

# Using Modeling and Simulation to Examine the Benefits of Medical Technology in a Simulated Combat Environment

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This paper shows how the authors used Modeling and Simulation (M&S) to examine the potential benefits of medical technology in simulated combat. Today, thanks to increased computer processing power, storage capacity and improved programming languages, M&S is used to duplicate and replicate systems, processes, procedures and activities; and, to support training and analysis requirements for numerous government and non-government organizations. As a result, the opportunity to leverage this work increases dramatically each year. The authors leveraged the work accomplished for the Army Medical Department Center for Strategic Studies where M&S was used to incorporate combat medics and medical transport vehicles into a simulated combat engagement with casualties. By leveraging this work and using the casualty and simulated combat environment as the starting points, the authors used M&S to incorporate the anticipated benefit of medical technology. The results of this initial effort are contained in this report.

**Keywords:** medical simulation, simulation environments, simulation modeling

## 1. Introduction

The Army decision to transform into modular units that are more deployable, lethal, survivable and joint directly impacts the Medical Community. The Medical Community must adjust to the fact that Army units will now be smaller, more lethal and fight at greater distances from fixed medical personnel and facilities. Likewise medical analysts must find ways to effectively and accurately determine the impact that increased distances, and time to travel to wounded soldiers in austere environments will have on medical force structure, technology and systems in order to provide decision makers needed information. For example, the effect of improved body armor and changes in enemy tactics, techniques, and procedures has led to a larger proportion of extremity injuries which are currently receiving medical analyst's attention. To assist medical analysts in obtaining improved information for decision makers, the authors discuss how M&S can be used to simulate a realistic combat environment where time, distance, recovery vehicle speed and soldier wound types are modeled specifically as a means to address this challenge.

## 2. Process

The process utilized to support this effort follows:

- Leveraging the work that was done in support of the Center for Army Medical Department (AMEDD) Strategic Studies, (CASS) including the use of:
  - an approved Training and Doctrine Command (TRADOC) scenario
  - the M&S tool Interactive Distributed Engineering Evaluation and Analysis Simulation (IDEEAS) to simulate a combat engagement
  - a Future Force Combat Battalion conducting simulated offensive operations against a technologically advanced Enemy Force
  - Friendly casualties that were treated and transported to an Ambulance Exchange Point (AXP) by newly developed Combat Medic (CM) entities and vehicles.
- Identifying and incorporating wounded soldiers Patient Condition (PC) Codes that could benefit from the technology being examined.
- Modeling the specific times associated with soldier wounding, medic notification, medic time to travel, treat (with and without the new technology) and transport to an AXP.
- Capturing relevant information (i.e. distance to wounded soldier, time to travel, treat and transport to the AXP) for each of the technologies to be modeled in order to do comparative analysis.
- Acquiring background information and establishing parameters for the medical technology to be examined.
- Incorporating the capability of the medical technology in terms of prolonging a wounded soldiers time before death.
- Establishing a base case with currently available medical technologies and a test case with new medical technology.
- Analyzing the results.

Each of these points is explained in more detail below.

### **3. Leveraged Work: The Study Completed for CASS**

#### *3.1 Scenario*

The TRADOC analysis center at Ft. Leavenworth (TRAC-Leavenworth) developed the study scenario to facilitate the early analysis of the Future Force in combat operations [1]. The scenario provided a context in which a Future Force Combat Battalion conducts offensive operations in 2015 against a technologically advanced enemy, referred to in the study as the Enemy Force.

The battalion fought using concepts from the *Combined Arms Brigade and FCS (Future Combat Systems) equipped Combat Battalion Concept (April 2001)*. TRADOC Deputy Chief of Staff for Intelligence (DCSINT) developed the study's Enemy forces, consistent with the Contemporary Operational Environment as of May 2001. The threat possessed technology commensurate with projected 2015 capabilities and employs adaptive tactics.

The scenario incorporates an AXP defined by CASS Subject Matter Experts (SMEs) and employs three Future Combat System – Evacuation (FCS-E) vehicles to provide treatment and evacuation support.

#### *3.2 The Engagement*

The engagement lasted approximately nine hours and was explicitly modeled using the IDEEAS tool. As will be discussed in more detail, IDEEAS is an entity-based constructive simulation, capable of force-on-force representations, that permits examination of concepts and parametric analysis at the engineering level of detail. The scope for the CASS modeling effort was an 80-kilometer by 80-kilometer geo-typical (i.e. roads, rails, towns, forests, etc.) terrain box. The Future Combat Battalion and Enemy Mechanized Brigade with limited Special Police assets were modeled in this effort. During the assault, the Combat Battalion received casualties which were the basis of the study.

#### *3.3 Modeling and Simulation Tool*

IDEEAS is the U.S. Army Aviation and Missile Command's primary large-scale engineering force-on-force simulation. IDEEAS is a high fidelity engineering and entity level, all digital, physics-based constructive simulation of modern battlefield weapons and sensor systems used in realistic battle scenarios. IDEEAS was designed to allow a complete integration of all of the environmental conditions present on the battlefield that may have an impact on the performance of "smart" weapons. IDEEAS provides the war fighter with the capability to rapidly evaluate engineering level changes in equipment, tactics, weather, terrain, command, control, communications, and intelligence. The primary goal of IDEEAS is to provide the user with the capability to efficiently perform engineering level "what if" analysis in the context of the realistic battlefield environment. Analyses are conducted in either batch mode for large parametric studies, or in "real time" distributed experiments, interacting with other constructive simulations, virtual prototypes, and appropriately instrumented live vehicles [2].

IDEEAS uses time-sequenced, event oriented deterministic scenarios that are based on approved standard scenarios. These highly detailed scenarios include the weapon system attributes; tactics techniques and procedures (TTP's), terrain and environmental conditions, and

both friendly and enemy force structures. This not only permits the evaluation of a particular system; it also allows the study of the system's interrelationship with other battlefield operating systems. Military analysts well versed in the art of warfare and knowledge of current and emerging weapons systems, work in concert with IDEEAS engineers to produce a scenario that withstands military and engineering scrutiny. All scenarios used in IDEEAS are refined to the lowest vehicle and soldier entity.

An IDEEAS battle scenario consists of four parts: (1) terrain, (2) environment, (3) forces, and (4) tactics. The terrain defines the surface over which the battle takes place. Not only does the terrain include the surface contour; it also includes features such as trees, buildings, roads, cultivated land, orchards, and rivers. The environment defines the atmospheric and battlefield conditions in which the battle takes place. The atmosphere includes temperature, humidity, wind speed and direction, and weather conditions such as rain, fog, mist, or snow. The battlefield conditions include the time of day, season, and battlefield contaminants such as smokes, fires and dust. The environment conditions significantly affect acquisition and engagement sensor performance. The forces describe the battle participants. Forces include the entity type of each participant and the number of each type available for battle, including combat loads and the organization of the forces. Tactics describe how the forces will conduct the battle, and includes offensive and defensive postures, location of forces, attack strategies, maneuver routes, and firing doctrine.

Vehicles possess attributes that permit them to be detected and killed by other objects. They have attributes such as, infrared, millimeter wave, and optical signatures and are mobile and vulnerable to damage and destruction. Weapons are object types that can kill other entities. Weapons have the attributes of trajectories, delivery accuracy and lethality. Vehicles with sensors detect opposing entities. Sensor types are forward looking infrared, televisions, direct view optics, radar and acoustics. Various combinations of vehicles, weapons, and sensors comprise an entity in IDEEAS.

