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OPEN-AIR ARTILLERY STRIKE IN A RURAL AREA: A HYPOTHETICAL SCENARIO

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ABSTRACT

The escalation of the Russian invasion in Ukraine, characterized by the deployment of conventional weapon systems, inflicts significant morbidity and mortality on the victims. It is imperative to ascertain optimal medical practices and disaster response strategies throughout the battlefield to minimize casualties and safeguard the well-being of medical and disaster responders. The challenges posed by large-scale battlefield threats can rapidly overwhelm healthcare providers due to the sheer number of victims, which can result in the depletion of medical supplies and insufficient training and resources. To address these issues, we utilized the SIMEDIS simulator to establish and implement a battlefield scenario involving an open-air artillery strike in a field. Mortality rates were calculated based on the application of bleeding control measures and the distribution policy for allocating victims to medical treatment facilities. Controlling hemorrhage remains the most crucial factor influencing mortality outcomes.

1 INTRODUCTION

Mass casualty incidents (MCIs) pose the greatest challenge for Emergency Medical Services (EMS) systems. These events require emergency responders to take extraordinary measures to cope with the exceptional flow of victims (see Gabbe et al. 2022 for a review). Examples of MCIs include natural disasters like earthquakes, floods, and tsunamis, as well as man-made incidents like plane crashes, terrorist attacks, and explosions. In modern conflicts and on the military battlefield, conventional weapon systems and improvised explosive devices are common. This results in an increase in the incidence of blast injuries among casualties which poses an additional strain on EMS response (Kluger et al. 2007; Champion et al. 2009; Champion et al. 2010). The golden standard in military medical procedures is the Allied Joint Doctrine for Medical Support AJP-4.10 (AJP-4.10 2019). In this document a list of definitions is given to describe the different casualty evacuation chains and medical entities on a battlefield. The definitions can be paralleled and interchanged with most policies used in the civilian sector providing simplifications and changes which define the concept of medical interoperability for NATO member and partner nations to

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support in case of a disaster. Unlike most civilian MCIs, the safety of the point of injury/point of exposure (PoI/PoE) may not be granted in the case of a continuous threat. Additional attacks during victim treatment and evacuation are possible, and aeromedical evacuation may be denied by anti-aircraft measures. Guidelines and disaster planning can be found in the literature but, in practice, it is very hard to forecast how events will unfold (Tallach and Brohi 2022). The consistent transfer of a victim from the PoI to a Role 1 (R1) and Role 2 (R2) Medical Treatment Facility (MTF) poses multiple challenges that experimentation can help address. To detect gaps in current capabilities, capacities, or the operational patient care pathway, computer simulation is a great tool able to assess a constellation of situations and the impact of a change in parameters which would be difficult to recreate in an exercise. With hypothetical testing, it is possible to determine what are the most important aspects which should not be overlooked by medical planners to prepare for the unexpected and reduce preventable morbidity and mortality of soldiers in the battlefield. Due to the complexity of warfighting and the lack of accurate reports on events, simulation thus presents great advantages. The current conflict in Ukraine is proving that practice is often far from the textbooks, medical supplies can be lacking fast, and infrastructures can be destroyed in the matter of days such that one can never really rely on what is available (MOAS 2022). As demonstrated in previous publications, we have built an MCI simulator, called SIMEDIS (Simulator of Medical Disasters) (Debacker et al. 2016; De Rouck et al. 2018). SIMEDIS has been used to determine best medical practices in an airport crash scenario and a sarin release scenario in a subway station (De Rouck et al. 2018; Benhassine et al 2002b). SIMEDIS allows replicating a crisis response by generating victims at a location with combination of both polytraumatic and CBRNe-related injuries. By using discrete-event simulation and priority queues, the program allows to quantify the number of dead casualties versus the number of resources and the timelines of treatment but also allows a better understanding of casualty flow versus time of the incident. It is also possible to create multiple attacks or threats and generate new victims dynamically, but in its current formulation, time is the real modifier of the system values. Section 2 presents the methodology towards building the scenario as well as describes the transport and the victim model. Section 3 presents the results and the discussion. We draw conclusions in Section 4.

