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DISCRETE-EVENT SIMULATION OF CONTESTED CASUALTY EVACUATION FROM THE FRONTLINES IN UKRAINE

Mehdi Benhassine[1], Kai Meisner[2], John Quinn[3], Marian Ivan[4], Ruben de Rouck[5], Michel Debacker[5], Ives Hubloue[5], Filip Van Utterbeeck[1]

[1]Dept. of Mathematics, Royal Military Academy, Brussels, BELGIUM
[2]Medical Service Capability and Force Development, Bundeswehr Medical Academy, München, GERMANY
[3]Prague Center for Global Health, Charles University, Prague, CZECH REPUBLIC
[4]Interoperability Branch, NATO Centre of Excellence for Military Medicine (NATO MILMED COE), Budapest, HUNGARY
[5]Research Group on Emergency and Disaster Medicine, Vrije Universiteit Brussel, Jette, BELGIUM

ABSTRACT

A scenario of casualty evacuations from the frontlines in Ukraine was simulated in SIMEDIS, incorporating persistent drone threats that restricted daytime evacuations. A stochastic discrete-event approach modeled casualty location and health progression. Casualties from a First-Person View drone explosion in a trench were simulated, incorporating controlled versus uncontrolled bleeding in rescue and stabilization efforts. Two evacuation strategies were compared: (A) transport to a nearby underground hospital with delays and (B) direct transport to a large hospital with potential targeting en route. Results showed that strategy A was safer for transport, but effective hemorrhage control was crucial for survival. Strategy A led to lower mortality than strategy B only when hemorrhage control was sufficient. Without it, both strategies resulted in similar mortality, emphasizing that blood loss was the primary cause of death in this simulation.

1 INTRODUCTION

The application of Modeling and Simulation for optimizing battlefield casualty evacuation remains underexplored despite its potential to enhance military medical planning. Several factors contribute to this gap. Military physicians and planners often operate without integrating insights from engineering and scientific disciplines within a multidisciplinary framework. Additionally, battlefield casualty evacuation is inherently complex, involving numerous human agents whose interactions depend on dynamic threats, resource availability, and clinical interventions. Over the past decade, the Royal Military Academy in close collaboration with the Research Group on Disaster and Disaster Medicine of the Vrije Universiteit Brussel developed and refined a disaster response simulator for several use-cases, mostly in a civilian response environment (Benhassine et al. 2024a; Benhassine et al. 2025). Recently, a battlefield response was modelled based on a NATO exercise scenario, as a proof-of-concept (Benhassine et al. 2024b). While the simulator has proven valuable for exercise planning and civilian disaster response, we proposed that it could also be adapted for more tactically and operationally relevant battlefield scenarios, such as those observed in Ukraine. Our multidisciplinary team—comprising engineers, scientists, military, and emergency physicians—engaged with NATO command structures, the NATO Centre of Excellence for Military Medicine, and Ukrainian frontline medics to refine these models. The casualty rates in Ukraine far exceed those seen in the Global War on Terror, necessitating rapid adaptation. The pervasive threat of drones has redefined casualty evacuation strategies; aerial threats negate traditional cover, necessitating innovations like underground (UG) yet mobile medical treatment facilities (MTF) (The Economist 2024). Modern battlefield injuries, primarily from blasts and fragmentation, result in traumatic brain injuries, burns, and hemorrhage (Champion et al. 2009). Hemorrhage is often associated with these injury mechanisms and the overuse of tourniquets (TQ), readily available to soldiers are generously used, sometimes in a superfluous way and are not always properly converted or downgraded in a timely manner resulting in preventable loss of limbs, avoidable complications, and clinical sequalae (Butler et al. 2024; Stevens et al. 2024). These outcomes from TQ use are anecdotally related to inadequate training and access to medical staff during Large-Scale Combat Operations (LSCO). Due to the life-saving nature of the TQ, their straightforward use is understandable, but training is required to help reduce preventable morbidity and mortality (Kragh et al. 2009). Nevertheless, looking at a larger post-injury timeframe, other factors related to hemorrhage are likely to ensue. The lethal triad encompasses three interrelated physiological derangements—hypothermia, acidosis, and coagulopathy—that collectively contribute to a self-reinforcing cycle of hemodynamic instability. The inclusion of hypocalcemia as a fourth critical factor expands this concept into what is now referred to as the "lethal diamond." Together, these conditions synergistically exacerbate hemorrhage and hinder effective resuscitation, significantly increasing the risk of preventable morbidity and mortality.(Giannoudi and Harwood 2016; Wray et al. 2021). For over a decade, our team has employed simulations to refine prehospital best practices (Debacker et al. 2016), initially focusing on civilian mass casualty incidents (MCI) response. However, the war in Ukraine necessitated model adaptations for more dynamic and complex threats. This study aims to further implement and refine these models for battlefield scenarios with prolonged casualty management timelines.