The model of an entity in IDEEAS depends on what the entity actually does during the encounter phase of combat. The entities employ several functions to acquire, engage and destroy targets. Possible functions an entity can perform include: Target acquisition, Target engagement, Mobility, Communication, and Survivability. In addition, the work performed for CASS resulted in the development of a Combat Medic entity and medical vehicle entity [3].

During simulated combat, the IDEEAS M&S tool produces a list of Friendly entities interdicted by Enemy fires, and Enemy entities interdicted by Friendly fires. The ordnance fired by both Friendly and Enemy platforms can be modeled as a distinct entity. The trajectory of the ordnance can be modeled based on the characteristics of the ordnance and prevailing environmental conditions. Based on the type of ordnance, the three-dimensional coordinates of the hit location, the vector of the ordnance, and Friendly/Enemy entity characteristics, the hit is assigned one of five types of damage: catastrophic kill, crew kill, mobility damaged, firepower damaged, mobility-firepower damaged. These categories are defined below.

- Catastrophic kill - the vehicle is inoperable and the crew is killed.
- Crew kill - most crew members are killed and others wounded with insufficient number to operate the vehicle.
- Mobility damaged - the vehicle is inoperable, weapon can still be used, some crew members may be injured or killed.
- Firepower damaged - the main gun on the vehicle is inoperable, some crew members are killed or injured.

- Mobility-firepower damaged - the vehicle and the main gun are inoperable and some crew members are killed or injured.

Using the capability within the IDEEAS tool, the authors worked with model developers to incorporate medical parameters for soldier’s killed-in-action (KIA), and wounded-in-action (WIA).

### 3.4 Medical Parameters

#### 3.4.1 The Deployable Medical System (DEPMEDS) PC Code

The DEPMEDS PC codes are a listing of 350 injury types maintained in the Joint Readiness Clinical Advisory Board website (4). These PC codes occur during deployment and combat operations and range from snake bites, to severe hearing impairment, to more serious injuries [4]. In order to support the injury requirements for the CASS study, a subset of common battlefield injuries was developed from the list. This subset included 184 PC codes. The remaining PC codes were not used due to their irrelevance to the CASS study. This subset list was further subdivided to support the requirements for the MRMC study so that certain PC codes could be randomly selected based on medical applicability to the technology being modeled (e.g. injuries requiring tourniquets) and provided to the modelers by medical SMEs. An example of the PC codes used for this study can be found in Appendix A, in Tables A1 and A2.

#### 3.4.2 Identifying WIA & KIA via the PC Code Cumulative Probability Distributions

For the CASS Study, in order to randomly select a PC code for each injury event; the probability of occurrence of each PC code was converted to a cumulative probability whose maximum value is 1.00. The default cumulative distribution is shown in Figure 1 below. The random selection of a particular PC code is done by drawing a random number from a uniform distribution bounded by 0 and 1, entering the ordinate axis on the left side and then selecting the PC code based upon the curve shown in Figure 1.

While the details for the algorithms associated with casualty generation and injury severity computations are not included in this paper due to page limitations, it is important to note that

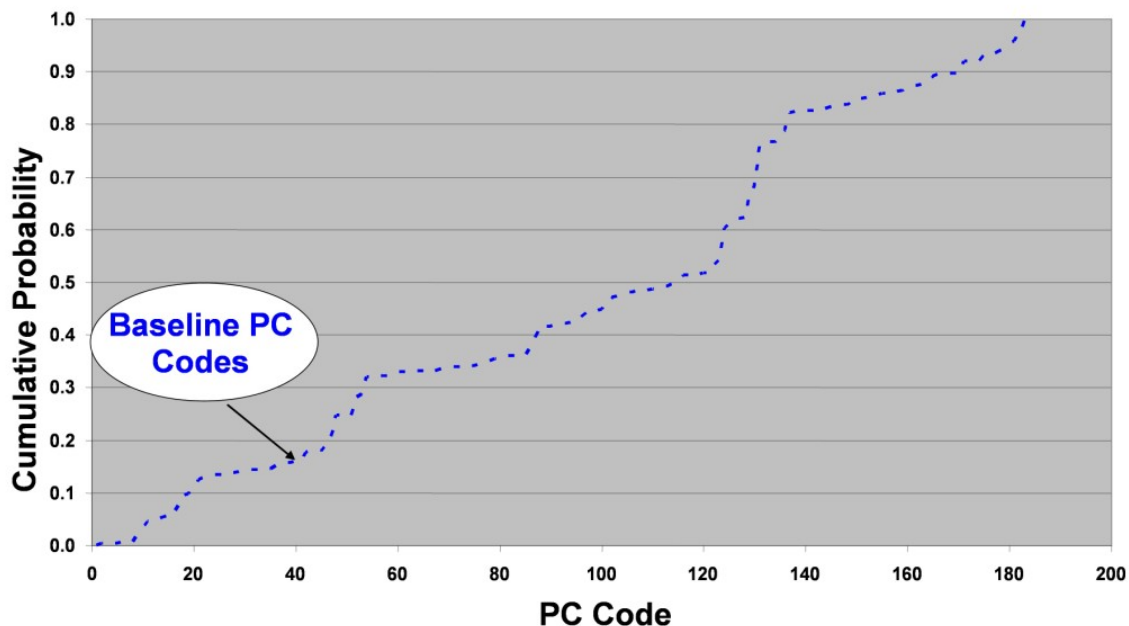


Figure 1. Cumulative Probability Distribution for Default Input Probability of Occurrence

they were developed in conjunction with military medical SMEs. The algorithms are explained in more detail in Appendix B and further background can be provided upon request.

### 3.4.3 WIA Probability of Death

As mentioned above, all WIA were individually assigned a DEPMEDS PC code based upon a uniformly random draw from the list of 184 codes (see Figure 1). This data set constitutes the default model PC code input for basic CM treatment of casualties. Based upon the PC Code selected, the WIA was also assigned a probability of death ( $P_d$ ) from Figure 2 below [6]. When the  $P_d$  was greater than zero, the WIA was assigned an initial “Time to Death” ( $T_d$ ) from the  $P_d$  and the no-treatment-curve shown in Figure 2.