2 METHODOLOGY

Using the SIMEDIS simulator, we created a scenario involving 156 victims of an 155mm artillery salvo in an open-field area where the salvo hits a refugee shelter. We positioned each victim in a field and used the road network and the surrounding civilian MTFs as Role 3 (R3) equivalents. The R1 was set close to the blast site. To assign the injuries and health state evolutions, we used the continuous victim model of Benhassine et al. (2022a). The model uses as input the Injury Severity Score (ISS) and can both represent lethal and non-lethal injuries with a shape-modifying parameter called γ. To estimate the victims' ISS, an ISS versus distance from each impact was determined based on the publication Champion et al. (2009). The use of ISS as a measure of injury severity is subject to debate, but it remains a verified tool for clinical research in trauma and has been used in previous blast injury incident analysis (Kluger et al. 2007; Leibovici et al. 1996; Hazell et al. 2022). It also keeps the same formalism as our previous scenarios. In addition, we used the model of Dullum (2010) to decide whether victims were hit by a fragment or shrapnel and were consequently bleeding. For bleeding victims, the NATO military medical concepts defined as buddy-aid or self-aid via tourniquet (TQ) application/hemostatic agents were modeled. The concept of buddy-aid is normally only applicable if the victim knows how to apply a tourniquet, which is normally reserved only to military or Tactical Combat Casualty Care (TCCC) trained personnel (Elster et al. 2013). We used refugees as victims to avoid any body armor mitigation which would have complicated the modeling of deflection of shrapnel and because we used civilian responders for simplicity in this scenario. We suppose therefore that the victims have received training in the application of TQs to avoid the added layer of modeling complexity that a military target would present. Another way of justification for the application of TQ by victims is that the refugee camp is filled with ex-military personnel or simply unprotected soldiers. This medical intervention is crucial with penetrating injuries and has shown to be a mandatory procedure to save lives (van Oostendorp et al. 2016). It could be possible to consider soldiers with armor in the future with additional modelling assumptions. Studies on the mitigation of fragment penetration realized on pigs demonstrated that armor could mitigate injuries from blasts such as blast lung but increases the lethal pressure threshold, leading to an increased incidence of traumatic brain injuries (Bass et al. 2011; Shridharani et al. 2012). Another study showed that overall, the ISS as defined by a sum of Abbreviated Injury Scores (AIS) would need to be more severe in the case of blast injuries (with the use of a modified AIS, called the AIS military (Champion et al. 2010)). To avoid these refinements in the definition of the ISS, we decided to use a simpler victim model defined with the civilian population in mind. We assumed the presence of a military enemy only to deliver the attack and decided the routes of evacuation in the opposite direction from the frontline. We supposed that military evacuation means are occupied in other areas of the country and that the civilian network is used to transport the victims to the hospitals and provide medical care. A number of civilian ground ambulances and firefighters were dispatched to the blast site in an order determined by the location of actual MTFs (local hospital network) and road traffic using a routing algorithm. Medical personnel staffed each ambulance able to provide the first treatments, while firefighters helped in bringing the victims to the R1. The Belgium health network was used to accommodate for victims and bed capacity as well as hospital capabilities were set by Subject Matter Experts (SMEs). We assumed that the site is safe after the attack and that no armored ambulances were needed, nor did we consider rotary wing medical assets for modeling simplicity. It would be a future addition to the simulator to consider a more dynamical evacuation and transfer of patients. The objective of this contribution is to model a disaster scenario of battlefield magnitude in a location where the civilian healthcare system is intact in a hypothetical setting.