2 METHODS

2.1 Simulator Description

SIMEDIS (Simulation for the Assessment and Optimization of Medical Disaster Management) (Debacker et al. 2016) is a computer simulation tool that helps experts understand and test how emergency medical services should respond when many people are injured at once — a situation known as an MCI. SIMEDIS uses a method called stochastic discrete-event simulation, modeling real-life events (like people arriving at hospitals or receiving treatment under urgent conditions) one by one in the order they happen and includes random variations and a dynamic environment. By running different scenarios, SIMEDIS helps evaluate response strategies to provide actionable insights for their improvement. The term "improvement" includes minimizing mortality outcomes and optimizing casualty flow, so they are admitted as fast as the healthcare system allows for, considering transport assets, and rate of admissions in hospitals. The simulator is rooted in queuing theory prioritized on clinical triage where patients are modelled as processes. This methodology does not directly involve human factors and behaviors such as panic, or decision-making outside of scripting in the scenario. Recently, SIMEDIS was applied in a military exercise context, where entity names were replaced with military equivalents, and where concepts like TQ application, self-aid/buddy-aid, Damage Control Resuscitation (DCR), and Damage Control Surgery (DCS) were added (Benhassine et al. 2024b).

2.2 Adaptation of the Patient Model for controlled vs uncontrolled bleeding

The modeling of casualties in the SIMEDIS health state at any given time is governed by a mathematical model influenced by injury type, medical procedures, and the patient's age (Benhassine et al. 2023). The evolution equation used in the simulation is derived from a modified Gompertz function. Unlike the classical Gompertz model, which typically describes mortality or decay over time, this modified version incorporates an additional shape parameter, γ. The inclusion of γ introduces greater flexibility into the model by adjusting the curvature and growth dynamics of the survival function. Notably, when the value of γ is strictly maintained within the interval (0, 1), it prevents the health state from reaching zero. As a result, patients modeled within the simulation can't survive indefinitely, reflecting long-term stability or chronic conditions without terminal decline under certain parameter settings. The health state of the patients is characterized by a metric called the SimedisScore (SS) which is comprised between 20 (fully healthy patient) to 0 (death). The time evolution of the SS is:

$$SS(t) = 20 - (20 - 20\ \mathrm{e}^{-\mathrm{e}^{(b-c*t)}})^{\gamma} \tag{1}$$

With b, c, and γ, parameters determined based on the patient injuries. We determine the parameters using an additional relationship between b and c by finding the *SS(t)* function's zero ($SS(t_{death})=0$):

$$t_{death} = (b - e)/c$$

Using Euler's number *e*, the corresponding value of *t* represents the "time of death," denoted as t_{death}. To determine the parameters b or c in the evolution equation, we establish an independent link between the estimated $t_{death}$and the severity of sustained injuries. These injuries are quantified using the Military Combat Injury Scale (MCIS), and more specifically the MCIS-NISS (MCIS-New Injury Severity Score) to account for injury severity, a metric designed for assessing trauma in combat settings (García Cañas et al. 2022). The MCIS-NISS functions similarly to the Injury Severity Score (ISS) commonly used in civilian prehospital and emergency care; however, it is tailored to capture the unique patterns and mechanisms of war-related injuries, such as blast trauma, penetrating wounds, and polytrauma scenarios encountered in military operations. This linkage allows for parameter calibration based on injury burden, enabling the model to more accurately reflect survival trajectories under combat conditions (Lawnick et al. 2013). This formula has been empirically determined in (Benhassine et al. 2023).

