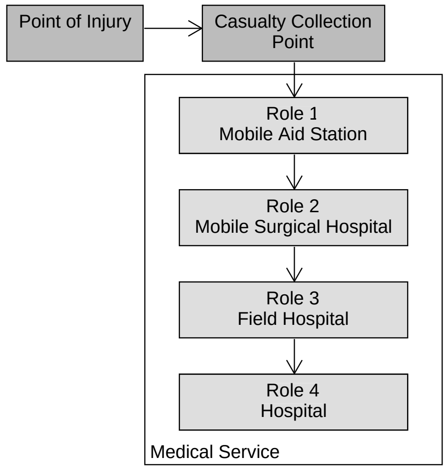

Figure 1: Patients are collected at a casualty collection point and receive treatment in four successive roles with increasing medical capabilities.

2 Related Work

For planning the medical evacuation, two different subproblems are commonly studied [8]. The location-allocation problem studies the best layout of the medical resources in combat scenarios.

The dispatching problem investigates different policies of utilizing the available resources to respond to the different requests. In addition to static planning, the response to various effects of battle dynamics must be considered, too [9]. For example, these effects can be triggered by resource shortfalls which then may require a dynamic relocation or redistribution of resources.

It has already been shown, that simulation is a useful tool to evaluate both of these subproblems and, therefore, assess the planning process of the medical evacuation chain [6]. Several models were described covering different aspects of the medical evacuation. For example, a model for investigating the transporter dispatching for the patient evacuation to Role 1 was presented [10].

Another research extends this approach by additionally analyzing the Role 1 treatment [11, 12]. Further, a model covering the medical evacuation until the Role 3 for an artillery strike scenario was proposed [13].

A simulation covering the medical evacuation from the CCPs to Role 3 is currently utilized by the Bundeswehr Medical Service [14, 15]:

Here, the patient arrival rates and injury patterns, as well as the quantitative and spatial distribution of medical resources such as facilities and transporters are adaptable.

3 Preliminary Considerations

First experiments with the existing model of the Bundeswehr Medical Service revealed that patients do not receive their required treatment due to limited surgery resources in Role 2 facilities [16]. An approach to avoid these bottlenecks is to skip early roles [4]. In this case, the intended treatment of both roles is provided in the higher one. This process is visualized in Figure 2. Here, the roles that can be skipped according to NATO [5] are presented with dashed arrows. For example, patients can be transported from Role 1 to Role 3 immediately, saving resources in the Role 2. This works since the higher roles extend the previous ones by additional capabilities and resources [4].

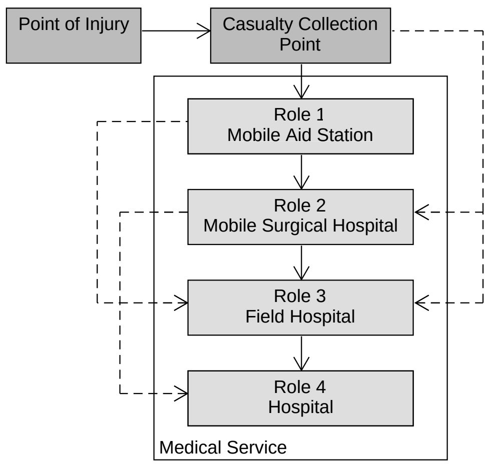

Figure 2: Certain roles of the evacuation chain can be skipped to avoid bottlenecks in early roles.

In another experiment, we investigated how flexible dispatching of transporters can affect the evacuation process [17]. For this purpose, a model covering the evacuation process from two CCPs to a Role 1 facility was utilized. It turns out, that the ability to reroute already dispatched transporters can significantly improve the evacuation process in terms of transporter utilization.

Furthermore, the waiting times of critical patients at the CCP could be reduced up to 30%, helping to comply with the NATO clinical timelines.

The earlier conducted experiments show, that patient evacuation can be significantly improved by applying flexible concepts like skipping roles and dynamic transporter rerouting. While real-world experience in this context is limited, conducting live exercise experiments to test different concepts are expensive, time consuming and therefore not sufficient. At the same time, the simulation model currently utilized by the Bundeswehr Medical Service does not offer the flexibility for testing such concepts [6]. Further, it was shown that none of the existing models allows sufficient investigation and optimization with regard to the introduced problems [6].

4 Conceptual Model

To allow a simulation-based analysis concerning the location-allocation and dispatching problem in a variety of dynamic scenarios, we propose a conceptual model for a flexible simulation.