2.1 SIMEDIS Simulator Modules Description

SIMEDIS comprises a victim model, a medical response model, and a resource manager. Victims are modeled as separate entities, possessing a set of properties, including their health state, injuries, position at the disaster site (using Universal Transverse Mercator (UTM) or Longitude-Latitude (LLA) coordinates), mobility/incapacity, and required treatments. Each victim evolves in parallel and interacts with the medical response model via a set of discrete events, such as when contact is made with medical personnel or when a victim arrives at the R1, R2, or R3. The victim's health state is evaluated at every interaction with the medical response model. The medical response model incorporates medical personnel means of transport and an MTF network, equipped with capabilities and capacities. At characteristic discrete times, such as when contact is made with medical personnel or when a victim arrives at the R1, R2, or R3, the arrival of ambulances and personnel is evaluated, health states are assessed, and medical procedures are executed on victims. The victim model consists of a set of analytical equations, which allow us to evaluate the health state at any given time. This represents an evolution from the discrete health state transitions defined in SIMEDIS' first formulation and development (Debacker et al. 2016; De Rouck et al. 2018). In addition to spontaneous evolutions dictated by the equations, each treatment (stabilizing, life-saving, or definitive) is modeled as a positive outcome modifier, allowing for improvements in the health state of the victims while still permitting the victims to succumb to their injuries if the treatment was not timely or sufficient. In the absence of a persistent threat following the attack, the first medical procedure advocated by TCCC after having sought cover, involves self-aid and buddy aid, consisting of a TQ application (Richey 2007; Kragh 2011; Lakstein 2003). If the victim is unable/unconscious, other surrounding victims can intervene and attempt to apply a TQ prior to bringing the unconscious victim to the R1. The first firefighter team arriving at the site is tasked with assisting in the evacuation of incapacitated or unable-to-walk victims towards the R1. The simulator can include a pre-triage step, which prioritizes the most critical victims to be evacuated first. This triage on-site can be conducted by either a doctor or the firefighters upon contact. Victims who can walk reach the R1 depending on whether they have assisted an incapacitated person or after a time calculated from their distance to the R1. Once each victim arrives at the R1, if medical personnel are available, they are triaged and assigned a NATO triage tag. From this point, transport resources are requested to bring the victim to an R2, where they will receive complete stabilizing treatments. The evolution of the victim's health state is a dynamic function based on the continuous model equations described in Benhassine et al. (2022a). The parameters associated with the health state evolutions are primarily based on the Injury Severity Score (ISS) of each victim but also consider age (seniors and infants are by nature more susceptible to health deterioration). Whenever a victim interacts with the response chain (e.g., receives treatment, arrives at a new location, begins transport), we record the state of the victim object, including current health state, mobility, triage level, and position on the map.

2.2 Artillery Salvo Modeling

In this scenario, we consider an artillery salvo of twelve 155mm shells fired by a battery of Howitzers located 30km South with a resulting Circular Error Probable (CEP) of 275m (Dullum 2010) for a cumulated fragment mass of 18kg with a speed at impact of 700m/s. The CEP corresponds to an area where 50% of the fragments will land after the explosion of the shell. The justification for the threat is based on the resulting injury data described in the reference papers. The precision of successive hits has a spread of 200x200 m. The blast pattern for a typical salvo follows a cardioid-like shape, depending on the direction of the artillery pieces (GICHD 2017) but each hit is assumed to be circular individually for simplicity of assigning distance from the blasts and victim positioning. For simplicity, we consider that each explosion is a ground explosion to neglect any mid-air blast as well as complex fragments projections. For each impact, we add 13 victims randomly distributed within the blast area to yield a total of 156 victims. The salvo hits do not occur simultaneously but are close in time preventing victims to flee. Then, for each impact, the victim coordinates are used to calculate the distance to ground zero of each strike and assign injuries.

2.3 Battlefield Victim Model

The victims' health state evolutions are described with the continuous victim model of Benhassine et al. (2022a). In this model, the Injury Severity Score (ISS) determines an estimated time of death and a modified Gompertz law models the dynamic modification of a combination of physiological parameters containing the Glasgow Coma Scale, the respiratory rate, the heart rate, systolic blood pressure and oxygen saturation. The combined effect of these parameters is merged into a single score named SimedisScore (SS). Each physiological parameter is scaled from 0 to 4, hence the SS ranges from 0 to 20. A victim with a SS of 0 is dead while a fully healthy individual has a score of 20. SS is not only a static evaluation of a victim's physiological parameters, but it also includes a dynamic evolution encompassed in the time dependence via the c parameter. In its original formulation both chemical and physical injuries were included, but in this paper only physical injuries are considered. The victims' health states have the following formulation (for physical trauma only). The time evolution of the SimedisScore (SS) is defined as

