

## **Logistic Simulation to Support Military Rescue Chains**

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### **ABSTRACT**

Modeling and simulation contribute to digitalization of logistics and medical service for Armed Forces and must reflect factors such as flexibility and robustness in a differentiated manner. This paper briefly outlines the existing approaches of logistic simulation and presents an approach for medical service based on a study with the Bundeswehr. The key question was when and under what conditions the rescue chain will reach its capacity limit in terms of the potential requirements (attack, wounded/illness in an operational environment). The purpose of the study was to find possible solutions for a national and multinational planning of sustainable medical service capabilities and procedures from a national point of view, based on the framework conditions and associated challenges, both in operations as sole capability guarantor and in cooperation with allied (or friendly) nations on the basis of the national medical service capability elements. For this purpose, the capabilities of the medical service elements of the rescue chain currently planned for an operation were analyzed with the help of a parameterizable, valid simulation model, considering their essential performance characteristics, the current operational principles and procedures of the German medical service. The study provided an orientation and a collection point for future investigations of the estimation of required qualitative and quantitative capabilities for the further development of the concept "Principles for Medical Support of the German Armed Forces in Operations."

### **ABOUT THE AUTHORS**

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### **INTRODUCTION**

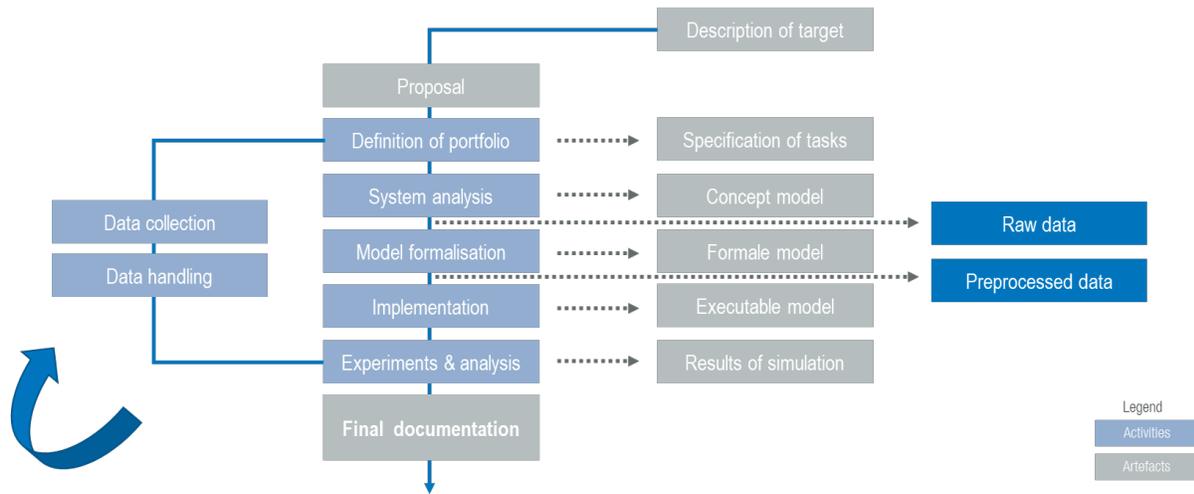
Foreseeing consequences, weighing options, and finally making a decision is the challenge that decision-makers in companies, politics, and administration have to face every day. Complex procedures, highly networked processes, and opaque framework conditions make it increasingly difficult to maintain an overview. A simulation is generally understood to be a model-based experiment. It enables analysis of a system by experimenting with a virtual replication of the system. The data and results obtained from the model calculations allow conclusions to be drawn that can be applied to the real system. Experiments offer the possibility to observe the model in different, also artificially created, scenarios and to investigate its behaviors. The resulting findings can finally be evaluated, analyzed and transferred to reality. In this paper, a study of the military rescue chain of the German armed forces is presented as an example of a using simulation to aid decision making. After presenting the approach and the military rescue chain use case, details of our model and the generated results are presented. Finally, the implications for the results are discussed and an outlook for future work is provided.