$$t_{death} = 43500\ (\mathrm{MCIS\_NISS})^{-1.95}$$

To account for hemorrhage independently of specific injury types, previous modeling efforts set γ to 0.97 when a TQ was applied, under the assumption that effective hemorrhage control would prevent death from exsanguination. This simplified approach is relevant within the timeframe of prehospital simulations, assuming that reaching a specialized hospital and undergoing surgery ensures survival in the early hours of the scenario. In previous scenarios involving major hemorrhage, the TQ was thus treated as an artifact under the assumption that its successful application guaranteed victim survival. As a first generalization, we introduce an additional condition of "death by lethal triad" if bleeding cannot be controlled by a TQ. In cases of junctional hemorrhage (those cases involving the groin, shoulder/armpits, or the neck), TQ applications are not feasible, and only upper and lower extremities can be managed in this way. For these patients, early DCS is the only way to help stop bleeding. In this scenario, we aim to examine the long-term consequences and progression of injuries, where clinical effects may lead to death days after injury but only for actively bleeding victims whom bleeding control via a TQ was unsuccessful. Despite the limited availability of systematically reported clinical data from the Ukrainian conflict, the modeling process is nonetheless informed by a combination of anecdotal observations, semi-empirical insights, and aggregated statistical data that permeate the operational theater. Importantly, several of the co-authors possess direct clinical knowledge and experience drawn from firsthand involvement in in conflict zones including LSCO. Their contributions are rooted in real-time observations, practical experiences, and de facto lessons learned under austere and high-intensity conditions. These insights focus particularly on the rapid evolution of warfare dynamics, especially the shifting paradigms in the use of blood and blood products in the context of DCR and DCS and fiber optic drones. This experiential knowledge enhances the model's relevance and situational fidelity, compensating for gaps in formal clinical reporting and enabling a nuanced representation of injury patterns and survival trajectories in modern high-intensity conflict. Leveraging modeling and simulation to evaluate these gaps presents opportunities for research, but requires proper abstraction and validation, to which we believe a novel approach to modeling TQ and bleeding in simulation is required. To ensure the prolonged effects or the injuries are represented, circulating blood volume is incorporated as a key patient property. As the metric depletes over time, we assume that the patients' blood volume will further deplete due to worsening trauma-induced coagulopathy, hypothermia, and acidosis. Due to these three connected effects, the blood volume diminishes at a faster rate until the patient's blood volume is less than 40 % at which point, we assume they go into hemorrhage shock and die by exsanguination (Cannon 2018).

2.2.1 Uncontrolled bleeding model

Let's assume that the patient's blood volume B_V (in liters) time evolution is a first-order decay function affected by blood loss and affected by progressively faster blood loss due to the lethal triad. The equation of the blood volume rate B_v (in liters/hour), can be written as a decreasing function of the form

$$dB_V/dt = -\alpha B_V$$

With a solution

$$B_V(t) = B_{V0}\, e^{-\alpha t} \tag{2}$$

With α an hemorrhage rate progressively increasing due to the consequence of the lethal triad:

$$\alpha = \alpha_0 + kt$$

Here, k represents the progressive effect of the lethal triad, and t is time. We can further assume that the hemorrhage rate is a function of the injury categories. The hemorrhage rates can be related to actual blood loss rates by using typical ranges of blood loss. For example, a femoral artery transection results in hemorrhage rates of approximately 2.5 L in a few minutes, whereas venous bleeding can result in rates of up to 0.5 L per hour (Eastridge et al. 2006; Holcomb et al. 2007). The threshold for mortality is $B_v < 40\%$ (Stainsby et al. 2000). Assuming a total blood volume of 5 liters, for α_0, we assume the following values, as summarized in Table 1:

Table 1 uncontrolled bleeding model design parameters for different injuries characteristic of drone explosions with associated bleeding rate α_0 and lethal triad progressive effect parameter k.

Injury Categories	Bleeding Rate (α_0) (hr^{-1})	Lethal triad factor k
Small limb wounds (shrapnel, soft tissue)	0.1-0.3	0.02
Major limb artery (femoral, brachial)	2.0-5.0	0.05
Torso wound (lung, liver, kidney)	0.5-2.0	0.1
Multiple penetrating wounds (moderate bleeding)	1.0-3.0	0.15
Massive hemorrhage (aorta, iliac artery)	> 10.0	0.3

2.2.2 Controlled bleeding model

If hemorrhage is peripheral and we can successfully control it via the application of a TQ, the external blood loss is stopped, but internal hemorrhage still occurs at a much lower rate β due to hypovolemia, such that

$$dB_V/dt = -\beta B_V$$

With $\beta \ll \alpha_0$.

$$B_V(t) = B_{V0}\, e^{-\beta(t-t_{TQ})} \tag{3}$$

With t_{TQ}, the TQ application time. Equations (2) and (3) allow to compute the patient's blood volume versus time to establish midterm effects of hemorrhage in the patient model to replace the simplified considerations modeled in (Benhassine et al. 2024a). We set β at 0.01/hour to estimate exsanguination due to hypovolemia at around 96h post injury, to consider incomplete hemostasis, plasma leakage and capillary permeability, and ongoing bleeding from non-tourniquetable injuries. In any case, the health state evolution of the patient will employ the SimedisScore, but hemorrhage is treated as a separate condition in the simulation. There is currently no consideration for long term TQ use, but loss of limb and complications are likely to occur. This generalization extends the patient model from a few hours to tens of hours. According to current Deployed Medicine standards (Deployed Medicine 2025), a trained individual must assess a TQ—ideally a healthcare professional—within 30 minutes of application, and it should not remain in place longer than two hours. If the two-hour threshold is exceeded, the TQ should be left in place, with removal deferred to a surgical setting due to the high risk of compartment syndrome and irreversible tissue damage. While there are publications discussing 'controlled exsanguination'—a technique involving staged TQ release after prolonged application—this approach is controversial, not widely endorsed, and is absent from formal guidelines.