We aim to cover the whole evacuation process, including the preclinical care from the CCP to the accomplished Role 3 treatment and the subsequent transportation to Role 4.

In our previous work, we proposed to perform the static evacuation chain planning via input data and parameters to adapt the simulation model [6]. The dynamic behavior of the objects, however, should be realized using submodels that can be flexibly adapted and exchanged without adjusting the simulation model itself. By providing a first prototype, we could verify the feasibility of this approach [18].

Based on our earlier considerations, we describe the different submodels in this section. For this purpose, we consider three different types of objects in our simulation model of the medical evacuation chain:

1. **Patients** are treated along the rescue chain. A treatment plan, which defines the necessary treatment steps, is derived from an assigned injury pattern. The patient's condition can deteriorate to the point of death, if treatment is not provided in time.

2. **Facilities** can accommodate patients and provide treatment. They differ in the kind of treatment that can be provided .

3. **Transporters** move patients between different facilities. They differ in the kind and number of patients that can be transported.

The different object types, together with their interactions, are visualized as gray rectangles in Figure 3. For analyzing different dispatching rules in various scenarios, the dynamic behavior of the simulated objects has to be adjustable easily. It must be possible to map a wide range of resource-dispatching strategies, particularly considering various evacuation concepts. At the same time, the combat scenarios, in which the concepts are tested, must be adaptable, too. This applies, for example, to the definition of changing patient arrival rates, troop movements, or resource breakdowns.

In order to achieve the required dynamics and flexibility, components of the simulation that need to be adapted are decoupled from the actual model as submodels. For each object type, a submodel is defined, encapsulating the structure and behavior of the associated object type. These submodels are visualized as yellow boxes around the different object types in Figure 3. The submodel *Patient*, for example, defines how the patient reacts to treatment as described in Section 4.1. It informs the submodel *Treatment* about state changes in the patient's health, which then might require a treatment adaptation. The submodels *Treatment* and *Transportation*, described in Section 4.2 and 4.3, respectively, define the internal behavior of the assigned object type. The allocation of the medical resources, however, is delegated to another submodel called *Resource Dispatching*. This submodel is introduced in Section 4.4.

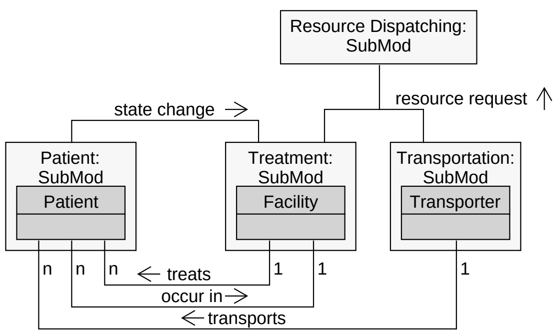

Figure 3: The model is composed of four different submodels (SubMod, yellow) and three types of simulated objects (gray).

4.1 Patient Submodel

Patients are transported and treated along the medical evacuation chain. Here, we subsume both injured and sick soldiers as patients. The corresponding submodel is shown in Figure 4 and is described in the following.

To ensure good adaptation, we divide each submodel into different subordinated submodels, each encapsulating a specific functionality. Here, we differentiate structure and dynamic behavior describing submodels.

The first one is visualized as a gray rectangle, the latter one as blue rectangles in Figure 4. The same applies to the submodels described later in this paper. Submodels describing the structure of simulated objects cover attributes and general internal behavior. While these are assumed to be fixed, we aim to ensure good adaptability for the dynamic behavior describing submodels by providing interfaces that can be used to implement own behavior.

The submodel *Patient Pattern* describes the static structure of the simulated patients. *Patient Arrival* generates patients and assigns injury and sickness patterns as well as the according treatment plan. For defining the arrival rates, different aspects like the number of troops in contact and the current combat situation can be considered.

Currently, we generate the patients using a Poission process with arrival rates determined by domain experts. Later, we plan to derive the patient arrivals from another combat simulation. The dynamic behavior of each patient is described in the corresponding submodel *Patient Behavior*. It defines how the health state of each patient changes based on a treatment plan.

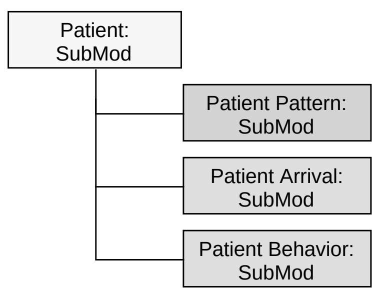

Figure 4: The submodel (SubMod) *Patient* consists of one structure describing submodel (gray) and to behavior describing submodels (blue).