Simulations are successfully applied in numerous industries. Well-known examples are weather and climate calculations, flight simulators or medical simulations (Banks, 1998), including current forecast models for the spread of COVID-19. Simulations are also prominently used in logistics, for example in the planning of production facilities and production lines, in the operation and use of fleet systems or storage facilities, and in transport and capacity planning (Lars Mönch, 2011). Basically, there are hardly any limits to the use of simulations. Almost every procedure, every process can be modeled and reproduced with the help of the appropriate method. Nevertheless, simulations should only ever be developed for meaningful questions, such as, “How is a system likely to behave with certain parameters, factors, and influences,” and should not be regarded as the solution to all problems. The use of simulation has been established for several decades in production and logistics processes. The same approaches can be used as a problem-solving method for armed forces as well.

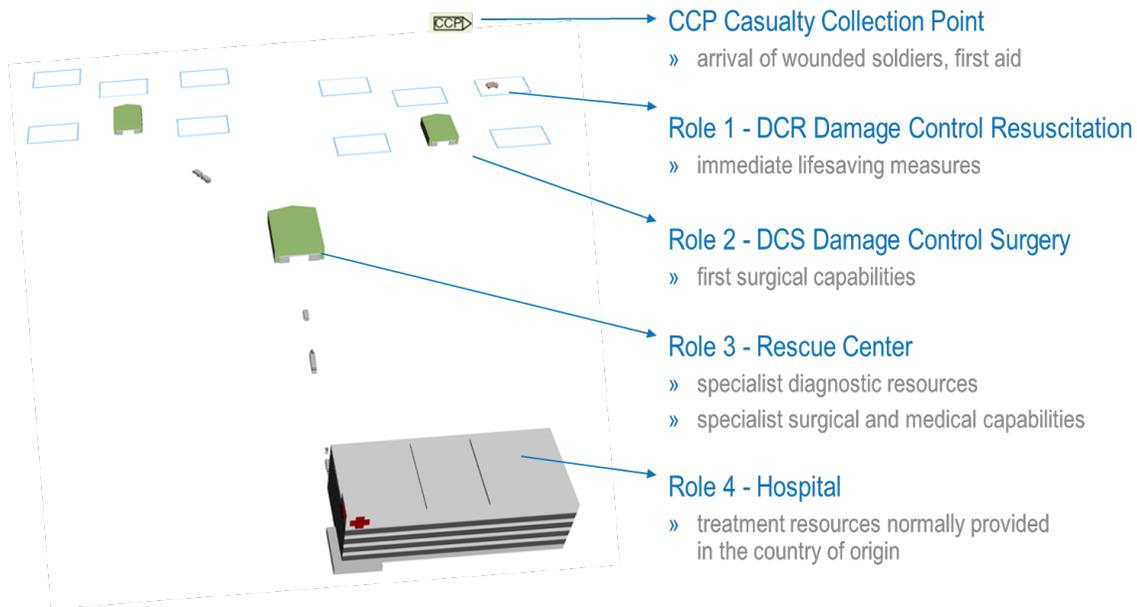
For our simulation study, an approach was derived from the Arbeitsgemeinschaft Simulation working group (ASIM) process model (Rabe, S.Spiekermann, and Wenzel, 2007). With the help of the extended process model, our study was structured into various phases (compare Figure 1). In an iterative process in conjunction with the customer, we eventually can answer the given project questions. Note, that the study was constantly validated through an independent Verification & Validation agent, as recommended in (SAAD, et al., 2015).

### **Military Rescue Chains - Case Study of the Bundeswehr Medical Service**

The study for the Bundeswehr, together with the University of the Armed Forces Munich, evaluated the concept and resource planning for the medical service to provide an orientation and collection point for researches of the estimation of required qualitative and quantitative capabilities. The impact of medical service elements and procedures in the chain of command from the company level (Casualty Collection Point) to the exit or to the provision to the exit from a level 3 facility (element) in the context of large operations is examined on the basis of simulations (see Figure 2).