$$SS(t) = a - (a - a * \exp^{(-\exp(b-c*t)})^{\gamma}. \tag{1}$$

The a parameter represents the maximum value of the SS, which is set to 20 for healthy individuals. The b and c parameters are the key drivers for the dynamic evolution. The b parameter characterizes the amount of time that the victim's health state stays constant, and the body can overcompensate the decrease in SS, then c represents the rate of decrease (how fast the victim can succumb to his injuries). Both b and c are linked to the zero of the SS function and thus the time of death of the victim if untreated. The γ parameter is a shaping parameter that prevents the SS to tend to 0 at large times and it is comprised between 0 and 1. If $\gamma = 1$, equation (1) becomes a Gompertz function which asymptotically tends to 0 and thus, the victim will die at the projected time of death. If γ is smaller than 1 SS tends to an asymptotic value of as $a - a^{\gamma}$ which is strictly positive if a is positive and γ is strictly smaller than 1. The medical link between the SS parameters and the victim time of death is tied to the ISS. From one point of view, the victim dies when SS values 0 which is the case when $t = (b - e)/c$ where e is Euler's number (Benhassine et al. 2022a). The link between the ISS and time of death has been studied in the literature (see the discussion and references from Benhassine et al. 2002a). The crucial modeling step is to obtain an ISS for the patients that corresponds to the threat. Leibovici (1996) provides an average value of the ISS for victims of explosions where the median ISS is set to 4 based on data from terrorist bombings in open space and this number rises to 18 in closed spaces (bus interior for instance). This is caused by reflections of the blast wave in the confined space which increases the blast wave overpressure. Both the lethality of the bombings mentioned and the fact that these numbers are averaged provide little information about which values to assign to the artillery victims, but it does show some characteristic difference of open-air vs confined spaces. One of the main differences is also the fact that indoor explosions include both shockwave reflections and thus higher overpressure responsible for more trauma as well as environmental debris being projected towards the victims, or the victims being projected towards the walls, windows, or even other victims (GICHD 2017). Modeling indoor explosions is complex and beyond the scope of the current work but it is a possibility in future research. In addition, we must bear in mind that the ISS has severe limitations and is a simple score which cannot capture the reality and unpredictability of health state evolutions in general. Nevertheless, the victim model is only one aspect or module of the SIMEDIS simulator and is the best approach that we currently have.

To obtain the ISS, one needs to determine the 3 worst injuries the patient has on different body location using the Abbreviated Injury Score. Injuries from blasts and explosions are comprised of the following (Champion et al. 2009):

- Primary injuries produced by the pressure/shockwave and typically include tympanic membrane rupture, as well as blast lung, bowel injuries, and central nervous system injuries.
- Secondary injuries caused by the penetration of fragments from fragmenting ammunitions which can lead to traumatic amputations and lacerations.
- Tertiary injuries are injuries sustained from victims being projected on structures or objects hitting individuals which are blunt or crush injuries.
- Quaternary blast injuries, depending on the type of ammunition used, smoke asphyxiation, chemical burns, and toxic inhalations.

Champion also explains the expected outcome an unprotected person could face versus distance from the ground zero of a 155mm explosion. Any impact falling at a distance shorter than 15m from a victim without ballistic protection is guaranteed to kill. Between 15 and 24m from the ground zero, death caused by fragments is likely. After 24m, injuries from fragments as well as auditory damage are expected up to 40m. After this distance and up to 500m, no primary blast injuries are expected. Secondary blast injuries remain possible, but the odds of life-threatening injuries are reduced (GICHD 2017). There are several lethality models available based, for instance on Bowen curves (Bowen 1968), but we decide to use a simpler approach by assigning ISS to victims based on their relative position to each impact. Using a kill radius of 15m and a lethal area of 800m (Dullum 2010), we deduced the following ISS to distance estimate (see Figure 1). Below 15m the ISS is 75 which is the maximum value it can take; it also means a 100% kill probability. Between 15 and 24m there is still a great chance of death, so the ISS decreases from 50 to 26. From 24m to the 150m distance the ISS decreases sharply until a plateau of 1-4 is reached terminating the discrete estimates. Using this data, a continuous fit is performed which yields an estimated ISS versus distance of $ISS = \min(75; 3 * 75/R)$ where R is the distance from the blast. The two datasets are displayed on Figure 1.

For successive hits, which is the case for an artillery salvo, each victim has the chance of being hit by a fragment or suffer from the shock wave and be injured. To estimate fragmentation effects, we use the definition in Dullum (2010). Dullum (2010) quantifies the effects of a bomblet by defining an incapacitation probability p(x,y) which depends on the position of the target at coordinate (x,y) with a hit located at (0,0) depending on the lethal area A_l of the bomblet. The interpretation of the lethal area is the total affected zone by the bomblet. The author then refines the lethal area in terms of number of fragments N to estimate the number of targets affected. When trying to estimate the effects on human targets, Dullum (2010) defines