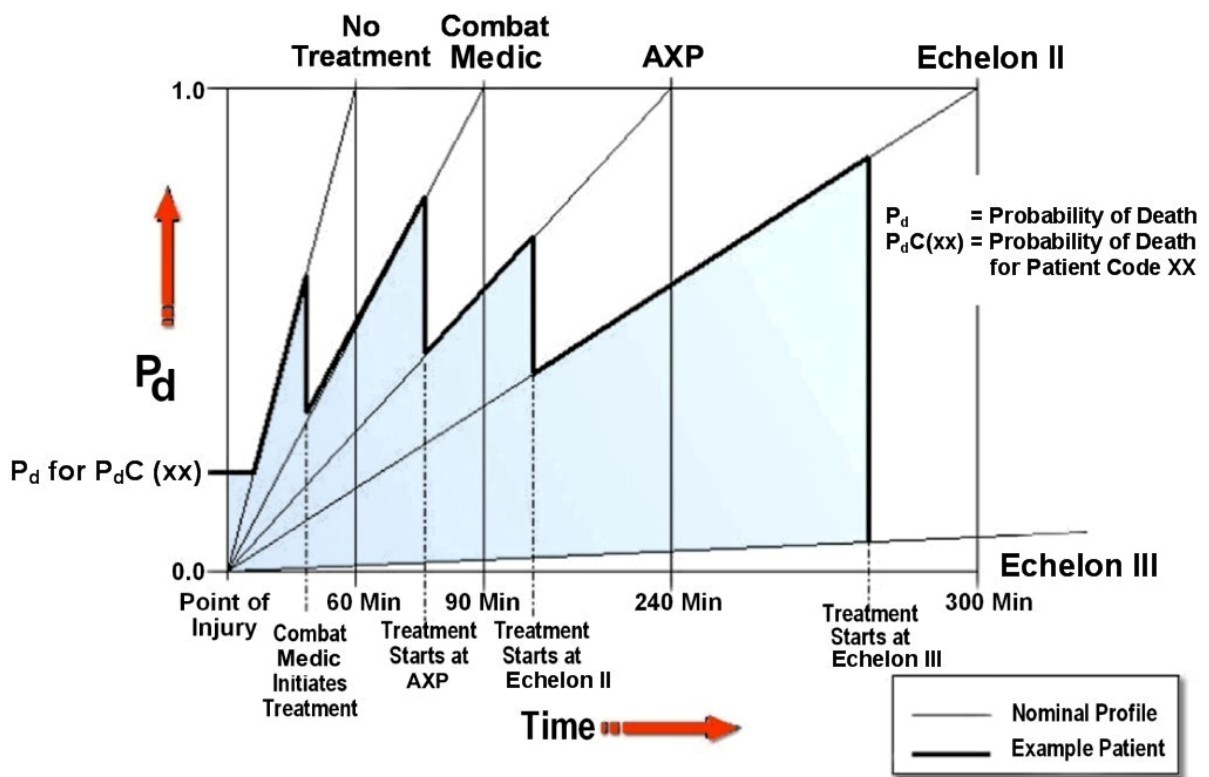


Figure 2. Time to Death Algorithm

### 3.4.4 Casualty Time to Treat Profiles

Each DEPMEDS PC has a corresponding Treatment Brief and Task, Time, Treater File. The Treatment Brief summarizes care delivered at each Echelon of Care. The Time, Task, Treater File provides greater detail, defining specific procedures, the time required for the procedure, who can perform the procedure, and necessary equipment and supplies. Each Echelon of Care, explained below, has increasing medical capability. Due to the nature of combat injury, allocation of Combat Health Support resources, and geography of the modern battlefield, elapsed time from time of injury to time treatment begins is a critical determinant of outcome.

### *3.5 Army Echelons of Medical Care*

The Army has five echelons, or levels, of care, each progressively more advanced. Echelon I care provides immediate first aid at the front line. This care is normally self aid, buddy aid, combat medic, and involves a battalion aid station (BAS). Echelon II care is division-level health service support and consists of surgical resuscitation provided by highly mobile forward surgical teams that directly support combatant units in the field. Echelon III care or corps-level health service support is provided through combat support hospitals—large facilities that take time to become fully operational but offer much more advanced medical, surgical, and trauma care, similar to a civilian trauma center. Echelon IV care is the first echelon at which definitive surgical management is provided outside the combat zone. Echelon V care is the final stage of evacuation to one of the major military centers in the United States, where definitive stabilization, reconstruction, and full rehabilitative care is performed.

### *3.6 Combat Health Support Plan*

For the CASS study, only Combat Medic (CM) treatment was considered. Following treatment, casualties were transported to the AXP, at which time the medical evacuation team returns to the field of battle to continue treating and retrieving casualties, if casualties are still waiting for treatment or the medical evacuation returns to a point behind the Company Command vehicle to which it is assigned to await orders to move to new injury sites.

### *3.7 Parameters & Assumptions for the CASS Study*

The following parameters were employed to guide model development:

- Future Combat Vehicle – Evacuation (FCS-E) vehicles (medical evacuation vehicles) are dedicated for treatment and evacuation of casualties within the assigned unit only.
- The FCS-E traversed the battlefield to wounded soldiers at 25 KPH.
- Distance between the wounded soldier and evacuation vehicles and medical personnel are specifically modeled in kilometers.
- Time to travel from the AXP to the wounded soldiers given an assumed KPH factor will be modeled.
- Soldiers KIA were not moved by the FCS-E.
- Upon notification, the FCS-E or medical evacuation vehicle moves from the vicinity of the Command vehicle to the casualty.
- At the Point of Injury, the CM will provide Echelon I treatment, and then evacuate the casualty to the Ambulance Exchange Point (AXP). The evacuation to the AXP depends on one of two things:
  - 1) the medical evacuation vehicle will continue moving to the next injury site and treat and load casualties until the medical vehicle has reached capacity.
  - 2) all sites have been visited and casualties cared for. Once capacity has been reached or all casualties cared for, the medical evacuation vehicle evacuates the casualties to the AXP. The amount of time required to administer Echelon I treatment is based on the PC for the casualty.

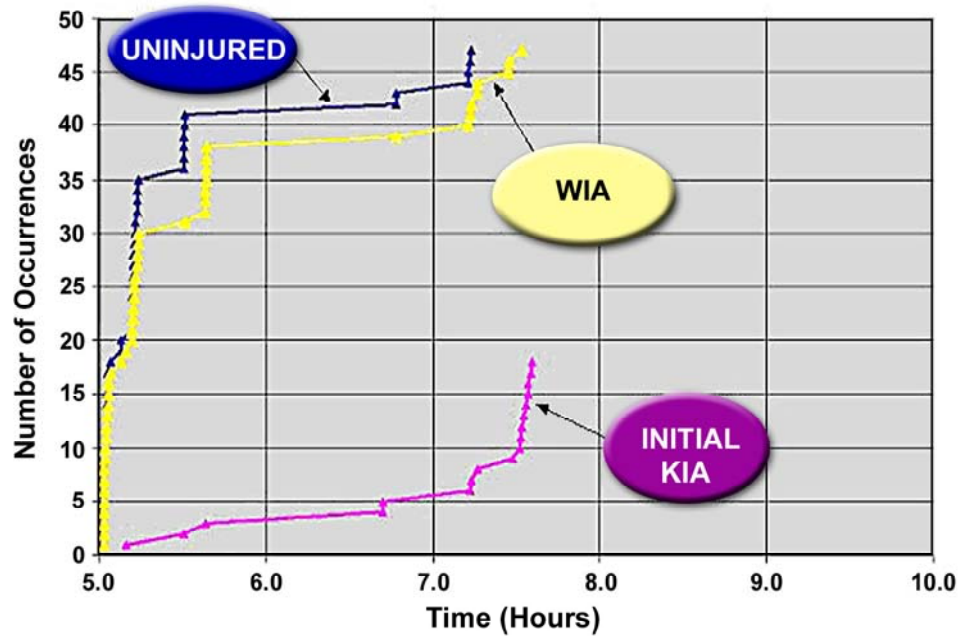
- The CM will respond to casualties based on proximity to the CM not severity of injury. This point is to be expected due to the CM being embedded as part of the maneuver unit. The CM will be expected to handle almost all types of injuries sustained on the current battlefield by providing stabilizing care. Also, a remote triage capability is not included in the simulation as CMs will not normally perform that function but only attempt to save the injured service personnel. The FCS-E moves in a round robin fashion, moving to the closest injury site based upon distance. The FCS-E continues traveling to all assigned injury sites until either all assigned sites have been visited or until the FCS-E has reached capacity.
- Treatment of injuries at the site is based upon severity of the injury. The availability of more than one CM does not alter the required treatment time for an individual casualty.
- The most critical casualties at each location will load first into the FCS-E. The number of casualties loaded is dependent on the FCS-E litter and ambulatory carrying capacity. The FCS-E will not transport KIA casualties in this study.
- The FCS-E vehicle can carry 4 litter patients or 6 ambulatory patients; it can also carry 2 litter and 3 ambulatory casualties.
- As discussed earlier in the medical levels of care, the AXP will co-locate with the Battalion Aid Station (BAS). The BAS will locate in the vicinity of the battalion command vehicle.
- Upon off loading of casualties, the FCS-E will move to collect the next casualty or return to the vicinity of the unit command vehicle.
- Medical evacuation by air was not modeled due to the threat of ground to air missiles.
- Enemy casualties were not treated or transported in this initial study.