**Figure 1 - Enhanced Process Model (Wenzel, 2007)**



**Figure 2 - Military Rescue Chain**

Within an Operational Scenario Description (OSD), the Bundeswehr specified the structures and sequences of a scenario to be considered, which served as the basis for the modeling. The required simulation model was parameterizable and was operated by trained personnel of the Bundeswehr. This approach enabled the investigation of current and future operational concepts and made the model development independent from restricted data that have to be used as input.

The resulting investigation tool was created based on the Structured Problem Description (SPD). The project follows the Model Documentation and Simulation Guide (SAAD, et al. 2015) to document the development of the model. For this purpose, the conceptual model and the formal model were created. This was followed by the derivation of the executable model and its documentation, which was the basis for the analyses and experiments used here.

In essence, the study result enables a basis for decision support, provided that the model is used within the specified limits. A simulation of the rescue chain with spatially dynamic treatment facilities and realistic effective times requires further development of the model. Nevertheless, the study results can enable the owner to provide early insight into the performance of trends in the development of capabilities.

## THE MODEL

All models developed for the implementation of the simulation were documented according to the "Guideline of Model Documentation" of ITIS GmbH as required from the model owner for all developed simulations. The object structures and interconnections were formally documented with the help of UML class diagrams. The state spaces of the objects were documented with the help of UML state charts. State and property changes of the objects were initiated from behavior that was modelled with the help of UML activity diagrams. The Military Rescue Chain was designed with the help of three sub-models. For each sub-model, the underlying part of the real system was identified and all input and output parameters were linked. Each sub-model was defined with an independent structure and behavior model. Additionally, all connections to the other sub-models were identified. Figure 3 shows an overview of all developed sub-models and their interconnections.

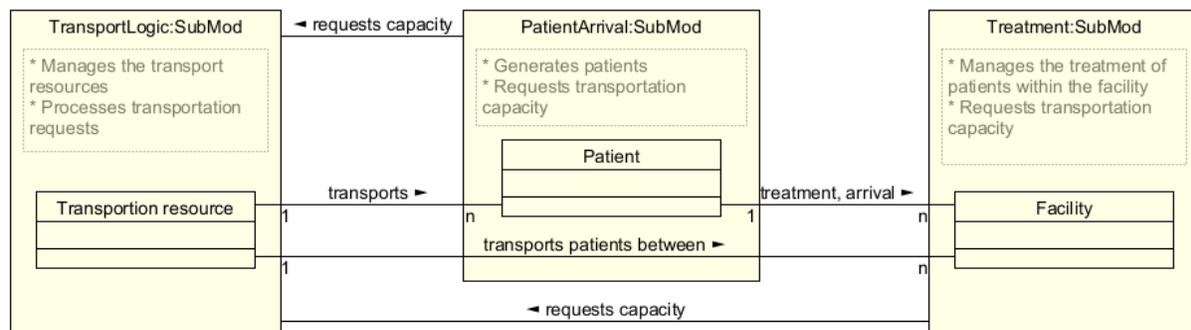


Figure 3 - Developed Sub-Models

The PatientArrival sub-model was dedicated to the arrival process. It managed the temporal distribution and the location of the patient arrivals. The term patient was used in the following and summarized wounded or diseased soldiers. Transportation requests were sent to the TransportLogic sub-model. This sub-model managed all transportation resources and distributed patients according to selected strategies. Patients were transported between different treatment facilities. The Treatment sub-model controlled the patients within these facilities. That sub-model managed all resources within the medical facilities and distributed patients according to selected strategies and priorities to the defined resources. Figure 3 also highlights the three main structure objects considered in the simulation (main simulation entities): Transportation resource, Patient, and Facility. All three objects were described with the help of a Finite-state machine. Different triggers for state changes are part of the different sub-models. In the following sections, we give a brief overview of the designed sub-models.