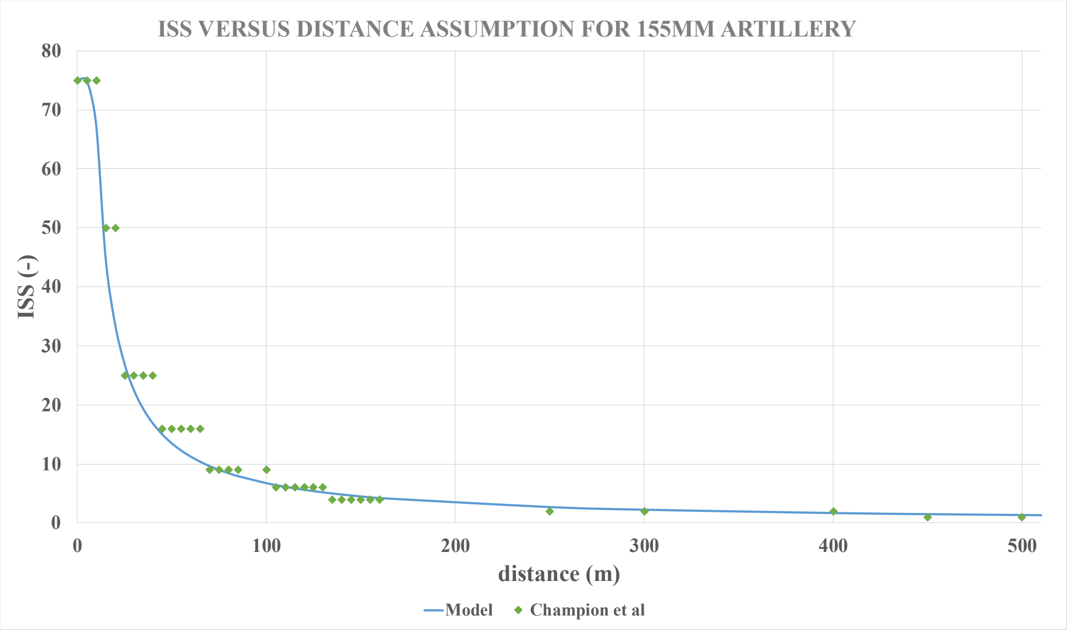

Figure 1: ISS versus distance used in the artillery victim model.

the fragment penetration probability as a function of the number of fragments, the body area exposed to the charge and the lethal area (which in our case, is known from the paper of Champion et al. 2009). When a warhead fragments, disregarding any velocity loss and the curved trajectory of the fragments, the probability P_{hit} of being hit by a fragment can be expressed as

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

where N is the number of fragments (1000 was used, A is the average exposed body area (0.5 m²) for a human and r the distance from each impact. This value is commonly used in lethality models (Kokinakis and Sperrazza, 1965). We set the scenario attack time at 05h00 and expect that most victims would be asleep and the exposed area relative to blasts reduced. The incapacity probability of a victim is further defined as

$$P_{incap} = \exp(-\pi r^2/A_l), \tag{3}$$

where A_l is the lethal area set to 800 m² for 155mm ammunition (Champion et al. 2009). We decide to associate incapacity with the fact that the victim is unable to walk and needs evacuation by peers and/or firefighters on a stretcher. Deciding whether a victim sustains a lethal injury or not includes two conditions. Depending on the distance of a strike (thus twelve chances are tried), there is a set probability from distance relationship which results in setting γ to one. In addition, if a victim has been hit by a fragment, is bleeding and is also incapacitated, we suppose that he/she has been lethally injured. In this case, there are two ways that a victim can be saved: either a tourniquet is successfully applied and the patient can be stabilized until it reaches a hospital able to provide the life-saving interventions he/she needs, or the patient has been lethally injured but needs surgery that can effectively prevent him from dying and this condition can only be satisfied if the victim reaches the hospital before his SS reaches 0. Assuming that a TQ application is the only medical procedure needed for victims with fragments is a limiting assumption, but it captures one key medical element in the model, that is hemorrhage control priority over other life-saving interventions. For instance, chest decompression, and oxygen would be mandatory for many patients, but these are provided by first medical contacts, if fragments penetrate the torso area. There are severe limitations to the assumptions and modeling, i.e., the fragment distribution and secondary fragments expected if the blasts occurred in a camp would include secondary projectiles such as tent poles, kitchenware, bed frames but also humans and bones. By assuming that explosions are ground explosions on open terrain gives more relative validity to the modeling assumptions. It could be possible to refine the model and include these phenomena in a more empirical way and these effects will be included in future SIMEDIS scenarios.