The following assumptions were employed to guide development of the model:

- Ground lines of communication for medical evacuation were secure. There were no casualties among medical personnel or loss of Friendly FCS medical treatment or evacuation vehicles.
- 100% capability of all medical units is available to support the operation.
- Killed-in-Action (KIA) is composed of those dying immediately.
- Died of wounds are those that die as a function of time regardless of any treatment and those that are dead at specific events based upon the  $P_d$ .

### *3.8 Results and Discussion from the CASS Study:*

Table 1 provides representative complete casualty statistics for personnel wounded or killed following the impact of a Enemy weapon round. There were a total of 47 WIA and 17 KIA casualties. Figure 3 shows the cumulative number of KIA and WIA casualties, and uninjured crewmembers occurring in friendly vehicles attrited by Enemy fires over the course of the combat simulation.



**Figure 3.** Mounted / Dismounted Casualty Status at Weapon Impact

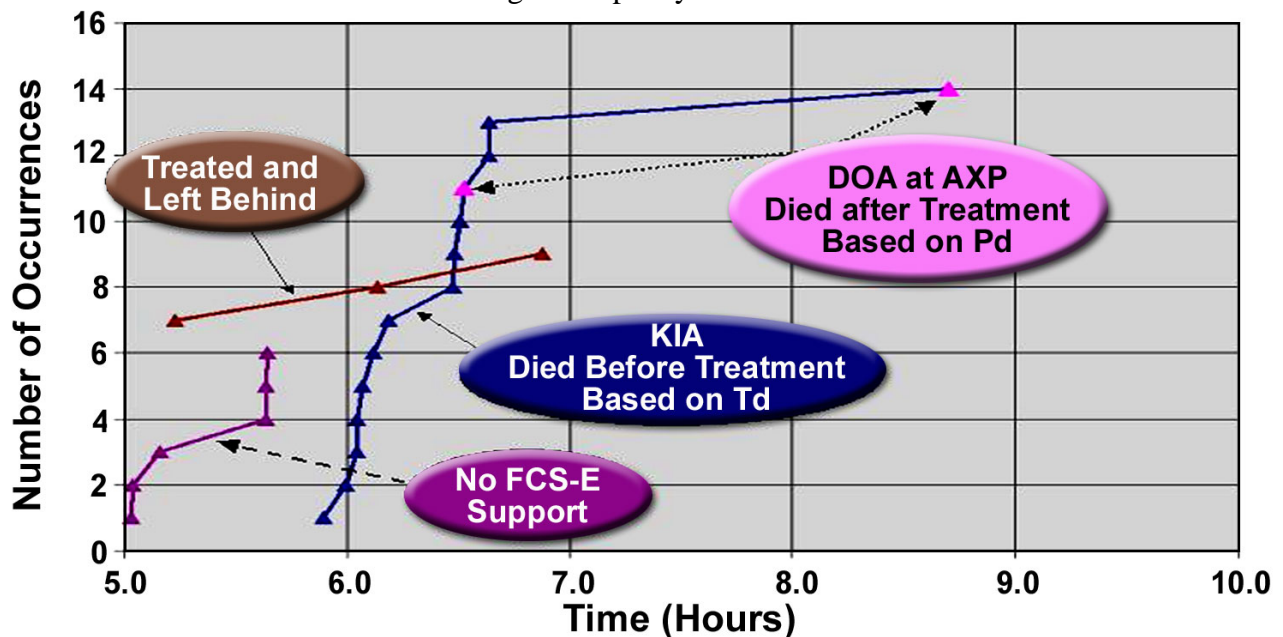
**Table 1. Casualty Statistics**

| Vehicle ID | Vehicle Type | Damage Type        | Crew Size | PC Code *      | KI A | WI A | Time of Injury (Hours) |
|------------|--------------|--------------------|-----------|----------------|------|------|------------------------|
| 60         | FCS-FCDR     | Mobility           | 3         | 46             |      | 1    | 5.030                  |
| 145        | FCS-CBT      | Catastrophic       | 3         | 88,131,46      |      | 3    | 5.030                  |
| 299        | FCS-FIFV     | Mobility           | 3         | 53             |      | 1    | 5.031                  |
| 148        | FCS-FIFV     | Mobility           | 3         | 42             |      | 1    | 5.034                  |
| 149        | FCS-FIFV     | Mobility           | 3         | 163,136        |      | 2    | 5.034                  |
| 311        | FCS-FIFV     | Mobility           | 3         | 129            |      | 1    | 5.037                  |
| 25         | FCS-FRSV     | Mobility           | 3         | 48             |      | 1    | 5.038                  |
| 288        | FCS-FIFV     | Mobility           | 3         | 175            |      | 1    | 5.042                  |
| 301        | FCS-FIFV     | Mobility           | 3         | 130            |      | 1    | 5.042                  |
| 304        | FCS-CBT      | Mobility           | 3         | 131            |      | 1    | 5.047                  |
| 150        | FCS-FIFV     | Catastrophic       | 3         | 165            |      | 1    | 5.053                  |
| 300        | FCS-FIFV     | Mobility           | 3         | 105,151        |      | 2    | 5.053                  |
| 20         | FCS-CBT-NLOS | Mobility           | 2         | 170            |      | 1    | 5.066                  |
| 10         | FCS-FC2V     | Mobility           | 3         | 138            |      | 1    | 5.128                  |
| 24         | FCS-CBT-NLOS | Catastrophic       | 2         | 10             | 1    | 1    | 5.158                  |
| 239        | FCS-FIFV     | Mobility           | 3         | 21             |      | 1    | 5.195                  |
| 167        | FCS-CBT      | Mobility           | 3         | 137            |      | 1    | 5.201                  |
| 210        | FCS-FIFV     | Mobility           | 3         | 18             |      | 1    | 5.201                  |
| 207        | FCS-CBT      | Mobility           | 3         | 90             |      | 1    | 5.206                  |
| 217        | FCS-FIFV     | Mobility           | 3         | 81,88          |      | 2    | 5.212                  |
| 191        | FCS-FIFV     | Mobility           | 3         | 129            |      | 1    | 5.218                  |
| 182        | FCS-FIFV     | Mobility           | 3         | 77             |      | 1    | 5.230                  |
| 170        | FCS-CBT      | Mobility           | 3         | 165            |      | 1    | 5.231                  |
| 206        | FCS-CBT      | Catastrophic       | 3         | 129,86         |      | 2    | 5.236                  |
| 272        | FCS-FC2V     | Catastrophic       | 3         | NA             | 1    |      | 5.504                  |
| 62         | FCS-FC2V     | Mobility           | 3         | 131            |      | 1    | 5.511                  |
| 277        | FCS-FAVLB    | Catastrophic       | 4         | 43,124,165     | 1    | 3    | 5.639                  |
| 281        | FCS-FAVLB    | Catastrophic       | 4         | 165,131,52,131 |      | 4    | 5.640                  |
| 101        | FCS-CDR      | Catastrophic       | 2         | NA             | 2    |      | 6.699                  |
| 169        | FCS-CBT      | Mobility-Firepower | 3         | 124            |      | 1    | 6.779                  |
| 117        | FCS-CBT      | Mobility-Firepower | 3         | 22             |      | 1    | 7.210                  |
| 118        | FCS-CBT      | Catastrophic       | 3         | 99             | 1    | 1    | 7.226                  |
| 115        | FCS-CBT      | Catastrophic       | 3         | 163            | 1    | 1    | 7.231                  |
| 120        | FCS-FIFV     | Catastrophic       | 3         | 54,124         | 1    | 2    | 7.270                  |
| 194        | BDIOCSW      | Mobility           | 1         | 103            |      | 1    | 7.452                  |