The treatment plan of a patient is defined as a state machine. Each state describes the current patient's condition and defines the necessary treatment step and requirements for transportation. In both cases, we distinguish three different types of preconditions that must be met by a facility or transporter:

1. **Capabilities** are the most general precondition. They must be met by the facility or transporter but do not get claimed or consumed by patients.
2. **Resources** extend capabilities as they are claimable by patients. Therefore, each resource can only be used by one patient at a time.
3. **Consumables** extend resources as they can only be seized once and become unavailable afterward.

Further, a time to treatment failure (TTF) is assigned to each step. Expiration of the TTF leads to a condition worsening and, therefore, a state change. This process is visualized in Figure 5, where the current patient state is presented as a gray box. As green and red boxes, the possible subsequent states are displayed, signifying a health improvement or worsening, respectively. If the required treatment step is applied in time, its success probability can be defined. An unsuccessful treatment also leads to a health worsening. In case of a successfully applied treatment step, the health condition improves. This way, the treatment plan has a tree structure, where the leaves indicate the end of the treatment process. Possible scenarios for ending the treatment are the patient's death, the return of the soldier to combat, or transportation to Role 4.

4.2 Treatment Submodel

The submodel *Treatment* describes the structure and behavior of the medical facilities. It consists of three subordinated submodels and is visualized in Figure 6. The structure and internal behavior of the facilities is described by the submodel *Facility*. As internal behavior, we designate the general treatment process as described later in this section. The dispatching of medical resources, however, is not part of this submodel, as explained earlier. The dynamic behavior of facilities includes breakdowns and relocations, modeled via *Facility Breakdown* and *Facility Relocation*, respectively. As breakdowns we consider facilities being destroyed and therefore not being available anymore to accommodate and treat patients.

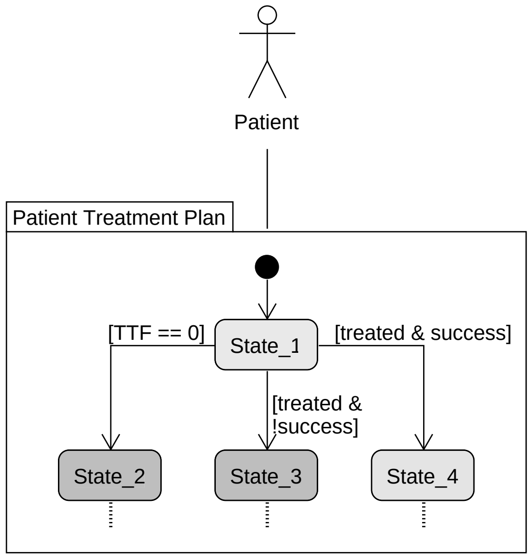

Figure 5: The treatment plan describes different health states together with the required treatment steps. Consecutive states represent a health improvement (green) or worsening (red).

Relocating a facility requires dismantling, transporting, and building up the considered facility. Therefore, each relocation includes a temporary facility breakdown. Initially, breakdowns and relocations are defined by schedules based on the results of a combat simulation.

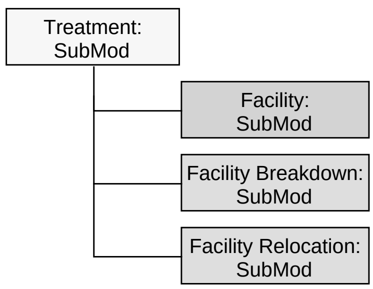

Figure 6: The submodel (SubMod) *Treatment* consists of one structure describing submodel (gray) and two behavior describing submodels (blue).

The internal behavior, modeled in *Facility*, describes the general treatment process applied to patients in the facilities. This process starts with a patient arriving at a considered facility. The following procedure is visualized in Figure 7.

In the first step, the facility checks whether the patient requires treatment. If not, the patient leaves the facility and exits the simulation. This is for example the case, if the considered facility is a Role 4, where modeling the treatment is beyond the scope of our simulation. If the patient needs to be treated, the facility checks whether the required treatment step can be performed.

For this purpose, the facility ensures that the required capabilities, resources, and consumables are available. If the treatment step can be completed, the facility requests the execution of the actual treatment. Otherwise, a transporter is requested to take the patient to a suitable facility.