2.4 EMS Resources and MTFs

The Belgian road network within OpenStreetMap was utilized to calculate the estimated time of arrival for EMS resources from surrounding R3s and fire departments to the scene. We used the fastest route algorithm of the OpenStreetMapX Julia package. A limitation of this method is the lack of real-time traffic data, which was estimated by dilating transport times based on actual data, using a factor of 1.7 throughout. Despite this, the algorithm provided accurate arrival time estimations for the first firefighter team and EMS responders, which were 4.27 and 8.68 minutes respectively, compared to real traffic estimates of 5 and 9 minutes, respectively. A total of 16 ambulances originating from surrounding R3s and fire stations arrived on the scene, with the last ambulance reaching the site after 39 minutes. These times are within reported times for studies evaluating the impact of scene time on injury scores and outcomes in prehospital management of victims (Spaite et al. 1991). Also, the estimations using the 1.7 scaling factor with the empty map and the real values were all below 17% for all ambulances and firefighters compared to real estimations. This modeling assumption is justified as the arrival times were varied stochastically to account for changes below 20%. The evacuation of victims from the PoI to a R3 transited from a R1 where triage was performed and then either a R2 where the victim was further stabilized or received Damage Control Surgery (DCS) before being handed over for specialized treatments. In our scenario, although there were sufficient R3s located in the surrounding area for treatment within the first hour, the limitation in transport resources shifted the arrival times past this window. Upon bringing the patient to an MTF, the ambulances were sent back to the R1 or R2 depending on policy. Then, the pool of ambulances increased by one.

2.5 Scenario Description

At 0500 on a clear morning, a battery of artillery pieces fires a volley of twelve shells towards the field surrounding the Lion's Mound in Waterloo, hitting a shelter that was being used by refugees awaiting relocation. For the purposes of this scenario, we assumed that the civilian healthcare facility (HCF) network has not been damaged and is operating at full capacity, with sufficient supplies available to avoid any shortages. We further assumed that the artillery battery was destroyed in a retaliatory air attack, and no further casualties were expected during the subsequent evacuation. Given this, there is no need to establish any specific safety corridor during the evacuation. In order of their travel distance, ground ambulances and firetrucks were dispatched to the blast site from nearby civilian MTFs. Before their arrival, we expected that able-bodied victims will have assisted those who were unable to move by providing initial life-saving treatments in the form of TQ applications, assuming they did not need such treatment themselves. Once the first EMS resources arrived, they transported the victims to an improvised R1 facility located in the parking area of the Waterloo Memorial. In real-life situations, it is not guaranteed that the EMS response will be flawless and without delay due to miscommunication. To account for these potential factors, we introduced stochastic variation of arrival times and use a normal distribution with a 20% variance from the expected value for each discrete event, including routing algorithm, victim triage, patient loading, and medical interventions.

3 RESULTS AND DISCUSSION

3.1 Initial Victim Injury Distribution

The dispersion of the artillery salvo in the presented scenario was calculated using a simple circle equation that accounts for the 200x200m spread characteristic of towed artillery and the given distances in the scenario. The twelve resulting hits had a total impact on 156 victims. To determine the initial health state of the victims, probabilities of fragment penetration and incapacity were calculated using equations (2) and (3), respectively. The exact location of each hit was placed in the vicinity of the UTM position of the Lion's Mound. The victims were generated radially around each hit within a 160mx160m rectangular area, resulting in a rate of 13 new casualties per hit. These values led to a resulting population with an average Injury Severity Score (ISS) of 17.6 ± 8.71, 40 victims with fragments (25.6%), 15 incapacitated victims, and 6 victims with both fragments and incapacity. The location of each artillery impact and initial victim positions are displayed in Figure 2.