|     |         |                    |   |    |   |   |       |
|-----|---------|--------------------|---|----|---|---|-------|
| 186 | BDIOCSW | Mobility           | 1 | 86 |   | 1 | 7.460 |
| 195 | BDIOCSW | Catastrophic       | 1 | NA | 1 |   | 7.476 |
| 213 | BDIOCSW | Catastrophic       | 1 | NA | 1 |   | 7.521 |
| 225 | BDIOCSW | Catastrophic       | 1 | NA | 1 |   | 7.527 |
| 230 | BDIM249 | Catastrophic       | 1 | NA | 1 |   | 7.532 |
| 220 | BDIOCSW | Mobility-Firepower | 1 | 52 |   | 1 | 7.532 |
| 212 | BDIOCSW | Catastrophic       | 1 | NA | 1 |   | 7.544 |
| 226 | BDIOCSW | Catastrophic       | 1 | NA | 1 |   | 7.557 |
| 228 | BDIOCSW | Catastrophic       | 1 | NA | 1 |   | 7.568 |
| 216 | BDIM249 | Catastrophic       | 1 | NA | 1 |   | 7.571 |
| 229 | BDIOCSW | Catastrophic       | 1 | NA | 1 |   | 7.591 |

- Please see definition of PC codes used in the analysis in Tables A1 and A2 of Appendix A

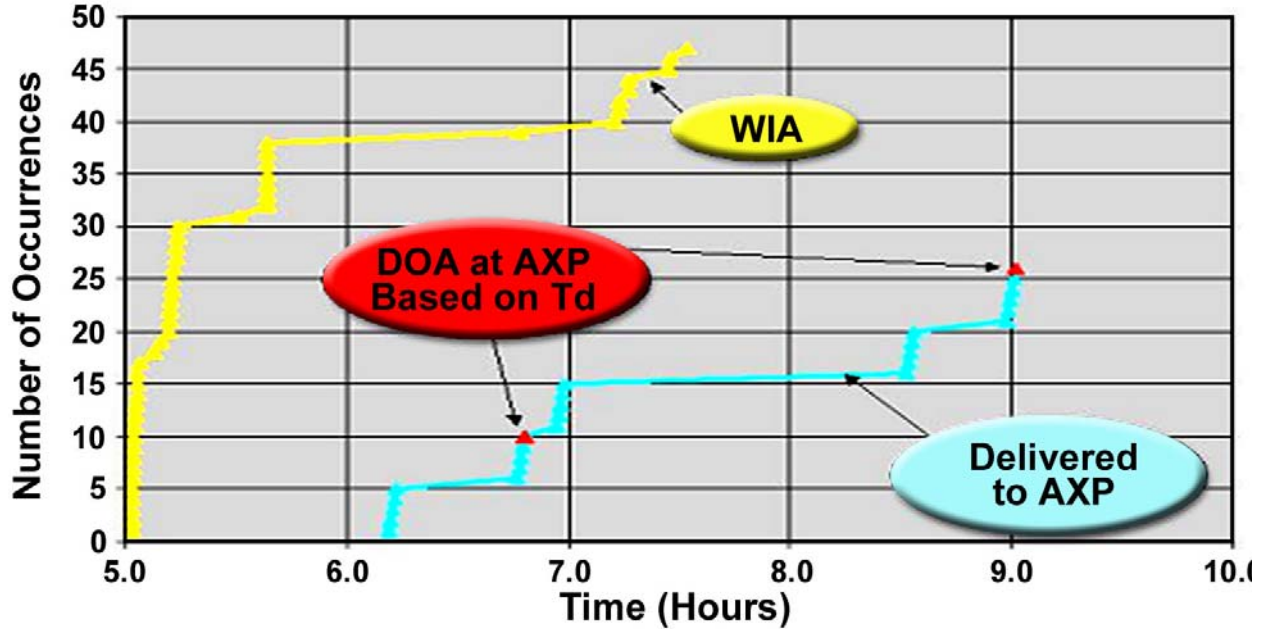
In Figure 4, 14 additional KIAs occurred as a function of time; two of these casualties die on board the FCS-E en route to the AXP. The authors emphasize that the data used in the Time to Death algorithm are drawn from SME opinion, not battlefield validated data. Figure 4 shows WIA casualties that die prior to reaching the BAS, which is a function of time based upon the  $P_d$  and Time to Death algorithm; accordingly, these casualties are reclassified as KIA casualties per Subject Matter Expert (SME) guidance. Figure 4 also shows the number of casualties not cleared from the battlefield. Three Combined Arms Company casualties were not cleared from the battlefield due to the FCS-E reaching full capacity



**Figure 4.** KIA Time History and Casualties Not Cleared from the Battlefield

Figure 5 shows casualties delivered to the AXP. Grouping of symbols occurs at the time the FCS-E reaches the AXP. Each symbol represents a casualty as they are being unloaded; after SME discussion, 30 seconds to unload an ambulatory casualty and 2.5 minutes to unload each

litter casualty was entered into the modeling parameters. In total, there were 5 deliveries made to



the AXP.

**Figure 5.** Casualties Delivered to the AXP by FCS-E Vehicles Supporting the Combined Arms Companies

From Figure 5, it is apparent that approximately one hour elapses before the first casualties arrive at the AXP. Also, the last casualties arrive at the AXP approximately one hour after the last casualty occurs.

#### 4. Process Used to Model Medical Technology

In its simple form, the process used to model medical technology involves three steps as follows:

Step 1 involves running a base case including generating results where friendly casualties occur on the battlefield and are treated by combat medical personnel with current technologies. The model captures times and distances relating to location of injury, type of injury, time of injury, time medical personnel were notified, time to travel, treat and transport to next level of care, and location on the battlefield of the medical personnel.

Step 2 involves running the base case again including generating results with new medical technologies available (e.g. prolonging the time before death) to medical personnel.

Step 3 involves doing a comparative analysis of the two.

Steps 1 and 3 are straightforward and require no further explanation. Step 2, however, is more complex due in part because of the challenges associated with obtaining information and data needed on a particular technology in order to model the benefits/value effectively. This aspect of the effort is explained in more detail below.

Determining the true value of a proposed medical technology on the battlefield is difficult without some sort of testing and analysis. Medical personnel must determine the value of the technology in terms of reducing the impact of the injury (e.g. reducing the loss of blood), increasing the soldier's chance of survival by increasing the time before death, reducing the time to apply the new technology, etc. In the medical community, this information is often obtained by testing the new technology on animals to determine its potential benefit. Once completed, a comparison is made between the benefit to the animal and the potential benefit to wounded soldiers in the battlefield. Another approach to test medical technology is through clinical trials. In situations where a technology has not been tested on animals or undergone clinical trials or in some cases been developed, or being only proposed through research objectives, medical personnel are forced to rely on SME input. Unfortunately, none of the above provides the means to examine the benefit of the technology, if available, or being developed, in a battlefield setting.