2.3 First Person View Drone Effects

The First Person View (FPV) drone (The Washington Post 2025) effects were adapted and scaled down from the Shahed 136 model developed in (Benhassine et al. 2024a), considering that this drone had an explosive charge equivalent of 7 kgs (typically an RPG warhead) (Reuters 2025). We scaled the effect model by one third from the Shahed model setting the MCIS versus distance as

$$MCIS = \max\,(75, (75/r)) \tag{4}$$

To determine if victims are bleeding, we calculate the probability of being hit (P_{hit}) by a fragment from the explosion using the following equation originally presented in which takes into account the number of fragments in the explosion and the exposed area, and the distance from the blast epicenter:

$$P_{hit} = 1 - \exp\,(-NA\;/\;(4\pi r^2))$$

2.4 Scenario

As a use-case to illustrate the updated patient model, a hypothetical scenario is set to occur at the current Ukraine frontline location reported in the Jan 10, 2025, Live Universal Awareness Map (LiveuaMap 2025) in an area situated southwest of the Zaporizhzhia power plant close to Havrilyvka on the western bank of the Dniepr river. A Ukrainian squad is hit by a FPV drone, and the explosion results in 8 soldiers being injured, sustaining barotrauma and compressible hemorrhage for 4 of them. The triage breakout is initially 3 T1, 5 T2. We voluntarily reduce the number of casualties to align with a more realistic depiction of small unit tactics, and the lack of force concentration in the battlefield. We suppose that despite the successful application of TQs and successful management of immediate mortality due to major hemorrhage, austere conditions in the location of the hit requires an evacuation to the rear to find an MTF able to provide further care and stabilization. Unfortunately, consistent transport using ambulances is not possible in this scenario, and we suppose that the victims must wait until nighttime for safe evacuation. The Casualty Collection Point (CCP) is set at the Estate Falz-Fein. The first MTF in the rear is set in Novovoskerensk'e (MTF A – R1 UG) and is operating UG. The closest R3 is set in the Hospital for War Veterans in Mikolayïv (MTF B

- R3) designated to be the destination for the casualties in this scenario. In one evacuation strategy (named strategy A), casualties reach MTF A and are held for 24h before being transferred to MTF B. In the second one (strategy B), casualties wait for ambulances to transport them from the CCP to MTF B. We define an “ambush probability” for both strategies. Strategy A is more careful by design, and the ambush probability is set to 5%. Meaning that during the evacuations, there is a 5% chance of being hit by a FPV drone, resulting in the death of the transported patient. We did not consider that the ambulance personnel were affected, but we removed the targeted ambulance from the pool. In strategy B, the ambush probability is set to 30% to account for the longer travel time and exposure of the transport to drone threats. During ambulance transport, patients are given stabilizing treatment. We did not employ a hybrid approach with T1 patients being transferred to MTF B for DCS, and T2 patients limited at MTF A, but it could be explored in a future scenario. The initial position of victims and MTFs are visualized in Figure 1.

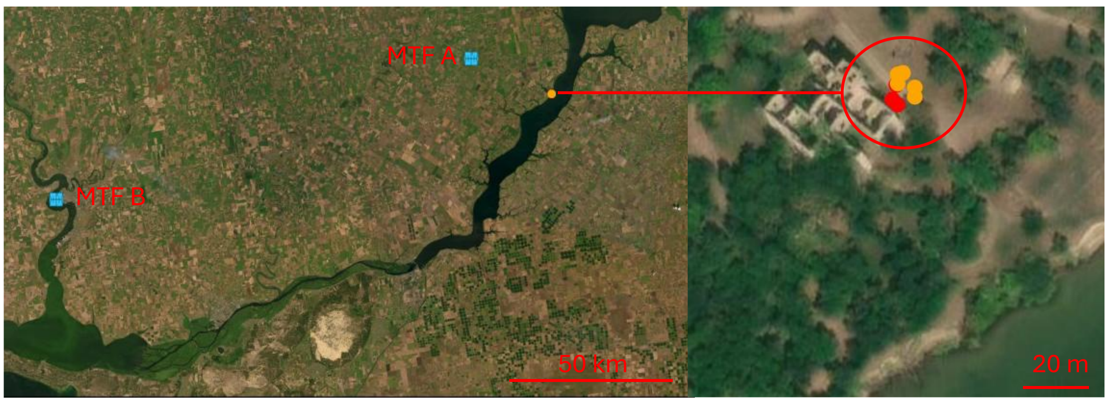

Figure 1: Aerial views as part of simulation outputs to visualize the initial location of victims (as colored dots with the following code: red is T1, orange is T2), On the left part, a zoomed out view with the blue icons representing MTF locations (MTF A, and MTF B).