### PatientArrival sub-model

The PatientArrival sub-model managed the arrival of the patients in different locations and the allocation of diseases and wounds. Several different kinds of wounds and diseases were considered. The allocation defined the treatment of

the wounded or sick soldier. The battlefield was divided into several different zones that have different patient arrival distributions. The distributions were derived from NATO guidelines and recommendations.

A special emphasis was given to the ability to vary the intensity of the arrival rate depending on time and location. A discretized version of a nonstationary spatio-temporal Poisson process (Zhang und Zheng, 2020) was implemented. Accordingly, each battlefield zone was assigned a time dependent intensity pattern. The pattern defined a relative intensity of arrivals for given time spans, e.g., we model a huge wave of wounded by defining that 50 percent of wounded should arrive between 6:30 and 7:00 on the first day. The relative intensity values were scaled automatically to achieve time-dependent arrival rates that resulted in a defined overall expected number of arrivals. The given expected number of arrivals were derived from the previously mentioned NATO guidelines as a fraction of the current troop strength. The flexibility of the model approach allowed the implementation of various arrival strategies derived from battlefield simulations.

### **TransportLogic Sub-Model**

A need for transportation was requested with the arrival of the patient in the battlefield and with the finishing of the treatments in a facility. Different wounds and diseases have different requirements on transportations resources. The TransportLogic sub-model manages the transportation requests and allocates patients to resources. The sub-model mirrors the processes currently applied in the German Bundeswehr and is able to support future resources and procedures.

### **Treatment Sub-Model**

The treatment in a medical facility was defined by the wound or disease pattern of the patient. In general, a treatment can allocate different resources within a facility. Only medical equipment was considered a resource in a facility, medical stuff was not explicitly modelled. Every wound and disease not only defined the necessary treatment resources and times but also defined a maximum time a patient can survive untreated (i.e., lethal time). If this time passes without treatment, the patient changed its state to 'not treatable' and all bounded resources were released. Not-treatable patients were not considered for the TransportLogic sub-model. The treatment, lethal times, and necessary resources were derived from results from different expert committees and partially derived from models developed for simulation-supported framework exercises "Simulationsgestützte Rahmenübung SIRA."

The executable model was implemented with the help of AnyLogic and Java. A separate visualization as part of the AnyLogic model was developed for validation purposes. The visualization, realized with AnyLogic, is shown in Figures 4 and 5. The input and output of the executable model followed the schema represented in Figure 6. All objects and corresponding parameterizations were derived from an input model represented with the help of MS EXCEL files. The input model was transformed into the executable model.