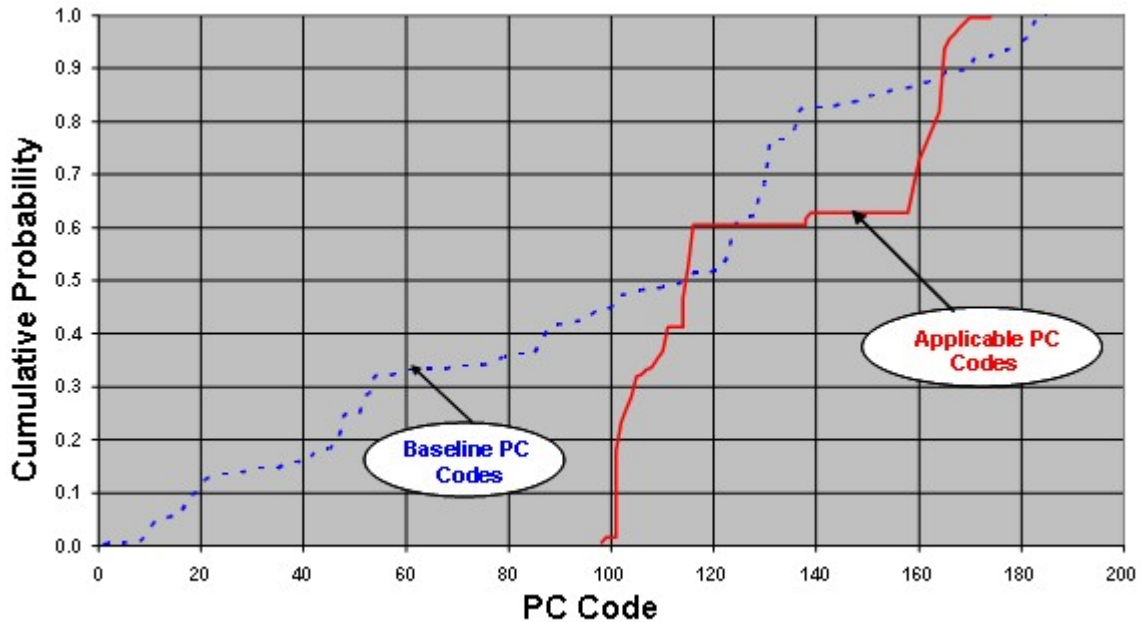
## **5. Incorporating Medical Technology into the IDEEAS M&S Tool**

Incorporating medical technology that benefits soldiers on the battlefield into the IDEEAS M&S tool was a straightforward process that expanded upon the tool's ability to identify and track injuries, and specifically model time and distance factors. In the CASS Study, the M&S tool modeled wounded soldiers and time and distance specifically. The results of this study provided the authors with the means to now incorporate a technology that increases a wounded soldier's time before death. This was accomplished by using the tool's capability to model specific time of injury, time the technology was applied, time it took for medical personnel to arrive at the wounded soldier's location based on projected battlefield conditions, speed and distance factors, and time to treat, load and travel back to the next level of care. Hence, M&S provides the means to model wounded soldiers with and without certain technologies and enables medical SMEs to examine the technologies impact against realistic time and distance factors associated with simulated battlefield conditions.

## **6. Modified PC Code**

M&S also provides the means to adjust the patient condition (PC) Code medical parameter input data from the PC Codes and Associated Medical Input Parameters assigned by Center for AMEDD Strategic Studies (CASS) personnel to reflect the need for or use of a particular new technology. Hence, rather than conduct a random pull from all 184 possible injury types used in the CASS study, the modelers can reduce the list of injury types so that a soldier would have at least a 50% chance of receiving a wound requiring the medical technology being examined.

Figure 6 illustrates the cumulative probability used for a particular technology that stops bleeding. The dashed blue line is the same as that used in the CASS study and shown in Figure 1. The solid red line shows the cumulative distribution when a subset of the 184 PC codes is used. This subset contains the PC codes for excessive bleeding injuries.



**Figure 6. Cumulative Probability Distribution of 50% Occurrence of Applicable PC Codes**

## 7. Impact of Medical Technology on Other Medical Resources

The simulated battle used to support this initial study provided the means to incorporate the benefits of medical technology on wounded soldiers. As expected, when fewer soldiers die on the battlefield as a result of using the new technology, more will require medical treatment. In addition, as was discussed during the Army Medical Department (AMEDD) Transformation Workshops in 2002 [7], the lethality and accuracy of new weapon systems is going to increase the number of wounded enemy soldiers which will also impact friendly medical personnel and resources. Insights from the study on medical personnel and resources follow:

- Medical technology that saves a soldier’s life results in increased workload for surgical personnel and resources.
- The lethality and accuracy of new weapons systems may inflict far more casualties on friendly and enemy forces than in previous conflicts.
- While not examined in this initial study, enemy casualties will require medical attention and consume friendly medical personnel and medical resources.
- Overall, given the combination of advanced medical technology that prevents soldiers from dying on the battlefield and increased enemy casualties due to enhanced weapon accuracy and lethality, friendly medical personnel can expect an increased workload and an increased demand for medical resources during future conflicts.

## 8. Summary

The initial effort performed for MRMC demonstrated how an engineering level, physics-based, entity level force-on-force constructive M&S tool like IDEEAS combined with medical SMEs and medical data can be used to model and simulate the following key battlefield factors:

- Soldiers KIA
- Soldiers WIA

- Type of soldier wound
- Time of soldier wounding
- Time medical personnel notified
- Location of medical personnel on the battlefield
- Time medical personnel take to travel to the wounded soldier
- Time medical personnel take to treat the wounded soldier given medical information from the time, task treater file
- Time to travel to multiple locations to pick up wounded soldiers until capacity in the medical evacuation vehicle is reached
- Time to travel back to the next level of care (i.e. AXP)
- Medical evacuation vehicles
- Combat Medic entity
- Distance from the wounded soldier to medical personnel
- Distance between wounded soldiers
- Distance from wounded soldier to next level of care
- Total number of wounded soldiers requiring medical attention
- Medical technology (e.g. technologies that can stop bleeding)
- Comparative analysis using a base case without and test case with new medical technology
- Benefit of Medical technology in terms of prolonging a wounded soldier's time to death (e.g. simulating medical technology that stops bleeding)
- Impact of delaying the movement of medical personnel to wounded soldiers due to battlefield conditions
- Battlefield conditions associated with time and distance on wounded soldiers

Bold entries are the basis for utilizing this scenario and conducting multiple medical modeling studies to be reported in the medical literature.

## 9. Conclusions

The capability of Modeling and Simulation tools has increased drastically within the last ten years. Increased computer processing power, combined with high end terrain generation and software engineering tools that reduce the time and effort to develop sophisticated algorithms, create an environment where realistic conditions, battlefield settings, and weapons effects can be established and modeled to support detailed studies and analysis of different types of systems and technologies. This initial study demonstrated that a Force-on Force, entity based modeling and simulation tool can be used to model the benefit of medical technology that prolongs a soldier's life on a simulated battlefield by specifically examining the factors of time and distance with the benefit of the technology. Therefore, the authors conclude that M&S tools capable of simulating realistic battlefield conditions and modeling time and distance factors specifically; combined with precise requirements definition and experimental design, including algorithm development can be used to:

- Examine the potential benefit of a new, existing or proposed medical technology in a simulated battlefield setting.

- Provide improved information to decision makers.
- Offer some justification for future medical research and development efforts.