2.5 Parametric Space and simulation parameters

We considered thirty simulation runs, in which we added a stochastic variation of 20-25% from the mean values, sampled from a triangular, log-normal, or truncated normal distribution to each discrete time point depending on the event. A triangular distribution was used for treatment times due to the lack of available data of timings in contested environments. Travel times were defaulted to log-normal with 25% allowed deviation, setting used in traffic flow modeling. A truncated normal distribution with variation of 20% for other times including triage, TQ application, and patient handoff. We did not characterize the implications of the distribution type for time variations due to the limited access to data, and because the clinical times were SME based and collected from a NATO live exercise (Benhassine et al. 2024b). We considered the two evacuation strategies with ambush rates of 0.05 (for strategy A) and 0.3 (for strategy B); TQ application was set to true or false; The parametric space thus was four (strategy^2*TQ^2 resulting in 4 parameter combinations). In both strategies, we made sure the ambulance number was sufficient, setting their number to eight (one per victim). Mean triage times were 2.5 minutes for patients. Loading and offloading times to and from ambulances was 1.43 mins. Mean Treatment times were 30 minutes for DCR and 60 minutes for DCS. The mean TQ application time was 1 minute.

3 RESULTS

3.1 Victim health state progressions versus time

The victim health model design parameters are displayed in Table 2. The initial position relative to the blast center was randomly set to a 10m radius, and victims resulting score using the MCIS-NISS were established using Equation (4). Then the *SS(t)* parameters (Equation 1) were derived and a projected time of death established. The bleeding model parameters were set using the ranges of table 1 in line with the MCIS-NISS, and if fragmentation injuries were present or not (and determined using the probabilistic approach).

Table 2 Victims of the FPV explosion, health state, and bleeding model parameters used in this scenario. Triage is the initial triage category, d the distance from the explosion, MCIS-NISS is calculated from the distance, b, c and γ are for equation (1). T_{death} is the projected window of time if no treatment is provided to the victim. α_0 and k are bleeding model parameters. Mechanism A is fragmentation injuries, B is fragmentation injuries, with amputation, and C is other blast injuries without hemorrhage.*: T2 victims without hemorrhage are not expected to die due to moderate injuries, hence γ is set to 0.8.

Victim #	triage	d (m)	MCIS-NISS	b	c	γ	t_{death} (min)	Mechanism	Bleeding (0/1)	α_0	k
1	2	3.57	21	-0.7	-0.03	1	114.9	A	1	0.1	0.02
2	1	1.69	44	-1.9	-0.03	1	27.15	A	1	1.0	0.1
3	2	3.95	19	-1.4	-0.03	1	139.6	A	1	0.2	0.02
4	1	1.11	67	-2.36	-0.03	1	11.96	B	1	3.0	0.15
5	2	3.75	20	-3.95	-0.03	0.8*	221.4	C	0	0	0
6	1	2.35	31	-1.11	-0.03	1	53.7	C	0	0	0
7	2	4.69	16	-3.05	-0.03	0.8*	195.2	C	0	0	0
8	2	3.12	24	-0.005	-0.03	0.8*	88.5	C	0	0	0

In the simulation, death of a patient is conditioned on (1) $SS(t) = 0$, (2) $B_v < 40\%$, or (3) successful FPV targeting. The events where the *SS* and B_v values are calculated are: when a victim is created, when TQ is applied, when the victim reaches the CCP, when triage occurs at the CCP, when transport from the CCP to the R1 starts, arrival at the R1, triage at the R1, DCR treatment (starts), and (ends) at the R1, transport from the R1 to the R3 starts, assessment mid transport to the R3, R3 arrival, triage at the R3, R3 treatment starts, and treatment ends at the R3. Treatments (DCR or DCS) are modeled as improvement functions on the SS(t) function. The holding time of 24h at the R1 is a timeout in the simulation, and no interim values are calculated supposing that victims survive the time window under care.

3.2 Evolution of patients' clinical timelines with/without TQ for strategy A

Only one replicate for each victim and parameter combinations is selected for visualization purposes of the patients with hemorrhage. Figure 2 shows the *SS(t)* and $B_v(t)$ values for strategy A. In practice, blood transfusion and TQ conversion may be performed in MTF A, potentially preventing limb loss, an effect not considered in this model but highly relevant for clinicians.