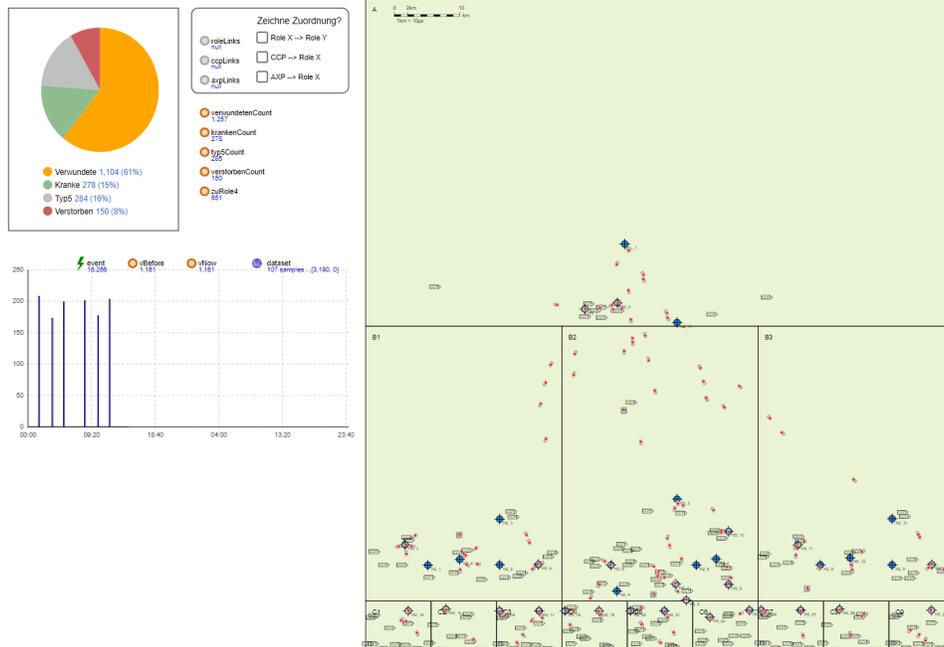


Figure 4 - Screenshot of AnyLogic Visualization

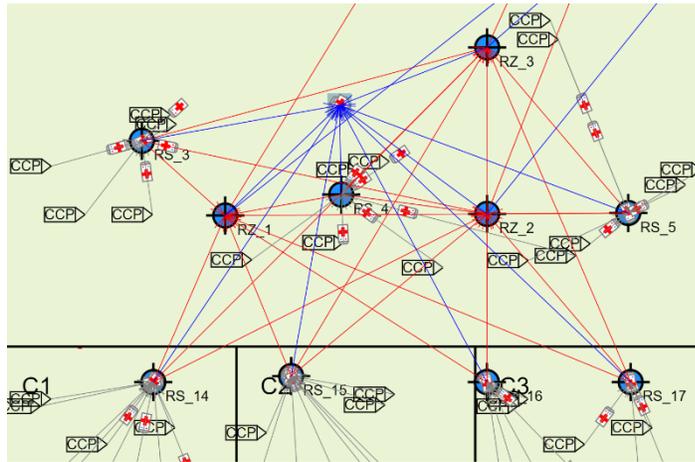


Figure 5 - Operational Space

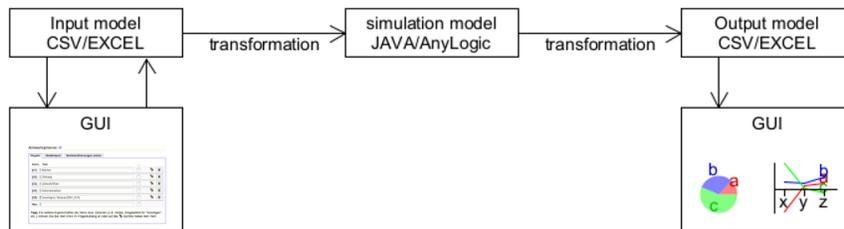
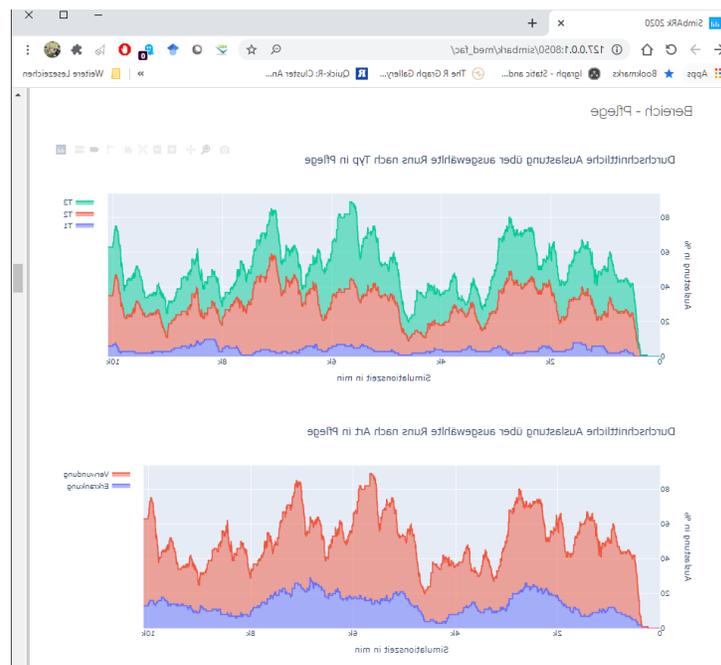