## 10. References

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- [2] Examples of studies supported by IDEEAS include:
- a. Joint Aviation Missile Unmanned System (JAMUS) studies to assess rapid battle space deconfliction.
  - b. Close-In Active Protection System (CIAPS) study to assess CIAPS performance in a relevant battlefield and environment context.
  - c. On-the-Move Radar Analysis to assess conceptual on-the-move radar operational missions in a tactically valid battlefield context study.
  - d. Extended Area Protection System (EAPS) study to evaluate candidate acquisition, fire control sensors and shooter technologies in an operational context.
  - e. High Velocity Outer Tier Defense Missile (HOT-D) study to assess operational mission in a tactically valid battlefield context.
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Appendix A

Table A1. Smart Tourniquet PC Codes

| PC Code | Prob of Injury % | Time To Treat (min) | Prob of Death (%) | Time to Death Before Treatment (min) | Priority of Treatment | Ambulatory Probability (%) | Description   |
|---------|------------------|---------------------|-------------------|--------------------------------------|-----------------------|----------------------------|---|
| 45      | 0.0078           | 18.5                | 0.00              |                                      | 1                     | 0.00                       | Wound Upper Arm Open Penetrating Lacerated Without Fracture Severe- With Nerve And/Or Vascular Injury               |
| 47      | 0.702            | 20                  | 0.00              |                                      | 1                     | 0.00                       | Wound Upper Arm Open With Fractures And Nerve And Vascular Injury Arm Non-Salvageable                               |
| 48      | 3.978            | 20                  | 0.00              |                                      | 2                     | 0.00                       | Wound Upper Arm Open With Fractures And Nerve Injury No Vascular Injury Arm Salvageable                             |
| 61      | 0.065            | 17.5                | 0.00              |                                      | 1                     | 0.00                       | Crush Injury Upper Extremity Severe- Limb Not Salvageable   |
| 62      | 0.065            | 16.5                | 0.00              |                                      | 2                     | 100.00                     | Crush Injury Upper Extremity Moderate- Limb Salvageable   |
| 69      | 0.234            | 23                  | 0.00              |                                      | 2                     | 100.00                     | Amputation Hand Traumatic Complete All Cases  |
| 70      | 0.234            | 23                  | 0.00              |                                      | 2                     | 50.00                      | Amputation Forearm Traumatic Complete All Cases   |
| 71      | 0.052            | 23                  | 6.90              | 55.9                                 | 2                     | 0.00                       | Amputation Full Arm Traumatic Complete All Cases  |
| 123     | 1.3248           | 23                  | 0.00              |                                      | 1                     | 0.00                       | Wound Thigh Open Lacerated Penetrating Perforating With Fracture And Nerve/Vascular Injury Limb Not Salvageable     |
| 124     | 5.2992           | 23                  | 0.00              |                                      | 1                     | 0.00                       | Wound Thigh Open Lacerated Penetrating Perforating With Fracture And Nerve And/Or Vascular Injury Limb Salvageable  |
| 130     | 1.8216           | 19                  | 0.00              |                                      | 1                     | 0.00                       | Wound Lower Leg Open Lacerated Penetrating Perforating With Fracture And Nerve/Vascular Injury Limb Not Salvageable |
| 136     | 0.7866           | 19.5                | 0.00              |                                      | 1                     | 0.00                       | Wound Ankle Foot Toes Open Penetrating Perforating With Fractures And Nerve/Vascular Injury Limb Not Salvageable    |
| 144     | 0.2668           | 16.5                | 0.00              |                                      | 1                     | 0.00                       | Amputation Foot Traumatic Complete All Cases  |
| 145     | 0.4508           | 16.5                | 0.00              |                                      | 1                     | 0.00                       | Amputation Below Knee Traumatic Complete All Cases  |
| 146     | 0.0276           | 19.5                | 29.30             | 42.4                                 | 1                     | 0.00                       | Amputation Traumatic Complete Requiring Hip Disarticulation   |
| 147     | 0.1748           | 19.5                | 1.30              | 59.2                                 | 1                     | 0.00                       | Amputation Above Knee Traumatic Complete  |
| 165     | 1.17             | 14.2                | 15.90             | 50.5                                 | 1                     | 0.00                       | Miw Brain And Lower Limbs Requiring Bilateral Above Knee Amputations  |
| 171     | 1.95             | 18.2                | 2.60              | 58.4                                 | 1                     | 0.00                       | Miw Chest With Pneumohemothorax And Limbs With Fracture And Vascular Injury   |
| 179     | 0.55604          | 15.5                | 1.30              | 59.2                                 | 1                     | 0.00                       | Miw Abdomen Pelvis Limbs Without Fracture Or Neurovascular Injury And Penetrating Perforating Wound Bladder         |

Appendix A (Continued)