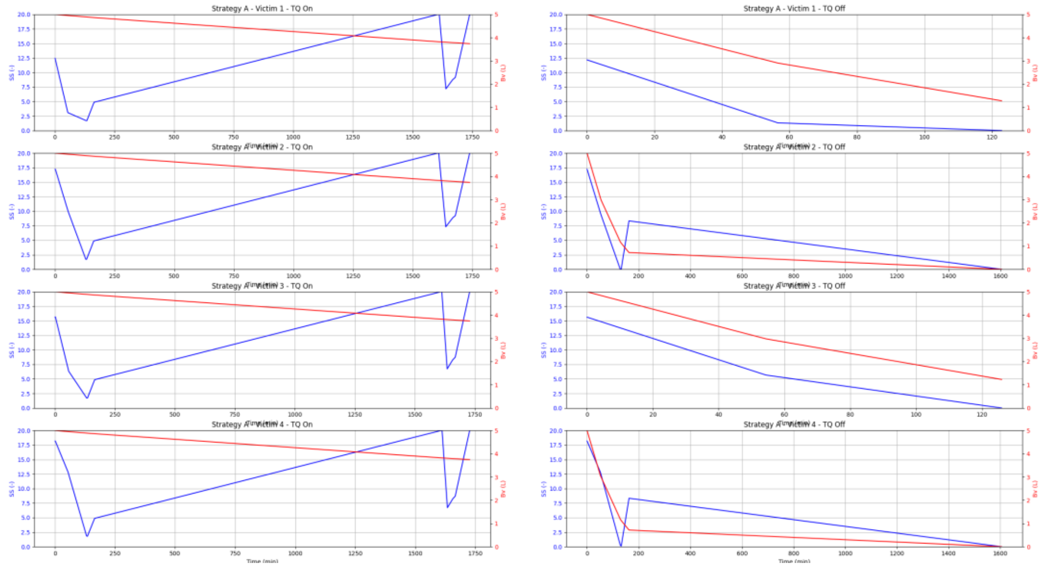

Figure 2: *SS(t)* and $B_v(t)$ values versus time for the 4 victims with hemorrhage, with and without TQ in strategy A. Each line insert corresponds to a victim. B_v in red and *SS(t)* in blue.

3.2 Patient simulated clinical timelines with/without TQ for strategy B

By design, strategy B aims at performing a direct and risky evacuation from the CCP towards the R3 in Mykolaïv. The timeline is shortened to a point where the absence of a TQ can result in survival if hemorrhage is not catastrophic. Not applying any hemorrhage control in strategy A is impossible due to the prolonged timeline. Therefore, setting TQ to false makes sense only in strategy B. We set the ambulances to originate from the R1 location, and supposed that during the R1 to R3 transfer, all transports were subjected to the 30% chance of being targeted. Figure 3 displays the clinical timelines in strategy B.

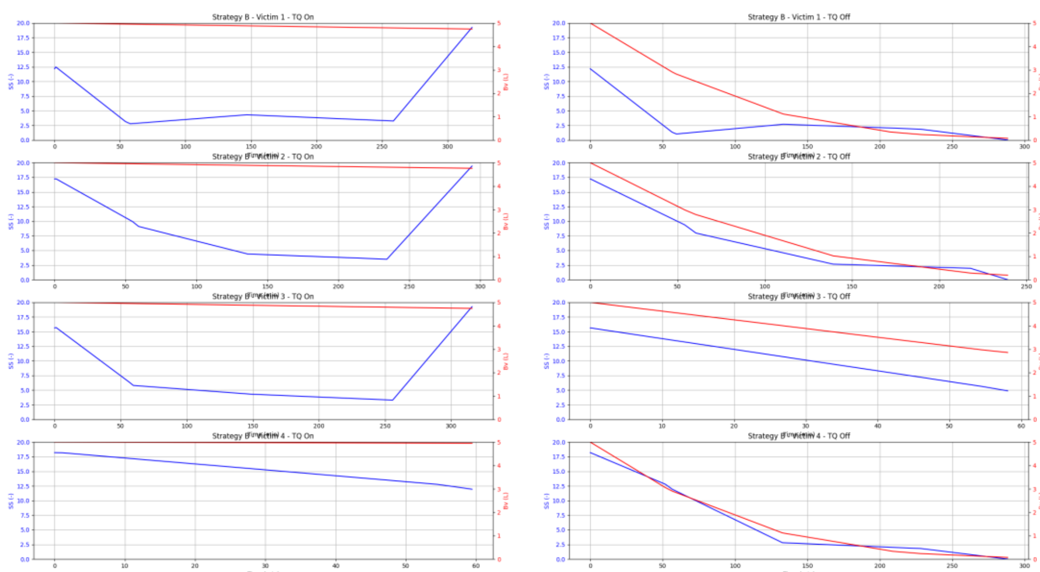

Figure 3: SS(t) and $B_v(t)$ values versus time for the 4 victims with hemorrhage, with and without TQ in strategy B. Each line corresponds to a victim.