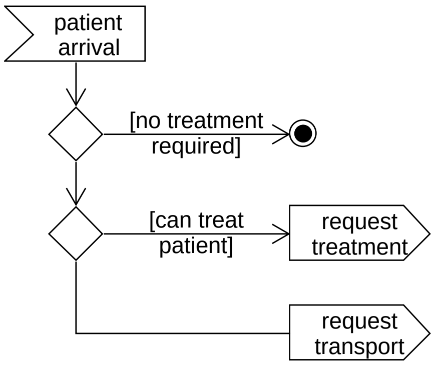

Figure 7: For arriving patients, the submodel *Facility* checks if the patient needs to be treated and whether the treatment step can be performed. Accordingly, transportation or treatment resources are requested.

The treatment resources and transporters are dispatched by the submodel *Resource Dispatching*, explained in Section 4.4. Once the treatment is scheduled, the facility receives a treatment task together with its prioritization, as displayed in Figure 8. Based on this task, the required consumables are assigned, if they are available.

In case they are not, the already assigned consumables from lower-prioritized tasks can be reassigned, if the treatment has not started yet.

In this case, the lower prioritized patient must be transported to another facility. If there is no reassignable consumable available, a transporter is requested to move the considered patient to another facility.

Once the consumables are assigned, the required resource is requested. The assignment is done based on the prioritization of the treatment task. To avoid deadlocks, we assume only one resource to be required for each step. This assumption aligns with the current simulation model of the Bundeswehr Medical Service mentioned in Section 3.

Once the required resource is available and assigned to the patient, the actual treatment is performed. The duration of this process is defined by the treatment step. Afterwards, a new patient arrival is sent, and the process from Figure 7 is restarted. This way, all subsequent treatment steps that can be performed in the current facility are executed. This procedure aligns with the assumptions of domain experts.

During the entire process, the patient's health condition can worsen, leading to a patient state change and different treatment requirements. In this case, the currently assigned treatment task is discarded, and a new patient arrival is sent. For the sake of clarity, we do not visualize this process in both Figures 7 and 8.

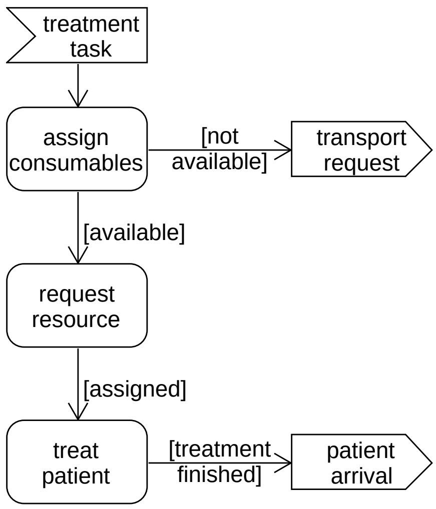

Figure 8: Facilities receive treatment tasks together with a prioritization. Available consumables and resources are assigned accordingly.

4.3 Transportation Submodel

The submodel *Transportation* is structured similarly to the previously described *Treatment*. It consists of two subordinated submodels, describing the structure and behavior of the transporters. It is visualized in Figure 9 and is described in the following.

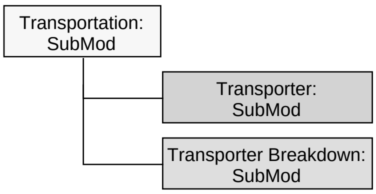

Figure 9: The submodel (SubMod) *Transportation* consists of one structure describing submodel (gray) and to behavior describing submodels (blue).

The submodel *Transporter* describes the structure and internal behavior of the transporters. In this submodel, the general processing of transport tasks is modeled, as explained later in this section. Again, the dispatching of transportation resources is not part of this submodel but is described in Section 4.4. The dynamic behavior of transporters includes breakdowns modeled via *Transporter Breakdown*. Transporters affected by a breakdown are not available for dispatching anymore. Similar to the breakdowns of facilities, they are initially defined by a schedule based on the results of a combat simulation.

Transporters receive transport tasks from the *Resource Dispatching* submodel. Each task is processed according to the diagram visualized in Figure 10. To each task, a facility as its destination is assigned together with the patients to be loaded and unloaded at this facility.