Figure 6 - Implementation Structure

The separation of the input and executable models allowed the configuration of the whole simulation independently from the developer of the executable model. That separation was necessary to enable the model development independent from access to classified data used to execute the simulation. The simulation output was processed into a Java output model that streamed results into MS EXCEL files. The designed output model captured every state change from all simulated entities. So, the complete behavior of all considered simulation entities could be retraced after a simulation run. The considered entities were: transportation resources; care units as part of the medical facilities; and patients. A developed post-processing algorithm analyzed the resulting simulation data and calculated, e.g., the number of considered entities, which share the same state at the same simulation time. Additionally, the algorithm was able to combine the output of any number of simulation runs. A dashboard for visualization was developed with the help of Python. The visualizations were based on the summarized data generated from the post-processing algorithm. The visualization showed general information about the involved simulation runs like the date and time the runs were executed, the length of the runs, and the number of patients generated. The visualization can answer general questions about the allocation of the treatment and transportation resources. It supported several filters, e.g., the type of resources or patients. The filter allowed different views of the systems states of interest. Figure 7 shows a screenshot of the developed dashboard. Both diagrams show the utilization of the same care unit organized by the type of the patient (first diagram) and to the type of the disease or injury (second diagram).



**Figure 7 – Python-based Dashboard**

The model developed represented the rescue chain in a simplified and conservatively estimated form in order to obtain robust statements on the one hand and at the same time reduce the model's susceptibility to error on the other hand. In principle, the model was designed to represent the capabilities of the treatment facilities in an ideal-typical and optimistic way. Accordingly, breakdowns of the rescue chain and identified bottlenecks were expected to be even more significant in reality. In particular, the neglected effect of third parties on the resources and treatment facilities of the ambulance service would lead to serious changes in the performance parameters in reality. The following list summarizes the general assumptions made during model development.

- The operational scenario under consideration was an operationally representative conflict case.

- The selected operation type was representative for conclusions in the sense of the rescue chain.
- Outages were purely personnel-related in the sense of deceased wounded / sick or missing soldiers; outages of medical forces were not included.
- The transportation of medical material or equipment was not considered.
- Host Nation Support had no impact on the military rescue chain.
- Support forces from other branches/organizational areas had no effect on the military rescue chain and were also not included as a potential source of wounded/sick (in current consideration with regard to an extension).
- At the time a wounded person enters the rescue chain, self and comrade assistance had already occurred.
- Each casualty had a clearly diagnosed underlying cause.
- Every wound or illness had a standardized treatment regimen that always required the same amount of time.
- During transport and during in-patient treatment, the set lethal time of a wounded was suspended.
- In each combat zone wounded were equally distributed to the respective casualty collection points.
- There was no time delay in loading and unloading of wounded.
- Means of transport always traveled at a constant speed (individually adjustable).
- Assignment and withdrawal of an inpatient treatment space occurred without time delay.
- Each treatment facility had an unlimited admission capacity.
- Each treatment facility maintained an overview of each patient's health status regardless of the number of wounded or ill patients present there.
- All deployed forces worked without breaks (24h / 7d).