3.3 Mortality outcomes across the parametric space

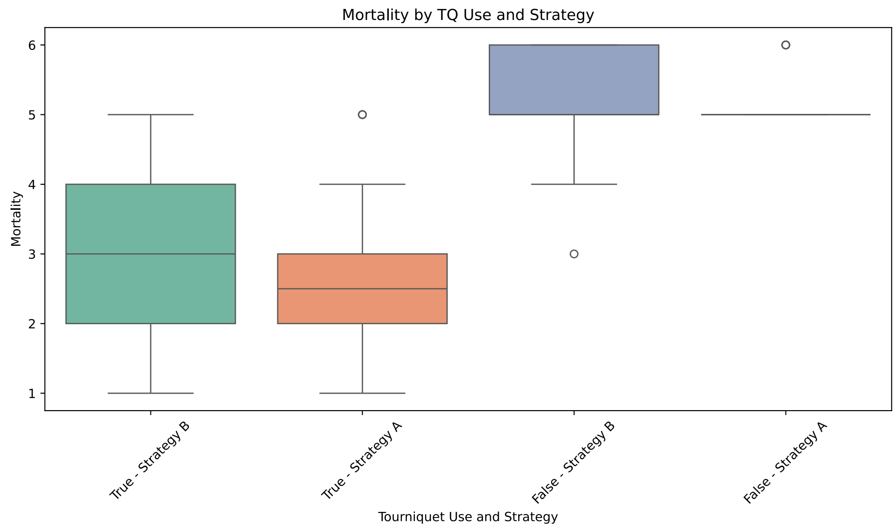

Figure 4: Mortality outcomes for both strategies, for 30 replications with 8 total patients, with and without TQ use (True/False in the x axis).

Multiple Linear Regression Analysis on the data shows that the average number of deaths across all runs is 3.94 ± 1.32. The resulting model demonstrated a high degree of explanatory power, with an R^2 value of 0.932, indicating that mortality outcomes could be explained by the combination of the predictors. While the model fit was strong, individual predictors did not reach statistical significance at conventional thresholds. The application of a tourniquet was associated with a decrease in mortality ($\Delta = -2.19$, $p = 0.168$, 95%-Confidence Interval (CI95): [-9.72; 5.33]), aligning with clinical expectations, though not statistically significant. The use of Strategy B showed a small, non-significant increase in mortality compared to Strategy A ($\Delta = 0.19$, $p = 0.80$, CI95: [-7.33; 7.72]). Mortality distributions for each parameter are displayed in Figure 4. These findings suggest potential trends toward improved survival with early hemorrhage control, but the lack of statistical significance may reflect limitations in sample size or outcome variability. During transport, patients were struck by FPVs 137 times across all simulation runs, resulting in an additional death each time. Out of these 137 hits, 126 occurred in strategy B, and 11 in strategy A. Future studies could refine this by incorporating more accurate values and modeling ambulance strikes as new PoI, with the potential for ambulance crews to become victims. The impact of terrain, and the use of other transport means (armored ambulances, unmanned autonomous vehicles) could also be considered.

4 DISCUSSION

The simulation model, now incorporating longer-term physiological effects of hemorrhage, offers a more robust platform for comparing tactical scenarios and exploring the consequences of combat environments where medical evacuation is routinely disrupted by enemy action. These high-threat and modern warfare environments challenge conventional assumptions around timely casualty care and demand new approaches to medical planning and decision-making. While the model retains a relatively simple structure for simulating the evolution of victim health states, it advances significantly beyond previous models that treated hemorrhage as a binary condition resolved by TQ use. This previous approach, while effective for extremity bleeding, neglected critical physiological mechanisms such as internal bleeding, the lethal triad, individual variations in clotting response, and the timing and delivery of blood products during DCR and DCS. The proposed model introduces variability and flexibility with different rates of hemorrhage, and a new condition for mortality in the simulation, which were up to now conditioned on TQ application. With this new approach, mortality outcomes can be larger, because a TQ doesn't warrant survival over longer post-injury timeframes. The new model introduces B_v as a continuous variable, enabling dynamic tracking of blood loss over time for each simulated patient. Though the direct linkage between blood loss and SS deterioration remains to be fully developed, it is anticipated that B_v will influence SS through changes in heart rate, blood pressure, and perfusion. The integration of whole blood transfusion into future iterations, along with outcome validation, will be essential to refining its predictive value. The model also opens discussion on preventable morbidity and mortality, which remains a significant issue in contemporary combat settings. Data suggests a substantial proportion of battlefield deaths could be avoided with timely, appropriate intervention, including access to blood products. This makes training all personnel—not just medics—in life-saving interventions critical. The widespread distribution and proper use of Individual First Aid Kits allow immediate control of the four main battlefield killers: hemorrhage, airway compromise, tension pneumothorax, and hypothermia. Self-aid and buddy-aid play vital roles in survivability and must be central to both tactical training and medical planning. Interoperability between military and civilian medical responders is also essential, especially in multinational or complex humanitarian missions. Coordinated systems for triage, evacuation, casualty tracking, and resupply ensure continuity of care and improve outcomes. Medical planning must account for prolonged field care and degraded medical infrastructure, especially when rapid access to DCR and DCS is compromised. In LSCO, continuous MCI may occur, requiring flexible, scalable responses across all echelons of care. In this context, simulation tools that integrate physiological realism, battlefield constraints, and evolving operational requirements are critical for training, planning, and decision-making. By aligning model outputs with clinical and field data, these tools can help reduce preventable deaths and improve casualty management under the most challenging conditions. The effect of FPV targeting on mortality during transport is not linked to the health state evolution. Optimal courses of actions should consider safety and urgency of care as a tradeoff, requiring further analysis on a larger cohort, hybrid evacuation approaches with armored vehicles, and access to data to better model the hemorrhage pathophysiology.