**Table A2. Chitosan Bandage PC Codes**

| PC Code | Prob of Injury (%) | Time to Treat (min) | Prob of Death (%) | Time to Death Before Treatment (min) | Priority of Treatment | Ambulatory Prob (%) | Description  |
|---------|--------------------|---------------------|-------------------|--------------------------------------|-----------------------|---------------------|--|
| 10      | 1.188              | 16                  | 0.00              |                                      | 2                     | 0.00                | Cerebral Contusion With Open Skull Fracture Moderate - Without Intracranial Fragments And/Or Depressed Skull Fracture              |
| 18      | 1.58449            | 16                  | 0.00              |                                      | 2                     | 0.00                | Wound Face Jaws & Neck Open Lacerated With Associated Fractures Excluding Spinal Fractures Moderate-W/Out Airway Obstruction       |
| 21      | 1.3552             | 11                  | 0.00              |                                      | 2                     | 100.00              | Eye Wound Severe - Loss Of Intraocular Fluid With/Without Retinal Detachment With Severe Lid Laceration Eye Not Salvageable.       |
| 22      | 0.54208            | 11                  | 0.00              |                                      | 3                     | 100.00              | Eye Wound Lacerated Moderate -Without Retinal Detachment Or Retinal Injury No Foreign Body Retained Without Loss Of Vitreous Fluid |
| 42      | 1.404              | 15                  | 0.00              |                                      | 3                     | 0.00                | Wound Shoulder Girdle Open With Bone Injury Severe - Joint Involvement   |
| 43      | 0.351              | 15                  | 0.00              |                                      | 3                     | 100.00              | Wound Shoulder Girdle Open With Bone Injury Moderate - No Joint Involvement  |
| 46      | 1.32               | 18                  | 0.00              |                                      | 3                     | 100.00              | Wound Upper Arm Open Penetrating Lacerated Without Fracture Moderate - Without Nerve Or Vascular Injury                            |
| 48      | 3.978              | 20                  | 0.00              |                                      | 2                     | 0.00                | Wound Upper Arm Open With Fractures And Nerve Injury No Vascular Injury Arm Salvageable  |
| 52      | 3.08               | 16                  | 0.00              |                                      | 3                     | 100.00              | Wound Forearm Open Lacerated Penetrating Without Bone Nerve Or Vascular Injury Moderate - Not Requiring Major Debridement          |
| 53      | 0.5265             | 18                  | 0.00              |                                      | 1                     | 0.00                | Wound Forearm Open Lacerated Penetrating With Fracture And With Nerve And Vascular Injury Forearm Not Salvageable                  |
| 54      | 2.9835             | 18                  | 0.00              |                                      | 2                     | 100.00              | Wound Forearm Open Lacerated Penetrating With Fracture And With Nerve And Vascular Injury Forearm Salvageable                      |
| 77      | 0.48               | 15                  | 0.00              |                                      | 2                     | 100.00              | Burn Thermal Partial Thickness Upper Extremities Greater Than 10% But Less Than 20% Of Total Body Area Involved                    |
| 81      | 0.108              | 11                  | 0.00              |                                      | 3                     | 100.00              | Fracture Ribs Closed Severe - Multiple Fractures   |
| 86      | 1.33               | 13                  | 0.00              |                                      | 3                     | 100.00              | Wound Thorax (Anterior Or Posterior) Open Superficial Lacerated Contused Abraded Avulsed Not Requiring Major Debridement           |
| 88      | 1.8                | 18                  | 2.60              | 58.4                                 | 1                     | 0.00                | Wound Thorax (Anterior or Posterior) Open Penetrating w/ Associated Rib Fractures & Pneumothorax Moderate Respiratory Distre       |
| 90      | 0.132              | 11                  | 0.00              |                                      | 3                     | 100.00              | Burn Thermal Superficial Trunk Greater Than 20% But Less Than 30% Of Total Body Area Involved                                      |
| 99      | 0.12768            | 11                  | 0.00              |                                      | 1                     | 0.00                | Wound Liver Closed Acute (Crush Fracture) Minor Liver Damage   |
| 103     | 0.2401             | 14                  | 25.00             | 45                                   | 1                     | 0.00                | Wound Abdominal Cavity Open With Penetrating Perforating Wound of Liver Major Damage   |
| 105     | 0.3773             | 15                  | 1.00              | 59.4                                 | 1                     | 0.00                | Wound Abdominal Cavity Open With Penetrating Perforating Wound Of Spleen   |
| 124     | 5.2992             | 23                  | 0.00              |                                      | 1                     | 0.00                | Wound Thigh Open Lacerated Penetrating Perforating With Fracture And Nerve And/Or Vascular Injury Limb Salvageable                 |
| 129     | 3.84               | 18                  | 0.00              |                                      | 3                     | 0.00                | Wound Lower Leg Open Lacerated Penetrating Perforating Without Fractures Not Requiring Major Debridemen                            |
| 130     | 1.8216             | 19                  | 0.00              |                                      | 1                     | 0.00                | Wound Lower Leg Open Lacerated Penetrating Perforating With Fracture And Nerve/Vascular Injury Limb Not Salvageable                |
| 131     | 7.2864             | 18                  | 0.10              | 59.9                                 | 1                     | 0.00                | Wound Lower Leg Open Lacerated Penetrating Perforating With Fracture And Nerve And/Or Vascular Injury Limb Salvageable             |
| 136     | 0.7866             | 19.5                | 0.00              |                                      | 1                     | 0.00                | Wound Ankle Foot Toes Open Penetrating Perforating With Fractures And Nerve/Vascular Injury Limb Not Salvageable                   |
| 137     | 3.1464             | 18                  | 0.00              |                                      | 1                     | 0.00                | Wound Ankle Foot Toes Open Penetrating Perforating With Fractures And Nerve And/Or Vascular Injury Limb Salvageable                |
| 138     | 0.115              | 18                  | 0.60              | 59.6                                 | 1                     | 0.00                | Crush Injury Lower Extremity Limb Not Salvageable  |
| 151     | 0.288              | 11                  | 0.00              |                                      | 3                     | 100.00              | Burn Thermal Superficial Lower Extremity And Genitalia Greater Than 15% But Less Than 30% Of Total Body Area Involved              |
| 163     | 0.22896            | 13.2                | 15.90             | 50.5                                 | 1                     | 0.00                | MIW Brain And Abdomen With Shock And Penetrating Perforating Wound Spleen  |
| 165     | 1.17               | 14.2                | 15.90             | 50.5                                 | 1                     | 0.00                | MIW Brain And Lower Limbs Requiring Bilateral Above Knee Amputations   |
| 170     | 0.10166            | 17                  | 6.90              | 55.9                                 | 1                     | 0.00                | MIW Chest With Pneumothorax And Abdomen With Penetrating Perforating Wound Liver   |
| 175     | 1.04666            | 15                  | 1.30              | 59.2                                 | 1                     | 0.00                | MIW Abdomen & Limbs With Penetrating Perforating Wound of Colon & Open Fracture And Neurovascular Injury of Salvageable Lower Li   |

## Appendix B

The following rules, extrapolated from available literature, were used to develop algorithms and assign casualties to damaged Friendly entities. Where available data were inadequate, best estimates were developed.

### 1. Enclosed vehicles

- a. The crew compartment is violated in a Catastrophic Kill. The probability of becoming a casualty is 0.5; the probability of the casualty being killed is 0.4. [8,9,10]
- b. For Mobility Damage or Firepower Damage, the probability of becoming a casualty is 0.10; the probability of the casualty being killed is zero.
- c. For combined Mobility Kill and Firepower Damage, the probability of becoming a casualty is 0.19; the probability of the casualty being killed is zero.

### 2. Dismounted infantry

- a. For Catastrophic Kill, the probability of becoming a casualty is 1.0; the probability of the casualty being killed is 1.0.
- b. For Mobility Damage, Firepower Damage, or combined Mobility Kill and Firepower Damage, the probability of becoming a casualty is 1.0; the probability of the casualty being killed is zero.

### 3. Dismounted crewmembers

For Crew Kill, the probability of being a casualty is the ratio of the minimum number of personnel required to operate the vehicle divided by the number of crewmembers. The probability of a casualty being killed is 0.60. A typical example is a 155 howitzer. Crew size is 11. The minimum number required to operate is 3. The probability of being a casualty is 0.27.

The outcome of the hit on the crew was expressed as number of KIA and WIA casualties. Based on available data, it could not be determined if crewmembers classified as KIA died immediately or died prior to reaching the first level of the combat health support system. For the purpose of this demonstration, assigned KIA casualties were assumed to die immediately upon weapon impact. In this simulation, KIA casualties also included those who died prior to receiving treatment by the Combat Medic and after treatment by the Combat Medic but prior to arrival at the BAS. No medical resources were allocated to treat KIA casualties who died immediately upon weapon impact or prior to the arrival of the Combat Medic. WIA casualties were randomly assigned a DEPMEDS PC Code within the simulation from standardized WIA PC Code frequency distributions. Based upon the PC Code, the WIA was assigned a  $P_d$ . Where the  $P_d$  was greater than zero, the WIA was assigned an initial Time to Death based on the appropriate Time to Death Algorithm for each DEPMEDS PC Code (See Figure 2). Friendly system kills, damage type, and casualties are summarized in Table 1.

## **Author Biographies**

**LTC Robert von Tersch, PhD** serves as senior medical planner for the Joint Requirements Office for Chemical, Biological, Radiological and Nuclear (CBRN) Defense of the Force Structure, Resources and Assessments Directorate, Joint Staff, Pentagon. He is responsible for leading the development and integration of future medical capabilities into the overall CBRN defense program, in coordination with the Services' medical departments and Combatant Command Surgeons. He provides medical defense analysis and consultation on all aspects of the CBRN joint program and represents the office in interactions with Service headquarters, other Joint Staff elements, the Office of the Secretary of Defense, Combatant Commands, other governmental agencies, academia, and industry.

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**Harry Birch** is a Project Manager for Science Application International Corporation Defense Solutions Group. In this position, he leads studies involving the use of Modeling and Simulation to support analysis of Army future force structure and weapons technology. He has co-authored several papers on the benefits of using modeling and simulation to support decisions on medical units and advanced technology. He is also a retired Air Force officer with 24 years of experience most of which served in joint duty assignments.