## **EXPERIMENTS & DISCUSSION**

All executed experiments were based on a scenario defined from the model owner, German Bundeswehr, and communicated via a formal scenario description (Planungsamt, 2018). Experiments based on that scenario were mainly performed to validate the simulation model. The defined resources, structures, and their deployment did not correspond to the real capabilities or deployments of the German Bundeswehr. Additionally, the modelled arrival of wounded or diseased was not mirroring an historical or expected real life event. The scenario was mainly designed to demonstrate the ability to configure complex real-world scenarios with the help of the implemented input model. However, the conducted experiments show that all expected weak points of the scenario could be identified. The simulation of the imaginary scenario showed overloads and associated high casualties. These overloads occurred primarily within the rescue chain, as it was not possible to complete the treatment plan required for the individual wounding patterns before the end of their individual lethal time. Specifically, the queues outside the critical care bays in role 2 and the queue outside the role 3 surgical bays were identified as sources of the highest loss of life. For the test scenario, this suggested a significant under-provision of critical care spaces in role 2 or overly generous critical care times. The situation was similar for the surgery spaces in role 3.

The model was designed to allow experiments with restricted data independent from the model developer. Therefore, the output model (compare Figure 6) focuses maximal flexibility. The output model had to guarantee that all important conclusions over the performance of the system can be derived from it. Therefore, the output model captured every state change of a simulated entity during the simulation. As previously described, considered entities are transportation resources, patients, and facilities. The transportation resource modeled available seats or stretchers and the facilities modeled the different care units. So, the resulting data could track all patient states. The output model gave insights about which seat was occupied by a patient from the transportation resource. Additionally, treatment/care unit used to treat a specific patient could be tracked during a specific time. Based on the described data, all necessary information about the simulated system can be derived. The following list gives an overview about the derived information, which was aggregated with the implemented post-processing algorithm.

- Treatment facility
  - Utilization and availability, resolved after wound/disease
  - Waiting patients inside facilities, resolved after wound/disease
- Transportation units
  - Utilization and availability, resolved after wound/disease
  - Waiting patients for transportation, resolved after wound/disease
- Patients
  - Arrival, waiting and treatment times and locations

The parametrized model developed in this effort depicted a robust, coarse, and conservative implementation of the rescue chain although reducing it to a mechanized division and its associated battlefield was not consistent with current concepts of the German Bundeswehr because this information is confidential. The model was explicitly built so that only weighty problem areas within a scenario will result in a bottleneck in the treatment of wounded or diseased personnel. Furthermore, the parametrization ensures that a wide variety of framework conditions, forms of deployment, and wounded/diseased scenarios can be modelled and its behaviors investigated. It should be clearly emphasized that the only dynamic element on the battlefield was the transportation resources. The treatment facilities were spatially static but can be deployed anywhere on the battlefield and their capabilities can be varied according to the owner's specifications.

In principle, the implemented conservative model was suitable to identify serious limitations such as mis-deployment / under-equipment of treatment facilities that occur when passing the rescue chain of wounded forces. Among other things, new forms of deployment due to their expanded capability profiles - such as new land or air (UAV) systems and capabilities - were not included in the current version of the simulation but can be mapped in further consideration.

An additional "relocation of treatment facilities" element in the simulation and potential limitations on the use of treatment and transport capabilities due to enemy action or fatigue effects could be incorporated. Also, the development/coupling of a simulation of supply through the logistic chain as a measure of a facility's operational capability would also add value. By means of these fine-granular model adjustments, there is a real opportunity to create a planning tool for optimizing deployment forms that can classify the resilience of individual deployment variants. The developed simulation model provided a robust and solid basis for the development of such a simulation-based planning tool.

In addition, the implementation of a wounded control system has the greatest potential to safely manage a temporary or localized increase in patient volume through the rescue chain. The wounded control system controls the movement and distribution of wounded to treatment facilities throughout the battlefield, considering the wound pattern, available treatment slots, deployable medical personnel, and available material resources. One possible outcome of a wounded control system could be the coupling between Patient Evacuation Coordination Cell (PECC) and logistical coordination because the determination of a wounded person's path along the rescue chain can also be associated with a corresponding forecast of consumptions at each treatment facility.