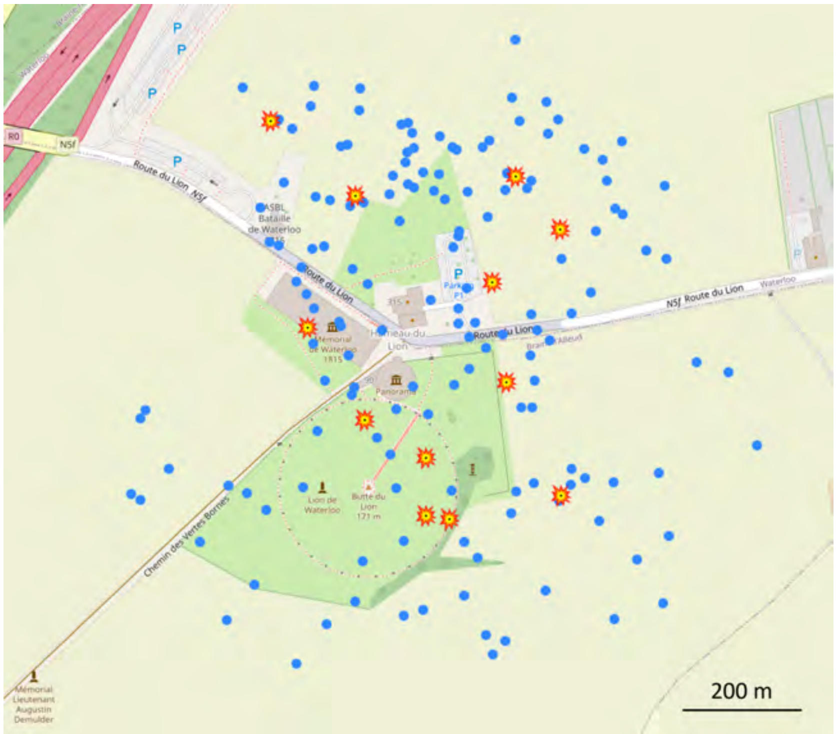

Figure 2: Initial situation after the salvo. Each hit is presented as an explosion icon. Victims are displayed as blue circles. The epicenter is located at the Lion's Head Mound (50°40'44" N, 4°24'18" E).

3.2 Mortality Estimation Versus Parameters Variation

The following parameters were varied: tourniquet application before transport "TQ" (True (T)/False (F)), evacuation policy "Policy" (ScoopRun vs StayPlay), triage on site for the evacuation of victims to the R1 "PreTriage" (T/F), transport supervision ("Low" meaning only paramedics, "Normal" is either doctor or nurse present on board), policy of victim distribution to the R3, "Hospdist" with values "SpreadOut" (the simulator checks if there is any available R3 which has both the capability to treat and the capacity to admit the victim) or "CloseFirst" (victims' distribution involves sending the victims to the closest R3 able to admit the victim, until it is saturated, then sending additional victims to the next available R3). The simulation runs consisted of ten replications to obtain statistical variations between parameter combinations. Multiple linear regression analysis was performed on the results. In the case of the refugee shelter used as hypothetical situation, we expect that TQ will not be performed but we still allowed for it, to demonstrate changes it would imply if the victims had knowledge and training of TQ application. Using Scoop and Run or Stay and Play is a current debate in disaster management where some EMS systems tend to favor the first (e.g., in the United States and Israel) over the second (e.g., in Belgium and France). Hospital distribution relates to the way that hospital admissions are being managed and finally supervision is designed as to weight both quality of medical care on board of ambulances versus the number of available personnel. Pretriage impacts the order of arrival for non-ambulatory victims to the first MTF. The results are displayed in Table 1 and regression analysis in Table 2.

Table 1: Mortality calculations (average across ten replications) for the scenario parameters. TQ is the use of the tourniquet algorithm, policy is ScoopRun vs Stay and Play, Pretriage is triage based evacuation for victims unable to walk, supervision is transport supervision, hospdist is the hospital distribution policy. Data is from ten replications allowing to display the variance.

Mortality (± error)	TQ	policy	pretriage	supervision	hospdist
11.8 ± 1.54	true	ScoopRun	true	Low	SpreadOut
11 ± 0.89	true	ScoopRun	true	Low	CloseFirst
20.7 ± 2.41	true	ScoopRun	true	Normal	SpreadOut
20.6 ± 1.85	true	ScoopRun	true	Normal	CloseFirst
11.8 ± 1.33	true	ScoopRun	false	Low	SpreadOut
11 ± 0.89	true	ScoopRun	false	Low	CloseFirst
20.9 ± 2.21	true	ScoopRun	false	Normal	SpreadOut
20.6 ± 1.96	true	ScoopRun	false	Normal	CloseFirst
21.1 ± 2.07	true	StayPlay	true	Low	SpreadOut
21.1 ± 2.07	true	StayPlay	true	Low	CloseFirst
21.1 ± 2.07	true	StayPlay	true	Normal	SpreadOut
21.1 ± 2.07	true	StayPlay	true	Normal	CloseFirst
21 ± 2.10	true	StayPlay	false	Low	SpreadOut
21 ± 2.10	true	StayPlay	false	Low	CloseFirst
21.1 ± 2.07	true	StayPlay	false	Normal	SpreadOut
21.1 ± 2.07	true	StayPlay	false	Normal	CloseFirst
19.8 ± 1.33	false	ScoopRun	true	Low	SpreadOut
18.9 ± 0.94	false	ScoopRun	true	Low	CloseFirst
40.8 ± 0.4	false	ScoopRun	true	Normal	SpreadOut
40.1 ± 0.54	false	ScoopRun	true	Normal	CloseFirst
19.8 ± 1.25	false	ScoopRun	false	Low	SpreadOut
18.7 ± 0.64	false	ScoopRun	false	Low	CloseFirst
40.3 ± 0.64	false	ScoopRun	false	Normal	SpreadOut
39.9 ± 0.7	false	ScoopRun	false	Normal	CloseFirst
40.9 ± 0.54	false	StayPlay	true	Low	SpreadOut
40.8 ± 0.4	false	StayPlay	true	Low	CloseFirst
41.1 ± 0.3	false	StayPlay	true	Normal	SpreadOut
41 ± 0	false	StayPlay	true	Normal	CloseFirst
41 ± 0.45	false	StayPlay	false	Low	SpreadOut
40.9 ± 0.3	false	StayPlay	false	Low	CloseFirst
41.1 ± 0.3	false	StayPlay	false	Normal	SpreadOut
41 ± 0	false	StayPlay	false	Normal	CloseFirst