In the first step, the transporter drives to its destination and unloads the specified patients. To start the treatment process, the *Treatment* submodel gets informed about the patient's arrival. In the next step, the patients get loaded according to the task. Patients in a transporter seize a resources, similar to the treatment process in the facilities. At the same time, transporters can have different configurations, specifying the type and number of resources available. Accordingly, for loading the patients, a suitable configuration must be determined by the transporter.

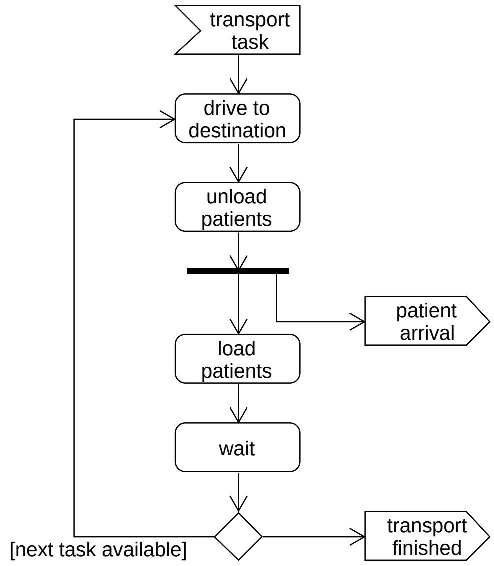

Figure 10: Transporters receive transport tasks specifying its destination as well as the patients to be loaded and unloaded there.

In case there is none, a new transport request is created for the patients who cannot be transported. After the patients have been loaded or unloaded, the transporter can wait for a specified amount of time at the facility for further patients to occur. In this time, the transport task can be adjusted by the *Resource Dispatching*, if required. Finally, the current transport task is processed, and the transporter checks whether a subsequent task is available. If yes, this task gets processed, too. Otherwise, the *Resource Dispatching* submodel gets informed about this transporter being available again.

4.4 Resource Dispatching Submodel

The dispatching of treatment and transportation resources is done by the *Resource Dispatching* submodel. It is divided into two subordinated submodels as shown in Figure 11.

The *Treatment Dispatching* coordinates the treatment of patients within the facilities. It receives treatment requests from the *Treatment* submodel, prioritizes the patients, and creates treatment tasks. These are then processed by the *Treatment* submodel as explained in Section 4.2. Selecting the facility for the patient treatment, however, is out of the scope of this submodel and is done by the *Transporter Dispatching*.

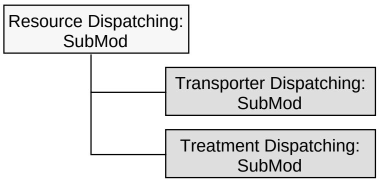

Figure 11: The submodel (SubMod) *Resource Dispatching* consists of *Transporter Dispatching* and *Facility Dispatching*, coordinating transportation and treatment resources, respectively.

For this purpose, incoming transport requests get prioritized. Then, the submodel checks whether a suitable transporter is available or if the requests can be added to existing transport tasks. Here, the submodel must consider both the for transportation and the following treatment in the approached facility required capabilities, resources, and consumables.

Transport requests that cannot be answered immediately are deferred. If a transporter becomes available, deferred requests can be assigned. If there is no open request, the transporter can be relocated. The *Transporter Dispatching* also must react to both, transporter and facility breakdowns. If a transporter is destroyed, new transportation requests are created for the patients already planned in future tasks of the considered transporter. In case of a destroyed facility, the transporters that are about to approach this facility need to be rerouted.

5 Conclusion and Outlook

In this paper, we proposed a conceptual model for a simulation of the medical evacuation chain. The goal of our model is to provide enough flexibility to test different dispatching strategies in various combat scenarios.

The underlying logistic problems were introduced and existing simulation models were discussed. Preliminary experiments showed, that the treatment of patients can be improved by applying dynamic dispatching concepts.

Currently available simulations, however, do not allow testing such concepts in highly dynamic combat scenarios.

Our conceptual model covers patients, medical facilities, and transporters as simulated objects.

For each object type, a submodel was proposed, which is further divided into subordinated submodels describing the structure, internal and dynamic behavior. Especially for the latter one, we ensure a high adaptability by providing appropriate interfaces.

This way, a wide range of dynamic combat scenarios can be modeled. Further, the dispatching of the treatment and transportation is outsourced to another submodel, offering the same adaptability. Here, we define which decisions have to be made in different situations while the rules used to make the decision can be easily adapted later.

With the proposed conceptual model and its high adaptability, we aim to support the planning process of the medical evacuation chain in the future. It allows testing different flexible dispatching strategies in a wide range of dynamic scenarios.