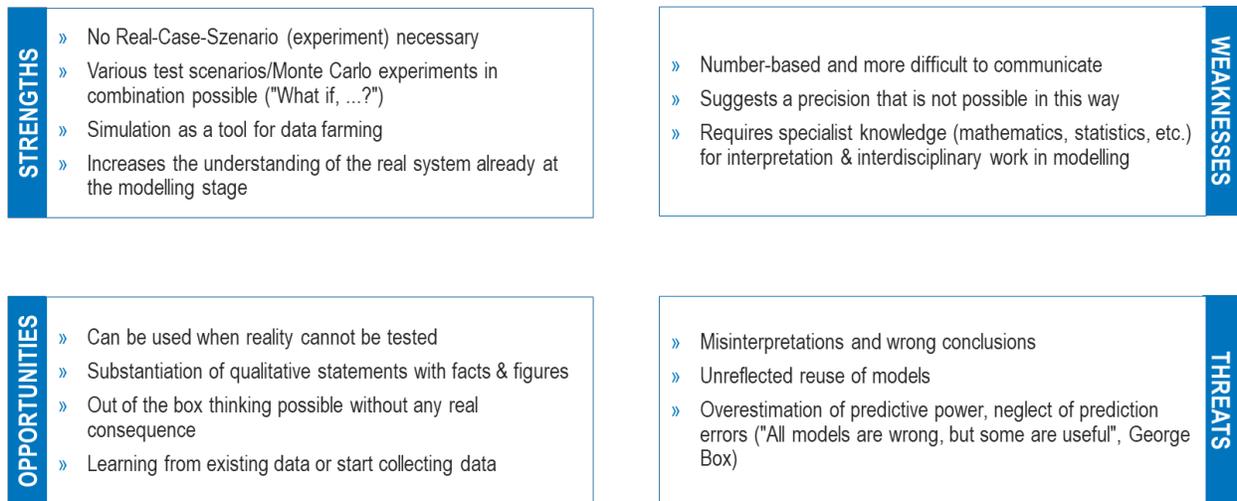
## **SUMMARY**

The developed simulation model allowed a detailed investigation of the medical rescue chain. Due to the separation of the input and the simulation model, the application of the simulation was independent from the model developers. Additionally, it was easy to insert or distribute new transportation or treatment resources during model development. Wounds or diseases with corresponding needs for treatment can be incorporated into the simulation with simple changes in the input model. Also, the robustness of the configuration of the arrival of patients can cover multiple scenarios. The developed model and simulation can be used for multinational medical rescue chains or other military

rescue chain questions for other nations as well. Additionally, the accomplished study shows that there was a variety of questions regarding the security of supply and the sustainability of military logistic chains that can be addressed with the help of simulation as well. The following list summarizes a few examples of questions which can be addressed with the help of simulation:

- Can I provide the required capabilities with the upper limit of troops in a robust and sustainable manner?
- Which logistical services are required and what is their scope?
- Are the resources (material and personnel) enough for the operation and / or what do I need (e.g. means of transport, storage space, spare parts, consumable goods, medical equipment, maintenance resources, parking areas, energy and media requirements and their dependencies)?
- Which means of transport, resources, drivers are available and ready for deployment at a given time and location?
- Which services / capabilities must be externally procured or establish a reserve in order to fulfil the mission (e.g., from other nations / armed forces or industry)?

In general, the analyses of real-world systems with the help of simulation is very promising especially in the context of logistics. For example, complex, dynamic processes and dependencies can be tested against each other and a valid and cost-efficient verification of concepts and processes can be easily achieved. Additionally, consequences and bottlenecks are known before and a realistic derivation of resource availability can be forecasted. With the advances in digitalisation and the corresponding collection of great amounts of data, the generation of simulation models which can process these collected data is the next logical step. However, there are also weaknesses and threats which must be addressed. Figure 8 summarizes strengths, opportunities but also outlines weaknesses and threats.



**Figure 8 – Strengths-Weaknesses-Opportunities-Threats Overview**

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