Table 2: Multiple Linear Regression Analysis for the parameters of Table 1. The only varied parameters with a significant effect on mortality are TQ application and Policy. Mean mortality is 20.975 ± 0.92. R^2 value is 0.9317.* denotes statistical significance.

Parameter Influence on Mortality	Mean change	p-value
TQ: yes	-10.74 ± 0.75	<< .001*
Policy: StayPlay	9.21 ± 0.75	<< .001*
PreTriage: true	-0.08 ± 0.75	0.914
Supervision: normal	-0.43 ± 0.75	0.572
Hospdist: SpreadOut	0.99 ± 0.75	0.199

Results from the simulation runs show the impact that TQ has on the number of dead casualties. The worst possible outcome is when no TQ are applied, and victims' transit through the R2 (StayPlay) instead of being quickly dispersed to available R3 around the MASCAL location. An interesting result also shows that using ScoopRun without TQ application results in average mortality like StayPlay with TQs (21.1 vs 19.8). These results need to be put in perspective that there are multiple R3 hospitals within 1 hour of ground zero and that all personnel and hospitals are fully equipped with medical supplies. Any life-saving interventions in the 10-minute window of the threat will increase the chances of survival to the lethally injured. Secondly the evacuation policy has a lesser marked impact. A limitation of this study is the absence of multiple blast sites and incidents which should stress the EMS response more. Surprisingly, we did not find similar approaches to modeling artillery strikes in the open-source literature. Most studies detailed the effects using different independent goals. Tools like the Joint Medical Planning Tool (Naval Health Research Center 2013) are not available in academia and the development of these software solutions are important not only to detect gaps but also provide solutions for the important field of disaster management. We believe the lack of similar approaches is partly because artillery models serve the purpose of casualty estimation and not disaster management and response with the same computer program.

4 CONCLUSIONS AND RESEARCH OUTLOOK

We utilized SIMEDIS to model victims in an artillery salvo attack on a civilian gathering shelter situated in an open-field area. The explosion and fragmentation modeling were based on simple assumptions drawn from analytical models. The ISS distribution of the victims is dependent on their position relative to each impact. An algorithm for routing estimated the expected arrival times of ambulances and firefighters. Bleeding control application and the positioning of R1 and R2 were fixed in the simulations before EMS arrival. Based on a continuous victim model, the symptomatic evolution of each victim was varied over time, and treatments were given either at R2 or during ambulance transport by modifying the continuous victim model parameters. The simulation included R3 MTFs surrounding the blast site, and definitive treatments upon arrival at these facilities were considered. We assumed that all EMS personnel performing treatments had unlimited medical supplies, but we acknowledge that these are simple assumptions, and additional effects could be modeled in the future. This could include different treatment effects based on specific injuries and a more constrained EMS response pool. SIMEDIS provides in one framework the entire disaster modeling from the threat up to the R3 admission and treatment including bed capacity, hospital capabilities and the routing of EMS resources. In the future, other relevant features will be added along with access to real patient data to augment the victim model and the possibility to simulate historical disasters to compare results. We included a map, making SIMEDIS a more versatile tool for various applications, including disaster preparedness and military tactical and operational planning. However, more threat diversity and validation based on historical events will be necessary. The simulator enables the quantification of the impact of restrictions in resources or changes to treatment timelines on victims, whose health state changes over time during the scenario. We intend to include more complex threats and effects in the future, such as the impact of terrain and safety of evacuation, and to provide more graphical outputs to enhance accessibility for users. Another crucial addition would be to generate victims over time while evacuations are taking place, creating multiple threats during the same simulation, thereby taking a significant next step towards a more realistic tool.

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