Therefore, we cannot only detect current bottlenecks but can test strategies for a more efficient usage of the currently available resources. In the next step, we aim to implement the executable simulation model. For this purpose, the interfaces of the different submodels need to be defined. This way, we want to ensure that various problem solvers and machine-learning approaches can be utilized for the dispatching submodels.

Acknowledgement

This research is part of the project "LogSimSanDstBw – Simulationsbasierte Logistikanalysen" and is funded by dtec.bw - Digitalization and Technology Research Center of the Bundeswehr. dtec.bw is funded by the European Union - NextGenerationEU.

References

[1] NATO. NATO - Topic: Strategic Concepts. 2022;URL `https://www.nato.int/cps/en/natohq/topics_56626.htm`.

[2] Cooper H, Schmitt E, Gibbons-Neff T. Soaring Death Toll Gives Grim Insight Into Russian Tactics. 2023; URL `https://www.nytimes.com/2023/02/02/us/politics/ukraine-russia-casualties.html`.

[3] US Department of Defense. Casualty Status. 2023;URL `https://www.defense.gov/casualty.pdf`.

[4] Neitzel C, Ladehof K. *Taktische Medizin*. Berlin Heidelberg: Springer, 2nd ed. 2015.

[5] NATO Standardization Office. AJP-4.10 Allied Joint Doctrine For Medical Support. 2019;URL https://www.coemed.org/files/stanags/01_AJP/AJP-4.10_EDC_V1_E_2228.pdf.

[6] Meisner K, Mayer T, Stein H, Leopold N, Uhlig T, Rose O. Konzeptionierung eines Simulationsmodells der Rettungskette unter Gefechtsbedingungen. In: *Simulation in Produktion und Logistik 2023*. 2023; .

[7] United States Department of the Army. ATP 4-02.2 Medical Evacuation. 2019;URL https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN17834_ATP%204-02x2%20FINAL%20WEB.pdf.

[8] Jenkins PR, Robbins MJ. *Military and Security Applications: Medical Evacuation*, pp. 1–7. Cham: Springer International Publishing. 2020;.

[9] Mayer D, Mattiesen B. Forschung und Fähigkeitsentwicklung im Sanitätsdienst der Bundeswehr. 2022;URL https://wehrmed.de/fuehrung-organisation/forschung-faehigkeitsentwicklung-im-sanitaetsdienst-der-bundeswehr.html.

[10] Frial VB. Evaluating the Military Medical Evacuation Dispatching and Delivery Problem via Simulation and Self-Exciting Hawkes Process. 2022;.

[11] Procházka D, Hodický J, Krejĉík M, Tesař A. Modelling and Simulation Support to Medical Treatment Chain in Role 1. In: *Modelling and Simulation for Autonomous Systems*. 2020; p. 464–477.

[12] Hodický J, Procházka D, Jersák R, Stodola P, Drozd J. Optimization of the Casualties' Treatment Process: Blended Military Experiment. *Entropy (Basel, Switzerland)*. 2020;22(6).

[13] Benhassine M, Van Utterbeeck F, De Rouck R, Debacker M, Hubloue I, Dhondt E, Quinn J. Open-Air Artillery Strike in a Rural Area: A Hypothetical Scenario. In: *Proceedings of the 2023 Winter Simulation Conference*. 2023; pp. 2391–2402.

[14] Kleint R, Mayer T, Uhlig T. Logistic Simulation to Support Military Rescue Chain. In: *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)*. 2021; .

[15] Kleint R, Geck A. Simulation-Based Decision Support for the Logistic System of the German Armed Forces. In: *Towards Training and Decision Support for Complex Multi-Domain Operations*. NATO Science and Technology Organization. 2022; .

[16] Kleint R, Geck A. Simulation-Based Decision Support for the Logistic System of the German Armed Forces. 2022;URL https://www.sto.nato.int/publications/STO%20Meeting%20Proceedings/STO-MP-MSG-184/MP-MSG-184-13P.pdf.

[17] Braam M, Uhlig T, Rose O. Simulation-based Analysis Of Dispatch Policies for Transportation in the Military Evacuation Chain. In: *CA2X2 Forum 2023*. 2023; .

[18] Meisner K, Stein H, Leopold N, Uhlig T, Rose O. A Modular Simulation Model for Mass Casualty Incidents. In: *Proceedings of the 2023 Winter Simulation Conference*. 2023; pp. 2403–2414.