5 CONCLUSIONS AND FUTURE RESEARCH

The simulation of a FPV drone attack on a squad happening in Ukraine was simulated with the SIMEDIS simulator. A new metric was introduced in the patient health state model to account for blood volume depletion. Both controlled and uncontrolled bleeding were added. For evacuation, two distinct strategies were simulated. The first strategy dealt with a low-footprint way of evacuating patients to an UG MTF, close to the CCP. Due to the persistent simulated attacks on medical transport, we introduced delays and holding times. After the holding time of 24h, transfer to the R3 was performed by night with only 5% chance of being hit by an FPV drone. In the second strategy, direct risky evacuation of patients from the CCP to a R3 hospital was simulated, but with a set percentage chance of being hit by a drone by 30%. The absence of TQ application resulted in the worst mortality outcomes, and only strategy B allowed patients to survive without a TQ, and only if the blood loss rate was low. Further research should incorporate larger victim numbers, variations in the attack rates, other hemorrhage control measures such as whole blood and hemostatic agents and their effect on modeling the health state. Leveraging real-life clinical datasets should also increase simulation validation. The integration of prolonged post-injury health state trajectories, combined with the modeling of contested evacuation scenarios, represents a significant advancement in the SIMEDIS simulator. These enhancements contribute to increased realism and operational relevance, thereby strengthening its utility as a decision-support tool for military medical planning and preparedness.

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AUTHOR BIOGRAPHIES

MEHDI BENHASSINE holds a PhD in physical sciences obtained in 2010 in the field of computational materials science. He joined the Royal Military Academy in 2021 to develop a simulator for battlefield medical care using discrete-event simulation techniques. He actively interacts with NATO and national bodies in partipating to Live exercises, and wargames. His main area of research is Modeling of Patient Physiology, and Disaster Response in civilian and military settings. His e-mail address is mehdi.benhassine@mil.be.

KAI MEISNER is currently employed at the Bundeswehr Medical Academy. He is an external Ph.D. candidate at the University of the Bundeswehr Munich, where he also received his M.Sc. degree in Computer Science. His research focuses on the simulation based analysis and optimization of the medical evacuation chain. He is a member of the ASIM. His e-mail address is kai.meisner@unibw.de.

JOHN QUINN is lead researcher at the Prague Center for Global Health and current staff Emergency Medicine doctor in London. Most recently he served as Medical Director for the non-governmental organization (NGO) Migrant Offshore Aid Station (MOAS) in Ukraine and prior to that post in Ukraine, Medical Officer to the Organization for Security Cooperation in Europe (OSCE) Special Monitoring Mission (SMM) in Ukraine. His e-mail address is john.quinn5@nhs.net.

MARIAN IVAN is a medical doctor and holds a Master of Public Health (MPH) degree. He has extensive experience working in NATO Command Structures, holding various positions in the Medical Division for six years, primarily at the operational level (Joint Force Command). Currently acting as Interoperability Standardisation officer at the NATO Centre of Excellence for Military Medicine (NATO MILMED COE) in Budapest, Hungary. He also leads Concept Development and Experimentation in the Vigorous Warrior Exercise Series. His email address is interop.standard2@coemed.org .

RUBEN DE ROUCK is a medical doctor who graduated in 2015 from Ghent University. He is pursuing a joint PhD at the Vrije Universiteit Brussel (VUB) and Royal Military Academy (RMA) in Belgium. His e-mail address is ruben.de.rouck@vub.be.

MICHEL DEBACKER graduated from the Vrije Universiteit Brussel as medical doctor in 1970. He is currently working as professor in disaster medicine and is the director of the disaster unit of the Research Group on Emergency and Disaster Medicine of the Vrije Universiteit Brussel. His e-mail is michel.debacker@vub.be.

IVES HUBLOUE is Chair of the Department of Emergency Medicine of the Universitair Ziekenhuis Brussel (UZ Brussel) and of the Research Group on Emergency and Disaster Medicine at the Medical School of the VUB (ReGEDiM Brussels). His e-mail address is ives.hubloue@vub.be.

FILIP VAN UTTERBEECK graduated from the Royal Military Academy in Brussels as a polytechnical engineer in 1995. He obtained a PhD in engineering sciences from the Katholieke Universiteit Leuven and the RMA in 2011. He currently lectures several courses in the fields of Management Science and Artificial Intelligence. His main area of research is simulation optimization and its applications in complex systems. His e-mail is filip.vanutterbeeck@mil.be.